University of Stuttgart
Institute for Large Area Microelectronics

Annual Report

2024

IGM
Institut für Grossflächige Mikroelektronik

Publisher

Universität Stuttgart / University of Stuttgart
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March 2025

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1 Preface

Dear friends of the Institute for Large Area Microelectronics,

We are pleased to present our activities and news of the year 2024 to our scientific cooperation partners, alumni and all our other friends.

In 2024, the institute could offer all the usual courses without any restrictions. Due to the increased efforts of the Department of Electrical Engineering and Information Technology towards internationalization, the institute is currently working on expanding the number of courses offered in English language. The focus is primarily on the translation of the module "Fundamentals of Electrical Engineering I/II". In the winter semester 2024/25 and summer semester 2025 the module "Fundamentals of Electrical Engineering I/II" is additionally offered in English for the first time.

In 2024, the joint research projects with IGM participation already mentioned in the last annual report were successfully continued. These are, in addition to a state-funded project in cooperation with an institute of the KIT (Karlsruhe Institute of Technology) for the demonstration of an additive assembly technology based on the UPD printer for an automotive radar that operates at 140 GHz, an EU-funded consortium for the production of micro LED displays as well as a BMBF consortium for the integration of liquid crystal based reconfigurable, intelligent surfaces for future 6G mobile networks. Furthermore, the already ongoing research work for the development of quantum-based gas sensors will be continued within the Research Training Group "Photonic Quantum Engineers" (GRK2642).

I would like to thank all friends of the institute for their support and inspiration and wish you all ongoing good health.

A special thank you to all employees for their tireless commitment ensuring the successful work of the institute on a daily basis. I also sincerely wish you and your families' health, happiness and all the best.

Stuttgart, March 2025

Prof. Dr.-Ing. Norbert Fruehauf

2 The Institute

The Institute for Large Area Microelectronics (IGM) is a research and education institute with a major focus on application-oriented research and development of new processes and materials for applications in display technologies.

With its more than 500m² of clean room area the Institute of Large Area Microelectronics operates one of the leading independent laboratories for the research and development of thin film electronics and thin film technology (TFTs) as well as their respective fields of application, e.g.:

- Flat panel displays (LCD, OLED)
- Smart Glass
- Optical signal processing
- Micro-electro-mechanical systems (MEMS)

The laboratory has always been focused on application-oriented research and portability to industrial grade production. Therefore, the clean room lab was designed to build complete active matrix LCDs on glass substrates of up to 16 inches squared. This capability to process such (relatively, for a research facility) large substrates gives the laboratory at the Institute for Large Area Microelectronics a unique position in all of Europe.

Besides the extensive research activities of the institute, the university teaching plays an important role. In teaching, the institute represents the fundamentals of electrical engineering as well as display and thin film technologies.

3 Staff Members

Function	Name	E-mail @igm.uni-stuttgart.de	Phone +49 711 685-
Head of Institute	Prof. Dr.-Ing. Norbert **Fruehauf**	norbert.fruehauf	66922
Vice Head of Institute/Head of Laboratory	Dipl.-Ing. Lothar **Rau**	lothar.rau	66927
Vice Head of Lab. Vice Head of Institute	Dipl.-Ing. Holger **Baur**	holger.baur	66926
Secretary	Birgit **Schuder**	birgit.schuder	66922
Facility Management	Joerg **Bachofer**	joerg.bachofer	66933
Scientific Staff	Marco **Dettling**, M.Sc.	marco.dettling	66932
	Florian **Kleber**, M.Sc (until 05/2024)	florian.kleber	69321
	Hanghang **Li**, M.Sc.	hanghang.li	69306
	Martin **Roemhild**, M.Sc.	martin.roemhild	66930
Vice Head of Institute	Dr.-Ing. Patrick **Schalberger**	patrick.schalberger	69320
	Yannick **Schellander**, M.Sc	yannick.schellander	66929
	Annika **Schmekal**, M.Sc.	annika.schmekal	66925
	Kai **Waldner**, M.Sc.	kai.waldner	66931
	Markus **Widmaier**, M.Sc.	markus.widmaier	69307
	Dipl.-Phys. Marc **Wilke**	marc.wilke	66904
Technical Staff	Daniela **Schalberger**, B.Sc. CTA	daniela.schalberger	69305
	Elisabeth **Schuler**	elisabeth.schuler	66908
Lecturer	Dr. Hagen **Klauk** Max-Planck-Institut	hagen.klauk@ fkf.mpg.de	0711/689-1401

4 Teaching

Professor Fruehauf offers lectures on fundamentals of electrical engineering, filter synthesis, optical signal processing, thin film technology and flat panel technology. Several lab courses allow the students to gain some hands-on experience complementing the lectures.

4.1 Lectures

All lectures are recorded and uploaded on ILIAS to give the best possible support to the students.

Fundamentals of Electrical Engineering 1

Lecturer: Prof. Dr.-Ing. Norbert Fruehauf

Winter semester, 1 semester, 1st semester Bachelor's program Electrical Engineering & Information Technology, Mechatronics and Renewable Energies. The lecture is offered in German and English.

- Introduction and overview
- Voltage and electric current
- Ohm's Law
- Electric power
- Kirchhoff's Laws
- Network analysis
- Electric field
- Capacities
- Magnetic field
- Induction Law

Fundamentals of Electrical Engineering 2

Lecturer: Prof. Dr.-Ing. Norbert Fruehauf

Summer semester, 1 semester, 2nd semester Bachelor's program Electrical Engineering & Information Technology, Mechatronics and Renewable Energies. The lecture is offered in German and English.

- Inductances
- Sinusoidally alternating quantities
- Circuits at alternating currents
- General two-poles
- Modulated sources
- Resonant circuits

The two-semester module "Fundamentals of Electrical Engineering" consists of:

- Weekly lecturers
- Bi-weekly lecture exercises
- Bi-weekly group exercises (Electrical Engineering & Information Technology B.Sc. and Renewable Energies B.Sc.: winter semester compulsory, Mechatronics B.Sc.: winter **and** summer semester compulsory)
- Lab course "Fundamentals of Electrical Engineering" (compulsory)

Important notice:
The module examination "Fundamentals of Electrical Engineering" is a mid-degree exam of Electrical Engineering and Information Technology B.Sc. The right for examination expires if the mid-degree exam is not passed until beginning of the 4th semester (inclusive a written retry).

Filter Synthesis

Lecturer: Prof. Dr.-Ing. Norbert Fruehauf

Winter semester, 1 semester, Master's program. This lecture is only offered in English.

- Introduction
- Mathematics foundations
- RLC-Two-Poles
- Realization of filters
- Transformation of RLC-circuits into active RC-circuits
- Synthesis of reactance four-poles
- RC-active circuits
- Synthesis of distributed circuits of grade two
- Empfindlichkeitstheorie
- Optimization of distributed circuits
- Switched Capacitor Filter

Thin Film Technology

Lecturer: Prof. Dr.-Ing. Norbert Fruehauf

Winter semester, 1 semester, Master's program. This lecture is only offered in English.

- Introduction and overview
- Vacuum thin film technology: vacuum technology, vapor deposition, sputtering, plasma deposition, growth and properties of thin films
- Non-vacuum deposition: spin coating, printing, chemical deposition
- Materials for substrates and surface treatment
- Structuring of thin films
- Metrology

Flat Panel Displays

Lecturer: Prof. Dr.-Ing. Norbert Fruehauf

Summer semester, 1 semester, Electrical Engineering and Information Technology B.Sc. / Photonic Engineering M.Sc.

- Overview: cathode ray tubes, flat panel display technologies, current technologies
- Physiology of sight: color theory, CIE 1931 color space, color filters
- Fundamentals of liquid crystal technology: electro-mechanical properties, variation of the potential energy, twisted and non-twisted lc cells
- Light propagation in optically anisotropic uni-axial media: Jones vectors, Jones matrices
- Liquid crystal technologies: optical transmission through the Fréedericksz cell, vertically aligned and twisted nematic lc cells, surface stabilized ferro electric lc cells
- Control of lc cells: direct addressing, passiv matrix, active matrix

Optical Signal Processing

Lecturer: Prof. Dr.-Ing. Norbert Fruehauf

Summer semester, 1 semester, Master's program. This lecture is only offered in English.

- Mathematic description of optical signals and optical systems
- Analogue optical signal processing: Fourier-transformation of optical signals, optical filters
- Optical storage: CD, DVD, Blu-Ray, holography
- Optical sensors
- Digital optical signal processing

Organic Transistors

Lecturer: Dr. Hagen Klauk

Winter semester, 1 semester

- Overview: applications for organic transistors, economical considerations, realizations and general properties of organic transistors
- Electronic properties of conjugated carbohydrates: localized and delocalized molecular orbitals, energy of orbitals
- Electronic properties of organic solid state structures: crystalline structure, diesperion, charge transport in partially crystalline layers
- Structure and implementation of organic transistors: selection of materials, stack and processing
- Functionality of organic transistors: channel, carrier injection, band model, analytical description of the characteristics
- Frequency dependence of organic transistors: analysis and optimization of the frequency limit
- Applications for organic transistors: flat panel displays, integrated circuits

4.2 Exercises

Fundamentals of Electrical Engineering 1 and 2 – Lecture Exercises
Contact person: Dr.-Ing. Patrick Schalberger
Winter and summer semester, 2 semesters, Bachelor's program

Fundamentals of Electrical Engineering 1 and 2 – Group Exercises
Contact person: Dr.-Ing. Patrick Schalberger
Winter and summer semester, Bachelor's program
Winter semester compulsory for Electrical Engineering & Information Technology B.Sc. and Renewable Energies B.Sc.
Winter **and** summer semester compulsory for Mechatronics B.Sc.

* The Lecture and Group Exercises are also offered in English
Contact person: Dipl.-Phys. Marc Wilke

Filter Synthesis Exercises (in English)
Contact person: Martin Roemhild, M.Sc.
Winter semester, 1 semester, Master's program

Thin Film Technology Exercises (in English)
Contact person: Markus Widmaier, M.Sc.
Winter semester, 1 semester, Master's program
The exercises are only available in English

Flat Panel Displays Exercises
Contact person: Marco Dettling, M.Sc.
Summer semester, 1 semester, Electrical Engineering & Information Technology B.Sc. and Photonic Engineering M.Sc.

Optical Signal Processing Exercises (in English)
Contact person: Martin Roemhild, M.Sc.
Summer semester, 1 semester, Master's program
The exercises are only offered in English

4.3 Lab Courses

Lab Course "Fundamentals of Electrical Engineering"

The lab course is an inter-institutional course and takes place in the second semester (summer semester). It is compulsory for Electrical Engineering and Information Technology B.Sc. and for Renewable Energies B.Sc.

In addition to demonstrating and reinforcing basic concepts of electrical engineering, including "capacities as blocks to direct currents", "basic circuits with transistors", and "simple voltage dividers using resistors", the experiment "transistor-based amplifier" in the lab course is designed to teach practical experience in the implementation and testing of an amplifier cuircuit using bipolar transistors. The students will build the circuit, expanding it step by step and testing the behavior. The resulting circuit will feature a photo-transistor to create a infrared receiver. Using a transmission circuit also built during the experiment, an audio signal can be transmitted wireless.

Advanced Lab Course "Flat Panel Displays"

The lab course is part of the Master's program and takes place as an one-week block course during the first week after the end of lecture period in the summer semester.

This lab course "Flat Panel Displays" focuses on the building of a display for a digital clock. This display is based on a seven-segment display with liquid crystals, polarizers, implemented on glass substrates. All processing steps, including sputtering ITO, spin coating with photo resist and poluimide, photo lithography, wet chemical structuring, and cell construction are performed by the participants in the clean room at the Institute for Large Area Microelectronics. Finally, the display is connected to an IC to form a simple alarm clock. The participants can retain the clock they have built.

Advanced Lab Course "Optical Signal Processing"

The lab course "Optical Signal Processing" is part of the Master's program and takes place in the winter semester during the lecture period. Students will perform experiments on topics including:

- Spatial and temporal coherence
- Collimation (homogenous plane waves)
- Imaging and Refraction
- Diffraction
- Fourier Optics
- Design and production of synthetic holograms

4.4 Degrees and Awards

The following Bachelor's, Research and Master's theses were successfully passed in 2022:

Bachelor's theses

Michel Becker
Characterization of Large Area Microelectronics Materials from DC to Sub-THz Frequencies

Alexander Belger
Enhancement of a semi-automatic sampling software for printing on complex three-dimensional structures

Hanna Lippmann
Capacitive arrays for spatially resolved measurements in nitric oxide
The bachelor's thesis was supervised together with Prof. Dr. Tilmann Pfau, Head of 5th Institute of Physics.

Research theses

Karishma Kishore
Combination of n-type IGZO and p-type LTPS Thin Film Transistors for Complementary Circuitry

Bhavesh Kothari
Investigation of Flip-Flops and Counters based on IGZO Thin Film Transistors

S. Akhil Aithal
Packaging of Integrated Circuits on Glass Substrates

Dheemanth Arun
Design and investigation of spatially distributed photodiodes

Rohit Gore
Analog-Digital-Converter circuits with IGZO TFTs

Emilia Fernandez
Vertical Channel Indium-Gallium-Zinc-Oxide Thin Film Transistors

Sabbir Suvo
Investigation of Dielectric Printing Materials for Additive Manufacturing of Ultraprecise 3D Shapes

Master‘s theses

Shao Qing Chen
Reducing the influence of hydrogen on the stability of IGZO-TFTs

Mansour Chabnari
Investigation of Coplanar Electrode Configurations for MEMS Devices

Linzi Ran
Phase-Locked-Loop Circuits with IGZO TFTs

Award

Best Poster Award
Florian Kleber, PhD student at the IGM, has been awarded with the "Best Poster Award" of the electronic displays Conference 2024 in Nuremberg for his poster "Design alternatives for IGZO transistors in shift registers".

5 Projects and Research Activities

Most research activities are third party funded. In addition to federal and European research grants, close cooperations with numerous industrial partners in Germany, Europe, but also in North America and Asia are important sources for funding and projects. Especially German companies profit from the extensive research activities at the Institute for Large Area Microelectronics allowing them to build their own know-how in the field of flat panel displays in a field that is otherwise dominated by companies from Asia.

The institute is currently doing research work on the following projects:

5.1 WAGNER-Project

The WAGNER-project, funded by the MWK Baden-Wuerttemberg, has the goal to develop an electronic packaging for an automotive radar that operates at 140 GHz that is fabricated by the Ultra-Precise Deposition (UPD) printing system. Recently introduced by XTPL, the UPD printer works by extruding a highly viscous ink through a very thin nozzle that is in contact with the substrate. This approach has unmatched precision and resolution for an additive process. The high precision enables UPD's use for fabricating waveguides, which are necessary for a functional chip interconnect at sub-THz frequencies. The framework of the InnovationCampus Future Mobility (ICM), of which WAGNER is a part of, has also led to extensive networking with several institutes of the University of Stuttgart and the Karlsruhe Institute of Technology (KIT). The project ended on July 31, 2024.

5.2 Research Training Group (GRK2642): Quantum Sensor

New Readout Concepts for the Electrical Readout of Optogalvanic Nitric Oxide Trace Gas Sensors

A trace gas sensor based on an optogalvanic detection of Rydberg states should allow the detection of nitric oxide (NO) in the low ppb range in a background vapor at atmospheric pressure. NO molecules in gas cells are excited to Rydberg states and subsequently ionized by collisions with the background gas. The charges are guided to electrodes and detected by current measurements. The electrical readout can outperform optical detection in terms of sensitivity and integration time. Thin film technology can be used to realize the electrical readout (electrode + transimpedance amplifier) on the vapor cell wall.

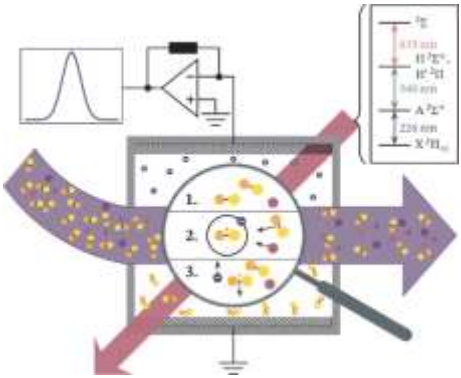


Fig. 1: Schematic operation principle for Rydberg based optogalvanic trace gas sensing

5.3 BAMBAM-Project

The EU funded project "BAMBAM" (Building Active MicroLED displays By Additive Manufacturing) started in September 2022. The goal is to develop innovative manufacturing methods for the future production of greener displays in Europe. The consortium consists of partners located all over Europe: Aledia (France), Xdisplay and X-Celeprint (Irleand), BARCO and QustomDot (Belgium), XTPL (Poland) and the Instiute for Large Area Microelectronics of the University of Stuttgart (Germany). The focus of research at IGM for the project is on electrical contacting of Micro LEDs and driver ICs by a new, high resolution printing method (Ultra-Precise Deposition) developed by XTPL as well as on manufacturing of additional functional structures in the display.

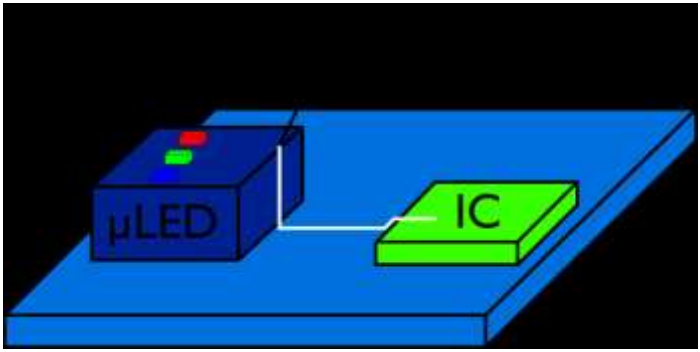


Fig. 2: Contacting of Micro LED and driver IC on pixel level by UPD printing

5.4 6G-LICRIS-Project

In October 2022, the BMBF funded joint research project 6G-LICRIS (Liquid Crystal Reconfigurable Intelligent Surfaces for 6G Mobile Networks) has been started. Consortium partners are Rohde & Schwarz, Ericsson, Merck, IMST, brown-iposs, Fraunhofer HHI, TU Berlin and the IGM oft the University of Stuttgart. Research topic is the integration of liquid crystal based intelligent, reflective surfaces in future 6G mobile networks. The RIS (Reconfigurable Intelligent Surfaces) shall improve network coverage by controlled reflection of radio waves and reduce power consumption compared to the usage of repeaters. The working principle is comparable to a two dimensional phased array antenna, where the phase difference between the single elements is influenced by locally controlling the orientation of liquid crystal molecules. First tasks of IGM are development and optimization of manufacturing processes for the LC based RIS elements and integration with an adapted (active) matrix technology. This is followed by the development of a dedicated addressing system and finalized by realization of complete RIS modules at IGM for characterization and network demonstrator integration at the project partners sites.

6 Talks and Conferences

January 22, 2024: Presentation at the IEEE Radio & Wireless Week 2024 in San Antonio, USA

On January 22, 2024, Martin Roemhild, PhD student at the IGM, gave a presentation entitled "Ultraprecise Printing of D-Band Transmission Lines" at the conference "IEEE Radio & Wireless Week 2024" which took place from January 21 to 24, 2024 in San Antonio, Texas, USA. The paper was created in cooperation with the co-authors Georg Gramlich, Holger Baur, Thomas Zwick and Norbert Fruehauf.

March 11, 2024: Talk at the GeMiC 2024 in Duisburg, Germany

On March 11, 2024, Martin Roemhild, PhD student at the IGM, gave a talk entitled "Ultraprecise Printing of D-Band Interconnects Using Dielectric Ramps" at the "German Microwave Conference (GeMiC) 2024" which took place from March 11 to 13, 2024 in Duisburg, Germany. The paper was created in cooperation with the co-authors Georg Gramlich, Jonathan Wendel, Holger Baur, Thomas Zwick and Norbert Fruehauf.

Fig. 3: Martin Roemhild gives a talk at the GeMiC 2024

April 10-11, 2024: Poster presentation at the edC 2024 in Nuremberg, Germany
Florian Kleber, PhD student at the GM, presented his poster entitled "Design alternatives for IGZO transistors in shift registers" at the "electronic displays Conference (edC)" and has been awarded with the "Best Poster Award".

April 11, 2024: Presentation at the edC 2024 in Nuremberg, Germany
On April 11, 2024, Kai Waldner, PhD student at the IGM, gave a presentation entitled "Eliminating TFT backplanes in microLED displays using ultra precise deposition (UPD) printed interconnects" at the "electronic displays Conference (edC)" which took place from April 10 to 11, 2024 in Nuremberg, Germany.

Fig. 4: Kai Waldner gives a talk at the electronic displays Conference 2024 in Nuremberg

March 27 – 29, 2024: Presentations at the ITC 2024 in Daejeon, Korea
Our PhD students Marco Dettling, Florian Kleber und Yannick Schellander participated in the "International Thin-Film Transistor Conference (ITC) 2024" in Daejeon, Korea from March 27 - 29, 2024 and presented the following papers/poster:

- Co-Processing of IGZO-TFTs and a-Si:H-Schottky Photodiodes and Mitigation of Degradation Effects (poster by Marco Dettling)
- High Frequency Shift Registers Using Depletion Type IGZO TFTs (presentation by Florian Kleber)
- Ultraviolet Phototransistors for Active-Matrix Sensor Arrays (presentation by Yannick Schellander)

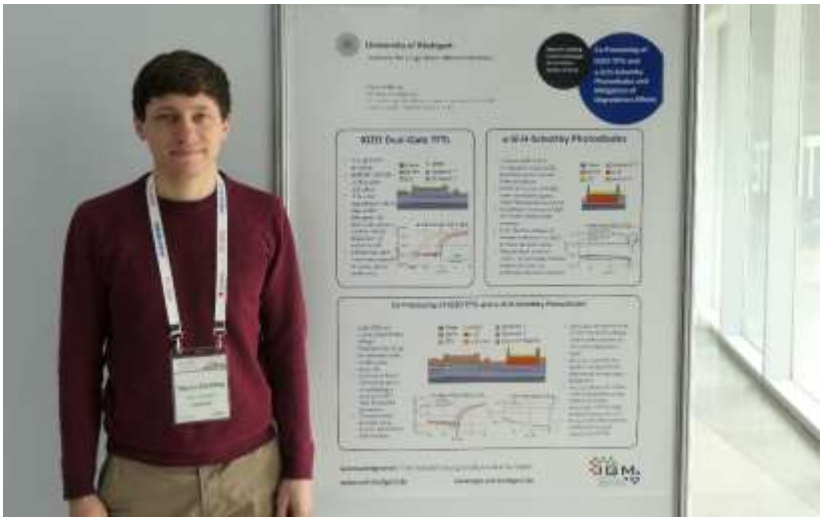


Fig. 5: Marco Dettling presents his poster entitled "Co-Processing of IGZO-TFTs and a-Si:H-Schottky Photodiodes and Mitigation of Degradation Effects" at the ITC 2024

Fig. 6: Florian Kleber gives a talk entitled "High Frequency Shift Registers Using Depletion Type IGZO TFTs" at the ITC 2024

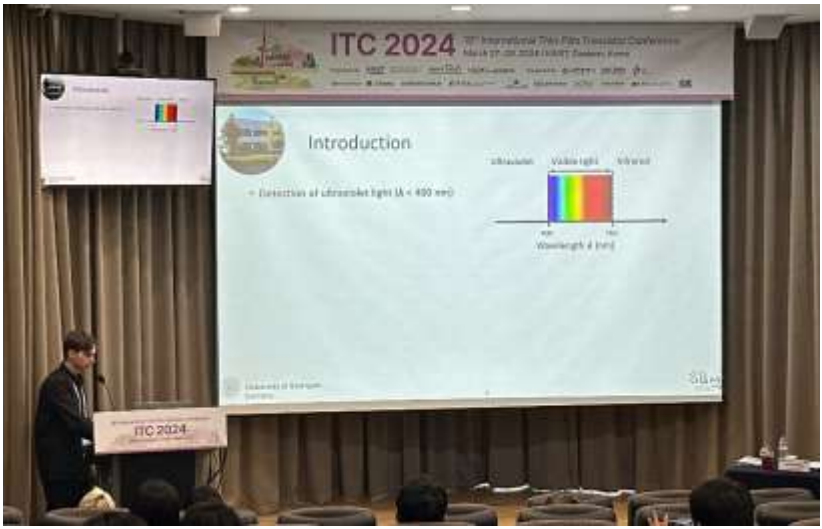


Fig. 7: Yannick Schellander gives a presentation entitled "Ultraviolet Phototransistors for Active-Matrix Sensor Arrays" at the ITC 2024

August 20, 2024: Talk at the SPIE Optics + Photonics in San Diego, USA
On August 20, 2024, Yannick Schellander, PhD student at the IGM, gave a presentation entitled "Highly efficient real-time spatially resolved sensing of ultraviolet light" at the conference "SPIE Optics + Photonics" which took place from August 18 to 22, 2024 in San Diego, USA.

Fig. 8: Yannick Schellander gives a talk at the conference SPIE Optics + Photonics 2024

September 20, 2024: Presentations at the Eurodisplay 2024 in Grenoble, France

Our PhD students Marco Dettling and Kai Waldner participated in the conference "Eurodisplay 2024" in Grenoble, France from September 18. to 20, 2024 and presented the following papers:

- Large-Area Hydrogenated Amorphous Silicon Schottky-Photosensor Arrays for Display
- Printed Chip Interconnects for MicroLED Displays

Fig. 9: Marco Dettling gives a talk entitled "Large-Area Hydrogenated Amorphous Silicon Schottky-Photosensor Arrays for Display Integration" at the Eurodisplay 2024

Fig. 10: Kai Waldner presents his paper "Printed Chip Interconnects for MicroLED Displays" at the Eurodisplay 2024

September 18, 2024: Presentation at the IEEE IFETC in Bologna, Italien
On September 18, 2024, Martin Roemhild, PhD student at the IGM, gave a presentation entitled "Process Considerations for Ultraprecise Deposition Printing on Flexible Substrates" at the "IEEE International Flexible Electronics Technology Conference 2024" which took place from September 15 to 18, 2024 in Bologna, Italy. The paper was created in cooperation with the co-authors Kai Waldner, Holger Baur and Norbert Fruehauf.

Fig. 11: Martin Roemhild gives a talk at the IFETC 2024 in Bologna

November 21, 2024: Presentation at the 2nd Summit Meeting 2024 in Schwetzingen, Germany
On November 21, 2024, Kai Waldner, PhD student at the IGM, gave a presentation entitled "Ultra-Precise Dispensing in MicroLED Display Manufacturing" at the 2nd Summit Meeting 2024 of the DFF (Deutsches Flachdisplay Forum) which took place in Schwetzingen, Germany.

December 4, 2024: Invited talk at the IDW '24 in Sapporo, Japan
On December 4, 2024, Prof. Fruehauf gave an invited talk entitled "Large Area Microelectronics Enabling Displays and Beyond" during the ”Display Night” at the IDW '24. The conference "International Display Workshop” took place from December 4 to 6, 2024 in Sapporo, Japan.

7 Publications

Collisional shift and broadening of Rydberg states in nitric oxide at room temperature
Munkes, F., Trachtmann, A., Kaspar, P., Anschütz, F., Hengel, P., Schellander, Y., Schalberger, P., Fruehauf, N., Anders, J., Löw, R., Pfau, T., Kübler, H. *Phys. Rev. A. 109, 032809 (2024).*
https://doi.org/10.1103/PhysRevA.109.032809.

A Four-Channel BiCMOS Transmitter for a Quantum Magnetometer Based on Nitrogen-Vacancy Centers in Diamond
Lotfi, H., Kern, M., Yang, Q., Unden, T., Striegler, N., Scharpf, J., Schalberger, P., Stöhr, R., Schwartz, I., Neumann, P., Anders, J.
IEEE Journal of Solid-State Circuits. 1–12 (2024).
https://doi.org/10.1109/JSSC.2024.3350995

Ultraprecise Printing of D-Band Interconnects Using Dielectric Ramps
Roemhild, M., Gramlich, G., Wendel, J., Baur, H., Zwick, T., Fruehauf, N.
2024 15th German Microwave Conference (GeMiC). pp. 57–60 (2024).
https://doi.org/10.23919/GeMiC59120.2024.10485303

Process Considerations for Ultraprecise Deposition Printing on Flexible Substrates
Roemhild, M., Waldner, K., Baur, H., Fruehauf, N.
IEEE International Flexible Electronics Technology Conference (IFETC) (2024) https://doi.org/10.1109/IFETC61155.2024.10771840

Highly efficient real-time spatially resolved sensing of ultraviolet light
Schellander, Y., Munkes, F., Trachtmann, A., Schalberger, P., Löw, R., Kübler, H., Pfau, T., Fruehauf, N.
Engheta, N., Noginov, M.A., and Zheludev, N.I. (eds.) Metamaterials, Metadevices, and Metasystems 2024. p. 1310906. SPIE (2024)
https://doi.org/10.1117/12.3028038

Eliminating TFT backplanes in microLED displays using ultra precise deposition (UPD) printed interconnects
Kai Waldner, Holger Baur, Florian Kleber, Norbert Fruehauf, Emmanuel Fuchs, Christophe Lincheneau, Aymeric Dufauret, Hugues Lebrun, Thibault Catelain, Denis Groeninck, Pierre Janioud, Clémence Lamaziere, Sandra Michel, Alin Fecioru, Prasanna Ramaswamy, Iwona Gradzka-Kurzaj, Sławomir Drozdek, Łukasz Witczak, Clint Meyer, Dave Keeshan, Matt Meitl,

Arthur Moisset, Mohammad Kiaee, Igor Nakonechnyi, Willem Walreven, Madeleine Vandenabeele, Patrick Willem, Matthias Cosaert
electronic displays Conference 2024 proceedings. (2024)

Dielectric Characterization of Adhesives for THz Packaging in WR6.5, WR3.4 and WR2.2 Bands
Gramlich, G., Speder, K., Roemhild, M., Baur, H., Fruehauf, N., Zwick, T., Bhutani, A.
18th European Conference on Antennas and Propagation (EuCAP). pp. 1–5 (2024). https://doi.org/10.23919/EuCAP60739.2024.10501389.

Printed Chip Interconnects for MicroLED Displays
Kai Waldner, Holger Baur, Patrick Schalberger, Norbert Fruehauf, Emmanuel Fuchs, Prasanna Ramaswamy, Nick Vanden Bulcke, Dave Keeshan, Sławomir Drozdek
EuroDisplay 2024 proceedings (2024)

8 Contribution to Organizations

- Chairman of the Board of Curators, Eduard-Rhein-Foundation, Germany
- Member of the Board of Curators, Institute for Microelectronics Stuttgart (IMS), Germany
- Regional Vice President Europe, SID Society of Information Display
- Member Active Matrix Committee, SID Society of Information Display
- Associate Editor, Journal of the Society of Information Display (JSID)
- Program Committee Member, AM-FPD, Japan
- Overseas Advisor, International Display Workshop (IDW), Japan

9 The Clean Room

The Institute for Large Area Microelectronics (IGM) possesses one of the largest university-based clean rooms for flat screen displays and similar systems in the world.

The facilities at the IGM include more than 500m^2 clean room space. The majority of that area or about 480m^2 are the main lab with a very high purity class for a research fertility (ISO5, less than 100 particles with a size of more than 0,5µm per cubic foot of air; ISO 4, less than 10 particles with a size of more than 0,5µm per cubic foot of air, in the area with the lithographic devices). The IGM is fully equipped to produce flat screens and similar thin film devices in near-industrial processes. The close similarity of the equipment and processes to industrial facility supports the technology transfer to industrial production lines.

A second, smaller clean room contains 3 MBraun glove boxes with a nitrogen inert atmosphere for the processing of organic semiconductors which are very sensitive to oxygen and humidity.

The following devices and facilities are available at the IGM:

Layer Deposition

- **PECVD:** The IGM features several PECVD reactors, including one Balzers (Oerlikon) KAI 1M reactor for the deposition of amorphous or poly-crystalline silicon (including doping), silicon nitrate, and silicon oxide on glass substrates up to 16 inches squared.
- **Sputtering:** Two Leybold ZV6000 inline-sputtering systems equipped with a total of 12 different targets (9 DC and 3 RF) are available at the IGM. Targets for typical display materials like chromium, aluminium, molydaenium but also gold, nickel, palladium, ITO, AZO, IGZO are available. Numerous additional targets can be mounted as necessary. The sputter system can handle substrates of up to 16 inches squared.The first ZV6000 sputtering-system had been fundamentally refurbished in 2017. In 2020, together with the company HS-Group GmbH, we had been able to perform the modernization of the second sputtering-system as well. Now, both systems are state-of-the-art regarding to PLC system control, user interface, gasflow control, pressure measurement/-control and substrate transport drive. This enables new possibilities for deposition process optimization and allows for a long term perspective of operating the machines.

- **Vapor Deposition:** The IGM offers access to a Lesker Spectros vapor deposition system with two separate sources for metallic material and eight sources for organic material. The system is integrated into the inert-gas glove boxes to enable oxygen and moisture free handling of OTFTs and OLEDs. In addition, the IGM features two older Balzers systems with thermal and electron beam vaporization systems. All vapor deposition systems can handle substrates of up to 6 inches squared.
- **Spin Coating:** The IGM operates several spin coaters for the deposition of photo resist and other liquids onto substrates of up to 16 inch squared. One smaller spin coater for substrates of up to 6 inches squared is integrated into the inert-gas glove boxes.
- **Printing:** Several printers for the direct deposition of structured layers are accessible at the IGM. Screen printers allow the large area deposition of material at a high volume but require a specifically made screen as a mask. A Dimatix inkjet printer can deposit almost any solution or suspension without the need for a complex physical mask. Additionally, the XTPL DELTA Ultra-Precise Deposition (UPD) printing system enables digital printing of highly precise patterns with linewidths below five microns at simultaneously high film thicknesses of several hundred nanometers. This allows for many new applications in the field of printed electronics, packaging or defect repair in thinfilm circuitry.

Photo Lithography

- **Lithography with Photo Masks:** The IGM is equipped with two contact exposure systems of type Süss MA6 for processing substrates of up to 6 inches squared. This allows for the realization of structures down to 3µm.
- **Direct Imaging:** The IGM features a Heidelberg Instruments DWL 400 direct imaging system that can realize structures down to 2µm on 16 inch squared substrates without requiring complex photo masks.

Layer Modification

- **Ion Implantation:** Access to an ion implantor type Eaton (Axcelis) NV3206 is offered at the IGM. The standard airlock has been replaced with a larger one allowing the processing of substrates up to 16 inches squared. The system can implant phosphorus, boron, fluor, and argon ions at up to 200kV.
- **Excimer-Laser:** A Sopra VEL Excimer Laser for the recrystallization of amorphous into polycrystalline silicon is available at the IGM. The XeCl

laser operates at a wavelength of 308nm and can fire 200ns pulses of up to 15J each at a target area of 67mm by 27mm. It can also be used to activate doping or to improve the crystal quality of other semiconductors. The system can process substrates of up to 16 inches squared using stitching.

- **UV-Ozone Treatment:** The IGM features a UV-Ozone system to clean substrates or to improve surface adhesion. The combination of highly reactive ozone and high energy light can remove organic contaminants and can activate the surface by freeing chemical bonds in surface molecules. The system can process substrates of up to 16 inches squared.

Liquid Crystal Technology

- **Rubbing:** The IGM offers access a Hörnell Rubbing system to structure the polyimide orientation layer by rubbing with a velvet roll.
- **Spacer Spray System:** The IGM operates an electrostatic spacer spray system type Accudyne for 5µm spherical polymer spacer used to ensure a uniform thickness of the liquid crystal cell. Additional different sizes of spacers can be sprayed or spin coated.
- **Glue Robot:** A Schiller 3-axis (xyz) gantry robot is used to apply glue frames in the assembly of the two substrates into one liquid crystal cell.
- **Filling Chamber:** The IGM utilizes a dedicated Balzers vacuum chamber with a movable substrate holder to fill cells with liquid crystals.
- **Cell Construction:** The IGM featurs a wide array of additional tools supporting the micrometer alignment of sustrates.

All of the above systems can handle substrates of up to 16 inches squared.

Metrology

- **Waferprober:** A Süss wafer prober in combination with a Keithley 4100 semi conductor measurement system allows for the reliable characterization of TFTs and other semiconductor electronic elements. Additional picoampere meters allow measurements in the clean room, in climate boxes and in intert-gas boxes.
- **Viewing Angle Contrast Measuremen:** An Eldim EZ Contrast 160 system is used for high-speed measurements of luminance, contrast and color space of transmissive and reflective or self-illuminating displays both in absolute values and their viewing angle dependency.
- **Climate Chamber:** A climate chamber allows for the controlled exposure to precisely definite environments, facilitating the evaluation of systems under different conditions and the simulated aging at increased environmental temperatures.
- **Optical Microscopes:** Several optical microscopes allow for quick inspections of processed substrates. Substrates of up to 16 inches squared can be checked.
- **Scanning Electron Microscope:** For inspections at resolutions above the limits of optical microscopes the IGM features a JEOL JSM 6100 SEM. This system has been modified for digital image generation.
- **Atomic Force Microscope:** The IGM features a DME AFM to determine surface topologies and surface roughness of layers.

Bonding

- **TAB Bonder:** Several TAB (Tape Automated Bonding) devices, both manual and semi-automatic, are available for bonding chips on foil (COF) driver chips onto glas substrates using anisotropically conductive adhesive film.
- **Flip-Chip Bonder:** Unmounted silicon chips can be bonded upside-down (flip-chip) directly onto display glas. This technique saves space on the substrate and is therefore well suited to tablet and smartphone displays. The IGM operates a Süss flip-chip bonder.

10 IGM-Activities

10.1 Girls' Day

With the slogan "We want to show you that experimenting, doing research and building are not just for boys!", the IGM participated in the Girls' Day with the topic "Mobilephone, Laptop & Co., how does a display actually work". The Girls' Day of the University of Stuttgart was held on April 25, 2024.

The schoolgirls got an insight how a display works: from the light ray to the physics up to the control. Each element was demonstrated in a small practical experiment. The schoolgirls could perform some of the experiments by themselves, such as building their own touchpad prototype.

Everyone had a lot of fun and the Institute for Large Area Microelectronics was happy to welcome so many participants.

Fig. 12: Yannick Schellander and Florian Kleber are supervising the schoolgirls while building their own touchpad-prototype

10.2 Science Day

Once a year, the University of Stuttgart opens its laboratory doors and invites to a day full of discoveries and insights into the world of science.

On June 8, 2024 the IGM participated again in the Science Day and provided an insight into large area microelectronics, especially in the application fields of display and sensor technology, but also in the current research in mobile communications by presenting exhibits and demonstrations at its booth. Furthermore, the IGM offered guided tours at its institute in order to give an insight in its more than 500m² clean room area.

Fig. 13: Marc Wilke (on the right) talks to a visitor at the IGM booth

10.3 Institute Excursion

The institute excursion took place on July 17, 2024 and the weather was fantastic. This time, we went to the disc golf course in Nuertingen where we played in small groups on a 12-hole course. The aim was to throw the disc into the basket with the fewest possible strokes. We had a lot of fun and had in between a small break with delicious coffee and cake at Café Heinrichs.

Afterwards, we walked to the Hochen viewing point and to the Schaber alpaca farm. Back in Nuertingen, we enjoyed a nice dinner in the Schlachthof-Braeu beer garden.

Fig. 14: IGM staff and students during the institute excursion

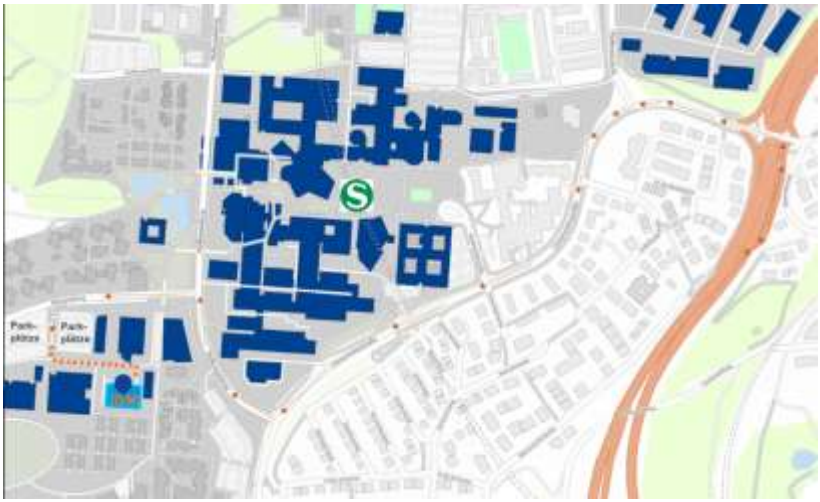
10.4 Christmas Party

The IGM invited “its” students and former employees to join the Christmas Party on December 10, 2024 in the premises of the institute. In a cozy atmosphere the participants enjoyed coffee and cake while exchanging ideas on all kinds of topics.

11 Directions and Maps

By car

Leave the highway "Autobahn A8" at the interchange "Autobahnkreuz Stuttgart-Vaihingen" and take the A831 / B14 in the direction of Vaihingen. Leave the B14 after the tunnel (careful: speed trap!) at the exit "Universität". At the traffic light turn left. Stay on "Universitätsstrasse" and later turn right into "Pfaffenwaldring". Then turn left into "Allmandring". Take the first entrance on the left and park your car on the university parking place. Now you only need to walk a few steps to the Institute of Large Area Microelectronics (IGM).



Map 1: By car to the Institute of Large Area Microelectronics

By public transport

Upon arrival at Stuttgart Main Station move towards the lower platforms (S-Bahn, green "S" as a logo). If you do not have a valid ticket for the S-Bahn to "Universität/University" you will need to get a ticket at one of the red ticket machines located near the top of the escalators down to the lower platforms. You will need a one-zone ticket. Choose your language, press the "VVS button" and then "1 zone". You will now be asked to choose between a "single-ticket" (one-way ticket) or a "4-journey-ticket" (multi-ticket usable for four trips). The "4-journey-ticket" has to be devalued before entering the train (small orange boxes).

Take one of the below S-Bahn trains at platform 101:

- S1 direction Herrenberg
- S2 direction Filderstadt
- S3 direction Flughafen

The S-Bahn comes every 5 to 20 minutes, depending on the time of day. Alight at the stop "Universtität/University" (about 10 minutes trip) and follow the way from the S-Bahn station to the Institute for Large Area Microelectronics (IGM). Please find a detailed way description on our website.

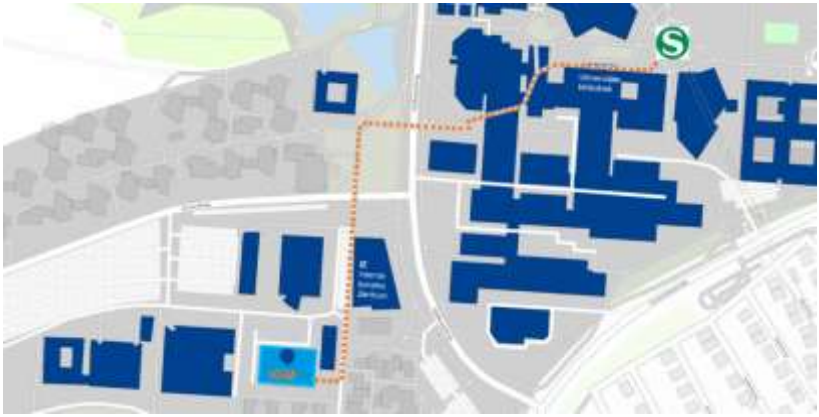
By plane

Upon arrival at the Stuttgart Airport you will exit the gate on level 1 (lower level). Go to the S-Bahn train station one level lower, marked with a large, green "S" logo. You will need to get a ticket at one of the red ticket machines located near the top of the escalators down to the lower platforms. You will need a two-zone ticket. Choose your language, press the "VVS button" and then "2 zones". You will now be asked to choose between a "single-ticket" (one-way ticket) or a "4-journey-ticket" (multi-ticket usable for four trips). The "4-journey-ticket" has to be devalued before entering the train (small orange boxes).

Take one of the below S-Bahn trains

- S2 direction Schorndorf
- S3 direction Backnang

and exit at S-Bahn station "Universtität/University" (about 17 minutes trip). Then follow the way to the Institute for Large Area Microelectronics (IGM). Please find a detailed way description on our website.



Map 2: Sidewalk from S-Bahn station University to IGM

12 Contact

You can contact us at:

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