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FRAUNHOFER RESEARCH INSTITUTION FOR ELECTRONIC NANO SYSTEMS ENAS

Annual Report 2009

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Reliability test equipment for the influence of humidity, temperature and vibration with online measurement of the electrical behavior of the device under test

cover photo: Fraunhofer ENAS, Jürgen Lösel

FRAUNHOFER ENAS

PREFACE

Dear friends and partners of the Fraunhofer Research Institution
for Electronic Nano Systems,
dear ladies and gentlemen,

The Fraunhofer Research Institution for Electronic Nano Systems ENAS can retrospectively look on a very successful year 2009. Independent on the downward economic trend the Fraunhofer ENAS reached a nearly constant research revenue from industrial customers.

A special highlight was the opening ceremony of the new building of Fraunhofer ENAS at the Smart Systems Campus Chemnitz after one and a half year of construction in the presence of Federal Minister for Education and Research Prof. Dr. Annette Schavan and Mr. Stanislaw Tillich, the Prime Minister of the State of Saxony on June 22. The new building contains 31 offices and 20 laboratories for 100 employees, a caferteria, an artrium and three oases in order to secure a convenient working atmosphere. The energy efficiency at and within the building was an important issue during planning process. The building will have very low power consumption. By means of an earth heat exchanger and the usage of water coming from a 62 m deep spring the building is temperature controlled.

The new building of Fraunhofer ENAS belongs to the Smart Systems Campus Chemnitz. Main parts of the campus have been finished and inaugurated within 2009, too. The start-up building and the building of the 3D-Micromac AG as well have been handed over to the owner and user. The campus combines the basic research carried out at the Chemnitz University of Technology with the applied research at the Fraunhofer Research Institution and the implementation of the ideas in young, growing companies within the start-up building.

In summer 2009 the department Advanced System Engineering ASE of Fraunhofer ENAS moved into the new offices and laboratories at the University of Paderborn. The University of Paderborn belongs to the main cooperation partners of ASE.

The growing revenue in the field of waferbonding resulted in the foundation of the department System Packaging in July 2009. In the focus of the applied research of the department are versatile technologies used for system integration of MEMS and NEMS at different levels of the packaging hierarchy, as well as patterning in micro and nano scale of surface areas in microsystems technology.

In December 2009 Prof. Sabine von Schorlemer, Saxon Ministry of Science and Culture, took part at the kickoff meeting of the nano system integration network of excellence nanett. Nanett is one of the successful initiatives of the second phase of the "Spitzenforschung und Innovation in den Neuen Ländern" program, funded by the Federal Ministry of Education and Research (BMBF). Under the direction of the Chemnitz University of Technology and the Fraunhofer ENAS this dynamic network of nine different partners was formed to bring together their competences in the field of applied nanotechnologies. Two universities, three Fraunhofer Institutes, three institutes of Leibniz Association and the Helmholtz Center in Berlin work together in this network.

Also in December that the printed battery of the department Printed Functionalities was chosen to the best five ideas in the technology area 2009 according to New York Times Magazine. The printable battery can be produced cost-effectively on a large scale. It was developed by a research team of the Fraunhofer Research Institution for Electronic Nano Systems ENAS in Chemnitz together with colleagues from Chemnitz University of Technology and Menippos GmbH.

The strategic alliance between the Fraunhofer ENAS and the Center for Microtechnologies ensured strong synergies in technology and device development also in 2009. The strong cooperation with the Fraunhofer IZM Berlin was especially continued in the field of nano assembly and packaging for MEMS and NEMS.

Fraunhofer ENAS works internationally. It cooperates very actively within in the European platform for smart systems integration EPoSS and is a member of groups, networks and alliances. Our representatives in Japan, China and Brazil support our international activities.

Liebe Freunde und Partner der Fraunhofer-Einrichtung für
Elektronische Nanosysteme,
sehr geehrte Damen und Herren,

die Fraunhofer-Einrichtung für Elektronische Nanosysteme ENAS kann auf ein erfolgreiches Jahr 2009 zurückblicken. So ist es der Fraunhofer ENAS gelungen, trotz wirtschaftlichem Abschwung einen annähernd konstanten Industrieertrag zu erreichen.

Ein besonderer Höhepunkt war die feierliche Einweihung des neuen Gebäudes der Fraunhofer ENAS am 22. Juni 2009 auf dem Smart Systems Campus Chemnitz nach anderthalbjähriger Bauzeit im Beisein der Bundesministerin für Bildung und Forschung, Frau Prof. Annette Schavan, und dem sächsischen Ministerpräsidenten, Herrn Stanislaw Tillich. Das neue Institutsgebäude bietet neben 31 Büro- und 20 Laborräumen für insgesamt 100 Mitarbeiterinnen und Mitarbeiter und einer Cafeteria auch einen Innenhof und drei Freiterrassen für eine angenehme Arbeitsatmosphäre. Ein wichtiger Aspekt bei der Planung war die Energieeffizienz am und im Gebäude. Mit einem Erdwärmetauscher und der Nutzung von Wasser aus einem 62 m tiefen Brunnen zur Gebäudetemperierung steht der Neubau für einen niedrigen Energieverbrauch.

Das neue Gebäude der Fraunhofer ENAS befindet sich auf dem Smart Systems Campus Chemnitz. Seine wesentlichen Bestandteile wurden in 2009 fertig gestellt und eingeweiht. So wurden das Start-up Gebäude und das Firmengebäude der 3D-Micromac AG ebenfalls an seine Nutzer übergeben. Dieser Campus verbindet Grundlagenforschung an der TU Chemnitz mit der angewandten Forschung an der Fraunhofer-Einrichtung sowie die Umsetzung der Ideen in jungen, wachsenden Unternehmen im Start-up Gebäude.

Im Sommer 2009 verlagerte die Abteilung Advanced System Engineering ASE ihren Wirkungsbereich in neue Büro- und Laborräume an der Universität Paderborn. Die Universität ist einer der wichtigsten Kooperationspartner für die Abteilung ASE in Paderborn.

Das kontinuierliche Wachstum des Umsatzes im Bereich Waferbonden führte im Juli 2009 zur Gründung der Abteilung System Packaging. Im Mittelpunkt der angewandten Forschung der Abteilung stehen vielfältige Technologien sowohl zur Systemintegration von mikro-elektro-mechanischen Systemen (MEMS) und nano-elektro-mechanischen Systemen (NEMS) in verschiedenen Stufen der Packaging-Hierarchie als auch zur Mikro- und Nanostrukturierung von Oberflächen in der Mikrosytemtechnik.

Im Dezember 2009 besuchte Prof. Sabine von Schorlemer, Sächsische Staatsministerin für Wissenschaft und Kunst, im Rahmen der Auftaktveranstaltung des Kompetenznetzwerkes für Nanosystemintegration, kurz: nanett, die Fraunhofer ENAS. Nanett ist eine der erfolgreichen Initiativen der zweiten Phase des Programms "Spitzenforschung und Innovation in den Neuen Ländern", gefördert durch das Bundesministerium für Bildung und Forschung (BMBF). Unter der Federführung der Technischen Universität Chemnitz und der Fraunhofer ENAS arbeiten neun Forschungseinrichtungen gemeinsam in den nächsten fünf Jahren auf dem Gebiet der Nanosystemintegration. Zu den Netzwerkpartnern gehören eine Universität, eine Fachhochschule, drei Fraunhofer-Institute, drei Leibniz-Institute und ein Helmholtz Zentrum.

Ebenfalls im Dezember kürte das New York Times Magazine die gedruckte Batterie der Abteilung Printed Functionalities der Fraunhofer ENAS zu einer der fünf besten Ideen 2009 im Technologiebereich. Diese druckbaren Batterien, die sich im großen Maßstab kostengünstig herstellen lassen, haben Forscherteams der Fraunhofer-Einrichtung für Elektronische Nanosysteme ENAS, der TU Chemnitz und der Menippos GmbH gemeinsam entwickelt.

The smart systems integration addresses the trend to even smaller multi functional, self organising systems with an interface for communication with the outside world. Smart systems technologies and their integration will have a significant impact on the competitiveness of entire sectors as aeronautics, automotive engineering, security, logistics, medical technology and process engineering. It will consequently contribute to solving major socio-economic problems in the health, environment, mobility and other domains.

The Fraunhofer Research Institution for Electronic Nano Systems is positioning itself to meet these challenges. The basic requirement for our continued success in research and development is, of course, the committed work of our staff. In our capacity as an research institution of Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V., research and development for industrial applications are our prime and natural concern. R&D work is carried out on behalf of large national and international companies as well as small and medium-sized enterprises, network operators and the public sector, such as State of Saxony, the Federal Government and the EU. The institute's success is rooted in the minds of its employees and their knowledge of details and relationships, products, technologies and processes. The institute's performing power is based on our staff's creativity and optimism as well as the support of many our business partners and sponsors. We would like to express our thanks to all of them.

Director of the Fraunhofer Research Institution for
Electronic Nano Systems ENAS

Prof. Dr. Thomas Gessner

Auch in 2009 sicherte die strategische Allianz zwischen der Fraunhofer-Einrichtung für Elektronische Nanosysteme und dem Zentrum für Mikrotechnologien der Technischen Universität Chemnitz Synergien in der Technologie und Systementwicklung. Für die inhaltliche Weiterentwicklung in Richtung der Mikro- und Nanosysteme wurde die enge Kooperation mit dem Fraunhofer IZM Berlin, insbesondere auf dem Gebiet der Nano-Aufbau- und Verbindungstechnik, weitergeführt.

Mit der Mitarbeit im Rahmen der Europäischen Plattform für Smart Systems Integration EPoSS, mit der Mitgliedschaft in Verbünden und Verbänden aber auch durch Repräsentanten in Japan, China und Brasilien ist die Fraunhofer ENAS international aufgestellt.
Die Smart Systems Integration adressiert den Trend zu immer kleineren multifunktionalen, sich selbst organisierenden Systemen mit Schnittstellen zur Kommunikation mit der Außenwelt. Die Technologien für intelligente Systeme und ihre Integration werden signifikant die Wettbewerbsfähigkeit der verschiedenen Branchen wie Luft- und Raumfahrt, Automobilbau, Sicherheit, Logistik, Medizin- und Prozesstechnik beeinflussen. Konsequenter Weise werden sie beitragen sozialökonomische Probleme im Bereich Gesundheit, Umwelt, Mobilität und anderen zu lösen.

Die Fraunhofer-Einrichtung für Elektronische Nanosysteme stellt sich diesen Herausforderungen. Grundvoraussetzung für unsere erfolgreichen Forschungs- und Entwicklungsleistungen ist der engagierte Einsatz der Mitarbeiterinnen und Mitarbeiter unseres Hauses.

Als Einrichtung der Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. ist für uns Forschung und Entwicklung für industrielle Anwendungen ein selbstverständliches Anliegen. Die Forschungs- und Entwicklungsarbeiten werden im Auftrag nationaler und internationaler Großunternehmen und KMUs, der öffentlichen Hand, des Landes Sachsen, Bund und EU durchgeführt. Der Erfolg eines jeden Unternehmens steckt in den Köpfen der Beschäftigten, ihrem Wissen über Details und Zusammenhänge, Produkte, Technologien und Verfahren. Die Leistungskraft der Einrichtung beruht auf Kreativität, Leistungsbereitschaft und Optimismus der Mitarbeiterinnen und Mitarbeiter sowie der Unterstützung durch zahlreiche Geschäftspartner und Förderer. Ihnen allen gilt mein besonderer Dank.

Der Leiter der Fraunhofer-Einrichtung für Elektronische
Nanosysteme ENAS

Prof. Dr. Thomas Geßner

FRAUNHOFER-GESELLSCHAFT - PROFILE

Research of practical utility

Research of practical utility lies at the heart of all activities pursued by the Fraunhofer-Gesellschaft. Founded in 1949, the research organization undertakes applied research that drives economic development and serves the wider benefit of society. Its services are solicited by customers and contractual partners in industry, the service sector and public administration.

At present, the Fraunhofer-Gesellschaft maintains more than 80 research units in Germany, including 59 Fraunhofer Institutes. The majority of the 17,000 staff members are qualified scientists and engineers, who work with an annual research budget of 1.6 billion euros. Of this sum, more than 1.3 billion euros is generated through contract research. Two thirds of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects. Only one third is contributed by the German federal and Länder governments in the form of base funding, enabling the institutes to work ahead on solutions to problems that will not become acutely relevant to industry and society until five or ten years from now.

Affiliated research centers and representative offices in Europe, the USA and Asia provide contact with the regions of greatest importance to present and future scientific progress and economic development.

With its clearly defined mission of application-oriented research and its focus on key technologies of relevance to the future, the Fraunhofer-Gesellschaft plays a prominent role in the German and European innovation process. Applied research has a knock-on effect that extends beyond the direct benefits perceived by the customer: Through their research and development work, the Fraunhofer Institutes help to reinforce the competitive strength of the economy in their local region, and throughout Germany and Europe. They do so by promoting innovation, strengthening the technological base, improving the acceptance of new technologies, and helping to train the urgently needed future generation of scientists and engineers.

As an employer, the Fraunhofer-Gesellschaft offers its staff the opportunity to develop the professional and personal skills that will allow them to take up positions of responsibility within their institute, at universities, in industry and in society. Students who choose to work on projects at the Fraunhofer Institutes have excellent prospects of starting and developing a career in industry by virtue of the practical training and experience they have acquired.

The Fraunhofer-Gesellschaft is a recognized non-profit organization that takes its name from Joseph von Fraunhofer (1787–1826), the illustrious Munich researcher, inventor and entrepreneur.

FRAUNHOFER-GESELLSCHAFT - IM PROFIL

Forschung für die Praxis

Forschen für die Praxis ist die zentrale Aufgabe der Fraunhofer-Gesellschaft. Die 1949 gegründete Forschungsorganisation betreibt anwendungsorientierte Forschung zum Nutzen der Wirtschaft und zum Vorteil der Gesellschaft. Vertragspartner und Auftraggeber sind Industrie- und Dienstleistungsunternehmen sowie die öffentliche Hand.

Die Fraunhofer-Gesellschaft betreibt in Deutschland derzeit mehr als 80 Forschungseinrichtungen, davon 59 Institute. 17.000 Mitarbeiterinnen und Mitarbeiter, überwiegend mit natur- oder ingenieurwissenschaftlicher Ausbildung, bearbeiten das jährliche Forschungsvolumen von 1,6 Milliarden Euro. Davon fallen 1,3 Milliarden Euro auf den Leistungsbereich Vertragsforschung. Zwei Drittel dieses Leistungsbereichs erwirtschaftet die Fraunhofer-Gesellschaft mit Aufträgen aus der Industrie und mit öffentlich finanzierten Forschungsprojekten. Nur ein Drittel wird von Bund und Ländern als Grundfinanzierung beigesteuert, damit die Institute Problemlösungen erarbeiten können, die erst in fünf oder zehn Jahren für Wirtschaft und Gesellschaft aktuell werden.

Niederlassungen in Europa, in den USA und in Asien sorgen für Kontakt zu den wichtigsten gegenwärtigen und zukünftigen Wissenschafts- und Wirtschaftsräumen.

Mit ihrer klaren Ausrichtung auf die angewandte Forschung und ihrer Fokussierung auf zukunftsrelevante Schlüsseltechnologien spielt die Fraunhofer-Gesellschaft eine zentrale Rolle im Innovationsprozess Deutschlands und Europas. Die Wirkung der angewandten Forschung geht über den direkten Nutzen für die Kunden hinaus: Mit ihrer Forschungs- und Entwicklungsarbeit tragen die Fraunhofer-Institute zur Wettbewerbsfähigkeit der Region, Deutschlands und Europas bei. Sie fördern Innovationen, stärken die technologische Leistungsfähigkeit, verbessern die Akzeptanz moderner Technik und sorgen für Aus- und Weiterbildung des dringend benötigten wissenschaftlich-technischen Nachwuchses.

Ihren Mitarbeiterinnen und Mitarbeitern bietet die Fraunhofer-Gesellschaft die Möglichkeit zur fachlichen und persönlichen Entwicklung für anspruchsvolle Positionen in ihren Instituten, an Hochschulen, in Wirtschaft und Gesellschaft. Studentinnen und Studenten eröffnen sich an Fraunhofer-Instituten wegen der praxisnahen Ausbildung und Erfahrung hervorragende Einstiegs- und Entwicklungschancen in Unternehmen.

Namensgeber der als gemeinnützig anerkannten Fraunhofer-Gesellschaft ist der Münchner Gelehrte Joseph von Fraunhofer (1787–1826), der als Forscher, Erfinder und Unternehmer gleichermaßen erfolgreich war.

FRAUNHOFER GROUP MICROELECTRONICS

The Fraunhofer ENAS belongs to the Fraunhofer Group for Microelectronics VμE since its foundation. This Fraunhofer Group coordinates the activities of the Fraunhofer Institutes working in the fields of microelectronics and micro integration. The Fraunhofer CNT, Fraunhofer ENAS, Fraunhofer ESK, Fraunhofer HHI, Fraunhofer IHF, Fraunhofer IIS, Fraunhofer IISB, Fraunhofer IMS, Fraunhofer IPMS, Fraunhofer ISIT, Fraunhofer IZM and the guest Fraunhofer FOKUS, Fraunhofer IZFP-D as well as Fraunhofer IDMT belong to this Fraunhofer Group. Its purpose is to recognize and anticipate new trends in microelectronics applications and to incorporate them in the future strategic plans of the member institutes.

This is generally done by defining joint focal areas of research and through joint projects. This working method enables the cooperating institutes to offer their customers, in particular innovative small and medium-sized firms, access to cutting-edge research and developments in applications at an extremely early stage, thus giving them a distinct competitive advantage.

The business areas of the Fraunhofer Group for Microelectronics are:

- Ambient assisted living
- Energy efficient systems and eMobility
- Communication and entertainment
- Light
- Security
- Technology

The office of the Fraunhofer Group for Microelectronics serves as a central liaison point. Acting in an advisory function, it provides support to the steering committee of the Group for Microelectronics in matters related to the coordination of research content and the planning of future work.

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FRAUNHOFER-VERBUND MIKROELEKTRONIK

Die Fraunhofer ENAS ist seit ihrer Gründung Mitglied im Fraunhofer-Verbund Mikroelektronik (VμE). Er koordiniert seit 1996 die Aktivitäten der auf den Gebieten der Mikroelektronik und Mikrointegration tätigen Fraunhofer-Institute: Fraunhofer CNT, Fraunhofer ENAS, Fraunhofer ESK, Fraunhofer HHI, Fraunhofer IHF, Fraunhofer IIS, Fraunhofer IISB, Fraunhofer IMS, Fraunhofer IPMS, Fraunhofer ISIT, Fraunhofer IZM und der Gastinstitute Fraunhofer FOKUS, Fraunhofer IZPF-D und Fraunhofer IDMT.

Die Aufgabe des Fraunhofer-Verbundes für Mikroelektronik besteht dabei im frühzeitigen Erkennen neuer Trends bei mikroelektronischen Anwendungen und deren Berücksichtigung bei der strategischen Weiterentwicklung der Verbundinstitute.

Dies geschieht vorwiegend in Form gemeinsamer Themenschwerpunkte und Projekte. Auf diesem Wege kann der Verbund insbesondere innovativen mittelständischen Unternehmen rechtzeitig zukunftsweisende Forschung und anwendungsorientierte Entwicklungen anbieten und so entscheidend zu deren Wettbewerbsfähigkeit beitragen.

Die Geschäftsfelder des Fraunhofer-Verbundes für Mikroelektronik sind:

- Ambient Assisted Living
- Energieeffiziente Systeme und eMobility
- Kommunikation und Unterhaltung
- Licht
- Sicherheit
- Technologie

Die Geschäftsstelle des Fraunhofer-Verbundes Mikroelektronik fungiert als zentrales Koordinierungsbüro. Sie berät und unterstützt das Direktorium des Verbundes Mikroelektronik bei Fragen der inhaltlichen Abstimmung und der fachlichen Zukunftsplanung.

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FRAUNHOFER ENAS PROFILE

Smart Systems Integration by Using Micro and Nanotechnologies

The Fraunhofer Research Institution for Electronic Nano Systems ENAS in Chemnitz focuses on research and development in the fields of smart systems integration by using micro and nanotechnologies with partners in Germany, Europe and world wide.
The micro and nanosystem technologies as well as electronics are playing a key role in today's product development and industrial progress. They enable the integration of mechanical, electrical, optical, chemical, biological and other functions into a very small space with dimensions ranging from sub micrometres up to some millimetres. Combined with intelligence, power supply and communication ability, these systems are multi-device integrated and should be developed for use inside the host. Systems integration will determine the economic success of manufacturers and users coming mostly from consumer electronics, telecommunication, mechanical engineering, medical technology and automotive. To ensure long-term competitiveness, a sophisticated technological potential is necessary. The Fraunhofer ENAS is positioning itself to meet these challenges and participates very actively in the further development of smart systems integration and the required bridging of the gap from NANO to MICRO and to the MACRO world.

The main research activities of the Fraunhofer ENAS can be classified into the following topics:
Multi Device Integration:
development of MEMS/NEMS, prototyping of sensor and actuator devices, integration of such devices together with micro- and nanoelectronic components into systems, design of components and systems, development and implementation of test and characterization of MEMS/NEMS; examples are miniaturized spectrometer, inclination sensors, high-precision acceleration sensors and gyroscopes, Fabry Perot Interferometer
Reliability of Micro and Nano Systems:
thermo-mechanical reliability of micro and nano components in high-tech systems, core competence combination of thermo-mechanical simulation with advanced experimental methods, security
Printed Functionalities:
utilizing ink-jet and mass printing technologies for efficient industrial fabrication processes of printed components for smart systems, technology development and adapted measurement techniques
Back-end of Line (BEOL):
material, process and technology development for manufacturing on-chip interconnects and metallization for nanoelectronics / 3D integration / multi device integration, simulation and modeling of processes, equipment and interconnect systems
System Packaging:
core competence in development and application of wafer bonding processes for MEMS/NEMS packaging (chip and wafer bonding including combinations of new materials and bonding at low temperatures), 3D patterning technologies for silicon and non-silicon materials, CMP (chemical mechanical polishing)
Advanced System Engineering:
electromagnetic reliability and compatibility, development and design of custom-specific electronic modules

The main research areas of Fraunhofer ENAS are clearly visible in the structure of this institution. Six departments belong to Fraunhofer ENAS: Multi Device Integration, Micro Materials Center Chemnitz, Printed Functionalities, Back-end of Line, System Packaging and Advanced System Engineering.

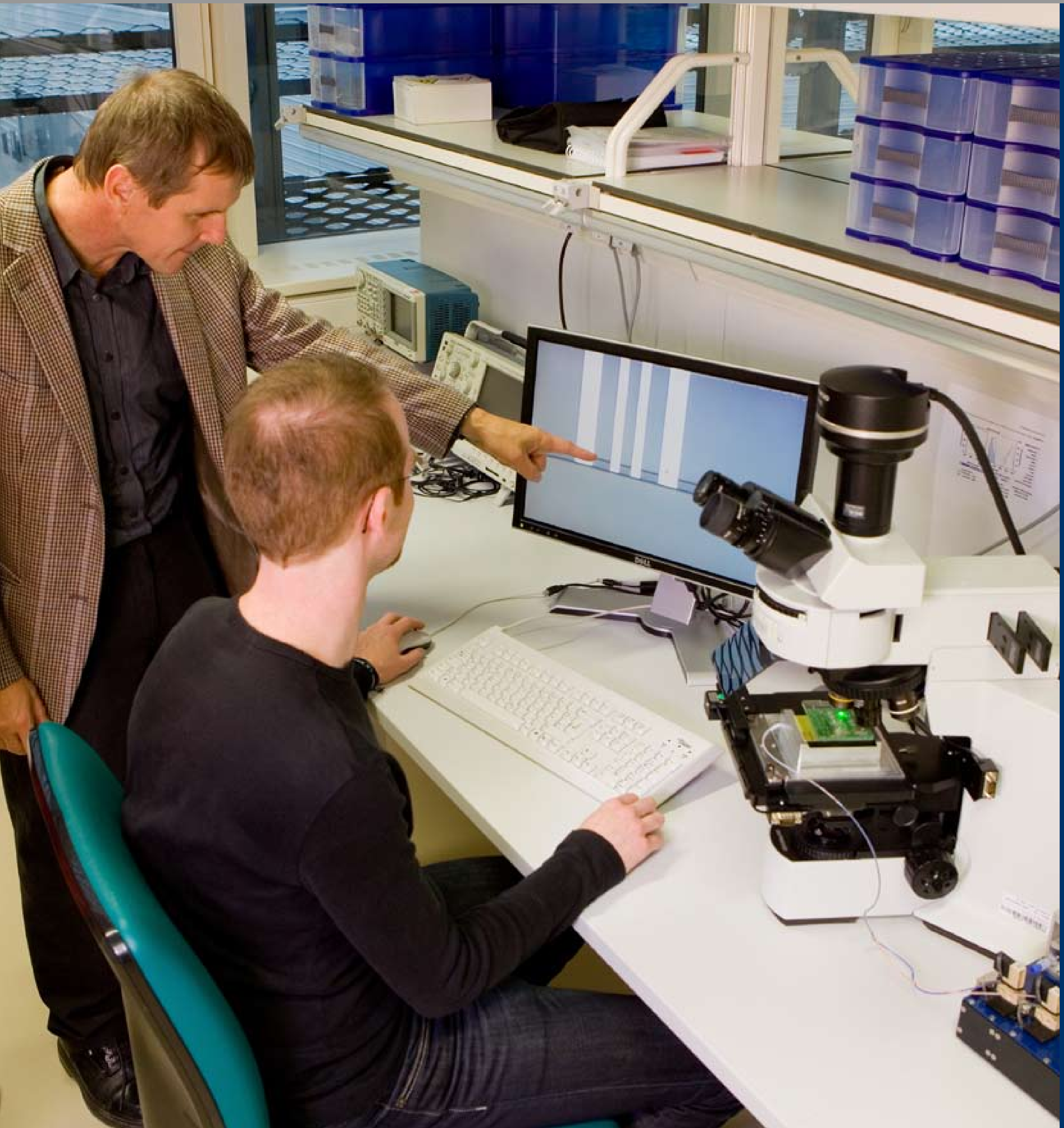
FRAUNHOFER ENAS IM PROFIL

Smart Systems Integration unter Nutzung von Mikro- und Nanotechnologien

Im Fokus der Fraunhofer-Einrichtung für Elektronische Nanosystem ENAS in Chemnitz steht die Forschung und Entwicklung auf dem Gebiet der Smart Systems Integration unter Nutzung von Mikro- und Nanotechnologien gemeinsam mit Partnern in Deutschland, Europa und der Welt.
Die Mikro- und Nanotechnologien sowie die Elektronik sind Schlüsseltechnologien gegenwärtiger Produktentwicklungen und des industriellen Fortschritts. Sie gestatten die Integration mechanischer, elektrischer, optischer, chemischer, biologischer und weiterer Funktionen auf engem Raum mit Dimensionen im Bereich von Submikrometern bis zu einigen Millimetern. Ausgestattet mit Intelligenz, einer autarken Energiequelle und der Möglichkeit der Kommunikation sind solche Systeme hoch integriert und für die Anwendung im Host entwickelt. Systemintegration wird zunehmend den ökonomischen Erfolg der Hersteller und Anwender der Konsumgüterelektronik, Telekommunikation, Maschinenbau, Medizintechnik und Automobilbau bestimmen. Um langfristig wettbewerbsfähig zu sein, ist ein hoch entwickeltes technologisches Potential unabdingbar. Die Fraunhofer ENAS stellt sich diesen Herausforderungen und arbeitet sehr aktiv an der weiteren Entwicklung der Smart Systems Integration und verbindet damit die Nano- mit der Mikrowelt der Forscher und Entwickler mit der Makrowelt der Anwender.

Die Hauptforschungsgebiete der Fraunhofer ENAS sind:
Multi Device Integration:
die Entwicklung von MEMS/NEMS (micro and nano electro mechanical systems), ihre Integration mit mikro- und nanoelektronischen Komponenten zu Systemen, die Entwicklung und Implementierung von Test und Charakterisierung von MEMS und NEMS; Beispiele sind miniaturisierte Spektrometer, Neigungssensoren, hoch präzise Beschleunigungssensoren, Fabry-Perot Interferometer
Zuverlässigkeit von Mikro-und Nanosystemen:
Thermo-mechanische Zuverlässigkeit von Mikro- und Nanokomponenten in Hightech-Systemen, Kombination von thermo-mechanischer Simulation mit experimentellen Methoden, Sicherheit
Gedruckte Funktionalitäten:
Anwendung von Inkjet- und Massendruckverfahren für effiziente industrielle Herstellungsprozesse von gedruckten Komponenten für intelligente Systeme, Technologieentwicklung und Entwicklung adaptierter Messtechnik
Back-end of Line (BEOL):
Materialien, Prozess- und Technologieentwicklung für die Herstellung von On-Chip-Interconnects und Metallisierung für 3D-Integration sowie Multi-Device-Integration, Simulation und Modellierung von Prozessen, Geräten und Interconnectsystemen
System Packaging:
Entwicklung und Anwendung von Waferbondverfahren für MEMS/NEMS Packaging, 3D-Patterning Technologien für Silizium und Nicht-Silizium-Materialien, CMP (Chemical Mechanical Polishing)
Advanced System Engineering:
Elektromagnetische Zuverlässigkeit und Verträglichkeit, Entwicklung und Design von kundenspezifischen elektronischen Modulen

Die wesentlichen Forschungsgebiete der Fraunhofer ENAS spiegeln sich in der Struktur der Einrichtung wider.
Zur Fraunhofer ENAS gehören sechs Abteilungen:
Multi Device Integration, Micro Materials Center Chemnitz, Printed Functionalities, Back-end of Line, System Packaging und Advanced System Engineering.



DEPARTMENTS AND CORE COMPETENCES

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DEPARTMENT MULTI DEVICE INTEGRATION

Head of the Department: Prof. Dr. Thomas Otto

The development of micro and nanosystem technologies (MEMS/NEMS), prototyping of sensor and actuator devices, integration of such devices together with micro and nanoelectronic components to systems, design of component and systems and development and implementation of test and characterization of MEMS/NEMS are the main activities of the department Multi Device Integration. Examples are micro mirror spectrometer, RF-MEMS, gyroscopes and lab-on-chip systems.

These core competences are described in detail for the following three groups:

MEMS/NEMS Design

Modern modeling and simulation technologies are essential to design innovative products in MEMS/NEMS. The development of such systems requires an understanding of different physical interactions. Numerous commercial and customized software tools are employed for design, analyzing and optimizing complex micro systems. They are used to analyze interactions of various physical effects in micro and nano systems. Coupled field analysis enables accurate, real-world simulations of MEMS devices such as electrostatic comb drives, fluid damping, thermo-mechanical induced packaging stress and piezoelectric transducer behavior. The scientists have comprehensive experience in the development of varied MEMS devices like accelerometers, inclinometers, gyroscopes, micro mirrors, radio frequency MEMS switches and micro fluidic devices.

The core competences concern modeling and simulation solutions in MEMS design, mask layout and combination of numerical simulations with experimental methods. The main MEMS simulation activities are structural analysis, electrostatics and magnetostatics, low-frequency electrics and magnetics, circuit coupling, acoustic structural coupling, electrostatic-structural coupling, fluid-structural coupling capability to calculate damping effects on device response, micro fluidics and piezoelectric calculations. The scientists have an extensive knowledge in MEMS technology and work closely together with technologists to develop process flows and proper design.

Service:

* MEMS/NEMS design and optimization on device and system level
* Mask design
* Support in MEMS technology development

The research is focused on:

* MEMS design and optimization methods on device and system level
* Development of MEMS applications
* Basic research in multiscale modeling methods for nano devices

MEMS/NEMS Components and Systems

Besides the development of classical micro systems the group ‘Systems and Components’ is mainly focused on systems which are based on polymers and nanocomposites. An important part of the group activities deals with microfluidics and low cost polymer-based actuators.

As molecular based medicine and genomic research become more and more mature, in-vitro diagnostic approaches gain increasing interest in the field of medical health care. Another trend focuses on bringing medical diagnostics closer to the patient and carrying out even complex biomedical analyses at the ‘point-of-care’. Integrated systems for in-vitro diagnostics are of great interest for both markets. Within a joint research project of seven institutes of the Fraunhofer-Gesellschaft, a technology platform has been developed which aims at providing the technological basis for an accelerated launch of new in-vitro diagnostic products (http://www.ivd-plattform.fraunhofer.de). Within this project, a complete microfluidic cartridge for in-vitro diagnostics has been developed at Fraunhofer ENAS. Due to its modular concept, the microfluidic platform is able to work with both, optical and electrochemical biosensors. The cartridges incorporate liquid reagents and integrated micropumps. As they are completely self-contained, the cartridges are able to run bio assays in a fully automated way.

Nanocomposite materials offer certain advantages over classical inorganic materials such as easy processing and nearly unlimited design of components. Additionally, typical included nanoeffects (e.g. quantum confinement) enhance the system performance substantially or provide completely new functionalities. But a big challenge is to bring nanoparticles, nanorods or nanowires in contact to the micro and macro world. To overcome these difficulties we favour different approaches such as use of special conditioned composits (interfaces, orientation of inclusions) or self-assembling technologies.

In current projects humidity and magnetic positioning sensors are being developed by means of nanocomposites. First results look very promising and it seems that the big advantage of composites, namely the separate conditioning of inorganic (nano)inclusions and the organic matrix, lead to cost efficient sensitive sensors with simultaneously high reliability and sensor lifetime.

Exemplary for the activities in the field of microoptics is the development and validation of infrared MEMS spectrometers. Such a miniaturized spectrometer has been developed in cooperation with the company Colour Control Farbmesstechnik GmbH Chemnitz. The systems can be configured for different wavelength bands and hence used in various applications. Food studies, environmental monitoring, medical diagnostics, metrology or the physical forensic analysis belong to the fields of application of this spectrometer.

Measurement, Test and Characterization

The test and characterization group offers the development and utilization of test technologies, test strategies and the accomplishment of measurements.

A method for extremely fast determination of dimensional and material parameters based on a combination of Finite Element Analysis (FEA) and measurement of eigenfrequencies has been developed in the recent years and is now improved and adapted to different classes of MEMS devises. This method comprises of a multivariable FEA which is done in parallel to the design and simulation of the behavior of the device only one time. In fabrication sequence, the eigenfrequencies are measured by optical vibration detection and electrostatic excitation of the sample by external optical transparent electrodes. A further step calculates the dimensions or material parameters by estimation algorithms. Since this kind of test is performed in less than two seconds and at wafer level, the test method can easily be applied in the MEMS fabrication line.

Furthermore, the development of test strategies for MEMS, MOEMS and RF-MEMS is a major concern. The aim is to assist MEMS fabrication by time effective test sequences to determine function parameters of MEMS, like sensitivity and cross-sensitivity, resonant modes, electrical properties of the transducers and optical or microwave performance. Very specific test sequences have to be applied to find defective chips in the earliest stage in fabrication to have the opportunity to control the fabrication process.

Amongst others, following instrumentation is available:

* MEMS motion test stage including wafer probe station, in-plane and out of plane motion analyzer, miniaturized vacuum chamber, LCR-meter, signal generator
* Topography measurement instrumentation and white light interferometer including stroboscopic illumination to measure dynamic deformation
* RF-MEMS test bench including wafer probe station, vector network analyzers up to 50 GHz, signal generators and spectrum analyzer.

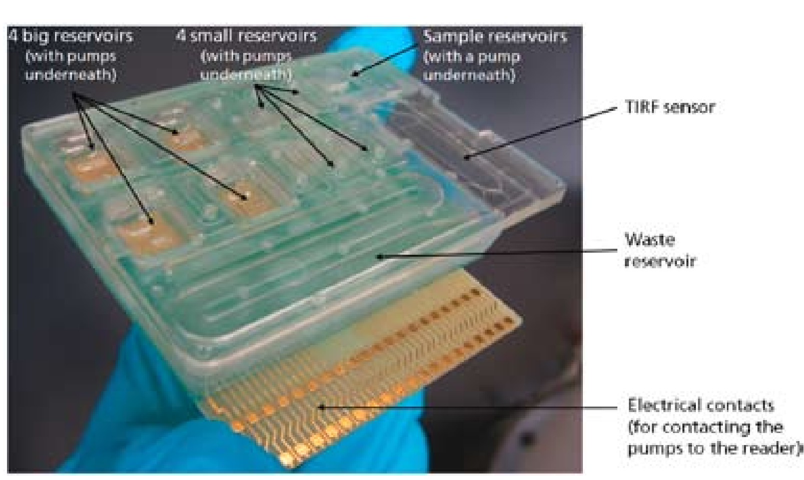

FIG. 1

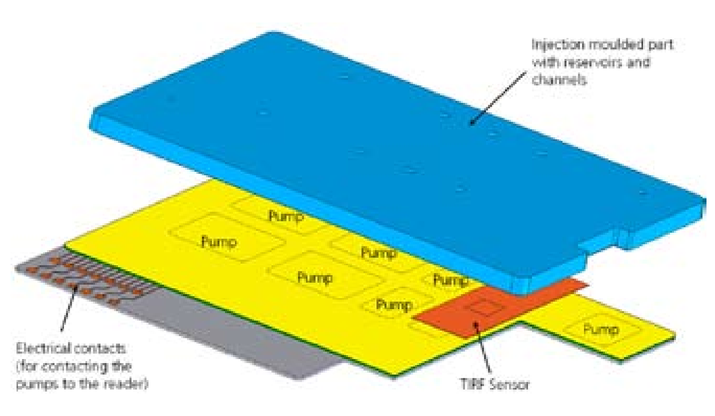

FIG. 2

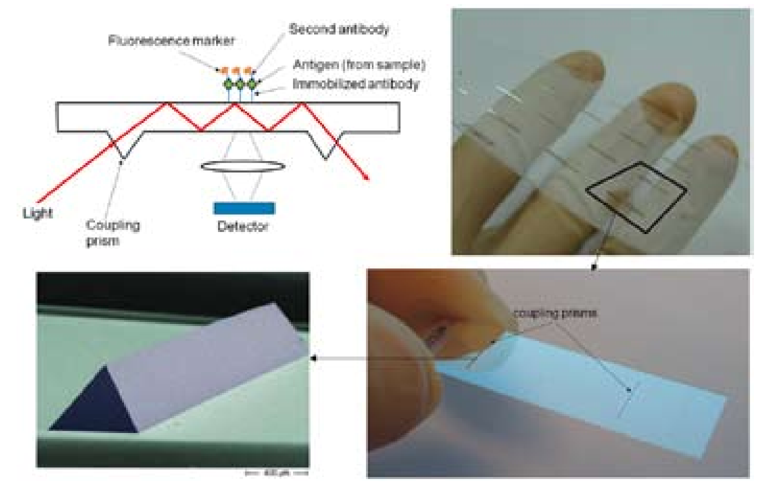

FIG. 3

FIG. 4

SELF-CONTAINED CARTRIDGES FOR IN-VITRO DIAGNOSTICS – THE FRAUNHOFER "IN-VITRO DIAGNOSTIC PLATFORM"

Jörg Nestler, Thomas Otto, Thomas Gessner

Due to recent advances in molecular medicine and genomic research, in-vitro diagnostics is playing an increasing role in the current and future health care system. Additionally, many applications (such as emergency medicine and infectious diseases) require a more de-centralized diagnostics, bringing even complex analyses from central labs closer to the patient. This trend is called point-of-care (PoC) diagnostics. Integrated microfluidic systems for in-vitro diagnostics are of great interest especially in the PoC diagnostic market. Specialized approaches have already been developed and successfully marketed, but were mainly focused on basic blood parameter determination.

Within the Fraunhofer "in-vitro diagnosic platform"– a joint research project of seven Fraunhofer Institutes [1] – a new, more flexible approach has been developed. The platform aims for a standardized processing of customers' bioassays using "translation rules" for translating the macroscale assays to an integrated microfluidic system. The modular system concept includes

- Optical and electrochemical biosensors (Fraunhofer IPM and ISIT)
- Readout instruments for electrochemical and optical biosensors (Fraunhofer IPM and ISIT)
- Biochip design and assay development (Fraunhofer IBMT and IGB)
- Active, self-contained, microfluidic cartridges (Fraunhofer ENAS and IAP)
- Complete fabrication and assembly technology (Fraunhofer IPA).

During the whole development process, the complete fabrication line is considered, avoiding the usual gap between "prototype" and "product" [1].

Cartridge Concept

As stated above, one aspect of the platform are self-contained, active microfluidic cartridges. These cartridges have been developed at Fraunhofer ENAS during the last years and can hold an electrochemical or optical biosensor, integrated reagents as well as integrated microfluidic actuators (pumps). Being used together with a readout instrument it can thus run a bioassay in a fully automated way without any fluidic interfaces to the readout instrument.

A complete cartridge is depicted in Fig. 1. The layout is adapted from the layout of half of a microtiter plate having outer dimensions of about (60 x 80) mm² and filling holes at the appropriate positions. The cartridge contains eight reservoirs with volumes between 65 µl and 130 µl, one sample reservoir (up to 65 µl), a sensor area and a waste reservoir. To avoid any fluidic interface to the readout instrument, reagents can be stored directly in the reservoirs and transported through the channel system by means of integrated low-cost pumps.

The microfluidic cartridges consist of two main parts (Fig. 2). The bottom part provides the integrated micropumps together with an electrical interface to the readout instrument. The injection moulded top part of the cartridge incorporates the reservoirs and the microfluidic channel system. The reservoirs can be filled from the top through filling holes.

As optical sensing element, a total internal reflection fluorescence (TIRF) sensor can be mounted into the cartridge. For this sensing principle, light is coupled into a thin polymer foil by means of a coupling prism (Fig. 3). The light propagates in the foil by total internal reflection. The evanescent field of this light is then able to excite fluorochromes on the surface of the foil [2-4]. To ensure a high surface quality (low straylight), and to fabricate the coupling prisms, precise polymer hot embossing (at wafer scale) on a Suss SB8 substrate bonder has been used [2] at Fraunhofer ENAS (Fig. 3).

Integrated Low-Cost Micropumps

As described earlier, integrated micropumps are one key element of the cartridges [4]. This avoids contamination and interfacing issues, but raises the concern of higher costs for the cartridge. The pumping principle for the integrated micropumps must therefore be chosen mainly based on cost considerations and reduced to the minimum functional requirements of the application.

Even though there is a large number of publications proposing many different kinds of operation principles for micropumps since the 1980s [5], only few are suited for the described application and its constraints. One of the most promising pumping principle is the electrochemical generation of gas, allowing for large deflections or displacements, having low power consumption and requiring almost no additional assembly.

Thus, a technology has been developed to integrate electrolytic micropumps on a flat substrate by using a hydrogel as electrolyte. The gel is sealed by a deformable polymer membrane with low permeability for water vapor.

The actuator part is bonded to an injection moulded part with reservoirs and a microfluidic channel system (Fig. 2). During pumping, the deformable membrane of the actuator part deflects into a reservoir in the top part, driving the liquid into the channel system towards the sensing region. In Fig. 4, all reservoirs have been filled with inked water to illustrate the pumping process. Three of the nine reservoirs are emptied sequentially as it can be seen by the different liquid colors in the sensing region.

The fabricated cartridges still can be used for different kinds of bio-/immunoassays. The decision on which assay to be run on a cartridge is only made by the antibodies spotted on the surface of the integrated biosensor (optical or electrochemical) and the liquids filled in the reservoirs. These last two steps can be carried out even months after the fabrication of the rest of the cartridge, making the fabrication independent of the final application.

Summary and Outlook

With the described platform, a sandwich immunoassay for detecting the inflammation marker CRP (C-reactive protein) was run on the cartridge. The results and more details have been reported in [3]. Besides immunoassays the platform and the technologies can be adopted also for many other (low-cost) applications in which an integrated, electrically controllable transport of liquids through micro channels is desired.

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[3] Brandenburg, A.; Curdt, F.; Nestler, J.; Otto, T.; Wunderlich, K.; Michel, D.: Integrated point of care testing system based on low cost polymer biochips, Proc. SPIE (7169), Photonics West 2009, pp. 7169-1.

[4] Nestler, J.; Schueller, M.; Morschhauser, A.; Otto, T.; Gessner, T.; Brandenburg, A.; Michel, D.; Bier, F. F.: Lowcost in-vitro diagnostic cartridges with integrated sensor, micropumps and reagents, Proc. Smart Systems Integration, Brussels, 2009 Mar 10-11 (ISBN 978-3-89838-616-6).

[5] Woias, P.: Micropumps - past, progress and future prospects, Sens. Act. B 105 (2005), pp. 28-38.

Legend:

Fig. 1: Working principle of the TIRF biosensor (top left) and 130 µm thick hot embossed sensor foil (at wafer scale, single sensor element and SEM image of coupling prism)

Fig. 2: Schematic drawing of the cartridge. It consists of a lower part with low-cost micropumps and their electrical contacts as well as an upper injection moulded part with microchannels and reservoirs

Fig. 3: Pumping out of the first three reservoirs facilitated by the integrated low-cost micropumps

Fig. 4: Fully assembled microfluidic cartridge with sensor

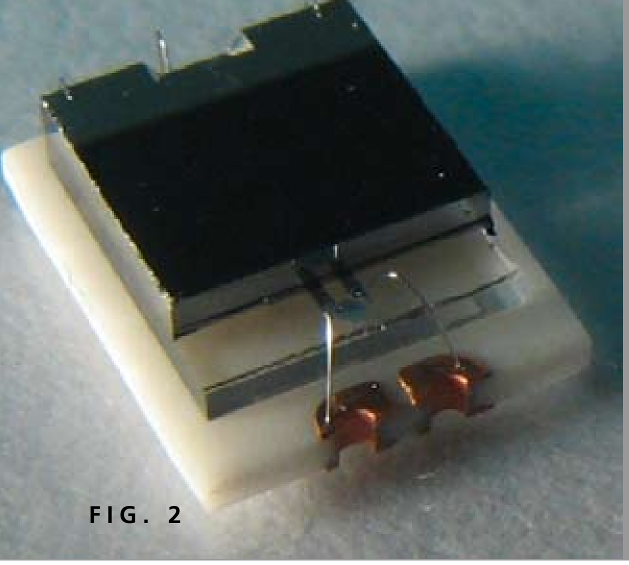

FIG. 2

FIG. 3

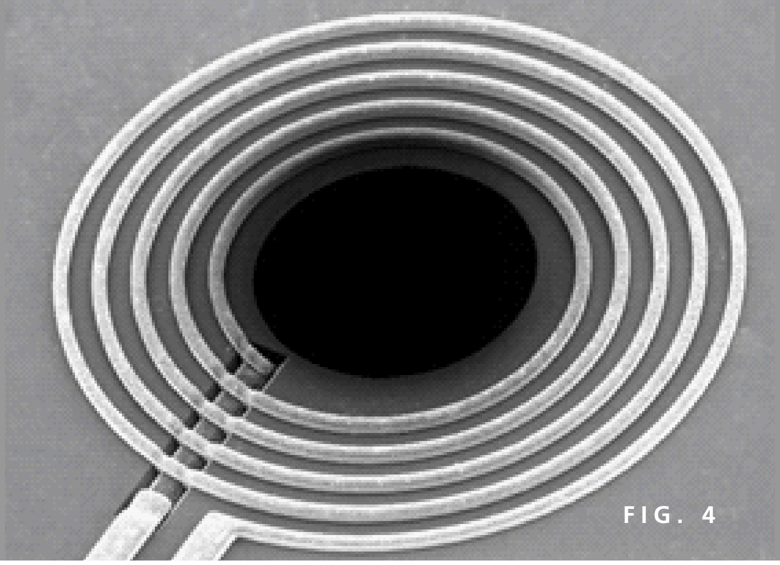

FIG. 4

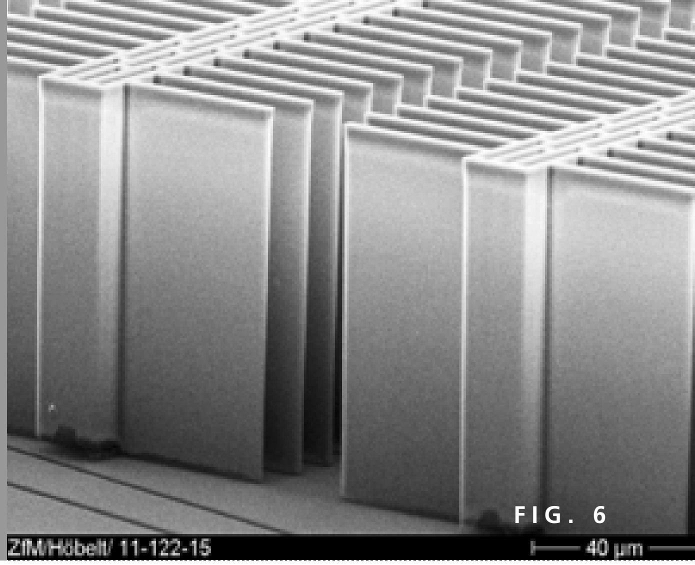

FIG. 6

RF-MEMS DEVICES ON C-SI SUBSTRATE

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The application of MEMS fabrication technologies for RF and microwave devices is paving the way to small, high quality passive components. High Q-factor micro coils, fast signal switches and tunable MEMS air gap capacitors (varactors) are the most important examples. An integration of passive components to electronic circuits on chip or their placement in the closest proximity of electronics becomes possible and reduces the size of the systems dramatically. Moreover, a superior system performance can be achieved. RF passives, which have been fabricated on c-Si substrate are in the focus of this report.

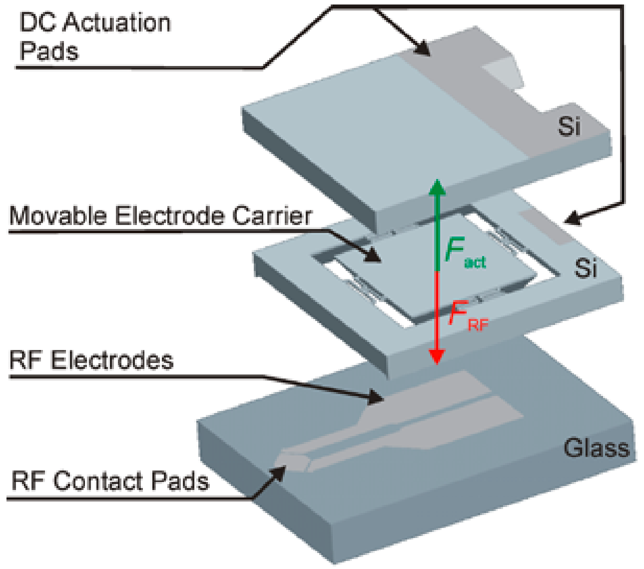

FIG. 1

Varactor

A parallel plate, metal-air-metal capacitance is the main part of this high Q-factor RF-MEMS varactor. The application of silicon bulk technology and wafer bonding processes allows the fabrication of large area electrodes with narrow electrode separation. Therewith, continuous tunability and rather high RF capacitance values (required for UHF applications) are obtained.

Typical reliability and functionality limiting issues of RF-MEMS varactors like charging and RF self-actuation are addressed by minimizing the electrode area covered with highly isolating dielectrics and by arranging the RF and DC actuation electrodes vertically (see Fig. 1). Since attractive forces, proportional to the square of the rms-voltage, are generated using the electrostatic principle, the DC actuation can be used to compensate detuning effects resulting from high RF amplitudes. Further on, intrinsic stability against high power RF bursts is achieved by the highly damped mechanical response. Consequently, it is prevented that resonance induced mechanical oscillation at narrow tone spacing and accompanying intermodulation generation occurs.

The diced and packaged device is shown in Fig. 2. Due to the use of a carrier substrate with plated castellation, it is possible to mount the device to a PCB by standard soldering techniques. Due to high resistivity silicon material the RF and DC are intrinsically isolated. Special biasing networks are not required.

Micro Coil for NMR Analysis of Nano Liter Samples

The application of NMR spectroscopy for the analysis in biochemistry is an important approach to understand the metabolic processes. Typically, only extremely small amount of sample substance is available. It does not match the size of commonly used coils of NMR probes and results in low signal to noise ratio. Micro coils with inner volumes in the nano liter range substantially improve the situation. The application of Si etching technologies and electroplating of 20 µm thick Cu coils in photo resist mold (Fig. 3) resulted in a chips which are stacked for realizing a Helmholtz configuration (Fig. 4). This setup provides superior performance regarding sensitivity and spectral resolution. Experimental results with a NMR probe head containing the micro coils show that metabolites in nano mol quantity are clearly detectable (Fig. 5).

Legend:

Fig. 1: Schematic view of a MEMS varactor
Fig. 2: Image of the varactor chip
Fig. 3: SEM view of a micro coil
Fig. 4: Components of the micro coil in Helmholtz configuration
Fig. 5: Measurement result (black curve) and simulation values of a mixture of metabolite, each with 1.3 nano mol quantity
Fig. 6: SEM view of a part of the actuation electrodes
Fig. 7: Micro photograph of the contact section of the switch with lateral actuation

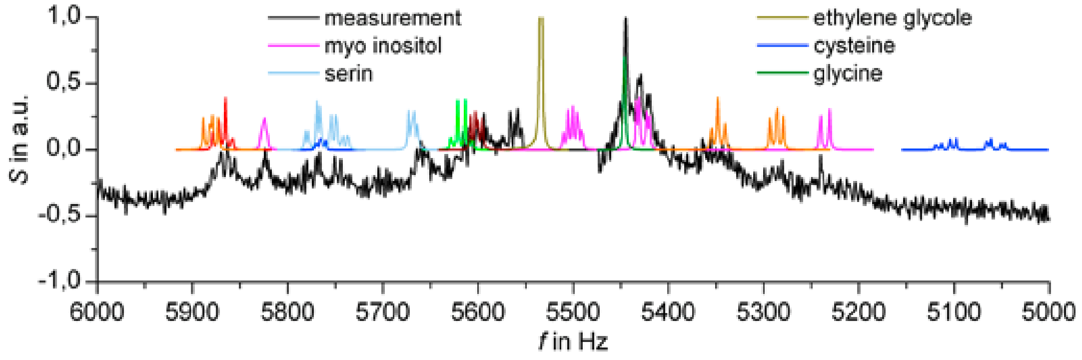

FIG. 5

RF Switch

Switches for RF application are ranking as the key components for integrated RF and microwave systems. An electrostatically actuated micro switch device with metal contact (Fig. 6) for the frequency range of up to 4 GHz has been developed.

The device is fabricated by high aspect ratio micromachining and wafer level packaging technologies and can be flip chip mounted. The actuation section based on lateral comb drives (Fig. 6) and the contact section (Fig. 7) are separate parts of the chip. Live time tests showed 10^9 switch cycles before breakdown.

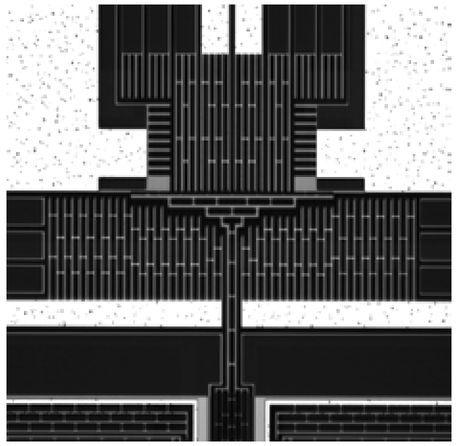

FIG. 7

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DEPARTMENT MICRO MATERIALS CENTER CHEMNITZ

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Competences

- Mechanical and thermal reliability (micro reliability and nano reliability of components, systems and devices)
- Lifetime analysis, lifetime prognosis and -optimization
- Crack and fracture simulation and test
- Local deformation analysis (microDAC, nanoDAC, FIBDAC, nanotom, EBSD, Raman, X-ray etc.)
- Security research using micro and nanotechnologies (micro security, safety and reliability combined)
- Reliability for Clean Technology (micro and nanotechnologies for Cleantech applications)
- Reliability for Space Research (JTI Clean Sky, MEMS, Sensors and Reliability)
- Micro reliability for automotive electronics and sensorics
- Complicated solder problems (micro solder, solder interconnects)
- Reliability for packaging and interconnects
- Reliability for medical systems
- Complex loading and reliability (vibration, humidity, thermal, mechanical, electrical, diffusion etc.)
- Reliability for micro and nanoelectronics

Available Methods for Reliability Evaluation and Optimization

- Thermal and thermomechanical field simulation based on parametrized modeling
- DOE Design of experiments- combined simulation and measuring
- Local deformation analysis using various techniques
- Selfstress analysis (e.g. in FIB)
- Vibration analysis combined wih reliability estimation techniques
- Lock-in thermography
- Moire technique (micromoire etc.)
- Laser metrology
- AFM, SPM (also humidity sensitive), acoustic AFM (AFAM) EBSD, micro and nanoRaman Strain Analysis
- Crack analysis by tomography (nanotom)
- Molecular modeling combined with experiments
- DIC- digital image correlation methods combined with various experiments

Research Highlights

1. Longterm Micro- and Nanoreliability Analysis in the new “Under the Earth MicroReliability Lab“

Fraunhofer ENAS established the first European ”Under the Earth Health Monitoring Microreliability Lab” for micro and nano components. In cycle test chambers under known environmental conditions experimental reliability investigations have been carried out (humidity, temperature, cyclic loading) in direct cooperations with industry (automotive, electronics) and research facilities (e.g. space research). Longterm reliability investigations take place which are to study in detail complex behavior of micro components and systems containing nano structured materials of different kind. This lab is determined to test new reliability strategies for micro and nano reliability applications and develop new “clean tech competencies“ in various applications for industry.

Strong cooperation with labs of other institutes and companies takes place in the frame of EUCEMAN, the European Center for Micro- and Nanoreliability. The department Micro Materials Center Chemnitz (MMCC) is on the way to become a European Reliability Keylab sponsored by Euceman (see http://www.euceman.com/).

2. New Research Group established for Clean Tech Reliability

In the department MMCC a new research group was established to develop the new field of reliability analysis for clean tech. One can describe the aim of this group by providing new ideas for reliability evaluation and optimization in the field of nano and microtechnologies with “clean or green” background.

The group is very active in the European Joint Technology Initiative (JTI) Clean Sky and coordinates workpackages in several EU projects in this field and is also very active in the frame of Fraunhofer research for JTI Clean Sky.

3. Outstanding Research Results in the Field Nanoelectronics Reliability Analysis

A research team of MMCC has dealt with low-k simulation for nanoelectronics in direct cooperation with AMD/GLOBALFOUNDRIES lobal Foundries simulation an experimental verification of BEOL low-k models have been carried out on the basis of most modern DOE analysis. Advanced crack avoidance strategies have been applied. The research activities were funded also by the State of Saxony. The project activities were coordinated by Dr. Auersperg from MMCC.

Another activity in the field of electronics reliability research was the cooperation with Infineon in the Medea Project ELIAS. This European Project was awarded as the best Medea project of EU in 2009. Dr. Dudek and his crew from the simulation group have found a lot of gratitude by industry for their research in this field.

The results of the MMCC team in direct cooperation with Fraunhofer IZM Berlin lad to a breakthrough in reliability analysis for special electronic components for automotive electronics applications.

4. EU Projects NanoPack and NanoInterface

The Micro Materials Center Berlin coworkers did a very good research in the field of nanoreliability analysis for new cooling concepts in electronic packaging. The Fraunhofer ENAS department in Chemnitz and the Fraunhofer IZM department in Berlin developed new technologies together with companies like BOSCH, IBM (Rüschlikon in Switzerland), Thales et al. The reliability analysis of these technologies carried out by the MMCC crew was an important constituent of the project. One work package is coordinated by Prof. Wunderle, Chair at Chemnitz University of Technology and member of MMCC at Fraunhofer ENAS.

In the EU project NanoInterface the group received good results for reliability analysis of packaging systems on the base of molecular modeling combined with experimental application.

5. New activities in Selfstress Measurement with NanoDAC/FIBDAC and new NanoRaman Experiments

In the group led by Dr. D. Vogel a new selfstress determination method has been developed on the basis of FIBDAC; the local deformation analysis carried out in the FIB using digital image correlation methods. Micro and nanoRaman experiments in the new Raman lab which is jointly operated by Fraunhofer IZM Berlin and Fraunhofer ENAS Chemnitz, have been shown to become more and more practical technique in advanced nanotechnology analytics. Combined nanoDAC, FIBDAC and nanoRaman investigations could be a very good approach in coming nano analytics for MEMS, NEMS and related smart systems as well.

THERMO-MECHANICAL RELIABILITY OF BEAM FORMING NETWORK FOR RF ORBIT APPLICATIONS

Dr. Johann-Peter Sommer

“MultiFeed”, a two years research project of IMST Kamp-Lintfort and Fraunhofer ENAS, started in April 2009. The target is to develop a configurable multi feed network for reflector antennas used in satellite communication (Ka band). A beam forming network (BFN) is applied to feed a group of single antennas which radiate onto an antenna reflector of a satellite in the orbit, and finally, to a well defined area on earth. This way, unsettled regions need not to be supplied, and high energetic efficiency can be achieved.

BFNs are very complex and have been manufactured up to now from a single piece of brass by high precision milling. This was an expensive and time-consuming process and resulted in relatively heavy parts. The idea of IMST was to design a low-weight BFN combining advanced materials and technologies, without any drawback in the electrical performance.

The BFN, which is under construction, needs for a series of LTCC parts (low temperature cofired ceramics) as sockets for the antennas, and a connecting board, consisting of several organic layers with RF-adapted properties for low permittivity and low loss. Due to the different thermal expansion of the materials, the interconnects between LTCC and the organic board have to be designed very carefully in order to ensure high reliability with respect to temperature differences between bright and earth shadow sides in the orbit.

Fig. 1 represents an initial design proposal of the interconnection area. Due to symmetry, the corresponding FE model had only to represent 1/12 of the part. The RF interconnection to the neighboring cell was detected to be the most critical detail with respect to temperature changes, Fig. 2, and will be in the centre of interest in the next phase of the project.

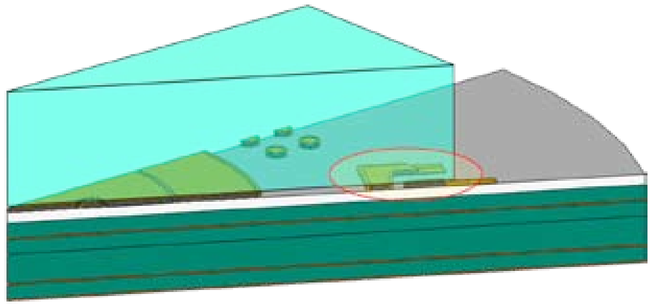

FIG. 1

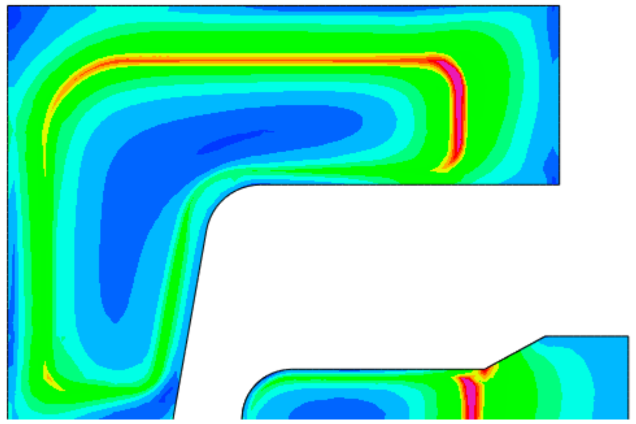

FIG. 2

Legend

Fig. 1: FE model for structural analysis of an interconnection in a beam forming network

Fig. 2: Stress concentrations at the interface between RF contact and solder, induced by alternating temperatures

The new “Under the Earth MicroReliability Lab” for longterm micro and nano reliability analysis.

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DEPARTMENT PRINTED FUNCTIONALITIES

Head of the Department: Prof. Dr. Reinhard R. Baumann

The department Printed Functionalities focuses on printing technologies for the manufacture of printed products which do not solely address the human visual sense. These printed products will have functionalities beyond color enabling them to perceive their neighborhood and their own state, allow the interaction with a user and the communication with computer networks, in short: convey them to an intelligent item of the internet of things.

Additionally printed functionalities can improve and enhance the performance and the architecture of smart systems e.g. by printed interconnectors or printed power modules.

The highlight of the department in 2009, contributing to the success of the whole Fraunhofer ENAS institution, has been the tremendous media response on the printed thin film battery developed in close cooperation of Andreas Willert (Fraunhofer ENAS), André Kreutzer (Menippos GmbH), Ulrike Geyer (Chemnitz University of Technology) and Reinhard Baumann (Fraunhofer ENAS) who headed the project from the very beginning. The initial press release came out during the nanotech exhibition in Tokyo/Japan in February 2009, followed by a series of commenting articles in the internet, in newspapers and journals. The highest profile in the media reached the team after the New York Times Magazine added the Fraunhofer ENAS batteries to the top five technology achievements of the year 2009 last December.

The idea of improved printed power sources has its roots in the garage of André Kreutzer and his early cooperation with Prof. Dr. Reinhard R. Baumann at the Institute of Print and Media Technology of the CUT. Kreutzer, Willert and Geyer carried out further basic research on the materials and developed an effective printing process to manufacture flexible and cheap power sources with an energy content which is adapted to the power requirement and the geometric form given by every single application. The Fraunhofer ENAS team is currently setting up new equipment for further contributions to the industrialization of the printing based production of integrated power sources.

The Fraunhofer ENAS thin film batteries are a convincing example of employing printing technologies for the deposition of functional materials in patterns required in subsequent technological steps.

Today's printers are equipped with highly advanced press and post-press technologies to produce high-quality print products. These products are solely made to be recognized by the human senses. Most commonly known is the visual reception of color and sharpness, sometimes even glossiness. Special varnishing techniques enable the printer to apply haptic elements to his products. Using special inks containing micro-encapsulated odorous substances even the human scent can be addressed. These printed functionalities are state-of-the-art and they are based on the traditional printing processes gravure, offset, flexo and screen printing as well as the digital printing processes electro photography and inkjet.

The today's printing technologies are well developed processes to transfer colored ink dots onto fiber based substrates, plastic foil or sheet metal. The print quality is satisfactory when the human eye sizes the well defined ensemble of screen dots as a halftone image or even a full tone area. In case of haptic or odor elements similar human sense based quality characteristics can be defined. Printing haptic or odor elements is going beyond traditional color printing, facilitating besides the regular functionality "color" further functionalities manufactured by printing.

On this note the term "Printed Functionality" goes far beyond color and we envision that the functionalities electrical conductivity, adapted dielectric properties, electrical semi-conductivity, electric power, electro-luminescence / light emission, sensing environment, surface protection, intelligence via chip or even catalysis will be manufactured by employing press and post-press technologies. And we expect that the digital printing technology inkjet will contribute substantially by enabling the deposition of very small amounts of expensive functional materials.

Under more general aspects printing is a highly efficient imagewise coating technology to deposit functional materials in a predefined thickness only at the right position on an appropriate substrate. Which means printing is an additive technology in contrast to subtractive technologies, characterized by coating the substrate with a continuous material film initially and remove the material imagewise from the substrate in expensive additional subsequent steps.

Given the today's high accuracy and reproducibility of printing based material deposition in conjunction with the remarkable potential for further developments, printing is expected to be the dominating technology for the fabrication of smart printed matter in high quantities. However, no single printing method is capable to offer an all-encompassing performance. Therefore, instead of using a single printing technology, combinations of contact printing methods (gravure, screen, flexo), inkjet printing, laser processing and further high volume production technologies need to be utilized. New modular machine concepts shall warrant a flexible design of manufacturing processes at reduced investment costs for smart packaging production. We expect a growing number of printed functionalities which in many applications will be supplemented by silicon-based micro and nano systems which are likewise developed in the Fraunhofer ENAS labs.

The evolution in the field of "printed smart objects" depends on the accomplishment of the challenges in the interdisciplinary development of complex functional inks, flexible manufacturing processes and modular machine systems with integrated analogue or digital manufacturing technologies.

If these printed smart objects shall be enabled to exchange data with computer networks they need to be stuffed with wireless Radio Frequency communication technology, typically consisting of a Si-chip and an antenna. The efficiency of RF communication strongly depends on the dielectric environment in which the antenna transmits the data. And in reality it is found that more or less every object needs an optimized antenna design for a reliable data communication. In case of printed objects it is obvious that the optimized antenna could be manufactured by printing it directly onto the object together with all the colors. The department Printed Functionalities follows these ideas and hence focuses currently, besides further challenges, on the design, printing and characterization of appropriate antennas.

For all these developments mentioned above we employ traditional and digital printing technologies to manufacture new printed products, taking advantage of the additive character of the printing technologies and their high productivity. We focus on drop-on-demand inkjet, screen, and gravure printing and we develop technologies for the integration of silicon electronics into printed smart objects. An important factor for success will be our close cooperation with the Chemnitz University of Technology and further local and global industrial and academic partners.

Competences

* Printed functionalities: conductivity, semi-conductivity, insulation, energy accumulation, catalysis, light based energy conversion
* Printed thin film batteries
* Printed smart objects with integrated micro/nano systems
* Device prototyping and industrialization of their manufacturing
* Characterization of inks, functional layers, components and systems

We offer the following services:

* precise deposition of liquid processible materials to form patterned layers with defined properties, utilizing printing technologies
* specific employment of inkjet techniques for resources-saving, additive material deposition
* printing-workflow development to optimize the manufacture of new functionalities
* material and layer characterization: viscosity, surface tension, morphology, electronic properties, layer zoning, layer interaction
* development of innovative components for specific applications based on printing technologies, e.g. flexible energy/battery systems
* printing of conducting patterns, e.g. antennas or electrodes.

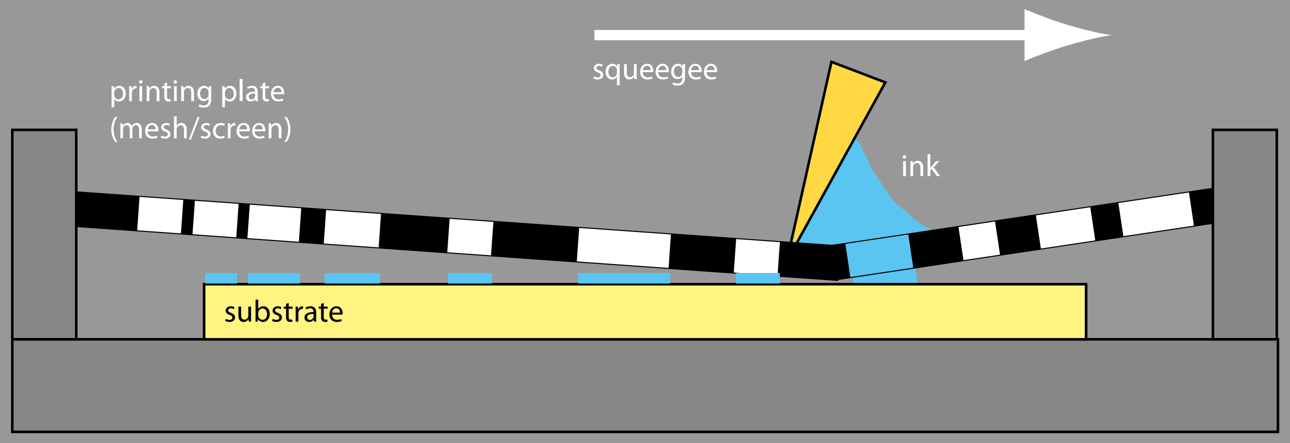

FIG. 1

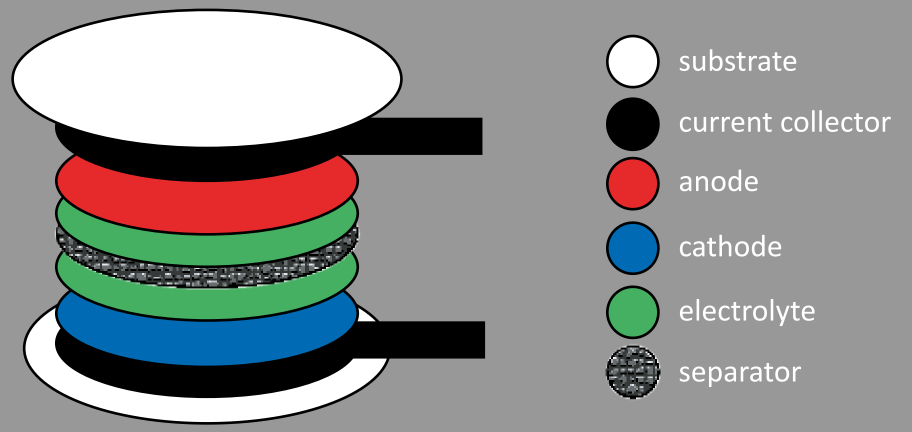

FIG. 2

THIN FILM BATTERY MANUFACTURED IN LAB ENVIRONMENT USING PRINTING TECHNOLOGIES

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Abstract

Printing technologies are highly productive and cost efficient production technologies, having the characteristic of being highly flexible. The term printed functionality describes all forms of interactivity, intelligence or additional electronic functions which may be transferred onto a substrate by using printing technologies [1]. This article describes the manufacturing of thin film batteries (TFB's) of the zinc manganese dioxide system by screen printing technology. This is to make sure that requirements on the independency of electronic components can be met in the future. Today electronic applications are ubiquitous and may be found in all areas of our daily life [2]. One of the basic requirements is their supply with electrical energy.

The requirements in the field of low end applications are manifold and met by TFB's in the following ways:

a) Production of TFB's in the same number as the product by integrating their manufacturing into the already existing production line.
b) Adjustment of the energy content of TFB's to the requirement of the product's demand over lifetime.
c) Fitting of geometrical shape of the TFB's to the product.
d) Electrical serial arrangement of single batteries to match the voltage requirement of the load (up to 6 V).
e) TFB's fulfill the requirements of high flexibility regarding dimensions, thickness, weight as well as nominal voltage and capacity.

In this paper we report on an approach to manufacture primary TFB's employing printing technologies. We describe the setup of the battery, the print process and the characterization of the batteries manufactured on lab-scale.

Introduction

Today electronic applications are ubiquitous and may be found in all areas of our daily life [2]. Furthermore the field of printed electronics offers unlimited opportunities with regard to the development of new products and manifold applications. One of the basic requirements is their supply with energy. This requires the availability of electrochemical energy storage devices meeting several demands like high flexibility regarding dimensions, thickness, weight as well as nominal voltage and capacity. These requirements can be met and electrochemical materials may be transferred to flexible substrates by using printing technologies. Furthermore there is an opportunity to directly integrate electrochemical energy storage devices into already existing or new production workflows. This may result in a remarkable increase in productivity.

We report on approaches to manufacture batteries employing printing technologies to get ready to meet future demands regarding the autonomy of electronic devices. These might be, e.g. intelligent chip and sensor cards, medical patches and plasters for transdermal medication and vital signs monitoring, as well as lab-on-chip analysis devices. The combination with other thin and flexible modules is intended whereby flexible displays and solar cells may be manufactured in a compatible manner and combined where required.

Methods

For the manufacturing of TFB's there are a number of requirements concerning how to process the needed materials. As printing technique screen printing was chosen. Screen printing is a versatile printing technology since it provides the opportunity of printing onto various flexible substrates such as paper, plastic foil or textiles [3, 4]. Another advantage of screen printing is its property to produce extra high layer thicknesses (typically 100 µm). Functional materials may be applied in any requested form by formulating functional materials to inks and pastes. Therefore screen printing qualifies perfectly for the fabrication of printed energy storage devices because the amount of chemical material is increased. The principle of screen printing is given in Fig. 1. A mesh is stretched in a metal form to build the screen for the printing process. The mesh is covered by a pattern to determine all areas of the substrate where printing ink shall be deposited (in Fig. 1 open mesh is white, covered mesh is black). The ink is put on the top side of the mesh. Using a squeegee sweeping from one side of the substrate towards the other the ink (in Fig. 1 blue) is deposited on the substrate. Afterwards the ink is dried if needed. The thickness of the applied layer can be controlled by the size of the mesh (gaps, thickness or type of screen).

Manufacturing

For the battery system the different battery components were applied layer by layer onto a flexible plastic substrate. The primary battery under discussion is a zinc-manganese dioxide system. As a first step the current collectors were printed onto a 50 µm thick PET (polyethylene-terephthalate) foil.

After drying the first layer the positive and negative electrode material was printed onto the regarding current collectors. The electrodes consist of manganese dioxide (positive) and zinc-based (negative) inks which were dried after their application. Subsequently both, positive and negative electrodes were coated with an electrolyte (based on zinc chloride) using a doctor blade. In the finishing step the batteries were encapsulated with high-performance adhesive tape using a proprietary assembling technique. While the current collector consists of a shelf material the other inks were formulated from different materials. The design scheme is shown in Fig. 2.

Results

The printed primary batteries are very thin and lightweight. A battery with a nominal voltage of 1.5 V has a thickness approx. 0.8 mm and weights approx. 0.8 g. Because the batteries are printed onto plastic foils they have the advantage of being flexible (Fig. 3, page 31) and the potential to be manufactured in a roll-to-roll printing process. Due to the characteristics of the involved materials the battery system is considered to be environmentally friendly.

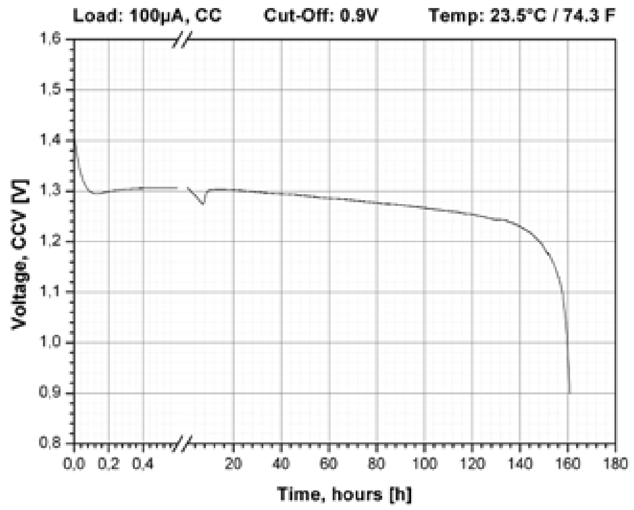

FIG. 4

Batteries are being characterized by their capacity and discharge characteristics. The data measured for a laboratory sample is given in Tab. 1 and Fig. 4.

Characteristics of the Zn-MnO$_2$ battery		
Nominal voltage	1.5, 3.0, 4.5, 6.0	V
Nominal capacity	> 2	mAh/cm^2
Thickness	approx. 0.8	mm
Weight	approx. 0.8	g

Tab. 1: characteristics of Zn-MnO$_2$ battery

A discharge curve of a printed primary battery is shown in fig. 4.

Conclusions and Outlook

The reported approach constitutes the basis for future developments towards a roll-to-roll fabrication of printed batteries although today some of the material application steps still have to be transformed into printing techniques. This opens new routes to integrate battery manufacturing into mass production of smart systems such as printed smart products. Thus, an assembly of printed batteries and devices, e.g. sensors, data loggers or RFID applications, will be possible in the near future. Next steps in research will be further performance enhancements of the batteries by improving the appropriate materials and their interaction.

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Legend

Fig. 1: Principle of screen printing

Fig. 2: Design scheme of printed battery (explosion plot)

Fig. 3: Printed primary battery with a nominal voltage of 3.0 V

Fig. 4: Battery discharge curve

FIG. 3

FIG. 1

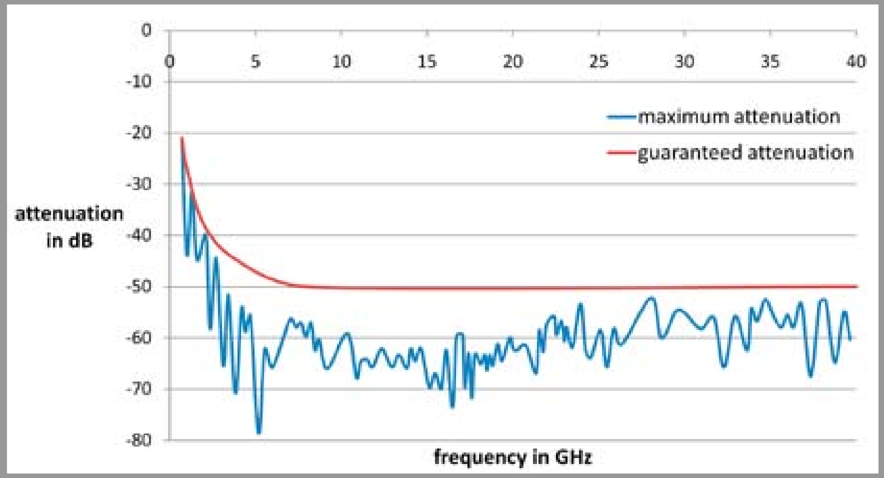

FIG. 2

FIG. 3

ANECHOIC CHAMBER FOR PRINTED ANTENNAS CHARACTERIZATION

Ralf Zichner, Reinhard R. Baumann

Abstract

Wireless communication systems are used in a number of research areas like microsystems technology, communication technology and consumer electronics. The number of applications has been growing every year as well as the requirements for wireless systems like communication range, data transfer rate and reliability. Key elements for wireless data communication are radio technology components like antennas, filters and directional coupler. For the reliable characterization of these components a defined electromagnetic environment is needed which ensures correct measurements. Such a RF-measuring anechoic chamber has been built in the Fraunhofer ENAS.

Introduction

In addition to microsystems technology and consumer electronics, Radio Frequency Identification technology (RFID) is one of the focal areas in the field of Printed Functionalities. Especially the development of adapted printable antennas which will be connected to standard silicon chips giving RFID transponders will contribute to the single item tagging of different objects -either of our everyday's life or as members of industrial supply chains- remarkably. In order to characterize these newly developed, printed antennas in high quality an electromagnetic shielded measuring environment without any reflections is definitely needed [1] which will similarly prevent the interferences of mobile phones or WLAN and Bluetooth applications. This environment has to eliminate the risk of unintentional injections of reflecting and back-scattering signals in the object to be measured.

Anechoic Chamber Characteristics

The anechoic chamber (Fig. 1), built in September 2009, has a usable volume of 3 m x 1.5 m x 2 m (L x W x H). The walls of the chamber are basically coated with a 0.1 mm aluminum foil. Hence the chamber has the properties of a Faraday cage. On the aluminum foil, pyramid shaped absorbers are mounted which absorb electromagnetic waves with a high absorbance, starting at about 30 MHz. The described architecture provides a measurement environment without any reflections. The bottom side of the chamber is easily removable via a modular assembly which makes it possible to enter the chamber and arrange different experimental set-ups very flexible.
Fig. 2 shows the attenuation behavior of the absorbers in dependence on the frequency of the electromagnetic field. Alternatively the quality of the absorbers could be defined under comprehension of the reflection coefficient [3]. The feeding signals into the chamber as well as the resulting signals of the experiment are led through four N-connector accesses and two individual designed adapters.

Addressable Measurement Scenarios

The described anechoic chamber allows in combination with high-end equipment (ROHDE & Schwarz network/spectrum analyzer ZVL6, signal generator SMA 100A and logarithmic periodic broadband antenna from Schwarzbeck) a complete characterization of high frequency components like printed antenna structures: (a) scattering parameter, (b) voltage standing wave ratio, (c) wave impedance and (d) absorption of the radiation starting in the ultra high frequency (UHF) band (300 MHz - 3 GHz) up to the lower end of the super high frequency (SHF) band (3 - 6 GHz). Fig. 3 shows a measurement scenario of a printed antenna applied to a dielectric substrate (wood).

Conclusions and Outlook

With the described absorber chamber, the Fraunhofer ENAS is able to carry out a broad spectrum of services regarding high frequency measurements and characterizations in a well defined measurement environment. The anechoic chamber is currently supporting several R&D projects directly. Requests from industrial and academic partners to support their analytical requirements are welcome and can be done quickly with a high quality standard.
One of the major aims of the Fraunhofer ENAS Printed Functionalities department is to foster the development of customized and low cost printed antennas for various and sometimes critical dielectric environments including metallic objects and liquid containing casks. The described anechoic chamber is one of the essential equipment to master the appropriate R&D challenges.

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Legend
Fig. 1: Anechoic chamber of Fraunhofer ENAS
Fig. 2: Manufacturer information of the attenuation behavior of the absorber [2]
Fig. 3: Example of a measurement scenario of a printed antenna on wood

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DEPARTMENT BACK-END OF LINE

Head of the Department: Prof. Dr. Stefan E. Schulz

Short Portrait

The Back-end of line (BEOL) in semiconductor processing and micro/nanoelectronics comprises the processing steps from contact level through to complete processing of the wafer prior to electrical testing, in other words, the entire interconnect system, including passivation.

The department BEOL works in close collaboration with the Center for Microtechnologies (ZfM) at the Chemnitz University of Technology on developing materials, processes and technologies for interconnect systems as well as on modeling and simulation of processes, equipment and interconnect systems. Application areas are micro and nanoelectronics, MEMS/NEMS, and 3D integration. In the field of 3D integration a close collaboration with the Fraunhofer IZM exists.

Trends

Ongoing downscaling has led to numerous diversifications of the interconnect systems over the past decade, depending largely on the product concerned. While transistors operate faster as their dimensions shrink, interconnects increasingly limit this gain in speed. The resistance-capacitance product (RC product) of the interconnect system rises with reduced dimensions, and thus also the signal delay. Suitable materials can contribute to a resistance and capacitance decrease and therefore compensate for the performance loss in the interconnect system. The past decade was affected by the introduction of copper technology and low-k dielectrics. Further innovations and challenges are expected in the following years from the employment of porous ultra low-k dielectrics and the accompanying new processes required, such as atomic layer deposition (ALD) for ultra-thin films. By further scaling copper interconnects, increasing line via and resistance will appear to be dramatic facing sub 30 nm dimensions. Intensive efforts in material and interface engineering as well as modeling and simulation of nanointerconnects will be necessary to address this issue. Future devices will implement nano structures like carbon nanotubes (CNT), which is addressed by fundamental research in this area.

Furthermore, the trend to explore the third dimension will require adaptation of existing interconnect technologies, e.g. to through silicon via metallization, and development of advanced processes like CVD barriers and seed layers for very high aspect ratios. 3D integration will play a major role in further increasing integration density by chip stacking as well as building smart multifunctional systems combining different technologies.

Fraunhofer ENAS as a competent partner is ready to address these challenges.

Competences

The main competences and long-term experiences of the department BEOL are in the fields of:

* Low-k and ULK dielectrics
* Metallization for micro and nanoelectronics
* Metallization for 3D integration
* Airgaps for low parasitic capacitances in nanoelectronic interconnect systems
* Process and equipment simulation and modeling
* Simulation and modeling of interconnect materials and systems
* Planarization and surface modification for BEOL and MEMS / NEMS fabrication

Special emphasis is placed on integrating low-k and porous ultra-low-k materials with material properties that require a modified integration pattern into copper damascene interconnect systems adapted to the respective material. For successful integration of those materials especially etching and cleaning techniques, low down force barrier and copper CMP, k-restore processes after patterning and diffusion barrier compatibility are investigated. For this and to evaluate porous low-k dielectrics properties, several optical, mechanical, thermal and electrical characterization techniques are applied.

New interconnect architectures continue to be developed, currently in particular airgaps. Here, not only the potential for manufacturing airgap structures is investigated, but also their electrical, thermal and mechanical impact on the interconnect system. Two approaches for wet etch removal of the sacrificial SiO_2 have been developed, called "Spacer" and "Mask" approach. Process step and technology development and optimization are accompanied by electrical, mechanical and thermal modeling and simulation of airgap containing interconnect systems.

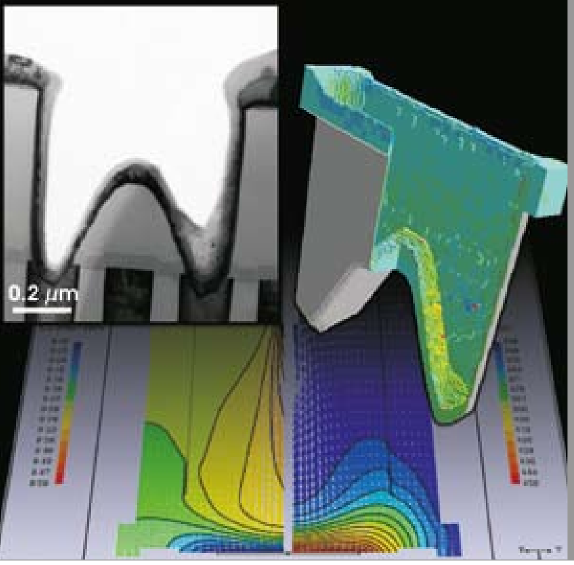
3D integration requires to metallize mostly high aspect ratio "through silicon vias" (TSVs). By providing several process solutions, like PVD and CVD barrier and seed layers, copper CVD and electroplating (ECD) different geometries can be addressed for various applications.

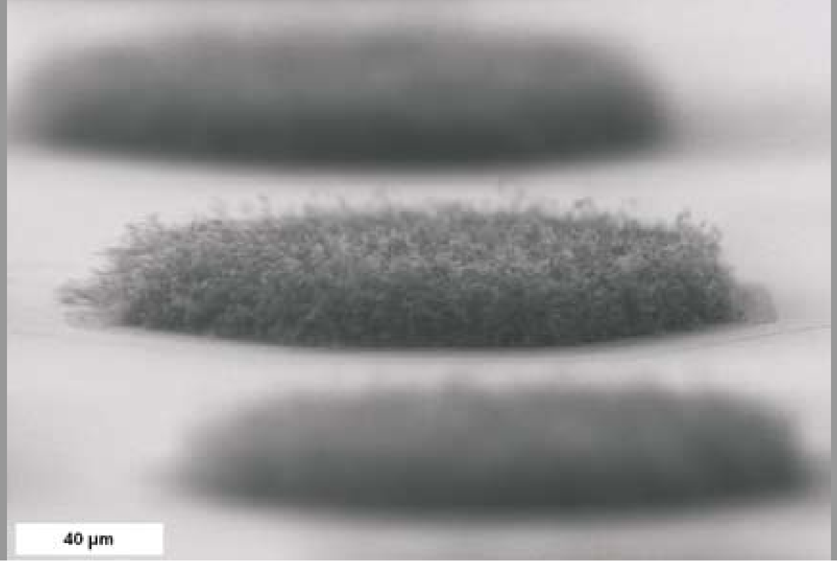
Developing new technologies requires new or optimized processes and equipment. To realize this Fraunhofer ENAS is developing advanced models and simulation tools, e.g. for PVD, CVD and CMP. They support the development of improved deposition and polishing techniques by optimizing process conditions, reactor configuration and feature topography. By means of appropriate simulations it is possible to estimate chances and risks of new technologies and to determine convenient process windows while minimizing costs of processing test runs with large scaled wafer diameters and batches. The gained knowledge and experience of the simulations are made available for our customers and partners to optimize process parameters and equipment.

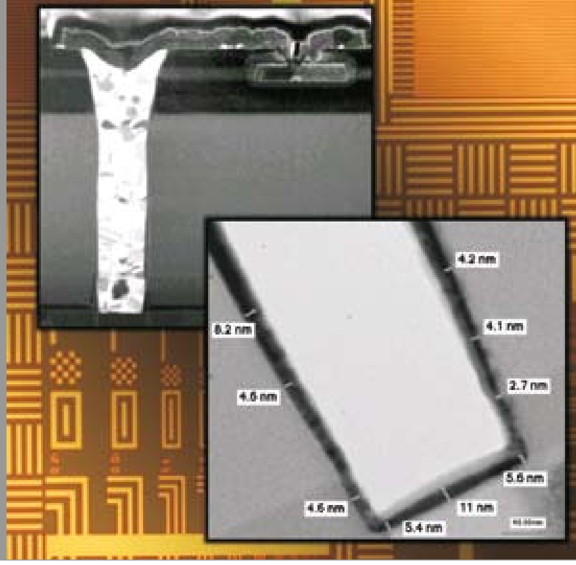
Services

We offer the following services related to the fields described above:

* Wafer processing (deposition, patterning, planarization)
* Thin film measurement and characterization
* R&D service for processes and technology development
* In-situ process diagnostics
* Modeling and simulation of processes and equipment
* Modeling and simulation of interconnect materials and systems







Results of R&D Projects in Brief

On-chip Interconnects

Airgap Structures developed within the European Integrated Projects NanoCMOS and PULLNANO showed the feasibility of the integration of air gap structures by using a sacrificial layer approach for relaxed pattern dimensions. The technology is based on a sacrificial SiO_2 layer, which is removed by buffered hydrofluoric acid solution (BHF). This work has been continued within the project I–COSEL in collaboration with the Fraunhofer CNT. Advanced e-beam lithography was applied to pattern copper damascene structures with critical dimensions down to 50 nm for later airgap formation and characterization and electromigration life time measurements.

Low-k Integration: In the field of low-k/ULK materials processing and integration a close collaboration exists with GLOBALFOUNDRIES and Air Products in the frame of the projects STRUCTURE, VERBINDEN/KUWANO and PULSAR. Using in-situ diagnostic methods in a fluorocarbon based etch process, e.g. guadrupole mass spectrometry, optical emission spectroscopy, laser absorption spectroscopy, and a langmuir probe, the etch reaction, the formation of a surface polymer film and the damage of the low-k material by ions, radicals and UV radiation have been analyzed more intensively.
Wet chemical cleaning processes for etch residue removal have been investigated regarding wetting conditions, low-k and Cu/CoWP compatibility. It was found that low surface energy solutions are needed to efficiently wet and remove low-energetic residues.
The restoration of low-k dielectrics damaged by plasma processes (ashing and etching) by using silylation in combination with UV-curing has been investigated (project STRUCTURE, cooperation with IOM Leipzig). The selection of the UV-wavelengths for curing and the processing sequence was found to be critical.

Metallization for 3D Interconnects

At Fraunhofer ENAS diffusion barrier and metallization processes for TSV fabrication are under investigation, e.g. in the projects Smartsense and JEMSiP_3D.
Process optimization regarding barrier quality and step coverage is done for TiN barrier and copper seed layer deposition with (MO)CVD. For copper seed layers the achieved step coverage is 90% for an aspect ratio AR=20.

Simulation and Modeling

In cooperation with GLOBALFOUNDRIES several investigations have been carried out regarding the scalability of PVD films and reliability parameters in the fabrication of present and future Cu/ULK metallization systems. Multi-scale modeling of copper seed layer and TaN barrier deposition by advanced PVD was carried out. The influence of process conditions and geometrical properties of via and trench structures on overhang formation, bottom and sidewall coverage has been studied using the simulation environment T2.
The consideration of the reliability of interconnect systems is focused on the understanding of dielectric breakdown in porous dielectrics. Several models have been developed with the objective to investigate process-induced influences.
As copper line dimensions approach the electron mean free path the size effect becomes a major challenge for the continuous device scaling. Therefore, the electronic transport properties of nano-scaled interconnects as well as of gold and copper quantum point contacts have been investigated using the Density Functional based Tight Binding method.
The electrical resistivity of copper interconnects with barrier and cap layers has been calculated by solving the Boltzmann Transport Equation for various transport mechanisms including electron-phonon scattering.

Nanostructures, Nanomaterials

In this field, the PhD students at Fraunhofer ENAS and ZfM work on development of a copper atomic layer deposition (ALD) process and the integration of carbon nanotubes (CNT) in interconnect systems and/or NEMS. This basic research is performed in the frame of the International Research Training Group (IRTG) “Materials and Concepts for Advanced Interconnects”.
For deposition of very thin Cu films we use thermal ALD between 100 and 130 °C from $[(^{n}Bu_3P)_2Cu(acac)]$ and wet O_2 for growing oxidic copper films with subsequent reduction.
Investigations to ECD seed layer application were carried out using 6 nm Cu ALD seed layer on Ru films. The ECD growth process exhibits advantages with respect to film morphology and resistivity both compared to blanket Ru as well as to Ru with a PVD Cu seed layer.
For the integration of CNTs, two approaches are pursued, the direct CNT growth by chemical vapour deposition (CVD) in interconnect systems and the dielectrophoresis of CNTs for NEMS. For CNT growth by CVD we work with different metallic catalyst systems (single metallic like Ni or Co as well as bimetallic catalysts) and different precursor gases, e.g. ethylene or acetylene. The predominant aim is to grow vertical and densely packed CNT-arrays at low temperatures with acceptable structural integrity.
The dielectrophoresis is more suitable for CNT integration in NEMS. High quality CNTs, selected into the required properties, were selectively deposited and aligned at low temperatures. The work is focused on CNT dispersions using different dispersing agents and cleaning and drying procedures.

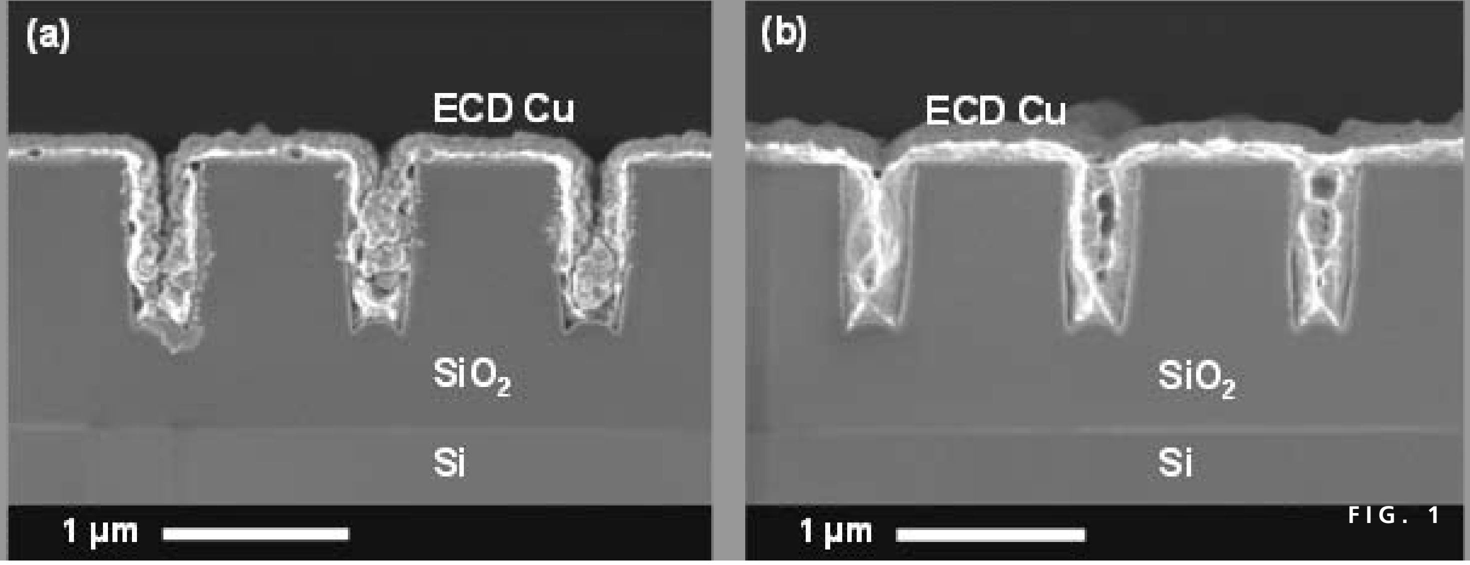


FIG. 1

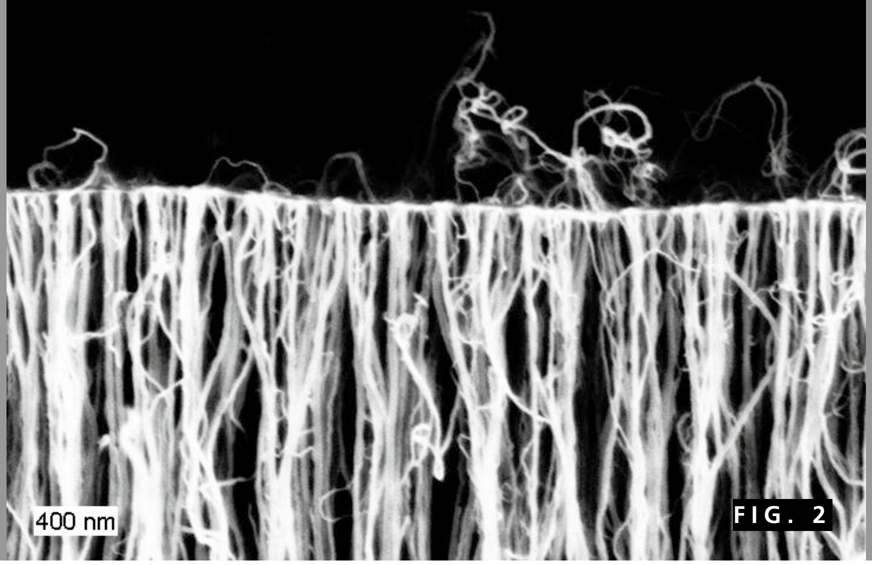


FIG. 2

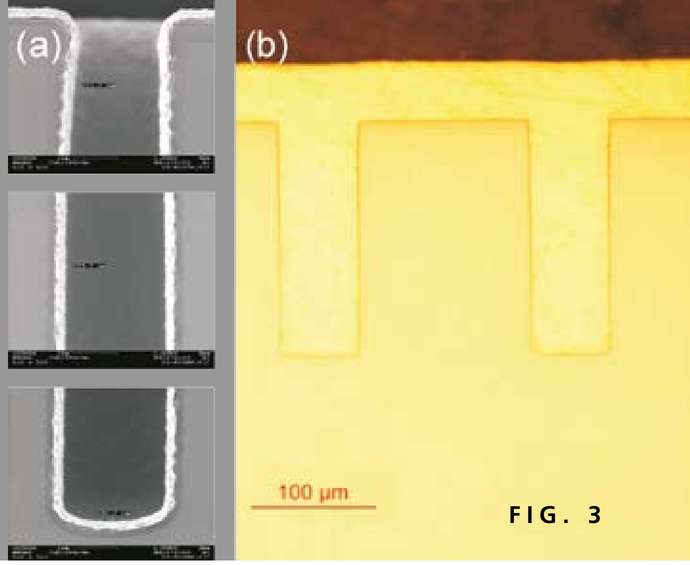


FIG. 3

FUTURE METALLIZATION CONCEPTS FOR ON-CHIP INTERCONNECTS AND 3D INTEGRATION

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Both trends “More Moore” as well as “More than Moore”, which are dominating the increasing performance of future micro and nanoelectronic components require the application of advanced materials and manufacturing processes as well as smart integration concepts. These issues are addressed within the department Back-end of Line (BEOL) due to our focus on metallization processes for both future on-chip interconnects and 3D integration.

In the field of on-chip interconnects, our group investigates new material and process technologies for via and trench metallization. Conventionally, this is accomplished by electrochemical deposition (ECD) of copper and a subsequent planarization via chemical mechanical polishing (CMP). The required seed layer for the ECD process is created by physical vapor deposition (PVD). In ultra-large scale integrated circuits (ULSI) having high aspect ratio features with dimensions in the range of a few nanometers, there will be limitations of the process performance on the one hand and of the interconnect performance on the other hand. The first issue is mostly related to the step coverage and film conformity of the PVD seed layer and can be accomplished by highly conformal deposition methods such as atomic layer deposition (ALD) for the seed layer growth. The second issue relates to the limitations of copper regarding its electrical conductivity and electromigration resistance. Hereby, completely new materials such as carbon nanotubes (CNTs) are seen as promising candidates to overcome this problem.

The current work regarding copper ALD at Fraunhofer ENAS Chemnitz, together with the Center for Microtechnologies and the Inorganic Chemistry Department at Chemnitz University of Technology, is concerned with thermal ALD at moderate temperatures for growing oxidic Cu films which are subsequently reduced. The Cu(I) β-diketonate precursor used in these studies is a liquid at room temperature and thus easier to handle than frequently utilized solids. Furthermore, it is non-fluorinated which helps avoiding a major source of adhesion problems as observed in Cu CVD from fluorinated substances. Smooth, adherent copper oxide films can be grown on SiO$_2$, TaN and Ru. To apply the ALD films as seed layers in subsequent electroplating processes, several reduction processes were under investigation. The most promising results so far are obtained using formic acid vapor. Seed layers produced in that manner were used for investigations of copper ECD on those films in comparison to thin PVD Cu and PVD Ru. Smooth films of Cu were obtained on blanket surfaces. Via and trench structures with 200 nm in width having a Ru/TaN barrier system could also be conformally coated with ECD Cu after ALD Cu seed layer deposition. The ECD results on ALD seeds outperformed the ones obtained on Ru seeds as well as the ones on thin PVD Cu seed layers, suggesting that a combination of Ru with ALD Cu could enable Cu metallization in future ULSI technology nodes (Fig. 1).
Regarding the implementation of CNTs as interconnects into future nano and microelectronic systems, the department BEOL applies the CVD method for the direct growth of CNTs. The conducted process developments include the investigation of different substrate/catalyst systems in combination with CVD parameters and equipment development. Multi walled CNTs (MWCNTs) with controllable diameters in the range from 10 to 20 nm in dense films are deposited at temperatures ranging from 450 °C to 700 °C. CNTs show relatively small defect densities and furthermore a vertical alignment of CNTs can be obtained (Fig. 2). Selective growth of CNTs was achieved in a single damascene architecture with a Cu/TiN metallization which has been already demonstrated in a feasibility study (CoNTemp project). Further activities concerning CNT integration concentrate on process development of dielectrophoretic (DEP) room temperature deposition of aligned CNTs for different sensor applications.

Another major research topic within the department of BEOL is the 3D system integration. Besides other key technologies in this topic, such as wafer thinning and wafer bonding, our group focuses on the fabrication of through silicon vias (TSV), especially on processes for the backfill of TSVs with copper as conductive material. For the metallization of the TSVs there are different approaches. One possibility is the complete fill of the TSVs. This is accomplished by MOCVD for TSVs with diameters < 5 µm and by ECD for larger TSVs. In the latter case, MOCVD is used to deposit the required seed layer and for the deposition of a diffusion barrier. The MOCVD processes were optimized with respect to step coverage of the TiN barrier and Cu seed layer. For TSVs with AR=4, a step coverage of the TiN barrier of 74% was obtained. For Cu seed layers, the achieved step coverage is 90% for an aspect ratio of 20 (Fig. 3a). For further optimization of the process performance a new chamber design including the possibility of advanced chamber cleaning procedures were developed in collaboration with the company Altatech. Investigations regarding TSV backfill by Cu ECD were carried out for different via geometries and for varying process parameters such as current density, mass flow, or chemistry. We obtained void free filling of TSVs having an aspect ratio (AR) of 3 (Fig. 3b). TSVs with AR=9 had only small seams and TSVs with AR=4 showed only small voids at the via bottom after the deposition. For the latter TSV dimensions void-free deposition is under investigation taking into account further process options such as pulse reverse plating.

Legend

Fig. 1: ECD Cu on SiO$_2$ patterns with a Ru/TaN film stack (a) without and (b) with an additional ALD Cu seed layer

Fig. 2: Vertically aligned MWNTs deposited in a directed growth technique

Fig. 3: Results of TSV processes: (a) highly conformal CVD seed layer and (b) ECD-filled TSV

FIG. 1

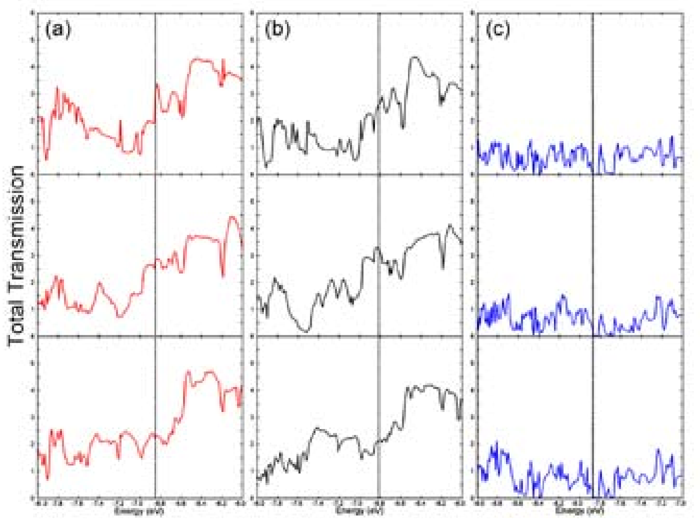


FIG. 2

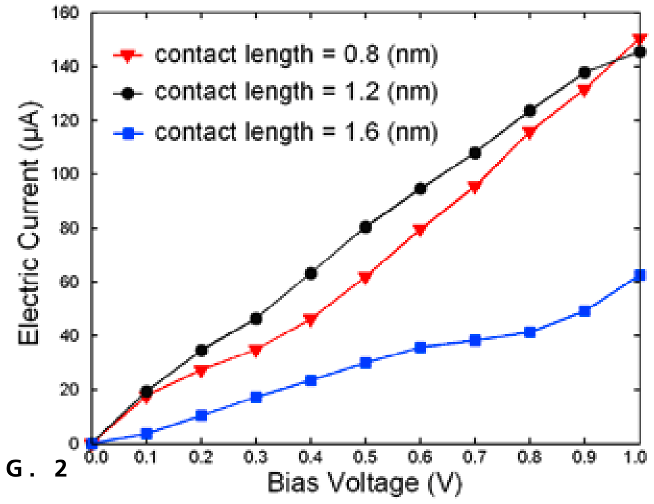


FIG. 3

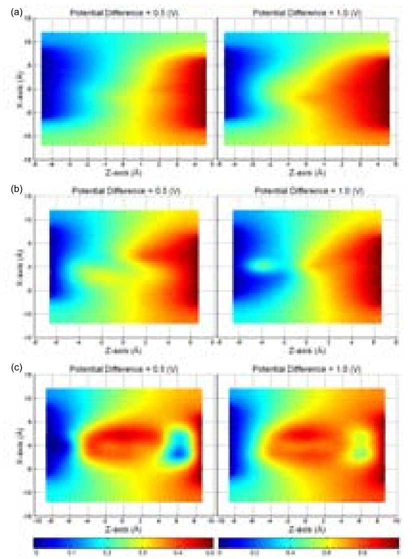
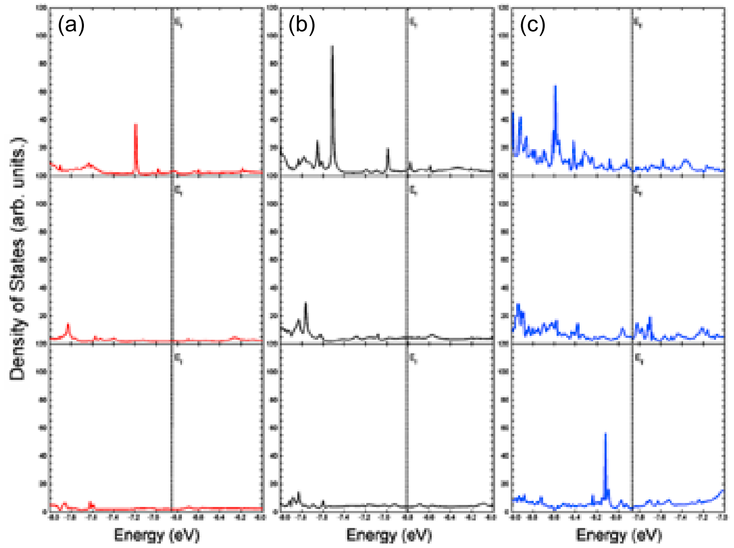


FIG. 4



GEOMETRY DEPENDENT I–V CHARACTERISTICS OF GOLD ATOMIC-SIZED CONTACTS

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Abstract

Atomic-sized contacts have attracted significant attention by continuing miniaturization of nanoscale electronic components for the two past decades. In present work, the electronic transport properties of gold atomic-sized contacts are studied using the non-equilibrium Green's function technique on the density functional tight binding method for modeling the geometry dependent I–V characteristics. The gold contacts are sandwiched between (001) electrodes, and the electronic current is deduced according to the Landauer formulation to study the effect of contact geometry structure.

Introduction

Electronic transport properties of nanocontacts are influenced by size and quantum effects which become more significant as the size of the contact approaches to atomic dimensions. The metal nanocontacts are mostly fabricated at quantum point contacts by the scanning tunneling microscope and the mechanically controllable break junction.

In present work, to study the dependency of electronic transport properties on the gold atomic-sized contact geometry, the theoretical analysis has been performed in the framework of non-equilibrium Green's function density functional tight binding method. This approach allows to calculate the Green's functions for ideal atomic positions of the contact and electrodes fully self consistently.

The calculation of I–V characteristic, conductance, potential difference and density of states are carried out to describe the geometry dependent effects.

The paper is organized as follows: in section II, we describe the method and model to study the system. Results are explained in section III, and a summary is given in section IV.

Materials and Methods

The gold atomic-sized contact sandwiched between gold electrodes in (001) direction is considered for three contact lengths with an extra gold atom as geometry defect in the longest contact. Calculations are performed using the non-equilibrium Green's function within the density functional tight binding method and the Landauer–Büttiker theory to obtain the conductance of the system. Interaction between the valence electrons is treated in the local density approximation. Since the applied bias changes the transport properties from those at the zero-bias limit, it is important to consider the effect of the applied bias in the theoretical studies. This is provided by the non-equilibrium Green's function method introduced by Keldysh to deal with the non-equilibrium situation.

Results and Discussion

The total transmission spectra with respect to the electron incident energy for external bias voltages of 0.0–1.0 V in three different contact geometries are shown in Fig. 1. The results indicate that the fluctuation amplitude of transmission spectra pares down by increasing the applied bias voltage. Furthermore, upon adding a geometry defect to the 1.6 nm contact, total transmission coefficients reduce significantly. The calculated I–V characteristic of each atomic-sized contact up to bias voltage of 1.0 V, depicted in Fig. 2, shows the dependency of I–V characteristic on contact length and defect. I–V curves of defect free contacts are almost the same and higher than that of 1.6 nm length with defect.

Conductance is determined by states close to the Fermi level, which leads to the net current, due to very small applied bias voltage. The conductance of 0.8, 1.2 and 1.6 nm contact lengths could be computed at room temperature and limit of zero bias voltage as 3.2 G_0, 2.6 G_0 and 0.1 G_0, respectively. Presence of an extra gold atom as geometry defect in the 1.6 nm contact, causes that the total transmission and hence current and conductance show strong reduction in comparison with defect free contacts. The effect of applied bias voltage appearing in the contact region is shown in Fig. 3. The differences in electrostatic potential with 0.5 V and 1.0 V from zero bias voltage in plane along the gold atomic-sized contact with the length of 0.8, 1.2 and 1.6 nm are plotted in Fig. 3. Unlike the potential difference of two short and defect free contacts, the potential difference of the longest contact with defect does not behave smoothly and the drop mainly occurs in the left side of the contact.

To gain more insight into the transport properties of gold atomic-sized contacts, density of states is presented as a function of incident electron energy by scattering states of contacts. More localized states appear below the Fermi energy as shown in Fig. 4. In addition, dramatically changes occur in the density of states by existing geometry defect in the 1.6 nm contact.

Conclusion

In this paper, performing non-equilibrium Green's function density functional tight binding method in gold atomic-sized contacts bridged between (001) electrodes, transmission spectra, I–V characteristics, voltage drop, and density of states of contacts have been computed as a function of contact geometry structure. Since these structures form the situation of ballistic conduction through a narrow channel connecting two electrodes, Landauer–Büttiker theory has been applied. Results have shown that as the contact approaches to more atomic-sized; the I–V characteristic behaves relatively the same and independently from the contact length, while I–V characteristic, conductance and potential difference strongly depend on the geometry defect presented in the longest contact. Based on numerical calculations, geometrical changes thus suggest being an important factor for varying the electronic transport properties.

Legend

Fig. 1: Total transmission spectra as a function of incident electron energy at bias voltage of 0.0, 0.5 and 1.0 V for three contact lengths (a) 0.8 nm, (b) 1.2 nm and (c) 1.6 nm. Contacts of 0.8 nm and 1.2 nm lengths are defect free, while an extra gold atom is considered as geometry defect in 1.6 nm contact. Dotted line shows the Fermi energy of contacts.

Fig. 2: I–V characteristic of gold atomic-sized contact.

Fig. 3: Potential differences in plane along the gold atomic-sized contact, (a) contact length=0.8 nm, (b) contact length=1.2 nm and (c) contact length=1.6 nm in two potential difference of 0.5 V and 1.0 V.

Fig. 4: Density of states for (a) contact length=0.8 nm, (b) contact length=1.2 nm and (c) contact length=1.6 nm, calculated in three bias voltages of 0.0, 0.5 and 1.0 V. Unlike the two short contacts, the longest contact is not defect free.

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DEPARTMENT SYSTEM PACKAGING

Head of the Department: Dr. Maik Wiemer

The department System Packaging growing out of the group Technologies/Wafer Bonding of the department Multi Device Integration was founded in July 2009. Dr. Maik Wiemer is the head of this new department System Packaging. Meanwhile 15 co-workers including scientific staff and student's assistance are working in the fields of packaging technologies for MEMS and NEMS covering topics from zero level packaging up to second level packaging. The potentials and the importance of packaging and system integration are abundant, ranging from hybrid integration of the components on application-specific substrate carriers over monolithic integration of electronic, sensing, and actuating components on a silicon substrate, to the vertical integration, in which stacking takes place in the third dimension on chip and wafer level. In addition to the functionality and reliability, the miniaturization and the smart systems integration are the greatest challenges for 'More-than-Moore' development. With the department's research work this trend results in new, customer-specific applications.

MEMS Packaging and 3D Integration

The meaning of MEMS packaging can be deduced from its portion of costs by producing a micro system. Herein, proportional costs ranging from 20 per cent to 95 per cent are likely to arise, whereas this wide margin results from specific application requirements. The MEMS package has to allow access for the desired mediums to be measured, like liquids, gases or light, but at the same it has to shield these materials from outer unwanted influences, and thus to guarantee long-term functionality. Current packaging technologies are not only applied to passive elements such as inertial or gas sensors, but also to active elements like micro mirrors and print heads. In view of the further advanced system integration, electronic components can also be implemented into the MEMS packaging.

In addition to the integration on wafer level and hybrid integration on chip level, integration technologies in the third dimension are developed. 3D integration has definite advantages. For one, it can reduce the size of a chip and for another it can improve the signal quality. In vertical stacks like this it is of importance to pay attention to the influence of each bonding technology on materials, but also on the electrical and thermal behavior of the whole system. To characterize and evaluate these technologies in terms of their tightness and strength, different measuring tools and valuation guidelines are available at the department System Packaging.

Wafer Bonding

The term wafer bonding describes all bonding techniques for joining two or more wafers with and without interlayer. Standard methods, such as the silicon direct bonding, the anodic, eutectic, adhesive and the glass frit bonding are used, but also enhanced for specific requirements. Actual research focuses on low-temperature bonding, with the process temperature below 200 °C. Another important field of research for these low-temperature procedures is the usage of nano scale effects. Examples for nano scale effects are reactive bonding with nano scaled multilayers, or the reduction of the melting temperature with only a few nanometer thick interlayers. Moreover, the laser assisted bonding allows selective bonding without any temperature influence on the functional elements.

Other methods for the technological developments are constituted by the increasing diversity of materials used in microsystems technology. Materials, in particular plastics, metals and ceramics are currently analyzed to embrace aspects such as temperature and media resistance and low costs during the product development. One example for this is the polymer bonding, which aims a tight bonding of plastics, covering the whole surface. Moreover, research is done in the fields of thermo compression bonding and the direct integration of functional ceramics.

All wafer bonding techniques are characterized in terms of their bonding quality, strength, and hermiticity. The competence of the department System Packaging involves the dicing and the chip and wire bonding as well as technologies for the integration of complex, miniaturized and even intelligent systems.

Surface Modification

One aspect that is of great importance when bonding substrates is their surface quality. Whereas, the roughness of the surfaces of relatively thick intermediate layers, such as glass paste or epoxy, plays a more or less subordinated role.It is the atomic contact between bonding partners in technologies without intermediate layers that is of great significance. Anodic bonding techniques require surfaces with a roughness Ra<1 nm. For other techniques a pre-treatment through specific processes, such as the plasma activation or the hydrophilisation is of importance.

Chemical mechanical polishing (CMP) is implemented and developed for microsystems technology as well as in the field of 3D integration. A challenge and subject of investigation for the CMP is the extreme aspect ratio between the structure dimension and the structure distance. In addition to the CMP of aluminum, copper and germanium, which are investigated for 3D integration processes, silicon and silicon dioxide can be polished. This, for instance, is of significance, when producing innovative SOI-substrates with buried silicide-layers, which are needed for the devices of the BiCMOS-technology.

In order to make use of the nano effects in MEMS packaging, the department System Packaging analyzes nano scale intermediate layers and layer systems. Furthermore, surface and material effects are investigated and characterized on the basis of metallic nano structures. These nano structures are applied to new bonding techniques on chip and wafer level. The aim of this procedure is to achieve a permanent and hermetic sealed joint between two wafers, using the lowest temperature influence into the system.

Molding micro and nano structures by embossing them enables a precise formation of optical and fluidic structures using a master tool. Here, the basic distinction is to make between hot and cold embossing processes. The process temperature when hot embossing glass, not sintered ceramics and thermoplastics is above the glass transition temperature of the respective material. The research work of the department System Packaging does not only include the development of embossing processes, but also the design and production of silicon master tools (equipped with non-stick coating, if necessary), tools with patterned photo resist and electroplated molded nickel tools (UV-LIGA).

Besides a wet-chemical pre-treatment of the wafer, it is possible to increase the bond strength of direct-bonded materials via chemical-reactive plasma discharge. This pre-treatment can be applied to the whole area, or to local points. Here similar stable bond interconnections as in high-temperature bonding can be realized, even at curing temperatures of only 200 °C. The plasma parameter adequate for this specific discharge, and thus for the activation, highly depends on the input power, the gasses used, the gas pressure, the glass tightness, the volume of the reactor and the geometry of the plasma chamber. According to this, the parameters have to be individually defined and adjusted for any application and for every material to be used.

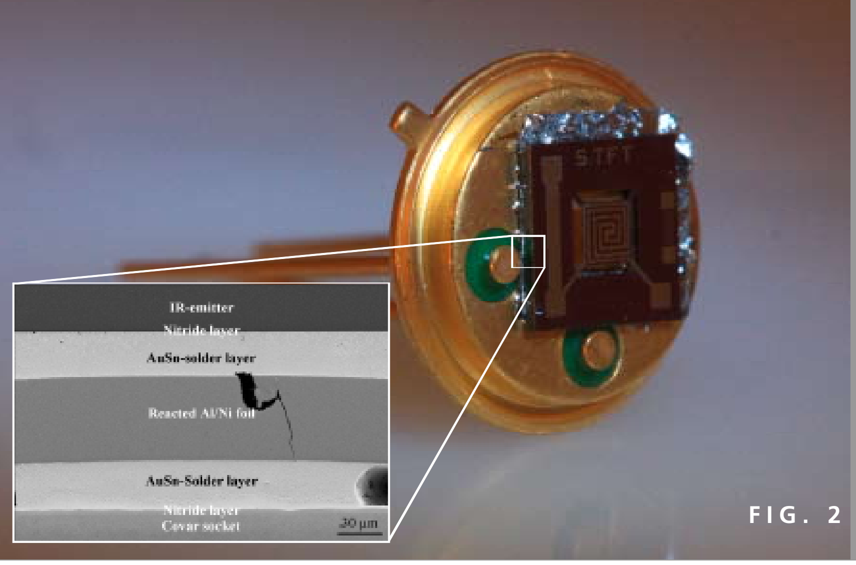

FIG. 2

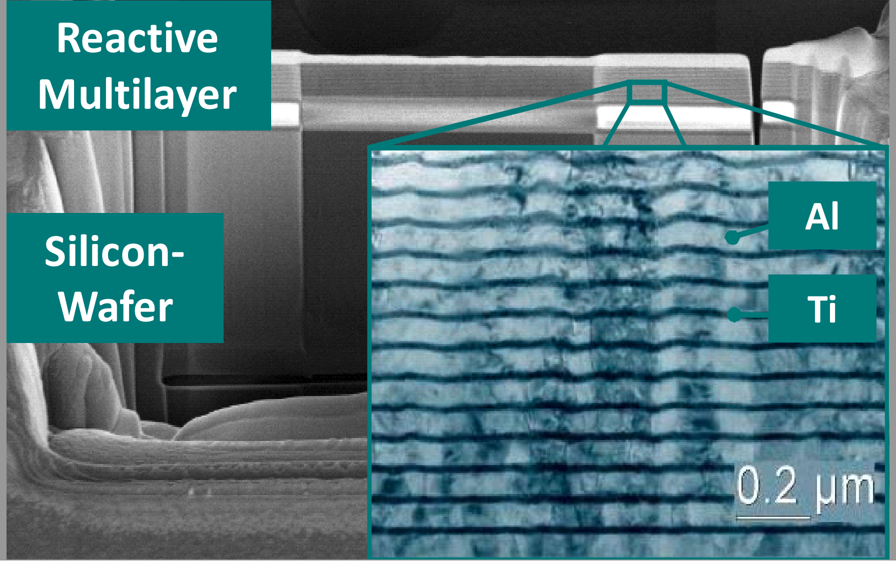

FIG. 3

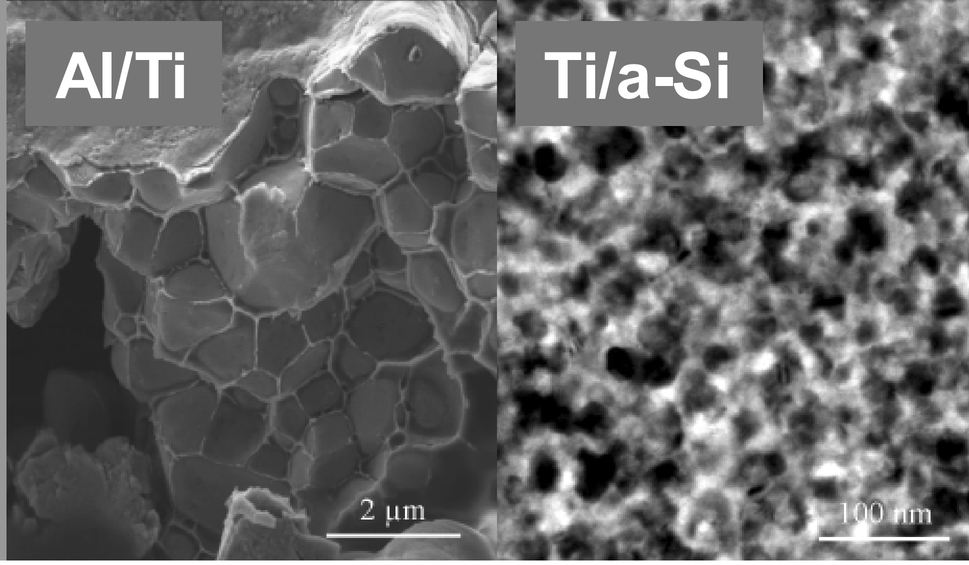

FIG. 4

REACTIVE NANO SCALE MATERIAL SYSTEMS FOR ROOM TEMPERATURE BONDING IN MICROSYSTEMS TECHNOLOGY

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The system integration and packaging of microelectronics, micromechanical and microanalysis systems are increasingly affected by three-dimensional chip stacking. Herein, the fabrication of bonding on wafer or chip scale is of major interest. Due to the integration of new materials, such as micro systems for medical applications, which consist mostly of temperature sensible components, the process temperature during the bonding process is the limiting factor. Therefore new low-temperature processes have been under investigation over the past years. In this research field one promising method is the local heating of the joint interface. A technique which uses an internal heat source is the so called reactive bonding. This technique is a possible method for mounting of microelectronic components and the hermetic sealing of microelectronic packages. It is based on the use of reactive nano scale multilayer systems, mostly in connection with additional layers (see also Fig. 1). The heat used for the bonding process is generated by a self-propagating exothermic reaction within the system [1]. The reaction is initiated by a small pulse of energy, such as an electrical spark. The decisive advantage of this technology is that the components to be joined are not exposed to high temperatures since the generated heat is localized to the bonding interface. Thus, temperature sensitive components and materials with different coefficients of thermal expansion (CTE), such as metals, polymers and ceramics, can potentially be joined without thermal damage [2].

Reactive multilayer systems have become of great interest in research for several years. The first commercialized reactive Al/Ni multilayers have been distributed as so called NanoFoil© by the company RNT (Reactive Nano Technologies, USA). The capability of reactive joining with these foils on chip level was researched by bonding different demonstrators, such as silicon IR emitters onto TO-sockets (Fig. 2), and quartz strain gauges onto stainless steel membranes.

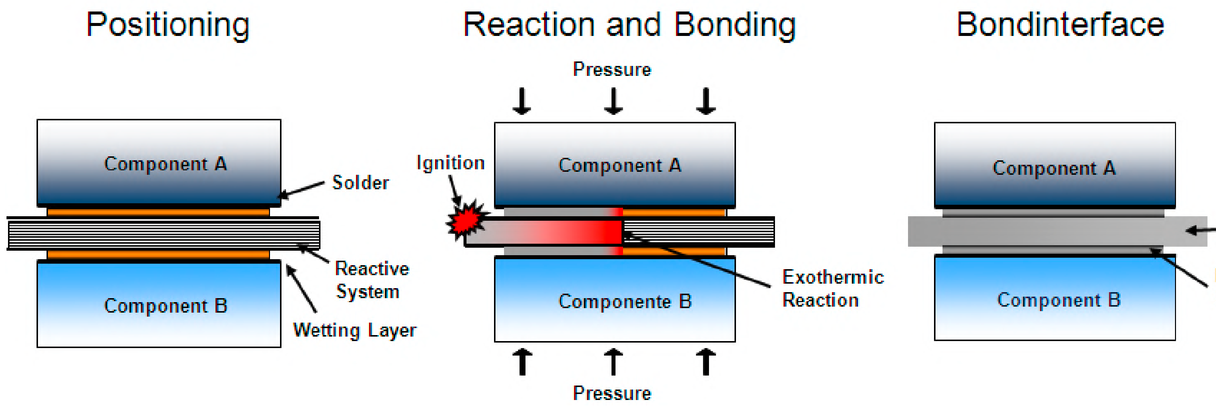

FIG. 1

The inset SEM image in Fig. 2 shows a good connection between the solder layer and the reacted foil multilayer system. No delamination was detected between the individual layers. Nevertheless, these foils are very difficult to handle, to pattern and to positioning, so that an application for wafer level bonding is not easy to evaluate. Thus, integrated multilayer films, such Ti/Al and Ti/a-Si, with a defined thickness in the nano scale were directly magnetron sputter deposited onto different substrates. The microstructure of deposited films and the corresponding reaction products were characterized by using high resolution electron microscopy methods like SEM, TEM and STEM in combination with special preparation techniques like the FIB lift-out method.
Fig. 3 shows a FIB prepared TEM lamellae and a TEM image of a reactive Ti/Al multilayer. The total layer thickness of the Al/Ti multilayer system was 1500 nm with a bilayer thickness of 60 nm.

In order to investigate the reaction product and the reaction characteristics the different systems were initiated by thermal and/or laser activation at room temperature. The multilayers showed very different reaction characteristics. The Ti/a-Si system, for example, is a highly reactive and explosive system, which is more reactive than the other two systems. In order to clarify this hypothesis the explosion of a Ti/a-Si system with a thickness of around 3 µm was detected during the magnetron sputtering process. The big advantage of this system in comparison to the Ni/Al foils and the produced Ti/Al system is that a small amount of layers (less than 50 bilayers) is sufficient to start the exothermic reaction onto the substrates. The other two systems require a much higher amount of layers (more than 300 bilayers). The disadvantage on the other hand is that the Ti/a-Si system reacts as a result of very small energy impulses, and thus the handling is difficult.
Fig. 4 shows the TEM images of the reaction products of Ni/Al and Ti/a-Si multilayer systems. The figures show a clearly modified structure after the reaction. The separated layers of the Ni/Al multilayer system have changed to a honeycomb pattern of AlNi grains. In contrary to the other systems showed the Ti/a-Si multilayer is a very fine grain powder after the explosive reaction.

The results showed that this technology enables the bonding of components with a high CTE mismatch or components with temperature sensitive materials. Furthermore, the directly deposited systems showed different reaction characteristics and the possibility to create such reactions in very thin systems so that bonding on wafer level is very promising.

References

[1] Weihs, T.P.: Handbook of Thin Film Process Technology. Glocker, D. A.; Shah, S.I (Eds.), Institute of Physics, 1997, pp. F7:1-F7:13.
[2] Braeuer, J.; Hofmann, L.; Wiemer, M.; Gessner, T.: Development and evaluation of nanoscale reactive structures for low-temperature bonding in Microsystems Technology. Mikrosystemtechnik Kongress 2009, Berlin, 2009 Oct 12-14; Proceedings.

Legend
Fig. 1: Principle of reactive bonding
Fig. 2: Bonded demonstrator (Inset shows the SEM cross section)
Fig. 3: FIB prepared TEM lamellae and TEM
Fig. 4: Microstructure of different reaction products

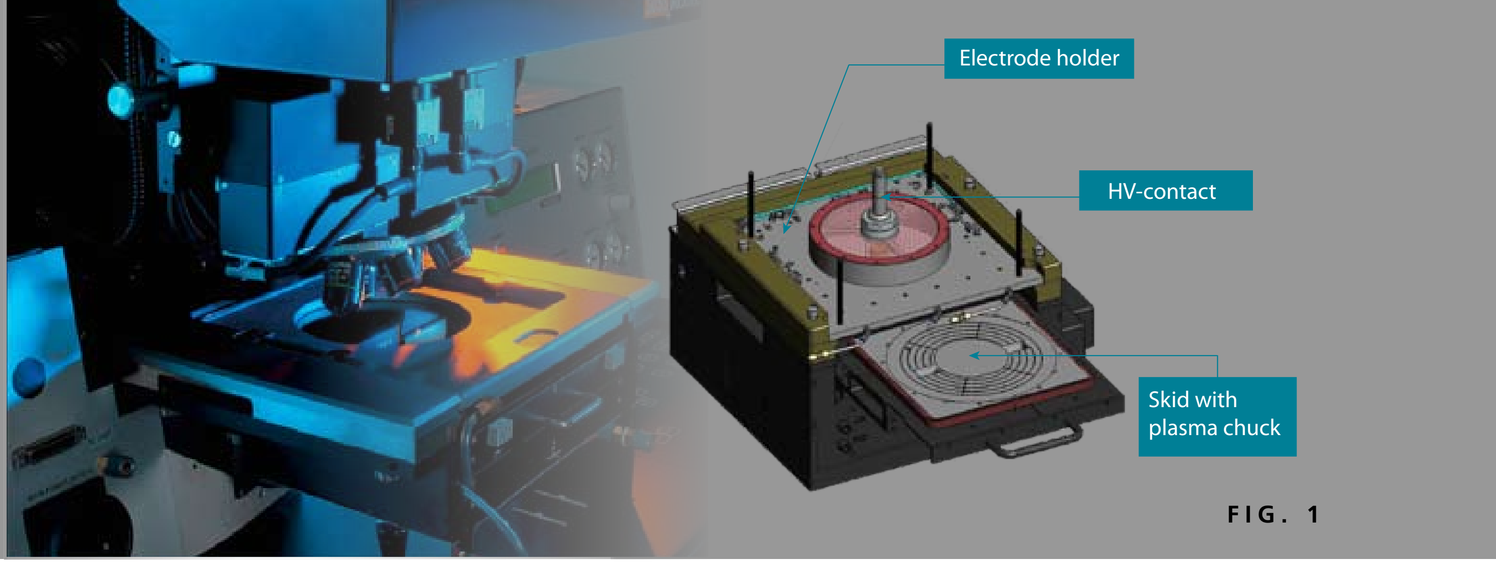

FIG. 1

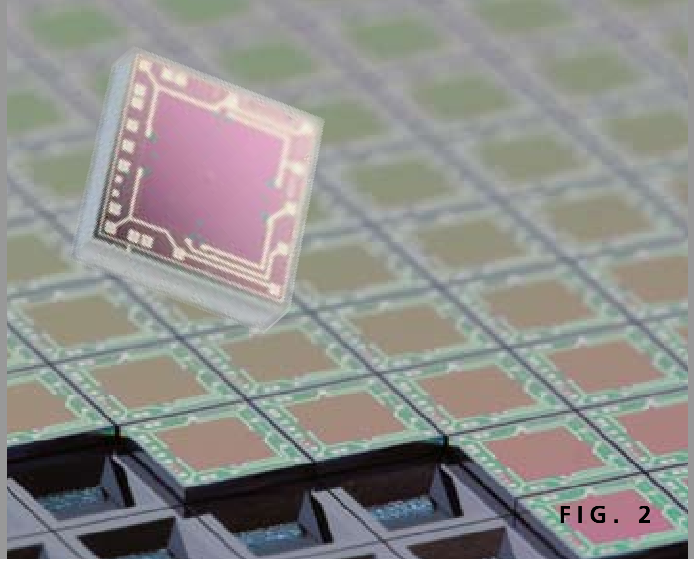

FIG. 2

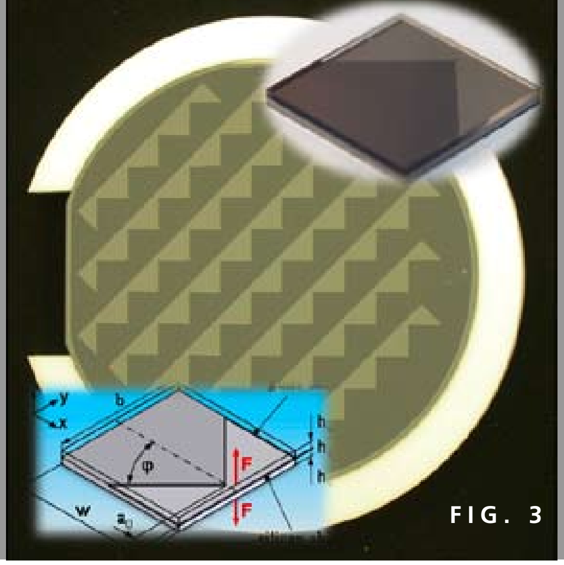

FIG. 3

LOW TEMPERATURE WAFER BONDING FOR MICROSYSTEMS USING DIELECTRIC BARRIER DISCHARGE

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One critical parameter in wafer level bonding is the process temperature. It should be kept as low as possible. Therefore the reasons are low-melting materials used for vias and different coefficients of thermal expansion (CTE) of the bonding partners.

In particular, direct bonding has a major advantage within the MEMS (Micro-Electro-Mechanical Systems) packaging because there are no additional intermediate layers like in eutectic or adhesive bonding needed. This technique uses the formation of covalent bonds if two clean and smooth surfaces are joined and subsequent annealed at temperatures above 800 °C. But for many applications it is essential to reduce these high temperatures. One possibility for this reduction is the usage of surface activating procedures prior to bonding, like low pressure plasma or ion beam treatment. Another opportunity for surface activation is the dielectric barrier discharge (DBD), which offers stable plasma at atmospheric pressure. The plasma system used for our experiments consisted of a grounded chuck serving as the wafer carrier and an indium tin oxide layer on a 750 µm thick glass wafer as a high voltage electrode covering the whole silicon wafer. The electrode was aligned with a distance of 500 µm from the substrate surface, and the gap was flushed with process gas. The discharge was powered by a 7010-type corona generator (Softal electronic GmbH) at a frequency of 28.5 kHz. The treatment time was generally 40 s [1]. Here the experiments have shown a significant increase of the bond strength for homogeneous Si/Si and heterogeneous material combinations like Si/glass. The surface activation with micro plasmas is an attractive topic for micro systems production. The transfer of the technique by implementation into the SUSS mask aligners is currently being evaluated (Fig. 1).

The technique of the surface activation with the dielectric barrier discharge on wafer level was researched by bonding different demonstrators, such as pressure sensor (Fig. 2). The process flow for the bonding procedure was chosen as follows. First, all wafers passed a cleaning in deionised water before the ambient pressure plasma process was applied. The plasma processes can be implemented with different process gases. Mainly used gases are nitrogen and oxygen or a mixture of both. Before bonding the wafers are rinsed once again with DI water. After direct bonding the wafer stack was annealed at 350 °C for 8 hours in nitrogen. In previous work an optimum for Si/Si bonding interface with the process gases nitrogen and synthetic air (80 vol.-% N_2 + 20 vol.-% O_2) plasma was evaluated. Therefore the Si wafers were treated with these gases. The separation into 5 mm x 5 mm elements with a dicing saw was used as a first rough test to check how many dies on the wafer were bonded or not. A comparison before and after the separation shows that there was only few delaminated chips located at the wafer edge. The Si/Si bonding interface of the pressure sensor was characterised by the burst-test. The burst-test with 76 bar shows, that the bond strength of a synthetic air plasma activated specimen is two times higher than a non activated reference wafer stack.

In the Si/glass study single side polished 4-inch (100)-type Si wafers were used. These wafers were 525 ± 25 µm thick with a 5 µm total thickness variation across the wafer below. The glass wafers were 4-inch Borofloat®33 with a thickness of 500 µm. At first all wafers pass a cleaning in standard RCA 1 and 2 solutions before the ambient pressure plasma process is applied. After the plasma process the Si wafers were rinsed with water in a spin dryer, in order to reduce particle concentration.

The wafers were directly bonded on air followed by the annealing of the wafer stacks at 250 °C for 6 hours in nitrogen. Due to the high surface roughness of the glass wafer an optional CMP step is necessary which significantly improves the bonding quality. Note the reference means a non activated wafer stack, which pass a CMP step and a cleaning in standard RCA 1 and RCA 2. The bond strengths of the Si/glass interface were characterized by the fracture toughness that was determined by the micro chevron test. The fracture toughness is a suitable value to describe the crack behavior of the bonded interface. Based on a micro-chevron-specimen and assuming Mode I crack opening, the fracture toughness can be determined experimentally and numerically (Fig. 3). The maximum force can be measured during a tensile test. The minimum of the stress intensity coefficient is determined by FE-simulation [2]. Fig. 4 shows, that the overall bond strength of a humid oxygen plasma (O2dH2O) activated Si/glass specimen is two times higher than the strength of the reference. In addition to that the bond strengths of this wafer stack are as high as a conventionally anodic bonded Si/glass wafer stacks. The fracture toughness (0.54 MPa√m) of the bonded interface is comparable to the bulk material in both bonding techniques.

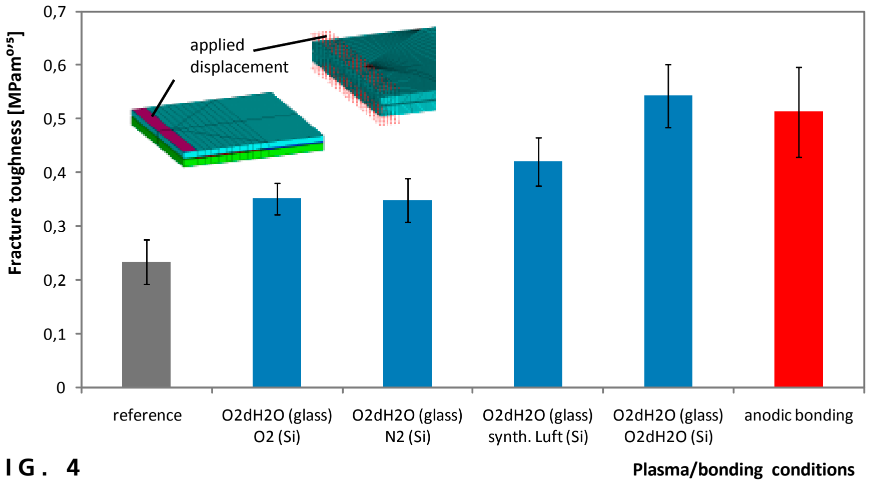

FIG. 4

References

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[2] Vogel, K. et al.: Crack propagation in Micro-Chevron-Test Samples of Direct Bonded Wafers. 26th Danubia-Adria Symposium on Advance in Experimental Mechanics, 23-26 Sept. 2009 Loeben, Austria, 2009.

Legend

Fig. 1: Plasma activation tool into SUSS mask aligner

Fig. 2: Pressure sensor (in cooperation with EPCOS AG)

Fig. 3: Image of a bonded micro-chevron Si/glass wafer stack (insets represent schematic drawing and test specimen)

Fig. 4: Fracture toughness for activated Si/glass wafer stacks

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DEPARTMENT ADVANCED SYSTEM ENGINEERING

Head of the Department: Dr. Christian Hedayat

Short Portrait

The department of Advanced System Engineering (ASE) focuses its research and development domains on the design, the simulation and the characterization of micro and nanoelectronic systems as well as circuit design, system integration and electromagnetic reliability. The department ASE works in close collaboration with the University of Paderborn on developing simulation methodologies for complex mixed signal heterogeneous micro and nanoelectronic systems as well as for specific wireless devices such as RFID-systems. The main topic of research is the characterization and the optimization of complex electronic systems by means of modeling, simulating and measuring the parasitic effects in order to assess the electromagnetic compatibility of the studied systems as well as the signal and clock integrity at high frequencies, not only at the IC-level but also for packages, modules and PCB. This research provides a crucial contribution to the development of reliable miniaturized systems.

The main competences and long-term experiences of the department ASE are in the fields of:

- RFID antennas and circuits
- Advanced 3D Near-EM-Field scanning system
- Advanced modeling and analysis of EMC and SI-effects
- Mobile wireless smart sensor systems
- EMC/EMR of micro and nanoelectronic systems
- Design methodologies for device integration
- Efficient modeling and simulation methodologies for Mixed-Signal Devices
- Model-based development methods for heterogeneous systems in package

Methods for the precise measurement and calculation of electromagnetic fields, and as well as circuit simulations, at an analogue and mixed signal level are employed to analyze the transmission behavior of micro and nanoelectronic systems (crosstalk, reflection, signal shape, transient behavior) in both frequency and time domains.

Furthermore RFID antennas and systems are developed for the use in harsh conditions and environments.

The application areas EMR and model driven design are the specialty of the ASE department which has developed efficient fast simulation methodologies (like black box modeling and event-driven modeling). These areas have been systematically developed and their success is reflected in numerous R&D projects in collaboration with industry partners, specifically MESDIE (MEDEA+), PARACHUTE (MEDEA+), EMCpack (PIDEA+), JTI-Clean Sky (EU) and PARIFLEX (BMBF).

The Fraunhofer ENAS department ASE closely cooperates with the University of Paderborn (Faculty of Electrical Engineering, Computer Science and Mathematics) within the competence network future EMC/RF-modeling and simulation methodologies. A very close cooperation exists especially with Prof. Dr. Ulrich Hilleringmann, Chair for Sensor Technology at the Departement of Electrical Engineering and Information Technology of the University of Paderborn.

Trends

Within complex modern micro and nanoelectronic devices, system-level top-down and bottom-up black box modeling approaches, analogue circuit and mixed-signal system simulation concepts, event-driven simulation methods, electromagnetic field analysis capabilities (including parasitic effects like crosstalk, reflection, attenuation and distortion) together with suitable measurement techniques are necessary to predict and to guarantee the reliability of the power supply system as well as the integrity of high-speed transmitting signals. For these trends the ASE department uses the most recent modeling and simulation approaches and employs adequate programming languages and tools.
This SI and PI analysis expertise is carried out and workflow procedures as well as tool integration are developed for HDP/HDI designs. The developed modeling and simulation concepts have been enclosed within a object-oriented libraries that have been implemented within the EDA-Tools of our industrial partners. In addition, ESD-overstress oriented analysis methodologies were developed for a better implementation within customer-specific design environments.
Based on its high-performance measurement equipments including an innovative self-developed Near-Field Scanning System, various microelectronic smart systems and integrated components can be optimally characterised with respect to physical and EMC/SI/RF increasing constraints.
Besides the efficient simulation and design of advanced hybrid 3D micro-packaged systems, a solid know-how is developed in the area of mixed-signal IC modeling and design methodologies for reliable clock synthesising systems (such as Phase Locked Loops).
The department ASE design activities concentrate not only on HDP/HDI industrial electronic systems for telecommunications, radar and automotive applications, but also on the challenging new area of energy harvesting and smart wireless and RFID systems embedding wireless transmission capabilities and autonomous sensor networks. For these wireless systems, the department focuses in particular on the design of optimized antenna and energy management strategies.
The Fraunhofer ENAS department ASE is ready to tackle all these challenges.

Competences

The main competences of the ASE department are:

- Mobile wireless smart sensor systems
- RFID antennas and circuits
- Advanced modeling and analysis of EMC and SI-effects
- EMC/EMR of micro and nanoelectronic systems
- Design methodologies for multiple device integration
- System modeling and simulation
- Model-based development methods for heterogeneous systems in package
- Advanced 3D Near-EM-Field scanning system

Services

We offer the following services:

- RF and EMC characterization and modeling
- Vector network analysers for 4 port measurement (300 KHz - 20 GHz)
- Vector network analysers for 4 port measurement (40 Mz - 50 GHz)
- RF-probing station for on-wafer measurements (300 µm Pitch Size, 40 GHz)
- 3D near-field scanner (high resolution, 9 kHz - 6.0 Hz)
- Vector network analysers for 2 port measurement (300 kHz - 8.6 GHz)
- Spectrum analyser (9 kHz - 26.5 GHz)
- EMC analyser (9 kHz - 2.9 GHz)
- Power meter with power sensors (100 kHz - 4.2 GHz, -30 dBm to +20 dBm)
- Digital oscilloscope (up to 500 MHz, 2.5 GSa/s)
- Communication signal analyser with 20 GHz TDR/sampling heads
- RF signal generator (up to 3.2 GHz, analogue modulations)
- RF pre-amplifier (9 kHz - 1.3 GHz, G=28 dB)
- Power amplifiers (10 kHz -1GHz, 30 W)
- Modeling and simulation competences
  - CST µWave Studio
  - Ansys (HFSS)
  - Cadence (HSPICE and Spectra)
  - Custom-specific solutions

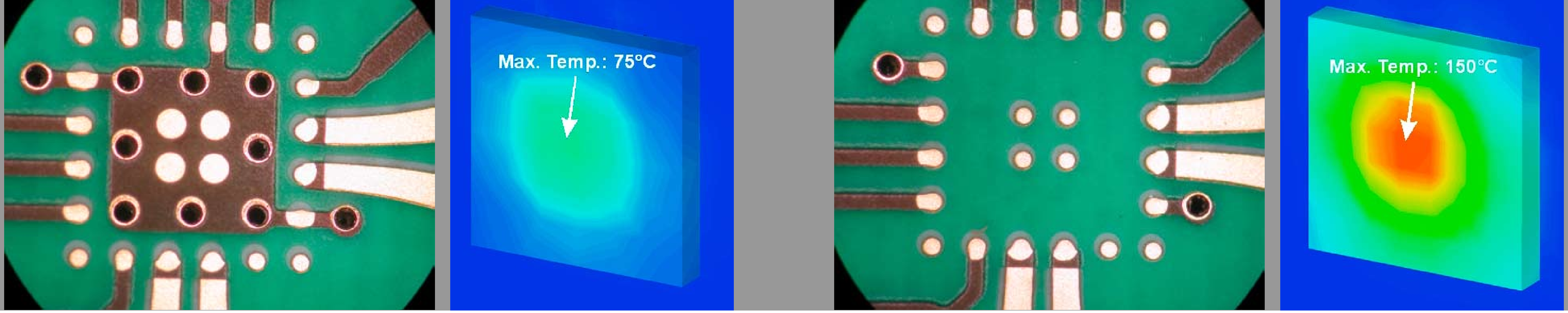


FIG. 4

MIXED-SIGNAL LINEAR AND NONLINEAR MODELING AND SIMULATION METHODS FOR HETEROGENEOUS SYSTEMS

Due to the mixed signal behavior, unique modeling techniques are developed for efficient and accurate simulations as well as profound characterizations. Charge-pump phase-locked loops (CP-PLL) are special mixed signal systems. They are widely used and are involved to synchronize an oscillator in phase and frequency and in frequency synthesis. If the PLL is absolutely synchronized, the phase error between the input signal and the oscillator signal is zero or at least a minimum. As soon as a phase error occurs, the oscillator will be readjusted until the phase error is zero or minimum. Supplementary, the PLL can be considered and used as a tracking filter for resonant systems. Therefore, picking up the capacitive or inductive variations in a resonant system, the PLL can be used in various high precision sensor applications. In these systems and especially in frequency synthesis, it is important to identify the overall state of the system along its transient stage. For this purpose, a monitoring circuitry is developed delivering reliable information about the status of the PLL's output signal. Fig.1 shows the course of the events that occur at the input of the VCO control voltage within the PLL, the phase zero crossing detection, the out-of-lock detection and the main output of the lock detection monitoring circuit. Thereby, the control voltage is proportional to the output frequency of the PLL. Obviously, by means of this monitoring circuit it can be decided whether the generated signal is reliable or not. The monitoring circuitry can be used for optimized gear-shifting techniques. In addition, an advanced and detailed top-down design flow for CP-PLL systems is developed.

For the simulation of miniaturized high frequency electrical circuits, fast and accurate macro models are needed. Therefore in the department ASE different mathematical modeling approaches have been analyzed, implemented and tested. On the one hand so called radial basis-function nets (RBFN) are used for the modeling of nonlinear circuits, e.g. input or output buffer. On the other hand, the vector fitting approach could successfully be applied in the linear case. The C++ vector fitting library developed at the ASE department is planned to be implemented within the EDA Tool with an industrial partner.

A further expertise of the department Advanced System Engineering focuses on the modeling, the simulation and the optimisation of customer specific devices. In cooperation with leading industrial partners, existing products (e.g. specific chip packages, PCB layouts) have been simulated and characterized in order to investigate the electrical and physical behavior of the structures. With these simulative methods, it is possible to detect the hidden reasons of critical effects causing failures that are not easily accessible by measurements. The example of Fig. 3 depicts the unwished electromagnetic coupling of two distant separated bond wires in an IC package. Fig. 4 shows the thermal influences of an IC on contacting structures.

While on the one hand the modeling methods are set-up in order to explain the behavior of existing structures, on the other hand they can be used for the detection of potential problems and the optimization of the system. Especially for applications with high processing costs (e.g. chip package fabrication), such simulative characterization methods lead to very cost-effective design-flows based on preliminary reliable modeling, simulation and optimisation results that precedes the fabrication of a prototype.

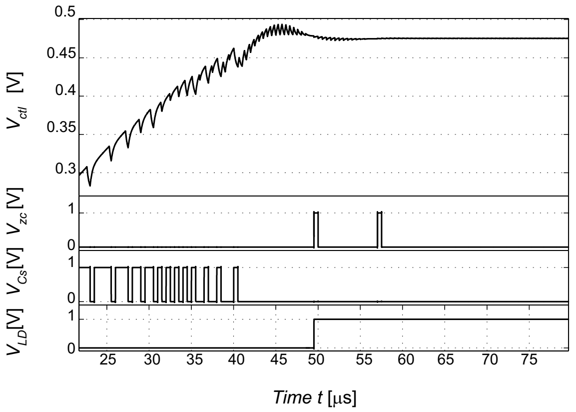


FIG. 1

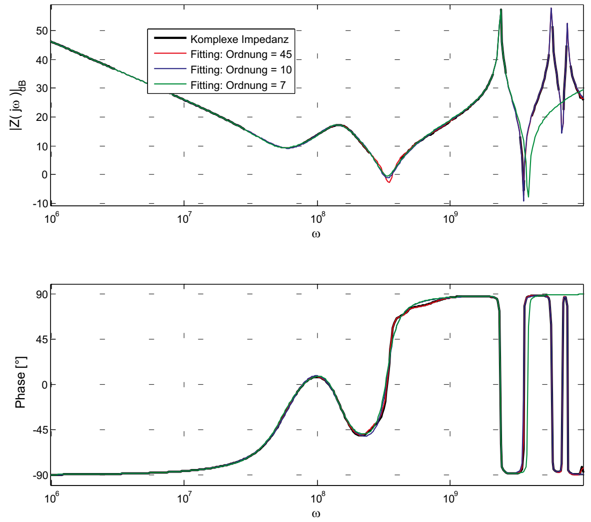


FIG. 2

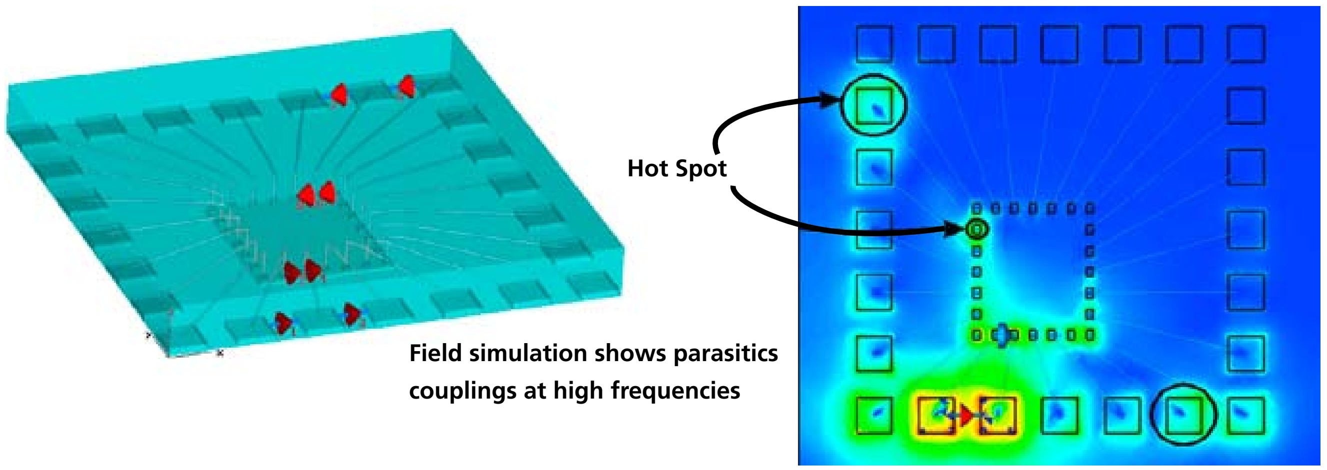


FIG. 3

Legend

Fig. 1: Course of events of the most important characteristics of the CP-PLL system detected by the monitoring circuitry (implemented in 90 nm technology of STM).

Fig. 2: Comparison of original transfer function with vector fitting models of different order

Fig. 3: Electrical simulation of chip packages for high frequency applications

Fig. 4: Modeling and simulation of thermal chip behavior in dependence of PCB footprint

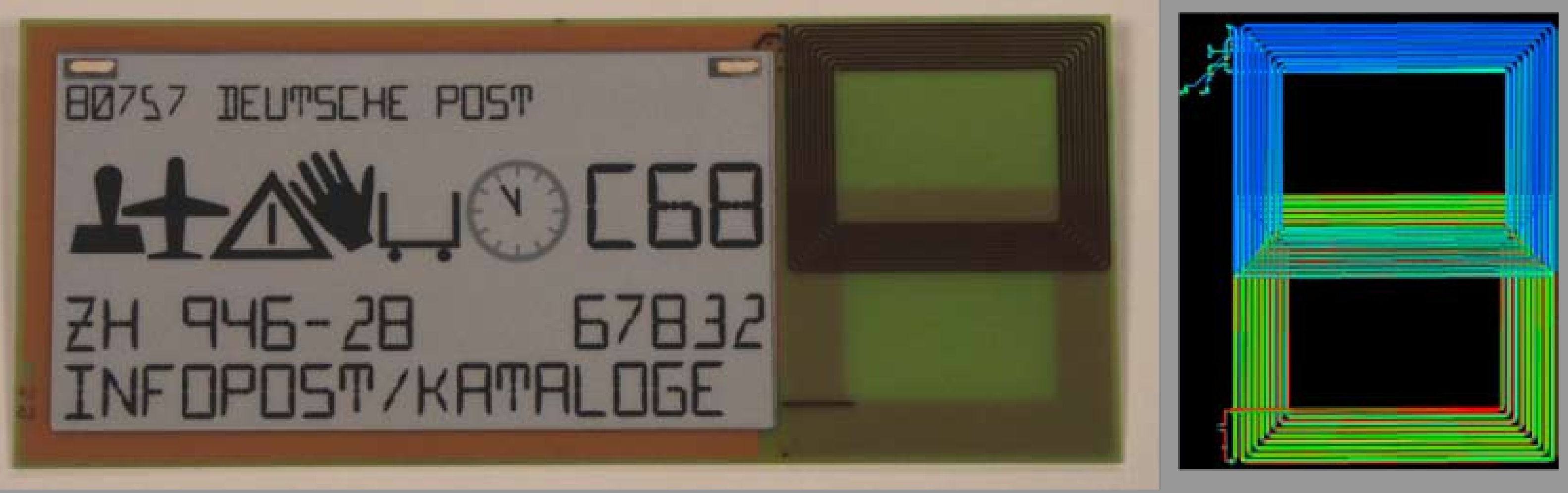
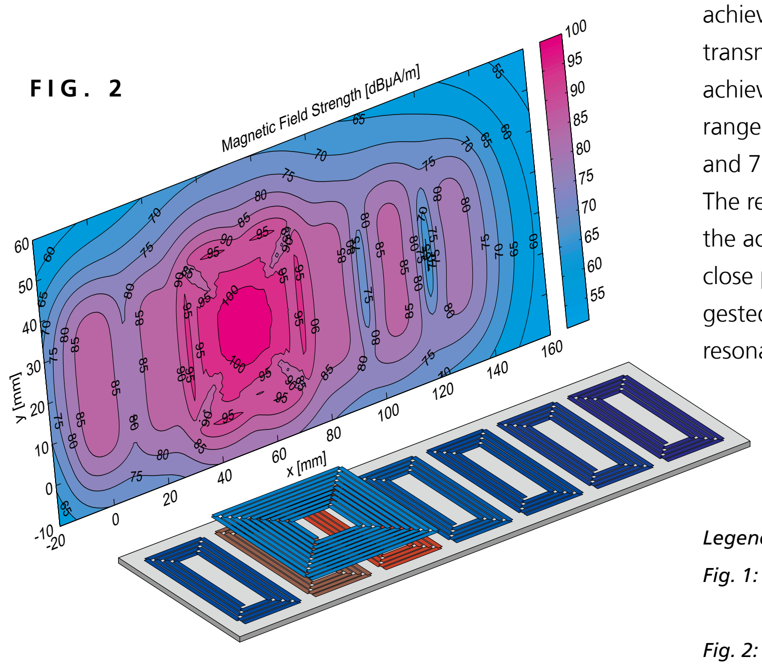


FIG. 1

WIRELESS ENERGY TRANSMISSION

The number of electronic devices used in industrial and private environments is steadily increasing. Due to the advances in semiconductor and microtechnology it is possible to greatly increase the functional range and decrease the overall device size. Even though the power consumption can be reduced with miniaturization, the energy supply of portable devices remains a challenge. Many different wireless communication interfaces already exist. The energy supply however is often provided by a chemical energy storage element or supplied by a galvanic contact. A wireless energy transmission would reduce the weight of portable devices and would simplify the handling.

FIG. 2



The research on wireless energy transmission of the Fraunhofer ENAS focuses on inductive coupled systems. Using this transmission method a reliable and efficient wireless transmission can be realized. In the BMBF funded research project PARIFLEX the department ASE developed in cooperation with the University of Paderborn a system capable of transmitting 80 mW for powering a passive RFID label containing a bi-stable e-Ink display. In parallel a communication link between the reader and the transponder was realized. The design of the antennas of the sender as well as the receiver is an important element of a wireless energy transmission system. For this purpose the department ASE developed adapted numerical field computation methods for the determination of the antenna parameters. These parameters can be optimized in order to fulfill the transmission range requirements and achieve a high efficiency. Furthermore a wireless energy transmission system setup at the department ASE was able to achieve a transmission of 15 W at 230 VDC and an operating range of up to one meter with an efficiency between 30% and 70%.

The research on emission reduced design is another focus of the activities. In a planar sender antenna array only coils in close proximity to the receiver carry a high current. The suggested passive setup based on the effect of multiple coupled resonant circuits allows for a low cost design.

Legend

Fig. 1: Simulated surface currents of an antenna of a wireless powered display transponder and the final demonstrator

Fig. 2: Simulation of an energy transmission antenna setup with reduced field emission

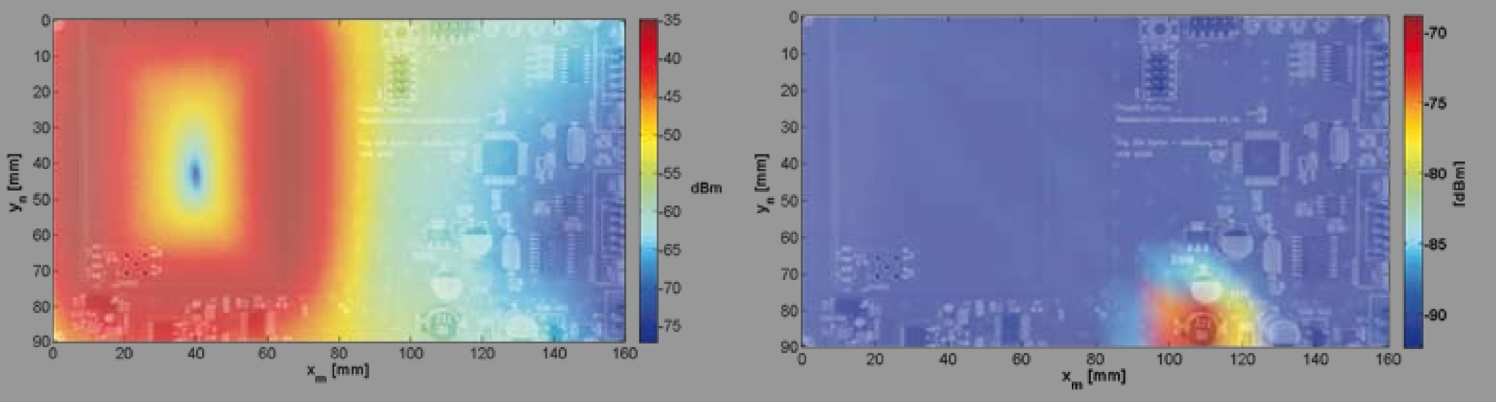


FIG. 1

NEAR FIELD SCANNING

The development of nowadays electronic systems becomes more complicated. On the one side the component dimensions are shrinking and on the other hand the signal to noise ratio as well as the absolute signal level decrease. Problems arise in the design of complex high density systems as all parasitic and coupling effects cannot be predicted during the design phase with the aid of classical EDA tools and the associated simulation approaches. It is extremely difficult to reason any possible malfunctions once prototyping has been completed. The possibility to visualize the EM-field distribution in time and frequency domains is a powerful tool for the designer in order to understand the way a disturbance may influence the system. Based on this analysis a targeted redesign can be carried out resulting in the correction of found malfunctions.

The Fraunhofer ENAS department ASE is developing a fully autonomous 3D near field scanning system which consists of a very high resolution positioning system, with a fast and broadband signal acquisition unit in the time and frequency domains. Software for the controlling and analysing of the measurement procedure is embedded in the scanning system.

In order to demonstrate the capabilities of this measurement system, an RFID reader unit is investigated in the following. The reader unit containing an integrated antenna is suspected to suffer from EMC related problems reducing its reading range. The coupling between the antenna, the digital control and the power supply will be investigated in order to pinpoint the problem. The on-board antenna might couple to the other system components causing EMC problems. In order to determine whether such a parasitic coupling is present or not the magnetic near field distribution at the carrier frequency of the RFID system has been investigated. Besides the strong magnetic fields present in the proximity of the integrated antenna no parasitic field coupling to other components can be noticed. The investigation of the entire spectrum reveals magnetic emissions at frequencies well below the operating frequency. The field distribution allows localization of the emission source in the power supply section of the RFID reader device. At the same time a parasitic field coupling among the emitting component and the integrated antenna can be excluded leaving a conducted propagation of the disturbance as the source of the reduced performance. Via a modification of the power supply circuitry the read range could be enhanced in order to fulfil the requirements.

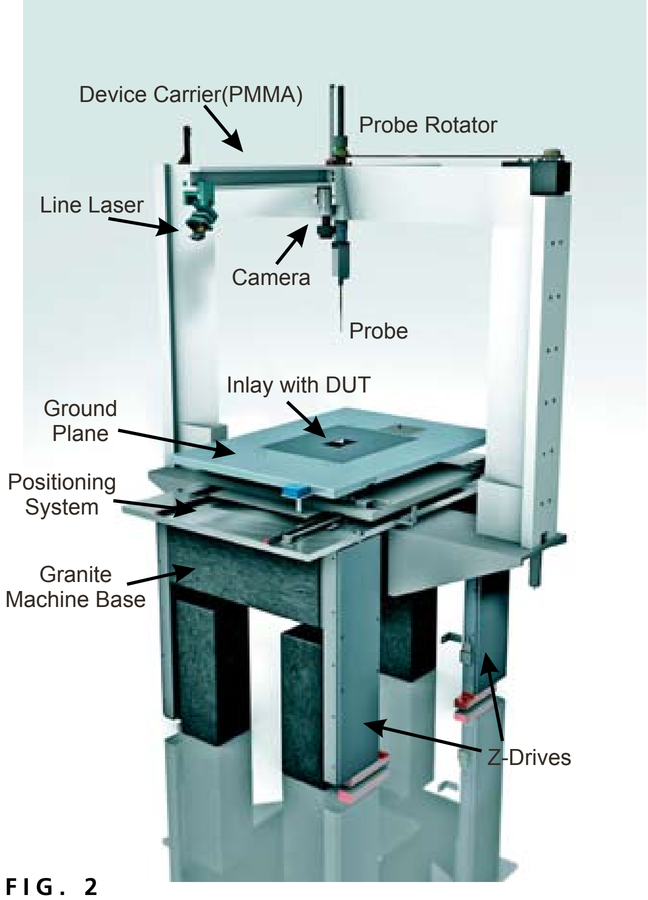


FIG. 2

Legend

Fig. 1: Measured tangential magnetic field distribution. top: 13.56 MHz, bottom: 150 kHz

Fig. 2: Hardware setup of the near-field scanner

COOPERATION

FRAUNHOFER ENAS - COOPERATION WITH NATIONAL AND INTERNATIONAL UNIVERSITIES

National Cooperation

Interdisciplinary cooperation is the key for success. The Fraunhofer Research Institution for Electronic Nano Systems cooperates with the faculties of Electrical Engineering & Information Technology, Natural Sciences and Mechanical Engineering of the Chemnitz University of Technology. The cooperation aims at generating synergies between the basic research conducted at the Chemnitz University of Technology (CUT) and the more application-oriented research at the Fraunhofer ENAS.

The departments Multi Device Integration and Back-End of Line closely cooperate with the Center for Microtechnologies (ZfM) of the Chemnitz University of Technology. With the Center for Microtechnogies, its clean rooms and technological equipment, the faculty of Electrical Engineering & Information Technology possess a special scientific operating unit. It is the basis for the production of prototypes and pilot-run series, for the development of technologies and materials as well as for the training of students, trainees and young researches in step with research and actual practice.

Furthermore, a very close collaboration exists between the department Micro Material Center Chemnitz and the Chair for Materials and Reliability of Microsystems which belongs also to the Center for Microtechnologies of the Chemnitz University of Technology. They cooperate in the fields of material characterization, simulation and experimental analytics.

Together with the ZfM the Fraunhofer ENAS carries out research and development in the fields micro and nanoelectronics, micro mechanics and microsystems technologies.

Main topics are:

- Development of technologies and components for micro and nano-electro-mechanical systems, like sensors, actuators, arrays
- Development of technologies for metallization systems in micro and nanoelectronics
- Design of components and systems
- Nanotechnologies, components and ultrathin functional layers

The cooperation results in a common use of equipment, facilities and infrastructure as well as in the cooperation in research projects.

A relatively new research topic of the smart systems integration are the printed functionalities, which are just well established at the Institute for Print and Media Technique of the faculty of Mechanical Engineering of the CUT. Using printing technologies conducting, insulating and semiconducting materials are printed and used for different functionalities, starting from antennas up to batteries.

The department Advanced System Engineering located in Paderborn continues the close cooperation with the University Paderborn especially in the field of electromagnetic reliability and compatibility.

International Cooperation

The Fraunhofer Research Institution for Electronic Nano Systems ENAS maintains a close contact with numerous other universities and research institutes via participation in projects and European technology platforms. In Asia, long-term cooperations exist with the Tohoku University in Sendai, the Fudan-University Shanghai and the Shanghai Jiao Tong University. Two examples will be given.

The cooperation of both, Fraunhofer ENAS and also Center for Microgtechnologies, with the Tohoku University Sendai in Japan is a very successful one. As a principal investigator Prof. Dr. Thomas Gessner got a own WPI research group belonging to the devision Device/Systems within the WPI Advanced Institute for Material Research. The group is managed by Prof. Yu-Ching Lin since November 2008. Focus of the research is smart systems integration of MEMS/NEMS, especially the integration of heat generating materials for wafer bonding, the CMOS-MEMS integration and the fabrication of nanostructures using self organising and self assembling.

Within the international graduate school “Materials and Concepts for Advanced Interconnects” young engineers work together with researchers from other German and Chinese universities. They are specialized in electrical engineering and microelectronics, material sciences as well as physicists and chemists and develope together new materials and processes as well as new concepts for interconnect systems in integrated circuits. The project makes essential contributions not only to the solution of problems of nanoelectronics. It supports and requests an interdisciplinary and cross-cultural communication and cooperation. Participants at this projects are the Institute of Physics, the Institute of Chemistry and the Center for Microtechnologies of the Chemnitz University of Technology as well as the Technical University Berlin, the Fudan-University Shanghai, the Shanghai Jiao Tong University, the Fraunhofer Institute for Microintegration and Reliability IZM and the Fraunhofer Research Institution for Electronic Nano Systems ENAS.

nanett
nano system integration
network of excellence

NANETT - NANO SYSTEM INTEGRATION NETWORK OF EXELLENCE

The research consortium nanett „nano system integration network of excellence - application of nano technologies for energy-efficient sensor systems“ is one of the successful initiatives of the second phase of the “Spitzenforschung und Innovation in den Neuen Ländern“ program, funded by the Federal Ministry of Education and Research (BMBF). Under the direction of the Chemnitz University of Technology and the Fraunhofer Research Institution for Electronic Nano Systems ENAS this dynamic network of nine different partners was formed to bring together their competences in the field of applied nanotechnologies. Using that approach of combining the capabilities of several renowned scientific institutions enables international and domestic top level research on a competitive basis. The grant of the BMBF for the whole R&D joint venture amounts to 14 million Euros. The project started in November 2009 at a duration of five years.
The greatest concern of the network is to be an attractive, competent and solid partner of the industry in the promising domain of nano and system integration technologies. To suit the requirements of high interdisciplinarity and due to huge invest costs for production and test equipment in the field of micro and nanotechnologies the usage of synergies by collaboration of different oriented research centers is essential for success and efficiency of joint research projects.

The following partners are cooperating within the nano system integration network of excellence:

- Chemnitz University of Technology (Faculty of Electrical Engineering and Information Technology, Faculty of Natural Sciences, Faculty of Mechanical Engineering and Faculty of Computer Science)
- the University of Applied Sciences Mittweida (FH)
- three Fraunhofer Institutes (Fraunhofer ENAS, Fraunhofer IZM and Fraunhofer IAP)
- three Institutes of the Leibniz Association (Leibniz IHP, Leibniz IFW and Leibniz IPF)
- the Helmholtz Zentrum Berlin (HZB)

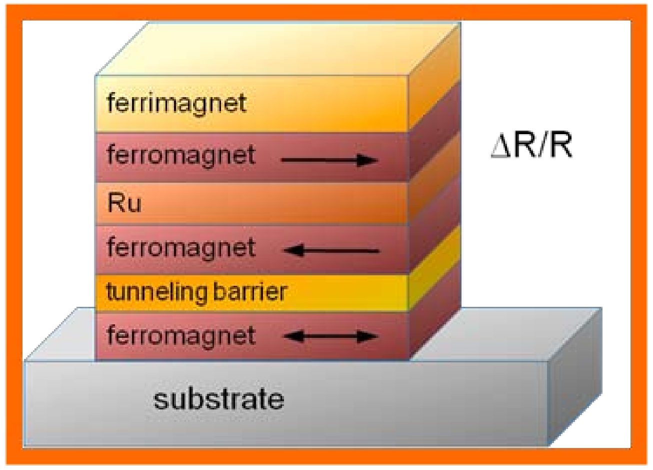
Fields of research are:

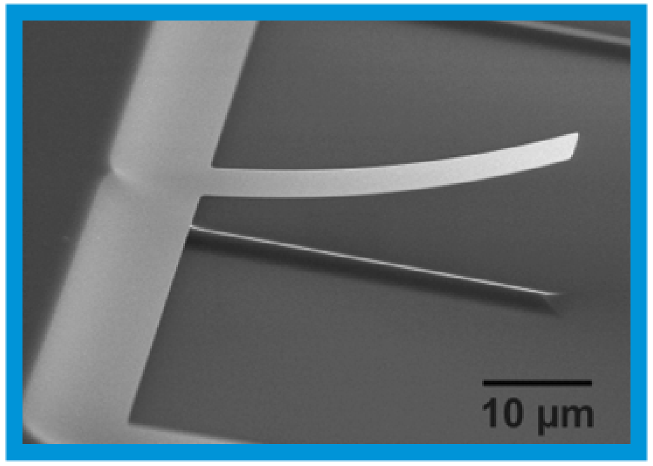
- Novel processes and technologies
  - Application of quantum mechanical phenomena and effects of nano structures
  - Significant improvement of resolution
- Micro-nano-integration
  - Integration of nano structures with electromechanical functionalities
  - “Enabling technology“ for implementation of new functionalities
- Nano materials
  Functional nano composite materials
  - Integration of sensor technologies and actuator
  - Engineering into constructional elements

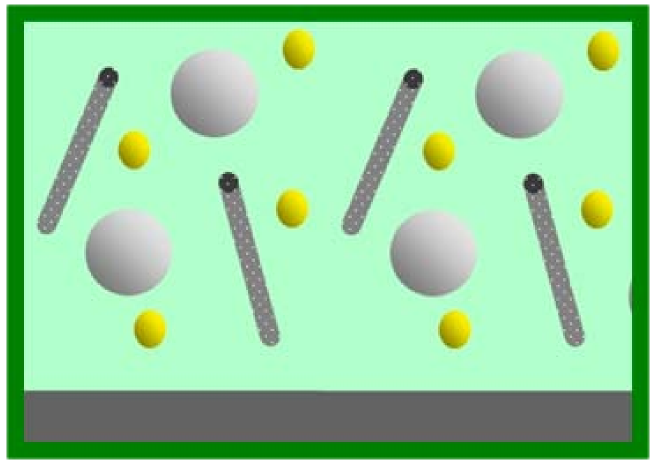
Objectives:
The most important objectives of the network are:

- Increase of the international visibility of the involved partners, especially of scientific and technical centers located at the Smart Systems Campus in Chemnitz by focusing of competences and integration of excellent scientists in promising application-oriented projects
- Combination of different research areas in common projects to suit the interdisciplinary requirements of nano system integration technology
- Link of universities, applied research centers and local industry at a supra-regional level to enable know-how and technology transfer as well as to improve its innovative energy
- Increase of added value of local small and medium-sized enterprises and therefore its competitiveness by implementation of smart components and systems into products
- Strength of attractiveness of R&D institutions for students and graduates by offering collaborations within ambitious and industry relevant research fields

For more information please visit our website:
http://www.nanett.org/







INTERNATIONAL RESEARCH TRAINING GROUP

"Materials and Concepts for Advanced Metallization"

Since April 1, 2006, the International Research Training Group (Internationales Graduiertenkolleg 1215) "Materials and Concepts for Advanced Interconnects", jointly sponsored by the German Research Foundation (DFG) and the Chinese Ministry of Education, has been established for 4.5 years between the following institutions:

- Chemnitz University of Technology with Institute of Physics, Institute of Chemistry and Center for Microtechnologies
- Fraunhofer Research Institution for Electronic Nano Systems ENAS
- Fraunhofer Institute for Reliability and Microintegration IZM
- Technical University Berlin
- Fudan University, Shanghai
- Shanghai Jiao Tong University

This International Research Training Group IRTG 1215 is the first of its kind at Chemnitz University of Technology. It is lead by Prof. Ran Liu of Fudan University as the coordinator on the Chinese side and Prof. Thomas Gessner on the German side. A graduate school like this offers brilliant young PhD students the unique opportunity to complete their PhD work within 2.5 to 3 years in a multidisciplinary environment. Up to 14 PhD students of the German and 20 of the Chinese partner institutions as well as a post-doctoral researcher at the Center for Microtechnologies are involved in the current program. The different individual backgrounds of the project partners bring together electrical and microelectronics engineers, materials scientists, physicists and chemists. In particular, the IRTG is working to develop novel materials and processes as well as new concepts for connecting the devices within integrated microelectronic circuits. Smaller contributions are being made in the field of device packaging and silicides for device fabrication. In this sense, the IRTG project is helping to solve problems currently encountered on the way to nanoelectronics.

Therefore, the research program of the IRTG concentrates on both applied and fundamental aspects and treats the mid- and long-term issues of microelectronics metallization. Atomic layer deposition (ALD) of metals, new precursors for metal-organic chemical vapor deposition (MOCVD), ultra low-k dielectrics and their mechanical and optical characterization together with inspection techniques on the nanoscale are considered. New and innovative concepts for future microelectronics such as carbon nanotube interconnects or molecular electronics along with silicides to form links to front-end of line processes are of interest, as well as the evaluation of manufacturing-worthy advanced materials. Moreover, the research program addresses reliability and packaging issues of micro devices. Highlighting links between fundamental materials properties, their characteristics on the nanoscale, technological aspects of materials and their applications to microelectronic devices is the main objective of the program.

Nevertheless, the principal idea of the IRTG is four-fold: The research program defines the framework of the activities and the topics of the PhD theses. This is accompanied by a specially tailored study program including lectures, seminars and laboratory courses to provide comprehensive special knowledge in the field of the IRTG. The third part of the program comprises annual schools held either in China or Germany, bringing together all participants of the IRTG and leading to vivid discussions during the presentation of the research results. Moreover, an exchange period of 3 to 6 months for every PhD student at one of the foreign partner institutions is another essential component. Besides special knowledge in the scientific field, these activities will provide intercultural competencies that cannot easily be gained otherwise.

Summer School 2009:
The 4th summer school of the International Research Training Group 1215 was held from May 12 to 17, 2009, in Shanghai. This event was organized by Prof. Chen Di of the Shanghai Jiao Tong University.
At the first two days of the summer school, 26 PhD. students from the German and Chinese party presented the status and progress of their work. For some of the presenters it was their first attendance to the annual summer school. Each presentation closed-up by questions from the audience. The international participants had the opportunity for further discussions as well as small talk during breaks for tea and meals.
The events were organized at both, the old and new campus of the Shanghai Jiao Tong University. The guests had an impressive visit of the very large new campus.
On May 15, the preparation of the new proposal for the International Research Training Group took the center stage of the involved professors. The event was opened by Prof. Thomas Gessner, speaker of the International Research Training Group. He demonstrated the activities of the Fraunhofer ENAS and the Center for Microtechnologies in connection with actual trends and processes in micro and nanotechnologies. Afterwards, the representatives of the single subprojects presented the focuses of prospective activities. Nine German and 11 Chinese subprojects for the follow-up application were already defined in advance. During the meeting, contents were discussed and possible interfaces as well as cooperations between the projects were pointed out.
A sightseeing tour for the PhD students was planned. They visited the Suzhou Industrial Park, the Bio Bay, the Suzhou Institute of Nano-Tech and Nano-Bionics (SNANO) and gained insight of the activities of the respective institution. Following, as part of the cultural framework program, the Humble Administrator's Garden (Zhuozheng Yuan) and the The Tiger Hill (Hu Qiu) were visited.
On May 16, all participants of the summer school could enjoy an impressive performance of Chinese acrobatics in the arts center Shanghai Circus World.
Due to earlier exchanges (mobility periode) of several PhD students between the Chinese and the German side, the event was accompanied by an active communication of all members. Especially the cultural framework program in a nice atmosphere made the communication between the participants of the summer school really pleasant.
On May 17, the event was completed by the dinner for the German guests and Chinese organizers. According to the attendants, the organization of this year's summer school was excellent.
For three German PhD students the summer school took place during their three-month exchange stay abroad in China. They were integrated very well in their respective groups and discovered good working conditions.

New proposal:
Beside the research activities of the IRTG program the preparation of the new project proposal was the main focus of the work in 2009. The new topic will be "Materials and Concepts for Advanced Interconnects and Nanostructures". The new topic combines both, "More Moore" as well as "More than Moore" related activities. The proposal was submitted to the German Research Foundation (DFG) at the end of October 2009. The evaluation of the first period of the IRTG program by the German Research Foundation is scheduled for the end of March 2010.

For further information please visit our webpage:
http://www.zfm.tu-chemnitz.de/irtg/

FRAUNHOFER ENAS WITH AN OWN RESEARCHER GROUP IN JAPAN

The Gessner group at the Advanced Institute of Materials Research of the World Premier International Research Center (WPI-AIMR) at the Tohoku University in Sendai

Prof. Dr. Thomas Gessner leads as one of 32 Principal Investigators a research group of WPI-AIMR (world premier research center - advanced institute for materials research). The WPI-AIMR is a special research institute hosted by the Tohoku University in Sendai. This research institute is funded by the Japanese government to support world class research with international cooperation. Prof. Gessner has been invited to lead a research group there. The Gessner group is one group within the research devision Device/Systems of the WPI-AIMR.

After a starting phase to setup the group in 2008 the basic research contents of the Gessner group have been defined in 2009:

* application of metallic glasses for MEMS devices
* fabrication and use of nanoporous metals
* development of bonding and integration technologies

Metallic glasses are amorphous alloys that exhibit glass transition point. In comparison with most metals, metallic glasses have high strength, superior elastically limit, anticorrosion and good wear resistance. Although the research in this field is not going on for a long time already, micro structures as used in MEMS could have been successfully created. Research activities of Gessner group are supported by Prof. Masayoshi Esashi. A Japanese-German research cooperation project is going on between Prof. Gessner and Prof. Esashi.

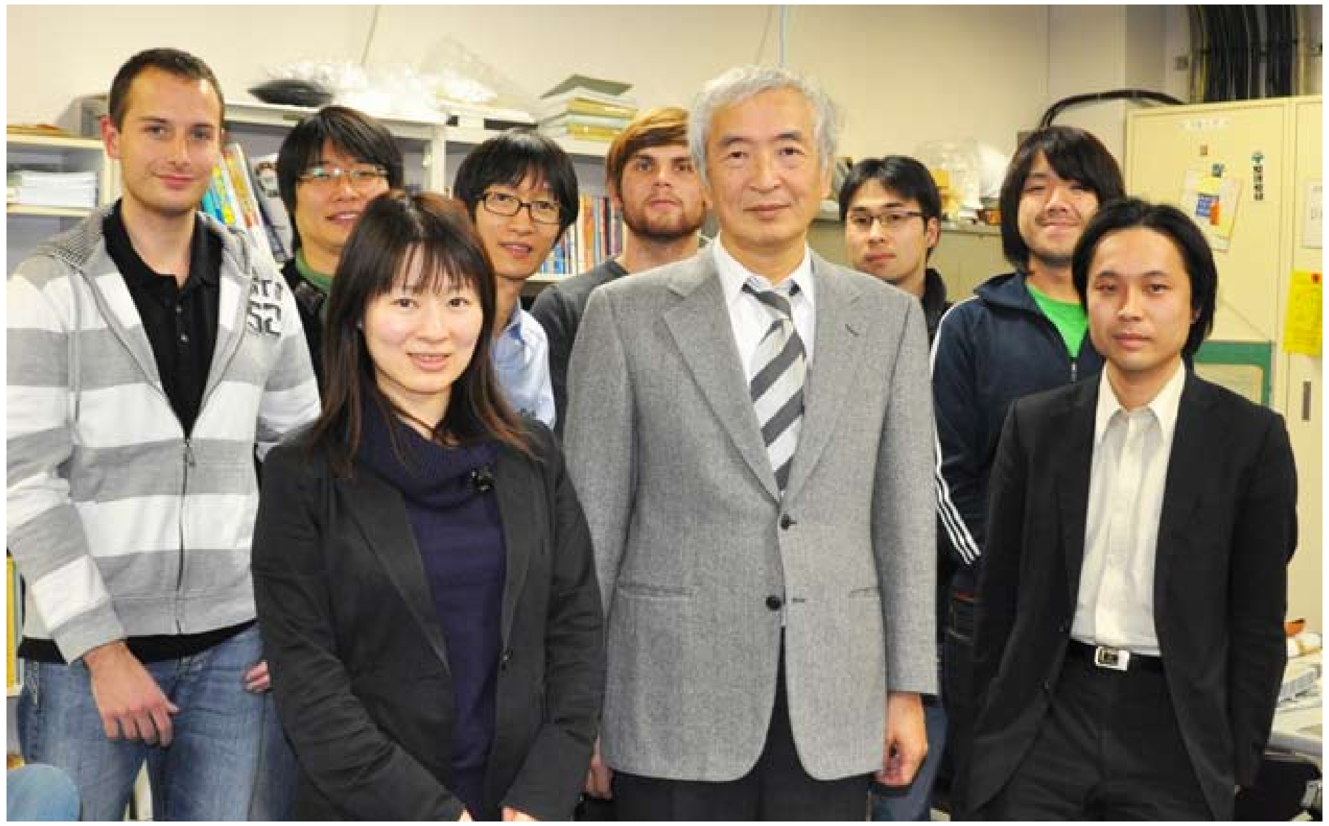
New researchers have joined the group in Sendai. Dr. Hsueh-An Yang started research in the field of bulk metallic glasses whereas Ms. Pei-Chun Chen has the task to investigate nanostructures. They work in the Gessner group aside from assistant Prof. Dr. Yu-Ching Lin and research associate Jae-Wung Lee. Also the group has started to host guest researcher students from Germany. This allows the students to experience world class research in a completely different social and working environment than Germany. On the other hand side the research group in Sendai profits from new ideas and additional staff. The first visiting student was Mr. Marco Haubold. He investigated new adhesion layers for metallic interlayer wafer bonding. He stayed from August and he returned to Germany in December after the successful completion of the project. As a second visiting student Mr. Frank Roscher arrived in the middle of November in Sendai. He worked in the field of deposition and structuring of metallic glasses. He stayed for five months in Sendai.

Prof. Yu-Ching Lin works as an assistent professor within the Gessner group. We shortly spoke with her:

Fraunhofer ENAS: Prof. Lin, what are you working on at the moment?
Prof. Lin: *I am currently working on MEMS bonding and new functional MEMS materials. I have researched on wafer bond technology since I was in Fraunhofer ENAS. When I moved to WPI-AIMR Tohoku University, I started fusion researches with experts from material science. MEMS bond technology is the key for system integration and packaging and is an important basic technology. For new MEMS material research, I believe every introduction of an innovative material to the MEMS will open a new regime of MEMS devices.*

Fraunhofer ENAS: What was the reason to attend WPI-AIMR?
Prof. Lin: *Fusion research is one of the main reasons why I came here. Before the WPI-AIMR was established, I spent time at the Tohoku University School of Engineering, and later at the Fraunhofer Research Institution for Electronic Nano Systems in Chemnitz, Germany. Having studied practical and theoretical engineering, I wanted to work in the basic materials science required to invent novel MEMS devices. Here I found three eager collaborators from the Bulk Metallic Glasses Group - Na Chen, Deng Pan and Dmitri Louzguine. In April 2009, we submitted a proposal for a fusion research project and launched a project aimed at applying bulk metallic glasses (BMGs) for MEMS device fabrication.*

About Prof. Dr. Yu-Ching Lin:
Yu-Ching Lin was born in Taiwan in 1976. In 2002 she got her master's degree at Department of Bio-Industrial Mechatronics Engineering of Taiwan University. After that she started a PhD study at Department of Mechatronics and Precision Engineering, Tohoku University in Sendai, Japan and got her PhD degree in 2006. Then she became assistant professor at Department of Bioengineering and Robotic, Tohoku University. From 2007 till 2008 she joined the MEMS packaging research group of Fraunhofer ENAS in Chemnitz, Germany. At present she is working as assistant professor at The World Premier International Research Center Advanced Institute for Materials Research (WPI-AIMR) of Tohoku University again.



Prof. Dr. Masayoshi Esashi (middle, front) and assistant Prof. Dr. Yu-Ching Lin (3rd on the left) with researchers of the Esashi group and the Gessner group as well as two German visiting scientists.

smart systems campus
TechnoPark Chemnitz

COOPERATION WITH UNIVERSITIES AND RESEARCH INSTITUTES (SELECTION)

Brandenburgische Technische Universität, Cottbus, Germany

CEA-LETI, Grenoble, France
CEA-Liten Grenoble, France
Chongqing University, Chongqing, China

École Nationale Supérieure des Mines de St-Étienne, France
ETH Zurich, Switzerland

Femto-ST, Besançon, Frankreich
Forschungszentrum Rossendorf, Germany
Fraunhofer CNT, Dresden, Germany
Fraunhofer IAP, Golm, Germany
Fraunhofer IBMT, Potsdam, Germany
Fraunhofer IISB, Erlangen, Germany
Fraunhofer ISIT, Itzehoe, Germany
Fraunhofer IWM, Halle, Germany
Fraunhofer IWS, Dresden, Germany
Fraunhofer IZM, Berlin and Munich, Germany
Fraunhofer LBF, Darmstadt, Germany
Fresenius, Germany
Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany
Friedrich-Schiller-Universität, Jena, Germany
Fudan University, Shanghai, China
Fundacao Centros de Referencia em Tecnologias Inovadoras – CERTI, Florianopolis, Brazil

IMEC, Leuven, Belgium
Institut für Solarenergieforschung Hameln-Emmerthal, Germany

Johannes Kepler Universität, Linz, Austria
Joseph Fourier University, Grenoble, France

Konkuk University, Chungju, Korea

Laboratoire d'Electronique, Antennes et Télécommunications, Sophia Antipolis (Nice), Frankreich
Leibniz IFW, Dresden, Germany
Leibniz IHP, Frankfurt/Oder, Germany
Leibniz INP, Greifswald, Germany
Leibniz IOM, Leipzig, Germany
Leibniz Universität, Hannover, Germany

Massachusetts Institute of Technology, Cambridge/Boston, USA
Max-Planck-Institut (MPI) für Mikrostrukturphysik, Halle, Germany
Mid Sweden University, Sweden

Royal Institute of Technology, Stockholm, Sweden

Shanghai Jiao Tong University, Shanghai, China

Tohoku University, Sendai, Japan
TSINGHUA University, Beijing, China
Technische Universität Dresden, Germany

Universidade Federal de Pernambuco, Recife, Brazil
University of Applied Siences Mittweida (FH), Laser Application Center, Germany
University of California, Berkley, USA
University of Nevada, Reno, USA
University of Nice-Sophia Antipolis, France
University of Paderborn, Paderborn, Germany
University Paris Diderot, France
University of Tokyo, Research Center for Advanced Science & Technology (RCAST), Tokyo, Japan

VTT Technical Research Centre, Finland
Westsächsische Hochschule Zwickau (FH), Zwickau, Germany
Xiamen University, Xiamen, China

SMART SYSTEMS CAMPUS CHEMNITZ

The Smart Systems Campus Chemnitz is an innovative network with expertise in micro and nanotechnologies as well as in smart systems integration. This technology park provides renowned scientific and technical centers with the entrepreneurial spirit and business acumen and an economic boost at a location where everything is on the spot. A close integration of science, applied research and industry is there an everyday reality and reflects a strategy that is being fulfilled.
The partners of the Smart Systems Campus Chemnitz are:

- Chemnitz University of Technology with Institute for Physics, Center for Microtechnologies (ZfM) and Center for Integrative Lightweigth Technology (ZIL)
- Fraunhofer Research Institution for Electronic Nano Systems ENAS
- Start-up Building
- Business park

The start-up building for young companies related to the sector mentioned before forms an important part of the campus. There is space for approx. 15 start-up companies. In the present time the following companies are working there:

- Berliner Nanotest und Design GmbH (common labs with EUCEMAN, Chemnitzer Werkstoffmechanik GmbH, AMIC Angewandte MicroMesstechnik GmbH, Amitronics GmbH, SEDEMAT GmbH, Clean Technologies Campus GmbH)
- memsfab (common lab with Leibniz IFW)
- EDC Electronic Design Chemnitz GmbH
- LSE Lightweigth Structures Engineering GmbH
- SiMetrics GmbH

The campus not only opens doors for young entrepreneurs in the start-up building, but expanding companies can also make use of neighboring space on a business park. Microsystems technology oriented companies can set up in business in line with their requirements on an area measuring up to 7 hectares.
The first company in the park is the 3D-Micromac AG which develops and manufactures highly efficient and innovative machines for laser micro machining.

LONGTIME COOPERATION WITH 3D-MICROMAC AG – AN INTERVIEW WITH TINO PETSCH

In 2009 the Smart Systems Campus Chemnitz has been finished leading to new possibilities for basic and applied research in the field of system integration using micro and nanotechnologies. The 3D-Micromac AG was the first company within the business park of this campus. For several years the Fraunhofer Research Institution for Electronic Nano Systems ENAS and the 3D-Micromac AG are cooperating. We spoke with Mr. Tino Petsch, the managing director, about his experiences with cooperative projects.

Fraunhofer ENAS: Mr. Petsch, the 3D-Micromac AG and the Fraunhofer ENAS have developed a long-term relationship of trust. What are the reasons for a SME to cooperate with Fraunhofer-Gesellschaft?
T. Petsch: *The 3D-Micromac AG has continuously grown since their foundation in 2002. The Fraunhofer-Gesellschaft für angewandte Forschung e.V. and so the Fraunhofer ENAS, which was the former branch Chemnitz of Fraunhofer IZM, supports not only industry-oriented research but carries out real applied research. Due to this fact 3D-Micromac AG as a medium-sized enterprise is able to shorten development times and time to market with the support of Fraunhofer ENAS and to keep own research costs at certain level.*

Fraunhofer ENAS: What services of Fraunhofer ENAS does your company use?
T. Petsch: *We use different services. Fraunhofer ENAS together with the Center for Microtechnologies is carrying out tests, characterization and analysis, which supports us in the evaluation and verification of our own developments. On the other hand, Fraunhofer ENAS has bought laser micromachining equipment from 3D-Micromac AG.*
We are cooperating on process developments in several projects. The staff of Fraunhofer ENAS has a specific knowledge, which allows them to solve problems in a profound and scientific manner. Together with the application oriented knowledge of our staff, we are able to develop first-class products. These first class products lead on the other hand to the fact that we have a good standing as technology leader in the market.

Fraunhofer ENAS: What has worked really well, what needs improvements?
T. Petsch: *The new Smart Systems Campus Chemnitz opened new possibilities for us. The ways have been dramatically shorten. This allows much better, much quicker and much more efficient cooperation between 3D-Micromac and Fraunhofer ENAS. By the way, we appreciate the open atmosphere in common discussions and the expertise of the staff of Fraunhofer ENAS and the Center for Microtechnologies.*

About Tino Petsch:
Tino Petsch was born in Chemnitz in 1967. After his industrial education as a precision mechanics he studied automation technology and mechanical engineering/technology. Since 1990 he founded and managed different companies in the IT and laser business. In 2002 he founded the 3D-Micromac AG as main share holder and is the CEO of this company. 3D-Micromac AG is one of the leading solution providers for laser micro machining.
He is also member of the board of the Laser Institute of Middle Saxony (LIM) and chairman of the workgroup “Laser in Photovoltaic Industry” from Silicon Saxony. Mr. Petsch has announced numerous patents and publications in the field of laser technology.

About 3D-Micromac:
3D-Micromac AG, a leading supplier of customized laser micro machining systems, develops and manufactures highly efficient state-of-the-art laser micromachining workstations for industry, research and science. These systems are used e.g. in facilities for production of photovoltaic systems, processing of semiconductors and medical applications. Processes used with laser micromachining are micro drilling, signing, cutting, 2D and 3D structuring and marking of various materials and thin films.
In parallel, 3D-Micromac is ready to develop new processes and technologies, or systems on customer’s demands as a qualified partner.

More information about 3D-Micromac AG:
http://www.3d-micromac.com/

Tino Petsch (3D-Micromac AG) and Prof. Dr. Thomas Gessner (Fraunhofer ENAS) in front of the pico second laser work station of 3D-Micromac AG

COOPERATION WITH INDUSTRY (SELECTION)

3D-Micromac AG, Chemnitz, Germany

ACREO, Kista, Sweden
Advanced Micro Devices (AMD), Sunnyvale, USA
Air Products and Chemicals, Inc., Carlsbad (CA) and Allentown (PA), USA
Alenia Aeronautics, Casoria, Italy
AMTEC GmbH, Chemnitz, Germany
Applied Materials, Santa Clara, USA and Dresden, Germany
Arentz Optibelt, Höxter, Germany

Berliner Nanotest and Design GmbH, Berlin, Germany
Boehringer, Ingelheim, Germany
Robert Bosch GmbH, Reutlingen & Stuttgart, Germany

CAD-FEM GmbH, Grafing, Germany
Chemnitzer Werkstoffmechanik GmbH, Chemnitz, Germany
Christmann Informationstechnik + Medien GmbH, Ilsede, Germany
Clean Tech Campus GmbH, Chemnitz, Germany
Colour Control Farbmeßtechnik GmbH, Chemnitz, Germany
Continental AG, Germany
CST AG, Darmstadt, Germany

DBI - Gastechnologisches Institut gGmbH, Freiberg, Germany
DBI - Gas- und Umwelttechnik GmbH, Leipzig, Germany
Drägerwerk AG & Co. KGaA, Lübeck, Germany
Diehl Hydrometer, Arnsbach, Germany

EADS Deutschland GmbH, Corporate Research Center Germany, Deptartment Microsystems, München, Germany
Elmos Semiconductor AG, Dortmund, Germany
Endress und Hauser AG & Co. KG, Germany
Envia M GmbH, Halle, Germany
EPCOS AG, Germany
Exalos AG, Schlieren, Switzerland

FACRI, Research Institute, Xi´an, China
FHR Anlagenbau GmbH, Ottendorf-Okrilla, Germany
First Sensor Technology GmbH, Berlin, Germany
Freiberger Compound Materials GmbH, Freiberg, Germany
Freudenberg Co. KG, Germany
Frottana Textil GmbH & Co. KG, Großschönau, Germany
FSG Automotive GmbH, Oelsnitz, Germany

GEMAC, Chemnitz, Germany
Gemalto, La Ciotat, France
GFaI, Teltow, Germany
GF Messtechnik, Teltow, Germany
Gesellschaft für Prozeßrechnerprogrammierung mbH (GPP), Chemnitz, Germany
GLOBALFOUNDRIES, Dresden, Germany
Gyrooptics Company Ltd., St. Petersburg, Russia

Hella, Lippstadt, Germany
Helenic Aerospace Industry S.A., Schimatari, Greece
Hispano Suiza, Colombes (Paris), France

IBM, Zurich, Switzerland
Inficon AG, Balzers, Liechtenstein
Infineon Technologies AG, Munich, Dresden and Warstein, Germany and Villach, Austria
InfraTec GmbH, Dresden, Germany
Intel, Sophia Antipolis, France

Jenoptik-LOT GmbH, Gera, Germany

KSG Leiterplatten GmbH, Gornsdorf, Germany

LITEF GmbH, Freiburg, Germany
LG Electronics, Korea

MELEXIS, Bevaix, Switzerland
memsfab GmbH, Chemnitz, Germany
Microelectronic Packaging Dresden GmbH, Dresden, Germany
Microtech GmbH, Gefell, Germany
Multitape GmbH, Büren-Ahden, Germany

neoplas control GmbH, Greifswald, Germany
NXP (founded by Philips), Eindhoven, The Netherlands, and Hamburg, Germany

Océ B.V., Venlo, The Netherlands

Panasonic Plasma Display Labaratory, Inc., Highland, New York, USA
Physikalisch-Technische Bundesanstalt Braunschweig (PTB), Germany
Philips Applied Technologies, Eindhoven, The Netherlands

Ricoh Company, Ltd., Yokohama, Japan
Roth & Rau Oberflächentechnik GmbH, Hohenstein-Ernstthal, Germany
RWE AG, Essen, Germany

Sagem Orga GmbH, Paderborn, Germany
Schaeffler Group, Germany
Schenker Deutschland AG, Dresden, Germany
Schott Mainz & Schott Glas, Landshut, Germany
Sedemat GmbH, Oelsnitz, Germany
Sempa Systems GmbH, Germany
Senseor, Sophia Antipolis, France
Sentech Instruments GmbH, Berlin, Germany
SICK AG, Waldkirch & Ottendorf-Okrilla, Germany
SF Automotive GmbH, Freiberg, Germany
Siegert TFT GmbH, Hermsdorf, Germany
SolviCore GmbH & Co. KG, Hanau, Germany
Solardynamik GmbH, Berlin, Germany
Sony Corp., Semiconductor Business Unit, Japan
ST Microelectronics, Crolles, France
Surrey NanoSystems Ltd, Newhaven/Guildford, U.K.
Suss Microtec AG Vaihingen, Munich and Sacka, Germany

Dr. Teschauer AG, Chemnitz, Germany
Thales-Avionics, Valence and Orsay, France
Toyota, Japan
Turboméca, Bordes, France

X-FAB Semiconductor Foundries AG, Erfurt and Dresden, Germany

Vowalun GmbH, Treuen, Germany
VW Oelsnitz, Germany

Winkor-Nixdorf, Paderborn, Germany

ZMD AG, Dresden, Germany

Grand opening ceremony of the new building of Fraunhofer ENAS in Chemnitz:
Prof. Dr. Thomas Gessner, Director of Fraunhofer ENAS, with Prof. Dr. Annette Schavan (left), Federal Ministry of Education and Research,
and Prime Minister Mr. Stanislaw Tillich (right), State of Saxony

EVENTS

GRAND OPENING CEREMONY OF THE NEW BUILDING OF FRAUNHOFER ENAS

The employees of Fraunhofer ENAS moved in the new research building constructed in 19 months.

On June 22, 2009, the new building of Fraunhofer ENAS opened its doors for the employees and guests. With its 31 offices and 20 laboratories, a caferteria, an artrium and three oases the building offers for 100 employees a convenient working atmosphere. The energy efficiency at and within the building was an important issue during the whole planning process. As result the new Fraunhofer building with its innovative facing and energy efficient building concept has very low power consumption. Systems for heat recovery are integrated in the building services engineering. The air temperature inside the building is controlled by means of an earth heat exchanger cooling and warming the air. Water coming from a 62 meter deep spring is also used for temperature control of the building, cooling the equipment and as raw water for processes. The European Fund for Regional Development, the Federal Ministry for Education and Research (BMBF) and the regional government of Saxony funded the construction.

The new Fraunhofer building is one part of the Smart Systems Campus Chemnitz. Furthermore, the Institute of Physics of Chemnitz University of Technology with the new clean room facilities of the Center for Microtechnologies as well as a start-up building for new entrepreneurs and a business park belong to this campus.

Almost 350 guests from Germany and abroad celebrated together with the Fraunhofer researchers the grand opening in Chemnitz. Prof. Dr. Annette Schavan, Federal Minister for Education and Research, showed in her speech that especially in times of crisis the chances of key technologies had to be identified and the transfer of research results in new products and services had to be pushed. In addition, Prof. Augusto Albuquerque, Head micro- and nanosystems at European Commission, explained that 'smart systems' contribute to a hugh value-added comparing to other technologies and the growing up of whole industry sectors.
Prime Minister Stanislaw Tillich, State of Saxony, congratulated to the new research building besides Prof. Dr. Alfred Gossner, Senior Vice President of Fraunhofer-Gesellschaft, Mrs. Barbara Ludwig, Lord Mayor of the City of Chemnitz, Prof. Dr. Klaus-Jürgen Matthes, President of Chemnitz University of Technology, Dr. Klaus Schymanietz, Vice President EADS Germany and EPoSS Chairman as well as Dr. Gert Teepe, Director Design Enablement GLOBALFOUNDRIES Dresden.

After the opening ceremony Prof. Dr. Gessner and his staff members presented their new research building, its laboratories and facilities to the national and international guests. Especially the imposing view from the building over the whole Smart Systems Campus impressed the guests.

EVENTS OF THE FRAUNHOFER ENAS

A new building offers new opportunities - Fraunhofer ENAS opened its doors to the public and to partners and creates a new environment for cooperations.

Opening Ceremony Fraunhofer ENAS in Paderborn

The department Advanced System Engineering ASE of the Fraunhofer ENAS was founded in Paderborn in 1999. A strong cooperation links the department ASE with the University of Paderborn. In 2009 the Fraunhofer ENAS and the University of Paderborn decided to enhance this cooperation by creating a spatial connection. So the Fraunhofer staff members of ASE moved into their new offices and laboratories on the campus of the University of Paderborn in August 2009.

In November 2009 the Fraunhofer ENAS celebrated together with its partners of the university and the industry an opening ceremony of its new rooms in Paderborn. Dr. Christian Hedayat, head of the department ASE, and Prof. Dr. Ulrich Hilleringmann, University of Paderborn, welcomed the guests. After different scientific presentations about the work of the department ASE, Prof. Dr. Thomas Geßner, director of Fraunhofer ENAS, and Prof. Dr. Nikolaus Risch, president of the University of Paderborn, handed over the rooms to the Fraunhofer staff in Paderborn officialy.
Dr. Christian Hedayat was very glad about the new location on the campus and emphasized the great advantage to research together and to develope now a closer synergy and communication.

Open House Day at the Smart Systems Campus Chemnitz

In September 2009 the Chemnitz University of Technology and Fraunhofer ENAS invited to an open house day on the Smart Systems Campus Chemnitz. The both research institutions presented the new builded campus of research in the middle of Chemnitz to interested citizens.

People became acquainted with the research field of microsystems technology and companies working within this research field at the Smart Systems Campus. The whole morning stood under the slogan „Hopfen meets Hightech“. The Big Band of Chemnitz University of Technology accompanied this morning event during the guests visited the new buildings of research and devolopments.

The program offered visiting tours through the research building and its laboratories of the Fraunhofer ENAS. Next to Fraunhofer ENAS five companies showed their working fields in the start-up building of the Smart Systems Campus. Also the people could visit in the new Center for Integrative Lightweight Technologies. An interesting tour offered a view inside the world of lightweight construction technologies. The morning turned around architecture as well as micro and nanotechnologies. The Smart Systems Campus presented innovative buildings with high-tech equipment but also a view to new technologies, developments and research topics.

First Meeting of the Advisory Board

In September 2009 the advisory board of Fraunhofer ENAS held its first meeting. The advisory board supports the board of directors of the Fraunhofer-Gesellschaft as well as the Institute´s management concerning strategic developments. The members of advisory board provide an interconnective network with industry and local organizations.

Thirteen representatives from industry, sciences and policy belong to the advisory board of Fraunhofer ENAS:

* Dr. Udo Bechtloff
  CEO, KSG Leiterplatten GmbH

* Prof. Dr. Hans-Jörg Fecht
  Director, Institute of Micro and Nanomaterials of the Ulm University

* Dr. habil. Maximilian Fleischer
  Siemens AG

* Dr. Arbogast M. Grunau
  Director Product Development, Schaeffler KG

* RD Dr. Ulrich Katenkamp
  Federal Ministry for Education and Research

* Dr. Jiri Marek
  Director Sensorics, Robert Bosch GmbH

* Prof. Klaus-Jürgen Matthes
  President, Chemnitz University of Technology

* Dr. Udo Nothelfer
  Vice President Fab 36, GLOBALFOUNDRIES

* Prof. Dr. Ulrich Schubert
  School of Chemistry and Earth Sciences, Jena University

* Uwe Schwarz
  Manager Development MEMS Technologies, X-FAB Semiconductor Foundries

* Helmut Warnecke
  CEO, Infineon Technologies Dresden GmbH & Co. OHG

* MR Christoph Zimmer-Conrad
  Saxon State Ministry of Economy and Labor

* MR Dr. Reinhard Zimmermann
  Saxon State Ministry of Sciene and Art

FRAUNHOFER ENAS AT EVENTS

In 2009 the Fraunhofer ENAS attended various events, conferences and trade fair all around the world.

Smart Systems Integration SSI 2009 in Brussels, Belgium

The third SMART SYSTEMS INTEGRATION, European Conference & Exhibition on Integration Issues of Miniaturized Systems – MEMS, MOEMS, ICs and Electronic Components, took place on March 10 to 11, 2009, in Brussels. 216 participants from 15 European countries, Japan, China, Taiwan and Israel attended the conference, organized by Mesago, Fraunhofer ENAS and Fraunhofer IZM. In his welcome presentation the chairman of the conference, Prof. Dr. Thomas Gessner, pointed out: "The European distribution gave the evidence that smart systems integration is a big issue especially in Germany, Belgium, France, the Netherlands, Italy and Spain."

The Smart Systems Integration Conference 2009 showed a snap shot of the European research work on this field. Experts and scientists from industry and institutes addressed and discussed various aspects of smart systems integration starting from technology and reliability, via development of components and materials up to best practise examples. This includes especially smart MedTech systems, systems for logistics applications, automotive and aeronautics. But smart systems will make our normal live not only more convenient, they will increase the security, too. Today, there are prototypes of smart systems as well as smart systems that have reached the state of commercial products. Several new ones have been presented on the SSI 2009 in Brussels. First time best paper and best poster have been selected and awarded sponsored by EPoSS and Fraunhofer ENAS.

The smart systems integration conference is part of the activities of EPoSS - the European Technology Platform for Smart Systems Integration. In the conference program there was a session track complied by EPoSS.

5th Fraunhofer-Gesellschaft Symposium in Sendai, Japan

The Fraunhofer ENAS participated at the 5th Fraunhofer-Gesellschaft Symposium in Sendai, Japan, in November 2009. As one of three Fraunhofer Institutes the Fraunhofer ENAS provided an overview about its investigations in smart systems integration. In 2009 all in all 105 people attended the Fraunhofer Symposium and the presentations of the Fraunhofer researchers and also the researchers of the Tohoku University in Sendai. The trend and the future of MEMS has been explained by Prof. Masayoshi Esashi, Tohoku University. Prof. Dr. Thomas Gessner, director of the Fraunhofer ENAS, gave a talk about MEMS/NEMS towards smart systems integration.

The Fraunhofer Symposium is an established event in Sendai which has been designed to give an overview of the latest developments in smart system integration of microelectronics and microsystems technologies. The Fraunhofer Symposium has attracted scientists and researchers from all over Germany and Japan. Top runners who drive the internal and international research development in the field of micro and nanotechnology, talked about the possibilities of MEMS technologies, cutting-edge technologies and technology innovation.

Kick-off Meeting nanett „nano system integration network of excellence" in Chemnitz, Germany

On December 7, 2009, the kick-off meeting of the nano system integration network of excellence nanett was hold at the Fraunhofer ENAS. Nanett is one of the successful initiatives of the second phase of the "Spitzenforschung und Innovation in den Neuen Ländern" program, funded by the Federal Ministry of Education and Research (BMBF).

During the kick-off meeting Prof. Sabine von Schorlemer, Saxon State Minister for Science and Culture, explained that it is necessary to build up sustainable and effective research cooperation in the newly formed German states even across their borders. She stated: "The integration of the Chemnitz University of Technology as well as the Fraunhofer Research Institution for Electronic Nano Systems are a guarantor for international competitive excellent research in the field of integration and technical use of nanotechnology."

Beside the four involved faculties of the Chemnitz University of Technology (Faculty of Electrical Engineering and Information Technology, Faculty of Natural Sciences, Faculty of Mechanical Engineering and Faculty of Computer Science) the University of Applied Sciences Mittweida, three Fraunhofer Institutes (Fraunhofer ENAS, Fraunhofer IZM and Fraunhofer IAP), three Institutions of the Leibniz Association (IHP, IFW and IPF) and the Helmholtz Zentrum Berlin (HZB) are linked in the nano system integration network of excellence.

Prof. Dr. Dietrich R. T. Zahn (left), vice-president for research at the Chemnitz University of Technology, Prof. Dr. Sabine von Schorlemer (middle), Saxon State Minister for Science and Culture, and Prof. Dr. Thomas Gessner (right), director of the Fraunhofer ENAS, at the kick-off meeting of nanett „nano system integration network of excellence" in Chemnitz.

Fraunhofer ENAS Trade Fair Activities 2009

In 2009 Fraunhofer ENAS presented its manifold activities at 15 tradeshows in Germany and abroad.

The year started with the nano tech exhibition in Tokyo/Japan. During this fair first time the printed battery of the department Printed Functionalities has been presented.
Together with Fraunhofer ENAS the partners of the Smart Systems Campus Chemnitz presented their activities in the field of nanotechnologies. Special emphasis was given to nano imprinting, nano composites as well as MEMS (micro electro mechanical system) and NEMS (nano electro mechanical system) packaging. This second visit at the nano tech in Tokyo was accompanied by a roadshow in Sendai, Osaka and Fukuoka.

From April 20 to 24, 2009, the worldwide biggest industrial fair, the HANNOVER MESSE, took place in Hannover, Germany. One of the 13 leading trade fairs was the fair MicroTechnology which showed the fields of micro and nanotechnology, for example micro systems integration, innovative materials and novel production methods. The Fraunhofer Research Institution for Electronic Nano Systems ENAS was located at the "IVAM Produktmarkt". The researchers from Chemnitz showed new developments in the fields of wafer bonding, 3D-integration, reliability and smart systems, e.g. a smart active rf ID label as well as a portable MEMS spectrometer.

From May 26 to 28, the fair SENSOR+TEST 2009 with concurrent conferences took place in Nuremberg, Germany. The international trade fair for sensors, measuring and testing technologies showed a complete and interdisciplinary overview about the entire spectrum of measuring and testing systems expertise. This was the first presentation of the Fraunhofer Research Institution for Electronic Nano Systems ENAS at the SENSOR+TEST 2009. The researchers from Chemnitz showed again new developments in the fields of wafer bonding, 3D-integration, reliability and smart systems.

In June 2009 Fraunhofer ENAS presented current developments at the Sensors expo and conference in Rosemont, Illinois, USA. This fair is one of the biggest and well-known events in the field of sensor. Besides, it is the only event in North America which was specialized on sensor and sensor integrated systems. The Fraunhofer ENAS presented new developments in the fields of 3D integration, printed functionalities as well as reliability and smart systems. One of the exhibits was an active smart RFID label, another one a printed thin film battery.

At the Paris Airshow 2009 the scientists of Fraunhofer ENAS presented together with other Fraunhofer Institutes their work within the European Cleansky project.
The Clean Sky Joint Technology Initiative is a partnership comprised of companies from the aeronautics sector (AgustaWestland, Airbus, Alenia, Dassault Aviation, EADS-CASA, Eurocopter, Fraunhofer Institutes, Liebherr, Thales, Rolls-Royce, SAAB and Safran) together with the European Union. The project has been granted a budget of 1.6 billion euros for the period 2007 to 2014. Of this, 800 million euros is sourced from the 7th EU Framework Program for Research, with the other half coming from the participating partners.

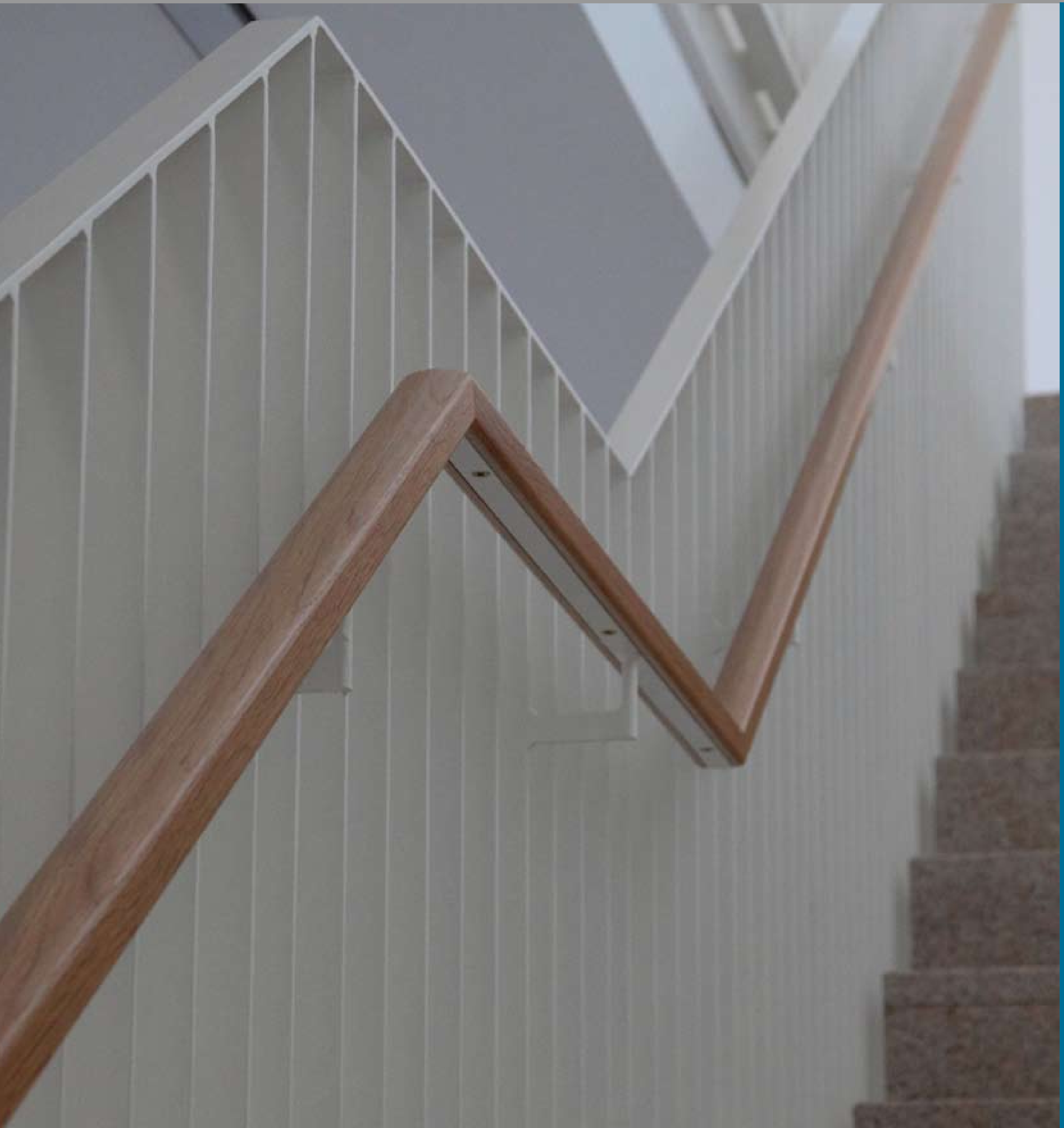
Within the summer break the scientists of Fraunhofer ENAS have presented their developments on the Micromachine exhibition in July in Tokyo. A miniaturized MIR/NIR spectrometer commonly developed with Colour Control GmbH, the printed battery, as well as the smart label and wafer bonding have been demonstrated.

In October 2009 the SEMICON Europa took place in Dresden for the first time. As a member of the Fraunhofer Group Microelectronics the Fraunhofer ENAS presented especially new developments of the department Back-end of Line. During that fair the project CoolSilicon has been awarded as selected place of the "Country of Ideas 2009".

The final stop in 2009 trade show circuit were the German Mikrosystemtechnik-Kongress in Berlin and the 9th Mikrosystemtechnik Symposium in Chemnitz.

FRAUNHOFER ENAS PARTICIPATION IN TRADE FAIRS 2009

February		
	nano tech 2009 - International Nanotechnology Exhibition & Conference	Tokyo, Japan
March		
	SMART SYSTEMS INTEGRATION 2009 - European Conference & Exhibition	Brussels, Belgium
	ECOGERMA 2009 - Trade Fair and Congress on Sustainable Technologies	Sao Paulo, Brazil
April		
	CIMNE 2009 - International Micro-Nano Expo	Shanghai, China
	Printed Electronics Europe 2009	Dresden, Germany
	HANNOVER MESSE 2009 - MicroTechnology	Hannover, Germany
May		
	Silicon Saxony Day	Dresden, Germany
	SENSOR+TEST 2009 - The Measurement Fair	Nuermberg, Germany
June		
	Sensors Expo & Conference	Rosemont, USA
	SIT 2009 - Sächsische Industrie- und Technologiemesse	Chemnitz, Germany
	SIAE 2009 - Paris Air Show	Paris, France
July		
	Exhibition Micromachine/MEMS 2009	Tokyo, Japan
October		
	SEMICON Europe 2009	Dresden, Germany
	MikroSystemTechnik Kongress 2009	Berlin, Germany
November		
	9. Fachtagung Mikrosystemtechnik -Mikromechanik & Mikroelektronik-	Chemnitz, Germany



FACTS & FIGURES

FRAUNHOFER ENAS IN FACTS
FRAUNHOFER ENAS IN ZAHLEN

Human Resources Development

Due to the increase of budget, the staff level of Fraunhofer ENAS increased in 2009. Overall, 10 employes joined the team, bringing the total staff at Fraunhofer ENAS in Chemnitz and Paderborn to 73 at the end of 2009.

The research institution also supports students with the opportunity to combine their studies with practical scientific work in the laboratories and offices of Fraunhofer ENAS. On an annual average 10 interns, undergraduates and students assistants were working.

The latter are proving to be a growing source for up-and-coming new scientists and technicians.

Financial Status, Equipment and Laboratory Investment

Within 2009 the budget of the Fraunhofer ENAS was 6.7 million euros.

Contracts from German and international industry and trade associations reached just 3 million euros, or in other words, 45 % of the total budget.

Own equipment investment of 0.65 million euros was realized in 2009. Additionally, 4.8 million euros have been invested as basic equipment for the new building and special financing.

Personalentwicklung

Basierend auf der Steigerung der Erträge erhöhte sich der Personalbestand der Fraunhofer ENAS in 2009. Es wurden 10 Mitarbeiterinnen und Mitarbeiter eingestellt, sodass 73 Personen an den Fraunhofer ENAS Standorten Chemnitz und Paderborn zum Ende 2009 beschäftigt waren.

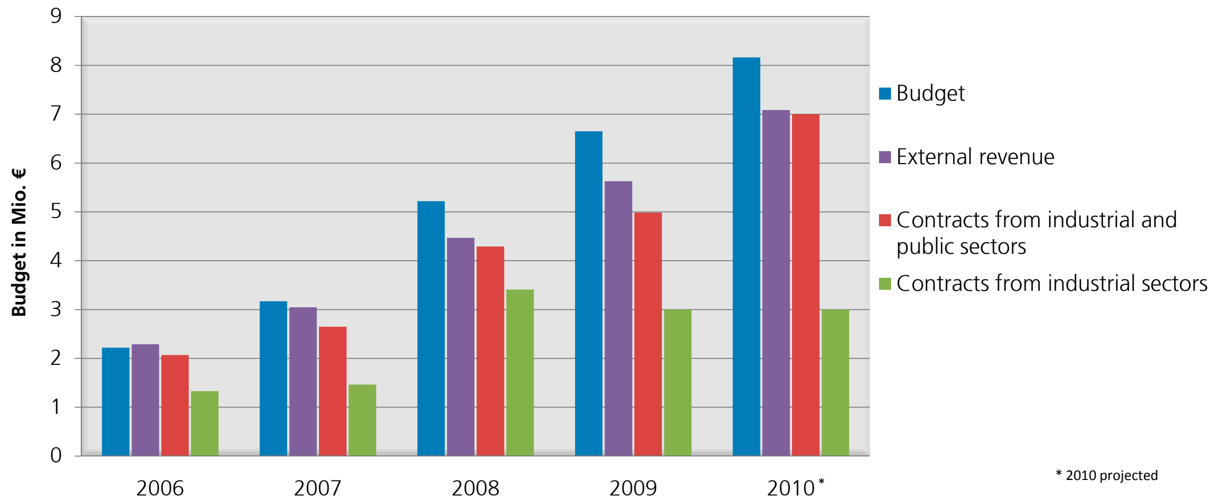
Zusätzlich bietet die Einrichtung Studentinnen und Studenten die Möglichkeit, ihr Studium mit praktischer wissenschaftlicher Arbeit in den Büros und Laboratorien der Fraunhofer ENAS zu kombinieren. Im Jahresdurchschnitt wurden 10 Praktikanten, Diplomanden und studentische Hilfskräfte betreut. Dieser Mitarbeiterstamm erweist sich in wachsendem Maße als Quelle für den Nachwuchs von Wissenschaftlern und Technikern.

Finanzielle Situation und Geräteinvestition

Im Jahr 2009 erreichte der Umsatz der Fraunhofer ENAS in Summe 6,7 Millionen Euro.

Die Aufträge aus deutschen und internationalen Industrieunternehmen erreichten eine Summe von 3 Millionen Euro, was einem Umsatzanteil von ca. 45 % entspricht.

Die eigenen Geräteinvestitionen im vergangenen Jahr betrugen 0,65 Millionen Euro. Darüber hinaus wurden 4,8 Millionen Euro für die Erstausstattung des neuen Gebäudes bzw. Sonderfinanzierung investiert.



* 2010 projected

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@ENAS.FRAUNHOFER.DE

MEMBERSHIPS (SELECTION)

acatech (Council of Technical Sciences of the Union of German Academies of Sciences)	Prof. T. Gessner	member
Academy of Sciences of Saxony, Leipzig, Germany	Prof. T. Gessner	member
Arnold Sommerfeld Gesellschaft zu Leipzig	Prof. B. Michel	scientific advisory board
Board of "KOWI", Service Partner for European R&D funding, Brussels, Belgium	Prof. T. Gessner	member
Conference on Safety and Security Systems in Europe	Prof. B. Michel	head of the conference committee
EPoSS (European Platt form of Smart Systems Integration)	Prof. T. Gessner	member of the steering group
European Center for Micro- and Nanoreliability (EUCEMAN)	Prof. B. Michel	president
EURELNET	Prof. B. Michel	member of executive board
European Security Research and Innovation Forum (ESRIF)	Prof. B. Michel	representative of Germany
German Science Foundation	Prof. T. Gessner	referee
International Young Scientists Conference Printing Future Days	Prof. R. Baumann	general chair
Materials for Advanced Metallization MAM	Prof. S. E. Schulz	member of scientific program committee
microsystems Technology Journal	Prof. B. Michel	editor in chief
Organics Electronics Association (oe-a)	Prof. R. Baumann	member of the board
Senatsausschuss Evaluierung der Wissenschaftsgemeinschaft Gottfried Wilhelm Leibniz (WGL)	Prof. T. Gessner	member
Smart Systems Integration Conference	Prof. T. Gessner	conference chair
Smart Systems Integration Conference	Prof. T. Otto Prof. B. Michel Dr. C. Hedayat Dr. K. Hiller	member of program committee
US-MRS-Conference "Advanced Metallization Conference" AMC	Prof. S. E. Schulz	member of the executive committee

AWARDS IN 2009

Awards for Prof. Dr. Bernd Michel and his Team of the Micro Material Center in Chemnitz and Berlin

On April 17, 2009, Prof. Dr. Bernd Michel received the EUCEMAN Award in the colloquium "Reliability for micro and nano" organized by the Faculty Electrical Engineering and Information Technology of the Chemnitz University of Technology. The prize was handed over by Prof. Dr. G.Q. Zhang, NXP Eindhoven, and Prof. Dr. N. Meyendorf, Fraunhofer IZFP. Within the colloquium the outstanding work of Prof. Michel has been recognized in the field of reliability. Together with his team he is working in the field of thermo-mechanical reliability of micro and nano systems as well as packaging. Special attention is paid to the transition from micro to nano. EUCEMAN (European Center for Micro- and Nanoreliability) promotes interdisciplinary research and development as well as cooperation in designated areas of reliability of materials, components, systems, tools and techniques with a particular focus on micro and nanotechnologies, including their applications for business, science and technology, as well as everyday-life concerns (household, leisure, sports, health, security, etc.). The main objective is the promotion and support of cooperation between scientists, the industry and society at large as well as in particular between research institutions and industry.

Also in April 2009 Prof. Dr. Bernd Michel got the IEEE EuroSimE Award, presented by EuroSimE Conference 2009 in Delft/ The Netherlands.

In May 2009 Prof. Michel received the Fraunhofer IZM Special Award presented for outstanding achievements in thermomechanical reliability in micro- and nanoelectronics.

The EC-Project ELIAS has been awarded as best European Medea/Catrene project 2009. It got the "Pierre-Noblanc Award of Excellence". Prof. Michel, Prof. Wunderle, Dr. Dudek, Mr. Doering, Mr. Schindler-Safkow as well as Dr. Wittler and Mr. Bouazza (both Fraunhofer IZM) received the price. They all belong to the Micro Materials Center which is located in Berlin at the Fraunhofer IZM and in Chemnitz at the Fraunhofer ENAS.

New York Times Magazine Chose the Printed Battery as One of the Best Ideas in 2009

Since nine years in December the New York Times Magazine publishes a list of ideas from A to Z, the most clever, important and just plain weird innovations from all corners of the thinking world. This year the printed battery of Fraunhofer ENAS belongs to the best five ideas in the technology area. First time the printed batteries have been presented at the nanotech exhibition in Japan in the spring 2009. The printable battery can be produced cost-effectively on a large scale. It was developed by a research team of the Fraunhofer Research Institution for Electronic Nano Systems ENAS in Chemnitz together with colleagues from Chemnitz University of Technology and Menippos GmbH. "Our goal is to be able to mass produce the batteries at a price of single digit cent range each," states Dr. Andreas Willert, deputy department manager at Fraunhofer ENAS.

The battery weights less than one gram and is less than one millimeter thick. It is possible to print it in serial connections up to four batteries with voltages of 1.5 to 6 V depending of the connection. The batteries are environment-friendly because they do not contain mercury. This new generation of batteries can be applied for medicine products or printed media.

The new type of battery is composed of different layers: a zinc anode and a manganesedioxide cathode, amongst others. Zinc and manganesedioxide react with one another and produce electricity. However, the anode and the cathode layer dissipate gradually during this chemical process. Therefore, the battery is suitable for applications which have a limited life span or a limited power requirement, for instance greeting cards.

Prism Award for Microspectrometer

In January 2010 InfraTec GmbH got the Prism Award for the microspectrometer based on a tunable MEMS Fabry Perot filter. This Fabry Perot interferometer was developed by Dr. Steffen Kurth, Fraunhofer ENAS, Dr. Karla Hiller, Center for Microtechnologies of Chemnitz University of Technology, and Dr. Norbert Neumann, InfraTec GmbH They earn the award in the category "Detectors, Sensing and Imaging Systems". Already in 2008 the researchers were awarded for the Fabry Perot interferometer with the AMA Sensor-Innovativpreis. The Prism Award underlines the high level of this product development.

The Prism Award is awarded by SPIE, the Society of Photographic Instrumentation Engineers, since 2008. SPIE presented the awards at the Photonics West in San Francisco, USA. It is the world biggest conference and exhibition for optical technologies.

The researcher team of the microspectrometer based on a tunable Fabry Perot filter with the Prism Award 2010 - from left to right: Dr. Norbert Neumann (InfraTec GmbH), Martin Ebermann (InfraTec GmbH), Dr. Karla Hiller (Center for Microtechnologies of Chemnitz University of Technology) and Dr. Steffen Kurth (Fraunhofer ENAS).

LECTURES

Chemnitz University of Technology
Chair Microtechnology

Process and Equipment Simulation
Lecturers: Prof. Dr. T. Gessner, Dr. R. Streiter

Advanced Integrated Circuit Technology
Lecturers: Prof. Dr. S. E. Schulz, Dr. R. Streiter

Microelectronics Technology
Lecturers: Prof. Dr. T. Gessner, Prof. Dr. S. E. Schulz

Micro Technology
Lecturers: Prof. Dr. T. Gessner, Dr. K. Hiller, Dr. A. Bertz

Microoptical systems
Lecturer: Prof. Dr. T. Otto

Technology of Micro and Nanosystems
Lecturers: Prof. Dr. T. Gessner, Dr. K. Hiller

Micro and Nano Technology
Lecturers: Prof. Dr. T. Gessner, Dr. K. Hiller

Lectures of International Research Training Group
Lecturer: Prof. Dr. S. E. Schulz

Chemnitz University of Technology
Chair for Materials and Reliability of Microsystems

Reliability of Micro and Nanosystems
Lecturer: Prof. Dr. B. Wunderle

Chemnitz University of Technology
Institute for Print and Media Technology

Ausgabesysteme I - Druckausgabegeräte allgemein Digital Fabrication - digitale Fabrikationstechniken
Lecturer: Prof. Dr. R. Baumann

Ausgabesysteme II - Druckausgabegeräte Inkjet + Elektrofotografie
Lecturer: Prof. Dr. R. Baumann

Druckvorstufe I - Druckdatenaufbereitung
Lecturer: Prof. Dr. R. Baumann

Druckvorstufe II - Vertiefung Druckdatenaufbereitung
Lecturer: Prof. Dr. R. Baumann

Medientechnisches Kolloquium
Lecturer: Prof. Dr. R. Baumann

Medientechnisches Kolloquium Output Systems II - Druckausgabegeräte Inkjet + Elektrofotografie, Visuelle Wiedergabequalität - technische Beurteilung von Druckausgaben
Lecturer: Prof. Dr. R. Baumann

Typografie und Gestaltung
Lecturer: Prof. Dr. R. Baumann

Farbtheorie/Farbmetrik - farbliche Wirkung insb. von Druckprodukten
Lecturer: Prof. Dr. R. Baumann

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PCT (Anmeldung) 10 2009 006 822.8

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Patent erteilt: DE 102008026097

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WO (Anmeldung) WO 2009/071076 A1

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