NanoNet+

Annual Workshop 2023

1D and 2D Materials and Devices for Electronic and Photonic Applications

11 – 13 September 2023

Jugendherberge Mortelgrund, Sayda, Germany

Jugendherberge Mortelgrund, Sayda, © by Peter Zahn

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

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HZDR HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

NanoNet+ Workshop 2023 - Sayda

Agenda

Place: Jugendherberge Sayda, Mortelgrund 8, 09616 Sayda, Tel. +49 (0) 37365 1277
Web-site: www.hzdr.de/NanoNet-Workshop2023
Updated: 06.09.2023 (PZ)

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF
NANONET

Monday, 11 September 2023

Start	Who	Durat.	Title	Notes
09:30			Bus departure Dresden-Hauptbahnhof, Bayrische Straße	
12:00			**Lunch**	
13:00	Erbe, A.	10	Welcome address	Chair: Erbe
13:10	Fekri, Z.	20+5	2D materials for sensing	
13:35	Niebauer, M.	20+5	Thickness Determination of 2D Materials via Optical Microspectroscopy in Combination with 4x4 Transfer Matrix Modeling	
14:00	Jagtap, N.	20+5	Change in mechanical properties of SiC nanoresonators using helium ion implantation	
14:30	Georgiev, V.	40+10	Simulations of Ultra-Scaled Electronic Devices with a Novel Flexible Nano-TCAD Nano-Electronic Simulator Software (NESS) environment	
15:20		90	Coffee + Poster Session	10 Posters
17:00		90	**Walking Tour Schwemmteiche** (start in front of hostel)	
19:00			**BBQ Dinner**	

Tuesday, 12 September 2023

Start	Who	Durat.	Title	Notes
09:00	Jamshidi, K.	20+5	Silicon ring resonators for communications and computing	Chair: Hamarly
09:25	He, M.	20+5	Towards Optical Parametric Oscillation in Silicon Ring Cavities	
09:50	Razavi, M.	40+10	Quantum Communications Networks: Prospects and Challenges	
10:40		30	Break	
11:10	Hamarly, R.	40+10	Netcast: Delocalized Photonic Deep Learning on the Internet's Edge	Chair: Jamshidi
12:00	Catunaenu, M.	20+5	Electric-field-induced second harmonic generation in SOI waveguides and resonators	
12:25	Rodriguez, B.	20+5	DNA Origami for Electronics	
12:50			**Group Photo** (stair cases in front of building)	
13:00			**Lunch**	
14:15	Departure		**Bus Tour Seiffen**	
15:00			**Schauwerkstatt Seiffen (Engl. tour)**	
16:15			**Coffe Break: Cafe 'Cafechen' Seiffen**	
17:15			**Seiffen Church (English Tour + Organ Play)**	
18:15			**Bus Departure from Stop 'Seiffen, Mitte'**	
19:00			**Dinner**	
20:30			**Brain Storming / Bowling**	

Wednesday, 13 September 2023

Start	Who	Durat.	Title	Notes
09:30	Ghosh, S.	20+5	Junctionless Nanowire Transistors: From Devices to Sensing Applications	Chair: Krause
09:55	Strobel, C.	20+5	Vertical Graphene-Based Transistors for Power Electronics, Optoelectronics and Radio-Frequency Applications	
10:20	Haluska, M.	40+10	CNFETs for sensing applications: Raman monitoring of individual SWCNTs during device fabrication process	
11:10		**30**	**Break**	
11:40	Kirchner, R.	40+10	Advanced 3D Fabrication for Functional Device Integration	Chair: Georgiev, Y.
12:30	Echresh, A.	20+5	Near-infrared photodetectors based on single germanium nanowires	
12:55		10	Prize Ceremony / Closing Words	
13:15			**Lunch**	
14:30			Departure: **Bus to Dresden-Hauptbahnhof**	

Breakfast will be served from 8 to 9 am. Rooms won't be available at arrival, but around 2 pm.
Rooms have to be **emptied at departure latest 9:30 - no exceptions.**

Your Notes

Talks

updated: 28.08.2023 (PZ)

15

List of Poster Contributions see page 19.

Simulations of Ultra-Scaled Electronic Devices with a Novel Flexible Nano-TCAD Nano-Electronic Simulator Software (NESS) environment

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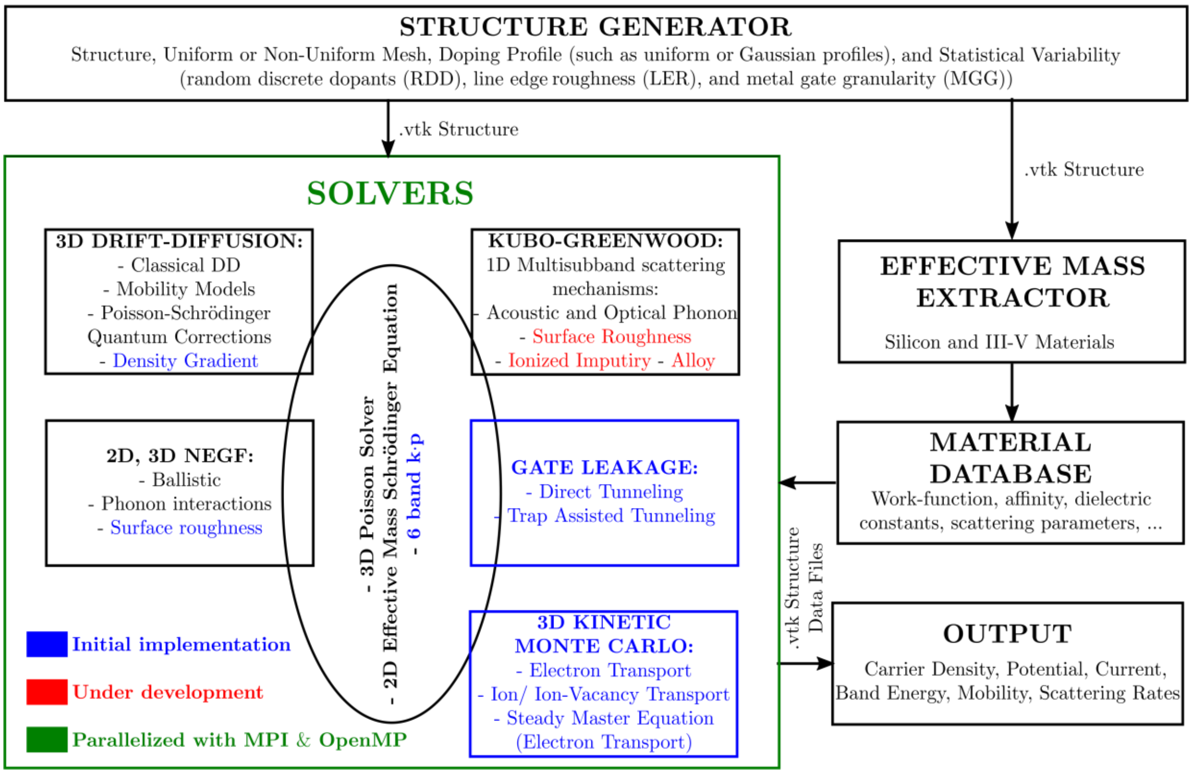
Simulation of conventional and emerging electronic devices using Technology Computer Aided Design (TCAD) tools has been an essential part of the semiconductor industry as well as academic research. Computational efficiency and accuracy of the numerical modelling are the key criteria on which quality and utility of a TCAD tool is ascertained. Further, the ability of the tool to incorporate different modelling paradigms and to be applicable to a wide range of device architectures and operating conditions is essential.

In this talk, I will provide an overview of the new device simulator NESS (Nano-Electronic Software Simulator) developed at Device Modelling Group at University of Glasgow. NESS is a fast, modular software with its own structure and mesh generators, and contains different modules for classical, semi-classical, and quantum transport solvers, mobility calculation, kinetic Monte-Carlo etc. NESS can simulate numerous device architectures such as nanowire and bulk transistors, tunnelling field effect transistors (TFET) and resonant tunnelling diodes. Moreover, NESS accounts for various sources of statistical variability in nano-size electronic devices and it can perform statistical simulations for thousands microscopically different devices.



Flowchart of NESS computational framework presenting its modular structure.

CNFETs for sensing applications: Raman monitoring of iSWCNTs during device fabrication process

M. Haluska, C. Roman, S. Jung, C. Gentili, C. Hierold
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Both theoretical predictions and practical demonstrations have attracted attention and raised hopes for applications of carbon nanotubes in various devices including sensors. Unfortunately, some challenges are still holding back the broader utilization of CNT based devices. The bottlenecks for CNT applications include targeted and reproducible synthesis, controlled integration of CNTs into functional devices as well as requirements on device recalibration frequency and lifetime.

In this contribution, we are focusing on application of Raman spectroscopy as practical monitor of CNT characteristics [1] during an optimization of individual fabrication steps. This method is nondestructive, relatively inexpensive and fast, especially if machine learning is utilized for spectra evaluation [2]. SWCNT's diameters, structural quality, induced strain, doping, some types of contamination as well as nanotube type can be estimated from the position of the Raman radial breathing mode (RBM), the ratio of D and G mode intensities and Raman mode shifts and profiles [1]. Fabrication of carbon nanotube field effect transistor (CNFET) gas sensors will be used as an example for showing the importance of the proper selection of both, device fabrication and monitoring conditions to avoid possible degradation of the nanotube properties. Our CNFETs were fabricated either by standard photo- or electron-beam lithography, or by an additive manufacturing utilizing mechanical transfer from "growth chips" into the final device structures. Individual SWCNTs used for CNTFET fabrication were synthesized using Fe nanoparticles prepared from ferritin or Fe thin film precursors by CVD at 825 - 875°C in CH_4/H_2 [3]. Improvement of CNFET devices based on the fabrication process monitoring results, for example, in eight times reduction in variation of CNTFET electrical ON-resistance with substrate-bound nanotubes [4] and significant reduction of the ON-resistance of suspended CNT-FET from MΩ to hundreds of kΩ range [5].

References:

[1] "Raman spectroscopy in graphene related system" A. Jorio, M. Dresselhaus, R. Saito, G. F. Dresselhaus Wiley-VCH (2011).

[2] "High-speed identification of suspended carbon nanotubes using Raman spectroscopy and deep learning" J. Zhang, M. L. Perrin, L. Barba, J. Overbeck, S. Jung, B. Grassy, A. Agal, R. Muff, R. Brönnimann, M. Haluska, C. Roman, C. Hierold, M. Jaggi, and M. Calame, Microsystems & Nanoengineering (2022)8:19.

[3] "Narrowing SWNT diameter distribution using size-separated ferritin-based Fe catalysts", L. Durrer, J. Greenwald, T. Helbling, M. Muoth, R. Riek, C. Hierold, Nanotechnology **20**, pp 355601-7 (2009).

[4] "Enabling fabrication of clean electrical contacts to carbon nanotubes using oxygen plasma ashing"
W. Liu, K. Chikkadi, C. Hierold, M. Haluska, *phys. Stat. solidi b*, 253, pp 2417-2423 (2016).

[5] "Understanding and improving carbon nanotube-electrode contact in bottom-contacted nanotube gas sensors" S. Jung, R. Hauert, M. Haluska, C. Roman, C. Hierold, Sensors and Actuators B, 331 129406 (2021).

Netcast: Delocalized Photonic Deep Learning on the Internet's Edge

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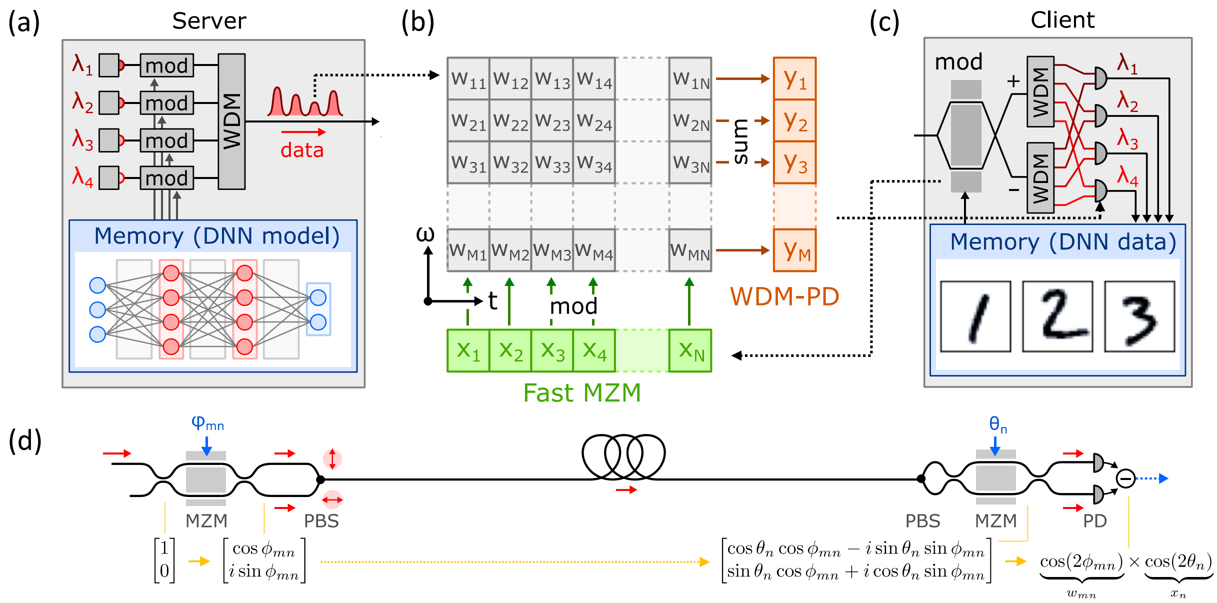
Machine learning has become ubiquitous in cloud computing and data centers, but recently, network and privacy constraints are pushing processing closer to the edge of the network on size, weight, and power (SWaP)-constrained smart sensors and end stations. In this talk, I propose NetCast, an optically accelerated "edge computing" protocol based on wavelength-division multiplexing (WDM), difference detection and integration, and optical weight delivery. Our protocol splits the computation over two components: a "weight server" consisting of a WDM modulator array, connected by an optical link to a SWaP-constrained client. We realized the NetCast protocol using a 48-MZM smart transceiver, fabricated on a 220-nm silicon-photonics process at OpSIS/IME (now AMF), capable of a total modulation bandwidth of 2.4 Tbps. The smart transceiver supports WDM, and we demonstrated multiplexing of 16 WDM lasers simultaneously transmitting through the chip with -10 dBm (100 µW) power per wavelength. For a field demonstration, weights are transmitted over 43 km of deployed optical fiber connecting MIT's main campus with MIT Lincoln Laboratory (MIT-LL), for a total round-trip distance of 86 km. We perform image classification over the link by running a benchmark inference task (MNIST) on a pre-trained deep neural network (DNN) using the NetCast hardware. The observed classification accuracy of 98.8%, performed using 3 THz of optical bandwidth over the deployed fiber, is statistically indistinguishable from the model's canonical accuracy, and is independent of whether the server and client are connected locally or over the 86-km link.



Advanced 3D Fabrication for Functional Device Integration

Jianran Zhang[1,3], Robert Kirchner[1,2,3]

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In my talk, I will cover two aspects of advanced 3D device integration: i) 3D MEMS folding technologies and ii) high-resolution functional 3D printing.

Since the concept of micro-scale origami was proposed, there were many different techniques to fabricate various 3D structures from micrometers to millimeters. Previous works mainly focused on single device-functionality, such as microscale antennas, inductors, sensors, or actuators. I am presenting the current status of our dry release wafer-scalable method for Al_2O_3-based origami cubes, paving the path towards the integration of logic transistors and circuits on all cube facets for a high MEMS integration density. I am addressing the current challenges related to folding behavior control especially using SiO_2 structural enhancement features (Fig. 1a).

3D direct laser writing techniques have significantly been improved in the last decades in terms of available tools, processes and materials. Among the available technologies, two-photon polymerization (2PP) based 3D direct laser writing is one of the highest resolving and yet fast printing method being available today. It has reached industrial maturity in some fields of application. Today, one of the largest challenges is both the availability of different printing materials as well as the capability for their efficient printing. With both materials and tooling in place, functional 3D printing meaning the integration of multimodal entities, such as structural, optical, mechanical, electrical or magnetic ones, becomes possible in a single print run. I am presenting the technology concept (Fig 1b) being currently commercialized via the HETEROMERGE GmbH as well as selected application examples.

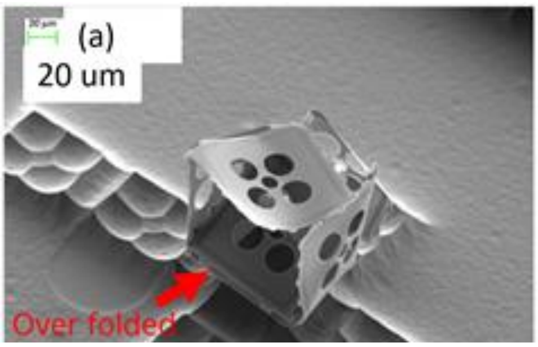

Figure 1a: SEM images of typical results in the current process state of design optimization for dry releasing Al2O3 structures from a silicon carrier.

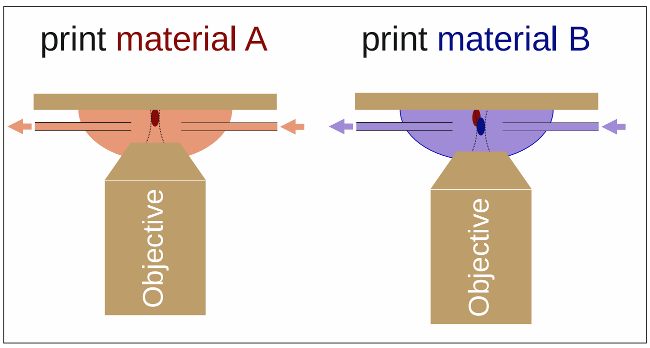

Figure 1b: Schematic of in situ material replacement for efficient high-resolution functional 3D micro-printing based on 2-photon polymerization based 3D laser writing.

Quantum Communications Networks: Prospects and Challenges

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Data security in the quantum era can be one of the key challenges that telecom operators will face in the coming years. With the recent trend in advanced quantum computing machines, the need for implementing alternative solutions for secure communications - those that do not rely on computational complexity assumptions - has become more urgent. This would be of special interest in scenarios that forward secrecy, or long-term security, is a requirement. Fortunately, there is a possible solution to this problem, known as quantum key distribution (QKD), whose security relies on the laws of physics as we understand them by quantum mechanics. QKD enables two users to securely exchange a secret key. This can, in principle, resolve the security issues that threatens the public-key cryptography schemes. In practice, however, a large-scale deployment of QKD in our current infrastructure will face certain challenges. This will nevertheless provide many opportunities for engineers and scientists alike to harness the power of quantum mechanics for our daily applications.

In this talk, I will give an overview of this technology and how it has evolved over the past few decades. I will also describe how the backbone networks could be enhanced, in multiple phases, to accommodate a global quantum communications network. Along the way, I will provide examples of ongoing projects across the world moving toward this ambitious goal. I will conclude by highlighting how engineering disciplines can contribute to this exciting endeavor.

Electric-field-induced second harmonic generation in SOI waveguides and resonators

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Silicon on insulator (SOI) has been for long a preferred photonic integration platform due to its reasonable performance (high light confinement, efficient coupling schemes, possibility to create electrical junctions through doping) and seamless compatibility with CMOS foundry processes. Silicon also possesses a quite large third-order nonlinear susceptibility $\chi^{(3)}$ which can lead to numerous useful applications such as third-order harmonic generation and or non-degenerate four-wave mixing. There are certain options available for creating a second-order nonlinearity $\chi^{(2)}$ in Silicon through crystalline lattice straining or by applying a strong electric field. The latter solution is known for producing electric-filed induced second harmonic generation (EFISH) and its implementation is eased by the electrical properties of the silicon film. Through periodic poling along the waveguide (PIN junctions) we can periodically change the $\chi^{(2)}$, thus compensating the phase mismatch between the interacting waves, techniques known as quasi-phase matching (QPM). We will discuss the design challenges of such devices that include identifying the correct poling period, waveguide cross-section engineering and simulating the electrical breakdown voltage. Our applications are designed to work with pumps at wavelengths above 2400 nm therefore avoiding excessive free carrier absorption losses. Expanding on this concept, integrating QPM waveguides in optical resonators has the potential to decrease the footprint and power budget requirements for the SHG devices.

Near-infrared photodetectors based on single germanium nanowires

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Abstract

Germanium (Ge) is a promising candidate for designing near-infrared photodetectors because of its bandgap (0.66 eV), which induces a large absorption coefficient at near-infrared wavelengths. Also, Ge has excellent compatibility of parallel processing with silicon technology [1,2]. Photodetectors based on Ge material have been fabricated with different structures such as metal-semiconductor-metal (MSM) and p−n junctions. On the other hand, the observation of high responsivity in semiconductor nanowires with a high surface-to-volume ratio has attracted growing interest in using nanowires in photodetectors. So far, significant efforts have been made to fabricate single nanowire-based photodetectors with different materials such as Si, Ge, and GaN to achieve miniaturized devices with high responsivity and short response time [3-5]. Hence, Ge nanowires are an excellent candidate to fabricate single nanowire-based near-infrared photodetectors.

In this work, we report on the fabrication and characterization of an axial p−n junction along Ge nanowires. First, through a resist mask created by electron beam lithography (EBL), the top Ge layers of germanium-on-insulator (GeOI) substrates were locally doped with phosphorus ions using ion beam implantation followed by rear-side flash lamp annealing. Then, the single Ge nanowire-based photodetectors containing an axial p−n junction were fabricated using EBL and inductively coupled plasma reactive ion etching. The fabricated single Ge nanowire devices demonstrate the rectifying current−voltage characteristic of a p−n diode in dark conditions. Moreover, the photo-response of the axial p−n junction-based photodetectors was investigated under light illumination with three different wavelengths: 637 nm, 785 nm, and 1550 nm. The measurements indicated that the fabricated photodetectors can be operated at zero bias and room temperature under ambient conditions. A high responsivity of 3.7×10^{2} AW^{-1} and a detectivity of 1.9×10^{13} $cmHz^{1/2}W^{-1}$ were observed at zero bias under illumination of a 785 nm laser diode. The responsivity of the single Ge NW photodetectors was increased by applying a reverse bias of 1 V.

[1] L. Virot, D. Benedikovic, B. Szelag, et al. Opt. Express 25(2017), 19487–19496.
[2] W. Chen, R. Liang, S. Zhang, et al. Nano Res. 13(2020), 127–132.
[3] K. Das, S. Mukherjee, S. Manna, et al. Nanoscale (6)2014,11232–11239.
[4] S. Cuesta, M. Spies, V. Boureau, et al. Nano Lett. 19(2019), 5506−5514.
[5] S. Mukherjee, K. Das, S. Das, and S. K. Ray, ACS Photonics 5(2018), 4170−4178

Field-effect transistor gas detector based on 2D materials

Z. Fekri[1,2], V. C. Köst[2], J. Zscharschuch[1], K. Nieweglowski[2], K. Watanabe[3], T. Taniguchi[3], K. Bock[2], and A. Erbe[1,2]

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Sensitive gas sensors are a key requirement for a large number of applications. Two-dimensional (2D) materials exhibit excellent properties for low power consumption sensing devices due to their ultra-high surface-to-volume ratios. In this work, we used 2D materials such as black phosphorus (BP) for developing a field-effect transistor (FET) gas sensor. We demonstrated CO_2-sensing performance at room temperature. A clear shift in current was observed during switching on and off the CO_2 flow. The ability to enhance the sensor response by modulating the gate voltage highlights the advantage of our FETs over resistor-based sensors. Our results show that the proposed method is a promising strategy to improve 2D materials CO2 detector and has a potential for applications in advanced gas-sensing devices.

Junctionless Nanowire Transistors: From Devices to Sensing Applications

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Downscaling of complementary metal-oxide-semiconductor (CMOS) technology is fraught with difficulties. As a result, novel devices and circuits, sophisticated nanomaterials, and enhanced fabrication processes have become increasingly important in recent decades. Particularly, silicon nanowires have been employed effectively in innovative electronic devices, including sensors, solar cells and in logic circuitry. Due to their high surface to volume ratio, silicon nanowires have been demonstrated as energy efficient devices, which is the key for the next generation of information processing [1]. Field-effect-transistors based on silicon nanowires have been extensively used for sensing applications since the compact nanoscale structures allow excellent regulation of electrostatic potential across the nanowire channel [2]. One such nanowire concept is junctionless nanowire transistor (JNT) [3]. A JNT is a highly doped nanowire channel without p-n junctions, where the gate electrode regulates the flow of charge carriers. Silicon JNTs have shown excellent sensitivity to record-low concentrations of the protein streptavidin in liquid phase [4]. However, they have not yet been operated as gas sensors.

In this work, we report the fabrication and characterization of silicon-based JNT devices and their initial tests as gas sensors. Intrinsic silicon-on-insulator (SOI) substrates are ion-implanted with phosphorus (n-type) dopant. Millisecond range flash lamp annealing (FLA) is used for dopant activation and implantation defect healing. Top-down approach is carried out for nanowire fabrication using electron beam lithography patterning of the negative resist HSQ followed by reactive ion etching [5,6]. Successive processes of rapid thermal oxidation and atomic layer deposition are performed to create SiO_2 and Al_2O_3 shell around the silicon nanowires, respectively. UV lithography and metal evaporation are employed to create 50 nm thick Nickel contacts to the nanowires. Electrical characterization of these JNTs is performed by back and top gating the nanowires. Unipolar device behavior is observed . However, these characteristics are changed after contact annealing leading to the ambipolarity in the devices. These devices exhibit an on/off ratio of ~10^6. To further investigate the ambipolar nature of the silicon JNTs, output characteristics are measured, which shows Schottky barrier-based behavior of the devices. Furthermore, van der Pauw and Hall Effect measurements are performed to determine their carrier concentration and hall mobility. Successive measurements of electrical characteristics of these devices are also performed in vacuum to compare them with the usual ambient measurements. Unfunctionalized JNTs are tested as sensors in purified air and NO_2 atmosphere. These sensor tests exhibited characteristic shifts in the transfer curve and a systematic increase and decrease of p- and n-type current, respectively, under the influence of NO_2. These tests confirmed the potential suitability of the ambipolar JNT as sensors in gaseous environment. Additionally, these devices will be functionalized and tested for electrical detection of atmospheric free radicals.

[1] Amato, M., et al., Chemical Reviews, 2014. **114**(2): p. 1371-1412.
[2] Wan, J., et al., Microelectronic Engineering, 2009. **86**(4–6): p. 1238-1242.
[3] Colinge J P, et al. Nature Nanotech. 2010 **5** 225-229.
[4] Georgiev, Y. M., et al., Nanotechnology, 2019 **30** 324001 (8pp).
[5] Khan, M. B., et al., Applied Sciences, 2019. **9**(17).
[6] Khan, M. B., et al. 2020 Device Research Conference (DRC). IEEE, 2020.

Towards Degenerate Optical Parametric Oscillation in Kerr Microresonators

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Optical parametric oscillators (OPOs) are critical for myriad applications such as optical frequency comb (OFC) generators, coherent Ising machines (CIMs), random number generators, photonic spiking neurons, and frequency conversion. Among the various photonic platforms, silicon nitride has emerged as an ideal Kerr medium, which enables CMOS-compatible photonic integration. In this study, we theoretically and numerically study the dual-pump optical parametric oscillations in Kerr nonlinear microresonators with the inclusion of the thermo-optic effect. Parametric gain at degeneracy points, which exceeds the intrinsic loss of the waveguide, can be achieved with both normal and anomalous dispersion by optimizing the pump power, detuning, and frequency offset. Our theoretical modeling includes the rich dynamic behaviors of the dual-pump cavity, such as bistability and chaotic behavior. Besides, the conditions for spectral phase transition, including the power threshold and critical point, have also been numerically investigated to achieve degenerate parametric oscillation. Notably, we analyze the phase-sensitive amplification regimes leading to phase bifurcation, which enables various applications in quantum random number generation, all-optical coherent Ising machines, and on-chip photon pairs generation. Towards the on-chip optical degenerate parametric oscillation, our study provides guidelines for Kerr-based microresonator designs considering the waveguide dimension for dispersion engineering and the power budgets.

Change in mechanical properties of SiC nanoresonators using helium ion implantation

Nagesh S. Jagtap*[1, 2], **Felix David**[3], **Philipp Bredol**[3], **Yannick Klaß**[3]
Eva Weig[3], **Manfred Helm**[1, 2], **Georgy Astakhov**[1], **Artur Erbe**[1, 2]

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Silicon carbide (SiC) is a suitable candidate for nanoelectromechanical systems due to its superior mechanical properties. It is also an interesting material platform to study the coupling of mechanical modes with localized spins associated with irradiation-induced defects. Such a spin-mechanical system can be used for quantum sensing applications [1].

The nanomechanical resonators in 3C-SiC are fabricated by standard semiconductor processing techniques such as electron beam lithography and reactive ion etching and are characterized using Fabry-Pérot interferometer. In the preliminary experiments, we focus on the material modification by helium ion broad beam implantation on strained 3C-SiC resonators. The effect of varying fluence on resonance frequencies and quality factors is studied. With the fluence of 1 X 10^{14} ions/cm^2, we observe decrease in resonant frequencies (~ 15%) and quality factors.

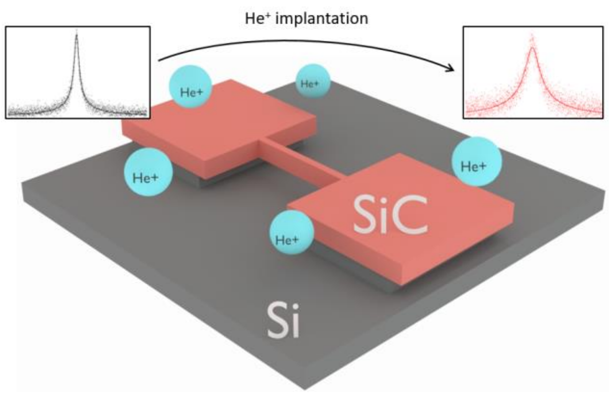

Figure 1: He^+ implantation on resonators in 3C-SiC [Insets show change in the resonance spectrum]

References

[1] A. V. Poshakinskiy and G. V. Astakhov, "Optically detected spin-mechanical resonance in silicon carbide membranes", PhysRevB.100.094104 (2019)

Silicon ring resonators for communications and computing

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Research in the field of integrated photonic devices and systems has been emerging faster than ever in recent years due to the efforts made by several research groups and commercial enterprises. Several foundries all over the world provide fabrication services to researchers to fabricate photonic components. In the IPD group, we use a fabless model to design photonic circuits to realize the functionalities required for several applications. For the realization of optical interconnects, adaptivity and energy efficiency are the main performance metrics. In this talk, the activities of the group in the context of the design and modeling of silicon ring resonators will be presented.

Thickness Determination of 2D Materials via Optical Microspectroscopy in Combination with 4x4 Transfer Matrix Modeling

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2D materials exhibit intriguing properties for (opto-)electronic devices. To be able to fully exploit their advantages, a precise knowledge of the materials' thickness is needed for tailoring the performance of a specific device as many of their features are thickness dependent. We present a nondestructive and technologically easily implementable approach for accurate thickness determination by combining optical reflectance measurements with a modular model containing a 4x4 transfer matrix method and the optical components relevant to light micro-spectroscopy, especially objective lenses with high numerical aperture [1]. This approach is suitable for small flakes or structures (due to a measurement spot size of approx. 3 µm) and is reliable and precise for thickness determination of various, even anisotropic materials as is exemplarily demonstrated for black phosphorus (BP), hexagonal boron nitride (hBN), molybdenum disulfide (MoS_2), tungsten diselenide (WSe_2), and highly oriented pyrolytic graphite (HOPG) in a thickness range from atomic layers up to more than 100 nm. The determined thicknesses are highly comparable to the results of other measurement techniques established for 2D materials like atomic force microscopy (AFM) but in contrast to AFM our method is well-suited even for encapsulated layers. Besides, due to the modularity of the approach, it is applicable to different measurement systems with only small adaptions.

References

[1] Schwarz, J., Niebauer, M., Koleśnik-Gray, M., Szabo, M., Baier, L., Chava, P., Erbe, A., Krstić, V., Rommel, M., Hutzler, A., Correlating Optical Microspectroscopy with 4×4 Transfer Matrix Modeling for Characterizing Birefringent Van der Waals Materials. *Small Methods* 2023, 2300618. https://doi.org/10.1002/smtd.202300618

DNA Origami for electronics

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The increasing demand for energy-efficient products gave rise to electronic fabs looking for new green manufacturing processes. Bottom-up techniques have the potential to reduce economic and environmental costs due to implementing low-dimensional materials with unique properties.

Bio-templates serve as potent fabrication tools for the controlled synthesis of nanowires with customizable dimensions. In this study, we present a comparative investigation of fabrication methodologies utilizing two distinct bio-templates: DNA origami and microtubules [1]. We demonstrated the formation of low-dimensional metallic nanostructures, which can be considered the building blocks for an electronic circuit [2]. These templates are used as molds to guide the placement and growth of metallic 1D nanowires [3]. This solution-based and high-resolution nanofabrication technique complements other nanolithography techniques such as electron-beam lithography and thermal scanning probe lithography. Thus, the shape of the nanostructures can be controlled and measured.

Electronic transport on these assemblies is non-ohmic and decreases at low temperatures. Temperature-dependent charge transport measurements reveal the dominating mechanisms along these wires [4].

[1] Foram M. Joshi, et al., Nano Lett. 22, **9**, 3659–3667 (2022).

[2] T. Bayrak, *et al.*, Nano Lett. **18**, 2116 (2018).

[3] J. Ye, *et al.*, Adv. Mater. **33**, 2100381 (2021).

[4] T. Bayrak, *et al.*, Scientific Reports **11**, 1922 (2021).

Vertical Graphene-Based Transistors for RF, Power Electronics, and Optoelectronic Applications

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Abstract — The combination of two-dimensional (2D) materials, such as graphene (Gr), with established thin films offers great opportunities for enabling next-generation vertical transistors for various applications. This paper gives a brief overview about different vertical transistor concepts using 2D materials proposed so far, e.g. the hot electron transistor (HET) and the Barristor. With the arrival of 2D materials, the HET also experienced a revival with predicted cut-off frequencies in the THz range. The Barristor overcomes the weak current saturation of lateral graphene field-effect transistors and high on-off ratios up to 10^7 were demonstrated, which are suitable parameters for logic applications. As will be discussed, when combining a semiconductor-graphene-semiconductor design of the simplest HET with the Barristor operating principle a new device, called graphene adjustable-barriers transistor (GABT), can be realized. This device holds great promise for RF, power electronics, and optoelectronic applications.

The successful demonstration of high performance HETs has long time been limited by the difficulty to scale the base thickness to below the electron mean free path of the carriers. To overcome this scaling problem, first prototypes of HETs with an ultra-thin graphene base have been demonstrated in 2013. The simplest graphene HET relies on a semiconductor-graphene-semiconductor (SGS) design. Another promising vertical graphene-based transistor is the Barristor. The Barristor operation is enabled by the field-induced tuning of a graphene-semiconductor Schottky barrier. When merging the semiconductor-graphene-semiconductor HET structure with the barristor operation principle, this leads to a new device, termed graphene adjustable-barriers transistor (GABT) [1]. For this device, graphene is embedded between two semiconductors. The device design is similar to the Barristor, except that the GABT uses a semiconductor instead of a metal-insulator structure for steering the device.

As will be discussed, the semiconductor gate offers new possibilities to use the device i.e. as an improved phototransistor or power semiconductor switch. For example, calculations show that ultra-high photo-gains exceeding 10^8 are feasible for a photo-GABT. This would be among the largest photodetector gains. In addition, the new photo-GABT is expected to have a very high bandwidth, which stems from the utilized unipolar Schottky design. On the other hand, greatly reduced gate charges are possible for a GaN-based GABT for power switching applications compared to similarly rated alternative Si and GaN devices. In this case, the semiconductor gate of the GaN-GABT could lead to increased robustness against electrostatic discharges (ESD), which is a critical factor, especially in the harsh environment of power electronics.

[1] C. Strobel *et al.*, "Novel Graphene Adjustable-Barrier Transistor with Ultra-High Current Gain," *ACS Appl. Mater. Interfaces*, vol. 14, no. 34, pp. 39249–39254, Aug. 2022.

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Optoelectronic Characterization of Metal-Organic Frameworks

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Metal-Organic Frameworks (MOFs) are crystalline materials comprising metal ions/clusters (inorganic) and organic ligands/molecules, interconnected to form 1D, 2D, or 3D networks via coordination bonds. Renowned for ordered crystallinity, porosity, stability, and tunability, MOFs find application potential in optoelectronics, including photodetectors. This research delves into the electrical and optical properties of Cu_4DHTTB (DHTTB = 2,5-dihydroxy-1-3,4,6-tetrathiolbenzene) MOF film. Investigation areas encompass temperature-dependent resistance behavior and time-constant computation following 633 nm laser exposure at varying powers, employing an exponential decay model. The decrease in resistance with increasing temperature provides confirmation of Cu_4DHTTB's semiconducting characteristic. While direct correlation between time constants and laser power remains elusive at present, the study's future trajectory involves cross-comparing time constant and responsivity across MOF films with distinct thickness and crystallinity at varying laser powers.

References

[1] Omar M. Yaghi, Michael O'Keeffe, Nathan W. Ockwig, Hee K. Chae, Mohamed Eddaoudi, and Jaheon Kim. Reticular synthesis and the design of new materials. *Nature*, 423 (6941): 705 – 714, Jun 2003.

[2] Huang, Xing & Shuai, Fu & Lin, Cong & Lu, Yang & Wang, Mingchao & Zhang, Peng & Huang, Chuanhui & Li, Zichao & Liao, Zhongquan & Zou, Ye & Jian, Li & Zhou, Shengqiang & Helm, Manfred & Petkov, Petko & Heine, Thomas & Bonn, Mischa & Wang, Hai & Feng, Xinliang & Dong, Renhao. (2023). Semiconducting Conjugated Coordination Polymer with High Charge Mobility Enabled by "4 + 2" Phenyl Ligands. *Journal of the American Chemical Society*, 145:4, 2430–2438, 2023

[3] Yuanjing Cui, Banglin Chen, and Guodong Qian. Luminescent properties and applications of metal-organic frameworks. In *Structure and Bonding*, 157, 27 – 88, 2014.

[4] H Arora, R Dong, T Venanzi, J Zscharschuch, Harald Schneider, Manfred Helm, Xinliang Feng, Enrique Cánovas, and Artur Erbe. Demonstration of a broadband photodetector based on a two-dimensional metal-organic framework. *Advanced Materials*, 32:9, 1907063, 2020.

[5] HN Abdelhamid, M Wilk-Kozubek, AM El-Zohry, Antonio Bermejo Gómez, Alejandro Valiente, Belén Martín-Matute, Anja-Verena Mudring, and Xiaodong Zou. Luminescence properties of a family of lanthanide metal-organic frameworks. *Microporous and Mesoporous Materials*, 279, 400-406, 2019.

Fabrication and characterisation of Junctionless Nanowire Transistors (JNTs) for gas-phase sensing

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Abstract

Over the past six decades, the primary approach to enhancing the performance of complementary metal-oxide-semiconductor (CMOS) transistors has predominantly been reducing their dimensions. This achievement is attributed to advancements in fabrication technology, such as lithography and etching techniques. Implementing classical scaling encounters significant obstacles with the advent of sub-20 nm CMOS technology nodes. Consequently, there has been a growing significance of novel devices, sophisticated nanomaterials, and superior manufacturing processes. Silicon nanowires have demonstrated efficacy in several electronic devices [1], such as thermoelectric energy harvesting [2], sensors [3], and solar cells [4].

Silicon nanowire-based field-effect transistors (FETs) use the advantageous high surface-to-volume ratio to effectively regulate conductance along a nanowire through the electrostatic potential exerted by the gate. In addition, nanowires have been employed in developing biological sensors with enhanced sensitivity. One of the most novel device designs under this subcategory is the junctionless nanowire transistor (JNT). A JNT comprises a nanowire channel that is heavily doped and possesses no p-n junctions. In this device, the movement of charge carriers is regulated by the voltage applied to the gate. The transistor is likely the most basic, offering advantages like easier manufacturing techniques and several functional benefits compared to traditional MOS devices. In addition, it has been demonstrated that JNTs exhibit exceptional performance when utilised as biosensors. The present research describes the fabrication process of junctionless transistors. Ion implantation is the method for doping intrinsic silicon-on-insulator (SOI) wafers. Flash Lamp Annealing (FLA) activates dopants and rectifies implantation errors. The fabrication of nanowires is achieved by a top-down methodology, employing electron beam lithography (EBL) and reactive ion etching (RIE) techniques. Electrical characterisation of the devices is carried out by back-gating the JNT devices. These JNT devices show varying device characteristics essential for sensing applications.

[1] Mikolajick, T., et al., Silicon nanowires – a versatile technology platform. physica status solidi (RRL) – Rapid Research Letters **7**(10): 793-799 (2013).
[2] Boukai, A.I., et al., Silicon nanowires as efficient thermoelectric materials. Nature **451**(7175): 168-171 (2008).
[3] Zheng, G., et al., Multiplexed electrical detection of cancer markers with nanowire sensor arrays. Nat Biotech **23**(10): 1294-1301 (2005).
[4] Tian, B., et al., Coaxial silicon nanowires as solar cells and nanoelectronic power sources. Nature **449**(7164): 885-889 (2007).

High-speed Forward-biased Silicon Mach-Zehnder Modulator

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Abstract: Large-scale integration has become the key to the solution to meet the increasing demand for data communication. Moreover, to provide high speed and energy efficiency together as well as compensate for the scaling bottleneck, the research preference is shifting towards the electro-optic domain. For applications like data center interconnects, silicon electro-optic modulators e.g., silicon Mach-Zehnder modulators (MZM) have become important blocks to fabricate integrated circuits. Over time, several modeling has been studied and several designs have been fabricated, which have been characterized experimentally in the lab to increase the modulation speed and ER while maintaining the power consumption, insertion loss, and $V_{\pi}L$ to a minimum level. In this poster, we review our attempts to optimize different parameters of forward-biased silicon modulators to utilize them for various applications, because it can achieve a higher level of integration and lower $V_{\pi}L$ compared to the reverse-biased configuration.

2D material patterning by t-SPL for neuromorphic computing

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The von Neumann bottleneck of conventional electronics is a problem for computing big data. Much research points to hardware-based processing paradigm inspired by the human brain. Particular attention is brought to the emerging field of 2D materials because of their ability to fabricate neuromorphic novel electronic devices. However, these 2D materials introduce a challenge to the fabrication of devices because of the fragile nature of their active layer.

Thermal scanning probe lithography (t-SPL) has proven to be a well-suited method for patterning 2D devices, as opposed to the other conventional CMOS processes like the UV (ultraviolet) and EB (electron beam) lithography method which degrades the properties of 2D materials. This work consists of fabricating 2D devices by patterning their contacts with the help of the t-SPL method. The method implies the use of the "bilayer lift-off" technique, suitable for patterning the 2D devices. We use PPA as the top-resist layer and PMMA-MA for the lift-off resist, adapting the technique for successful contact patterning.

Photon-pair generation with nonlinear optics

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Photon-pair generation through spontaneous parametric down-conversion (SPDC) in bulk crystals is extensively used for nonclassical light generation. For some specific applications, such as long-range quantum communications where interfacing with quantum memories based on atomic transitions is crucial, narrowband photon pairs sources are required. Here we present our latest results on cavity-enhanced SPDC process in optical resonators encompassing nonlinear crystals. We derive analytical expressions for the generation rate and spectral brightness of the source. We show that counter-propagating cavity-enhanced SPDC provides narrow-band pure heralded single-photons. In particular, our analysis suggests that when a pulsed pump with a duration of 200 ps illuminates a 1 mm-long lithium niobate crystal inside a singly-resonant cavity, the bandwidth of the counter and co-propagating photons will be around 120 MHz and 5.7 GHz, respectively, with heralded single-photon purity as high as 0.99. Due to small absorption probability of the non-resonant partner inside the cavity, heralding efficiency in this configuration can approach unity if the resonant partner is used as the herald.

Reactive Ion Etching for Fabrication of 3D Nanostructures in Silicon

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Reactive Ion Etching (RIE) is a dry etching technique widely utilised within the semiconductor industry for the fabrication of 3D nanostructures on wafer scale. This is achieved via the employment of chemically reactive plasma in combination with physical sputtering to produce the desired structures. This process allows for the highly directional etching capability and good mask selectivity of RIE, particularly in comparison to wet chemical-based and purely physical (e.g. ion milling) methodologies [1].

Within the duration of this Capstone project, I will focus on the fabrication of nanopillars in silicon for potential applications in photonics. Therefore, this project will present a detailed overview of the differing photonic structures produced by RIE.

References

[1] Huff M. et al. (2021) *Micromachines*, **12**(8) 991.

Tuneable Band Pass Filter in Silicon Nitride Platform

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Silicon nitride (Si_3N_4) photonic platform, which have a large bandgap, enables operation throughout wavelengths from the near ultraviolet to the mid-infrared. There are a wide range of applications based on this platform include low-threshold frequency combs, high-precision sensing, and frequency conversion. Microring resonators (MRR) are the most common device in the silicon nitride photonics platform due to their greatly field enhancement. The recorded quality factors or coupling conditions of MRR in silicon nitride platforms are mostly fixed. Hence a reconfigurable MRR with tuneable coupling conditions are highly desired.

Here in this work, the coupled-resonator optical waveguide (CROW) filter is designed to realize a variety of working conditions with very high extinction ratio. MRR is spanning from the “undercoupling” to “over-coupling” when the heater on one of the rings is applied with different voltages. Fig. 1a) shows design of a CROW filter with two identical rings with a radius (R), each with a coupling coefficient κ_1 between the rings and the bus waveguides and coupling coefficient κ_2 between the rings themselves. Each ring uses strip waveguides, which can only support the TE mode. The waveguide cross section is presented in Fig. 1b).

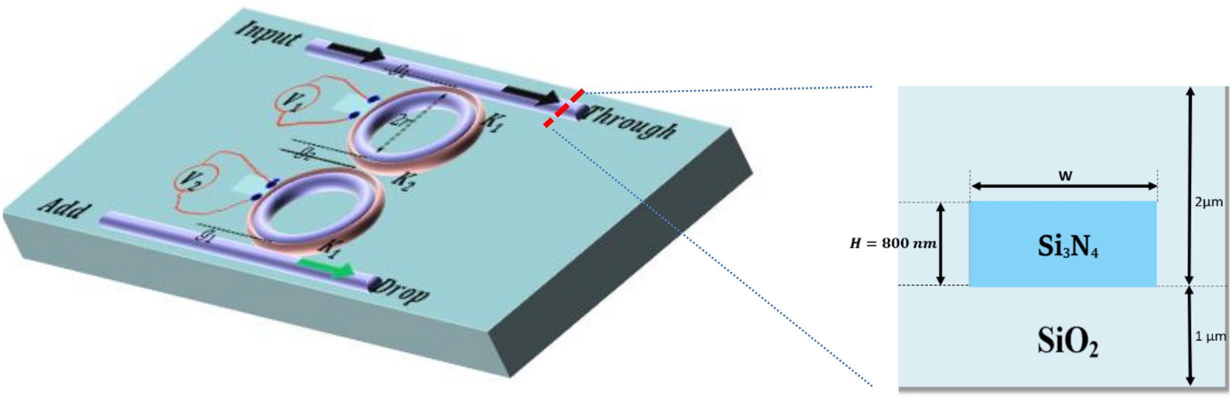

Figure .1 a) Schematic of a coupled-resonator optical waveguide (CROW) filter in SiN platform, which consists of two identical rings, each with a coupling coefficient κ_1 between the rings and the bus waveguides and coupling coefficient κ_2 between the rings themselves. b) Waveguide cross section.

Optimization of top-down fabrication of group IV nanostructures

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Abstract

Nanostructures based on group IV elements are promising candidates for a variety of applications, such as nanoelectronic and optoelectronic devices. In addition, Si-based photonic devices such as optical waveguides and microring resonators have attracted tremendous attention owing to their unprecedented small size and the capability to manufacture photonic circuitry with the help of existing CMOS fabrication technology [1, 2]. Despite the improvements in the fabrication processes, producing structures with low scattering loss with smooth sidewalls and low roughness is still one of the limitations faced [3]. The aim is to optimize the top-down processes for fabricating silicon waveguide-ring resonators by focusing on the etching process using inductively coupled plasma reactive ion etching (ICP-RIE).

In this work, we report on the fabrication and structural characterization of Si microring resonators. The resonator structures were patterned on a negative tone resist, Hydrogen silsesquioxane (HSQ), using electron beam lithography, followed by the development of HSQ in an aqueous solution of NaOH and NaCl (salty developer). Afterward, patterns were transferred Si using inductively coupled plasma reactive ion etching (ICP-RIE) with distinct recipes. Investigation of different dose factors and recipes made it possible to realize the optimum parameters to achieve resonator structures that have low surface roughness and smooth sidewalls. The resonator structures were characterized using SEM imaging to check the resonator structures after exposure and the etching processes. The tilted SEM imaging was carried out using FIB-SEM to investigate the sidewalls of the resonators. Also, Atomic force microscopy was performed to extract the depth profile and the surface roughness. The etch rate was determined using the ellipsometer.

[1] Bogaerts, W., de Heyn, P., van Vaerenbergh, T., de Vos, K., Kumar Selvaraja, S., Claes, T., Dumon, P., Bienstman, P., Thourhout, V., & Baets, R. ‘Silicon microring resonators’. Laser Photonics Rev, 6(1), 47–73, (2012). https://doi.org/10.1002/lpor.201100017

[2] Near Margalit., Chao Xiang., Steven M. Bowers., Alexis Bjorlin., Robert Blum., John E. Bowers. ‘Perspective on the future of silicon photonics and electronics’. Appl. Phys. Lett. 31 May 2021; 118 (22): 220501. https://doi.org/10.1063/5.0050117

[3] Zheng, Y., Gao, P., Jiang, L., Kai, X., & An Duan, J. ‘Surface Morphology of Silicon Waveguide after Reactive Ion Etching (RIE)’. (2019). https://doi.org/10.3390/coatings9080478.

Novel nonreciprocal devices using silicon microring modulators

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Despite the great progress in Photonic Integrated Circuits (PICs), on-chip integration of optical nonreciprocal devices has remained a challenge. Optical nonreciprocal devices are components that allow light to propagate only in one direction. Some of the applications of nonreciprocal devices are, preventing unwanted back reflection to the laser and hence stabilizing the laser operation and reducing the noise, facilitating full duplex communications, and realizing optical transistors and logic gates for on-chip all-optical information processing. Traditional approach to realize a nonreciprocal component is using the magneto optic effect, which inherently relies on applying a strong external magnetic field to the materials not compatible with the conventional CMOS process, hence it is not a reliable solution to achieve nonreciprocity in PICs. The other method is exploiting nonlinear effects, which unfortunately only works with high intensity optical input and is accompanied by unwanted harmonics, which is not compatible with all the applications. Utilizing temporal modulation is a novel method for achieving nonreciprocity in PICs. This method does not require deposition of any new material on silicon and applying high optical power and it can be implemented by the conventional foundry process in silicon. In this work we present our results for achieving nonreciprocity in a silicon optical ring resonator, by introducing two small time-modulated perturbations into the ring (Fig. 1). Furthermore, design guidelines for such a tunable optical isolator based on a standard CMOS foundry process, different trade-offs in the design and also the sensitivity analysis will be presented.

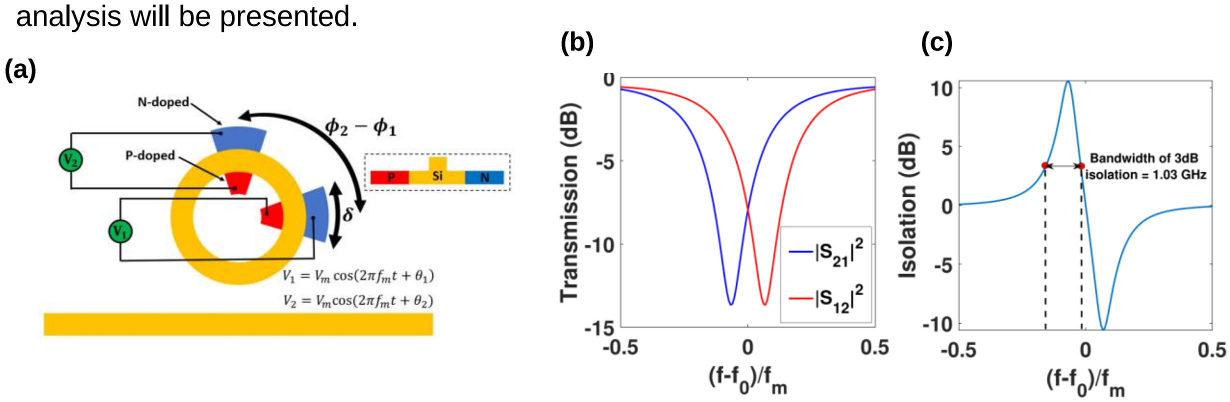

Fig. 1. (a) Ring resonator with two time-modulated point perturbations, side coupled to the bus waveguide. (b) Forward (S_{12}) and backward (S_{21}) power transmission spectrum of the time-modulated ring resonator and, (c) optical isolation ($|S_{12}|^2/|S_{21}|^2$) versus frequency.

Fabrication of high reflectivity m=3 neutron Ni/Ti supermirrors by reactive magnetron sputtering

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Neutron optics systems, particularly neutron guides and neutron focusing optics, have witnessed rapid improvements with the development and wide applications of neutron scattering and diffracting technology. Neutron supermirrors are indispensable in neutron research devices. As a traditional material selection pair, the Ni/Ti system is widely used owing to its large neutron scattering length density [1]. However, it exhibits a large interface width when prepared under a pure argon atmosphere, resulting in low reflectivity [2]. To improve the interface of Ni/Ti multilayers prepared by magnetron sputtering, researchers have adopted the modified deposition methods of reactive magnetron sputtering.

In this work, we aim to improve the interface diffusion and reflectivity of neutron Ni/Ti supermirrors by studying the effect of reactive sputtering nitrogen ratio on thin films. We fabricated different d-spacing Ni/Ti periodic multilayers and m=3 neutron supermirrors under two different sputtering gas atmospheres with nitrogen ratios of 12 and 20% during Ni sputtering. Grazing incident X-ray reflection, X-ray diffraction, and internal stress measurements were conducted on periodic multilayers. High-resolution transmission electron microscope, high angle annular dark field, selecting electron diffraction, and atomic force microscopy measurements were performed on the neutron supermirrors under two different sputtering gas atmospheres with nitrogen ratios of 12 and 20%. The results showed the improvement of the thin film interface and internal stress by optimizing the reactive sputtering gas ratio. Eventually, the m=3.05 Ni/Ti supermirrors deposited under 20% nitrogen mixed sputtering gas with neutron reflectivity of 0.89 were successfully fabricated.

References

[1] Bentley P M, Cooper-Jensen C P, Andersen K H. High intensity neutron beamlines [J]. Reviews of Accelerator Science and Technology, 2013, 6: 259-274.

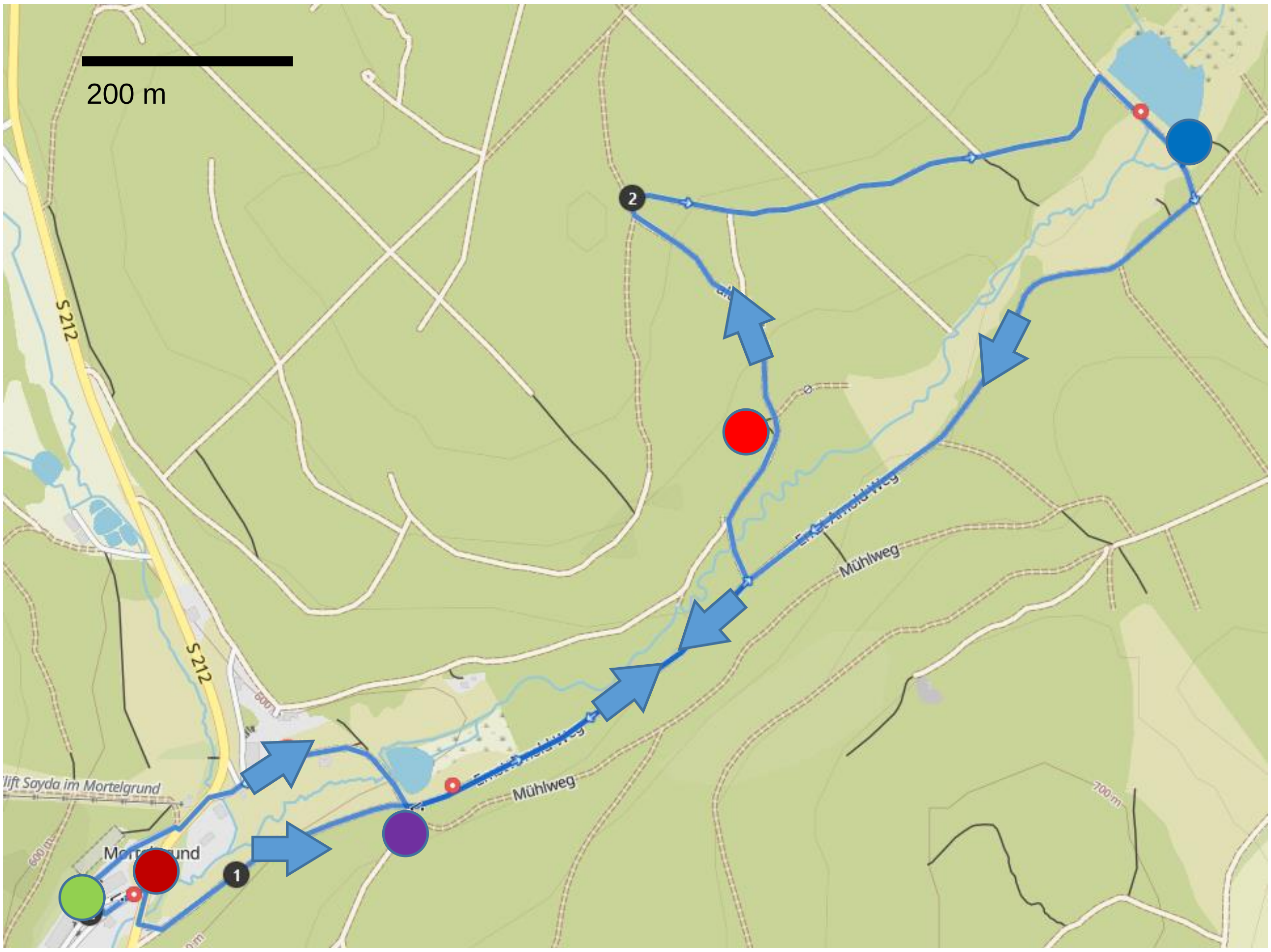
[2] Jankowski A F, Wall M A. Transmission electron microscopy of Ni/Ti neutron mirrors [J]. Thin Solid Films, 1989, 181(1-2): 305-312.

Your Notes

Sayda Mortelgrund

Bus Stop, route T737

Schwemmteiche



Map © Komoot.de (2023)

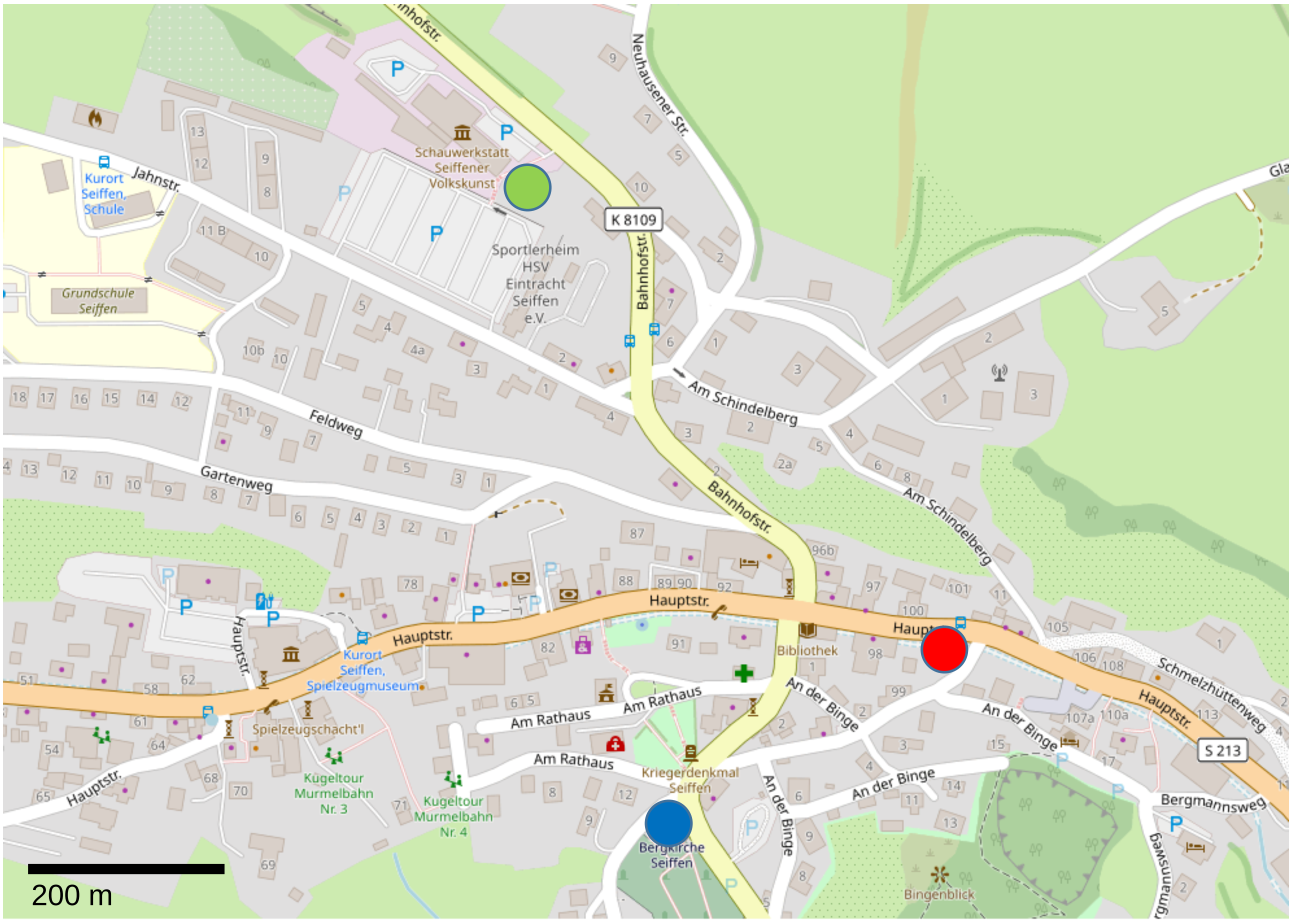
Youth Hostel (JH)

start Mon 5:00 pm.

Michaelis Stolln (old mine)

Saydaer ‚Maler-Weg‘ – Painters‘ Path

Seiffen



Map © Komoot.de (2023)

2:45 pm. Arrival by Bus – Schauwerkstatt

3:00 pm. English Tour – Schauwerkstatt

4:15 pm. Coffee - Cafe Caféchen

5:15 pm. English Tour + Organ play – Church

6:15 pm. Departure – Bus stop „Seiffen, Mitte“

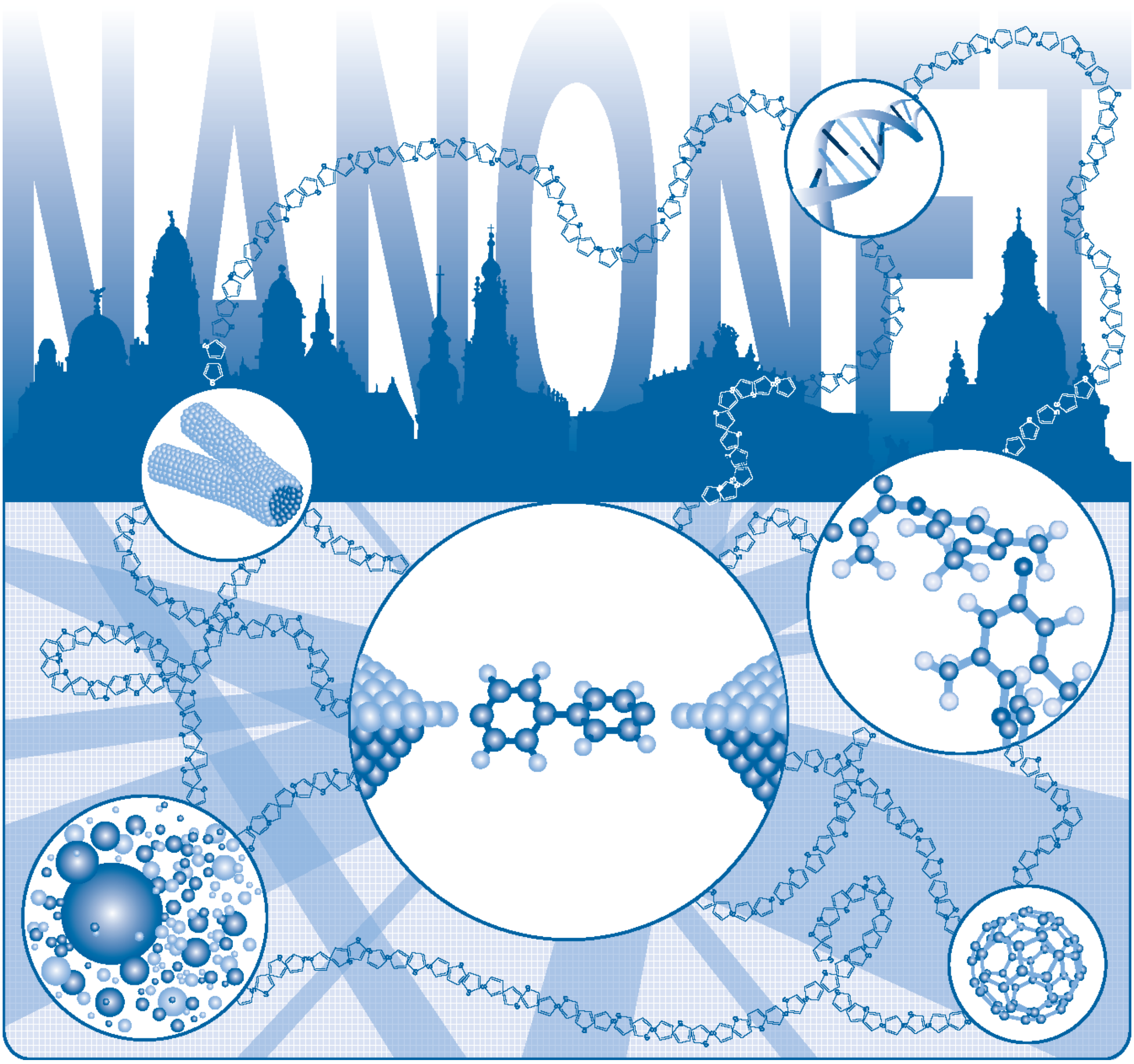
NanoNet+ Workshop 2023 - Sayda

Participants Updated: 05.09.2023 (PZ)

Name	First Name	Gender	Title	Institution
Babalola	Israel	Mr.		HZDR
Bhattacharya	Debadreeto	Mr.		HZDR
Catuneanu	Mircea	Mr.		TU Dresden
Dev	Sourav	Mr.		TU Dresden
Echresh	Ahmad	Mr.	Dr.	HZDR
Erbe	Artur	Mr.	Prof.	HZDR
Fejzaj	Deianira	Ms.		TU Dresden
Fekri	Zahra	Ms.		HZDR
Georgiev	Vihar	Mr.	Prof.	Univ Glasgow
Georgiev	Yordan	Mr.	Dr.	HZDR
Ghosh	Sayantan	Mr.		HZDR
Haluska	Miroslav	Mr.	Dr.	ETH Zurich
Hamerly	Ryan	Mr.	Dr.	MIT, USA
He	Menglong	Mr.		TU Dresden
Jagtap	Nagesh	Mr.		HZDR
Jamshidi	Kambiz	Mr.	Prof.	TU Dresden
Kielar	Charlotte	Ms.	Dr.	HZDR
Kirchner	Robert	Mr.	Dr.	TU Dresden
Krause	Matthias	Mr.	Dr.	HZDR
Lambeva	Nikol	Ms.	Dr.	HZDR
Mataji	Amid	Mr.	Dr.	TU Dresden
Nguyen	Susan	Ms.		TCD
Niebauer	Michael	Mr.		FAU Erlangen
Razavi	Mohsen	Mr.	Prof.	Univ Leeds
Rodriguez	Borja	Mr.		HZDR
Schönherr	Tommy	Mr.		HZDR
Shetewy	Abdou	Mr.		TU Dresden
Siddaveeranna	Bhavana	Ms.		HZDR
Strobel	Carsten	Mr.	Dr.	TU Dresden
Zahn	Peter	Mr.	Dr.	HZDR
Zarif	Arezoo	Ms.		TU Dresden
Zhang	Qiya	Ms.		HZDR

HZDR

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF



10th Annual Workshop since 2014