



Nordic Semiconductor Meeting 2011

Fuglsøcentret, Denmark

19-22 June 2011

Book of abstracts

Monday, 20. June 2011

08:55	H. P. Gunnlaugsson, Welcome <i>Energy and semiconductors and interactions with light (I), chairman; A. N. Larsen</i>
09:00	Antonio Marti, Progress in intermediate band solar cell research
09:40	Erik Stensrud Marstein, Light trapping in very thin crystalline silicon solar cells
10:20	Coffee break <i>Fundamental physics and ZnO (I), chairman; A. Marti</i>
10:50	Christian Uhrenfeldt, Near-infrared-ultraviolet absorption cross sections for Ge nanocrystals embedded in SiO ₂ thin films
11:30	V. Quemener, Electrical investigation of hydrothermally grown ZnO by DLTS
11:50	Chi kwong Tang, Pd Schottky contact on ZnO: Characterization and simulation
12:10	Lunch <i>Fundamental physics and ZnO (II), chairman; H. P. Gunnlaugsson</i>
13:40	Ulrich Wahl, Emission channeling lattice location experiments in semiconductors
14:20	D. Seghier, Ferromagnetism and point defects in cobalt-doped ZnO
14:40	T. E. Mølholt, Paramagnetism of Fe ³⁺ in ⁵⁷ Mn ⁺ implanted ZnO
15:00	Coffee break
15:30	Poster session
19:00	Dinner

Tuesday, 21. June 2011

	<i>Fundamental physics and defects, chairman; U. Wahl</i>
09:00	J. Slotte, Vacancies, divacancies and vacancy clusters in irradiated Germanium
09:40	Helge Malmbekk, Comparative study of hydrogen related defects in n- and p-type silicon
10:00	L. Vines, Impurity migration in bulk and thin film ZnO
10:20	Coffee break <i>Energy and semiconductors and interactions with light (II), chairman; C. Uhrenfeldt</i>
10:50	Thomas Garm Pedersen, Modeling of plasmon-enhanced solar cells
11:30	V. Khranovskyy, Novel light emitting and light controlled properties of ZnO nanostructures
11:50	Helge Weman, Semiconductor Nanowire Based Solar Cells-A Nordic Top-level Research Initiative
12:10	Lunch <i>SiC, chairman; H. Radamson</i>
13:40	M. Syväjärvi, Fluorescent SiC as new material for white LEDs
14:20	Einar Örn Sveinbjörnsson, Passivation of interface traps at the SiO ₂ /4H-SiC interface by alkali ions
15:00	Muhammad Usman, Position dependent traps investigation in 4H-SiC bipolar junction transistors
15:20	Coffee break
15:50	Conference excursion
19:00	Conference dinner
TBD	Fysikshow

Wednesday, 22. June 2011

	<i>Sensors and fabrication, chairman; M. Syväjärvi</i>
09:00	Erik V Thomsen, Sensors everywhere: An Electronic Patch
09:40	Sveinn Ólafsson, High Power Impulse Magnetron Sputtering of TiN and TiO ₂
10:00	Dirch Hjorth Petersen, Micro Hall effect - an emerging semiconductor metrology
10:20	Coffee break <i>Sensors, methods and characterization, chairman; S. Ólafsson</i>
10:50	Henry Radamson, Group IV-based heterostructures for IR detection
11:30	Yiyu Ou, Characterization of donor-acceptor-pair emission in fluorescent 6H-SiC
11:50	Thomas Pedersen, Microreactors for heterogenous catalysis
12:10	Arne Nylandsted Larsen, Closing remarks
12:20	Lunch
14:10	Departure

Preliminary 14/6 2011

Monday 20 June 2011
Oral program

Progress in intermediate band solar cell research

A.Martí and A.Luque

Instituto de Energía Solar – Universidad Politécnica de Madrid
ETSIT de Telecomunicación, Ciudad Univeritaria sn, 28040 Madrid, Spain

Email: amartil@etsit.upm.es

This work will provide an overview of the progress made to date in the research of intermediate band solar cells (IBSC). The general structure [1] of an IBSC is sketched in Fig. 1. It consists of an “intermediate band material” sandwiched in-between two conventional semiconductors of p and n type. The “intermediate band material”, that gives its name to the solar cell, is characterised by the existence of a collection of energy levels (intermediate band, IB) located in-between the conduction and valence bands (CB and VB). This IB divides the semiconductor bandgap, E_G , in two bandgaps E_L and E_H .

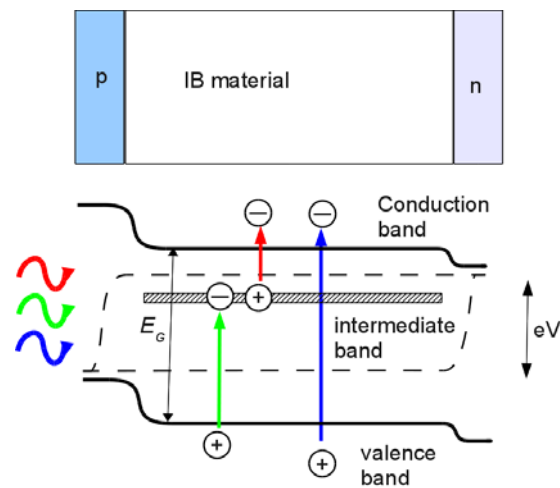


Figure 1. Conceptual representation of the structure and operation of an intermediate band solar cell.

The practical implementation of the IBSC requires: a) the absorption of two sub-bandgap photons where one photon pumps an electron from the VB to the IB and a second photon pumps an electron from IB to the conduction band CB; b) that carrier relaxation between bands occurs at a much lower rate than carrier relaxation within bands. The overview will cover several theoretical aspects of importance for the understanding of the operation of the IBSC at fundamental level as well as several material systems that have proven capable of actually implementing intermediate band solar cells (quantum dots [2] , ZnTe:O [3] and GaN_xAs_{1-x}[4] alloys).

References

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Light trapping in very thin crystalline silicon solar cells

E. S. Marstein¹

¹Department for Solar Energy, Institute for Energy Technology (IFE), Instituttveien 18, NO-2007 Kjeller,
Norway

Email: erik.stensrud.marstein@ife.no

Solar cells are rapidly becoming an important part of the electricity supply in several regions world-wide. This is the result of a monumental effort to reduce costs and increase efficiencies of solar cells and modules over the last decades. In order to enable continued growth in the use of solar cells for electricity production, costs must be further reduced. In this talk, the potential for reducing costs related to the use of semiconductor materials through the incorporation of light trapping structures will be discussed. While the concepts to be discussed are relevant for a range of solar cell technologies, thin crystalline silicon solar cells will be used as examples. First, the need for incorporating light trapping structures in order to prevent optical losses in thin solar cells will be shown. Thereafter, results from experiments using nanostructured surfaces that enable light trapping in crystalline silicon solar cells will be presented. Textured and nanoporous silicon surfaces, as well as photonic crystal structures will all be discussed. These structures have been formed using various wet chemical, electrochemical and colloidal patterning techniques. It will be shown that, although significant technological hurdles remain before the proposed structures can be used in low cost, large throughput production, the potential for maintaining efficiency even for very small wafer thicknesses is large.

Near-infrared-ultraviolet absorption cross sections for Ge nanocrystals embedded in SiO₂ thin films

C. Uhrenfeldt¹, J. Chevallier¹, A. Nylandsted Larsen¹ and B. Bech Nielsen¹

¹Department of Physics and Astronomy, Aarhus University, Ny Munkegade 120, DK-8000 Århus C, Denmark

Email: chru@phys.au.dk

Studies of semiconductor nanocrystals or quantum dots have become a vast area of research due to a number of interesting applications of these structures within optoelectronics as well as in photovoltaic devices, which are related to the effects of quantum confinement on the electronic states in the nanocrystals. For many application purposes an understanding of the important mechanisms in the interaction of these nanostructures with light when embedded in dielectric materials are of key importance. Despite of this fact, the optical properties of semiconductor nanocrystals remain poorly understood which hampers the practical use of such systems. Important information on these properties and on the interaction of the nanocrystals with light can be provided by studies of their absorption properties. In this work the absolute optical absorption cross sections of 2–6 nm Ge nanocrystals embedded in SiO₂ were measured in the near-infrared–ultraviolet spectral range. Thin layers of Ge sandwiched between SiO₂ layers were prepared in a multilayered configuration, which upon heat treatment at 800 °C led to multilayers of Ge nanocrystals with a narrow size distribution. In addition, samples containing Ge nanocrystals randomly distributed in SiO₂ films were also prepared in order to clarify the effects of the multilayer configuration on the optical properties. The measurements clearly show that the nanocrystal absorption per atom in the 1.5–5 eV spectral range is smaller than in bulk Ge atoms regardless of the nanocrystal size and that the absorption cross sections per atom for the nanocrystals are largely independent of the nanocrystal size. Moreover, we find that the absorption cross sections for small concentrations of Ge nanocrystals embedded in SiO₂ are quantitatively well described by the Mie theory using bulk values for the dielectric function of Ge in the spectral range investigated. Hence quantum confinement effects have only minor if any influence on the dominant features of the absorption spectra for spherical Ge nanocrystals embedded in SiO₂. For Ge nanocrystals ordered in multilayers we find that the experimental absorption cross section for the larger and more close packed nanocrystals exceeds that for similar concentrations of nanocrystals randomly distributed in the films, whereas this effect is not observed for multilayered samples with smaller and less densely packed nanocrystals. The combined results show that for all the Ge nanocrystals studied the nanocrystal shape and the matrix in which the nanocrystals are embedded, as well as the nanocrystal configuration play an important role in the optical response of the Ge nanocrystals and that these effects dominate the effects of quantum confinement in the absorption from spherical Ge nanocrystals embedded in SiO₂.

Electrical investigation of hydrothermally grown ZnO by DLTS

V.Quemener, L. Vines, E. V. Monakhov, B. G. Svensson

Center for Material Science and Nanotechnology, Department of Physics, University of Oslo.
Blindern, 0316 Oslo, Norway.
vincent.quemener@smn.uio.no

Zinc oxide is a wide band gap n-type semiconductor appearing as one of the most promising candidate to be used as Transparent Conducting Oxides (TCO) for photovoltaic applications. However, intrinsic and impurity related defects remain during the growth process and have a huge impact on the properties of ZnO. Thus, the identification of electrically active defects in ZnO remain a high challenge. In this respect, Deep level transient spectroscopy (DLTS) is a powerful technique to detect defects level in the band gap and several defects are commonly reported in the 30-300K temperature range. In addition, recent work have considerably improved the quality of Schottky contacts which can allow to push limits of the DLTS used at higher temperatures so that deeper region in the band gap can be analyzed. In this study, hydrothermally grown ZnO was annealed at 1400°C during 30 min in Ar ambient atmosphere followed by polishing and etching process. Finally, Pd Schottky contacts were formed by e-beam deposition on the Zn-face. The electronic properties were investigated by DLTS in 80-600K temperature range. The results show two peaks in the 300-600K temperature range, corresponding to energy position in the band gap of $E_c-1.0$ eV and $E_c-1.3$ eV, labelled E5 and E6, respectively (E_c denotes the conduction band edge). The origin of these defects is discussed.

Pd Schottky contact on ZnO: Characterization and simulation

C. K. Tang¹, L. Vines¹, B. G. Svensson¹ and E. V. Monakhov¹

¹University of Oslo, Physics department/Center for Materials science and Nanotechnology, P.O. Box 1048 Blindern,

Email: c.k.tang@smn.uio.no

Zinc oxide (ZnO) is becoming an attractive semiconductor material within optoelectronics and solar cell applications. Large efforts are put in understanding the properties of electrically active defects in ZnO using deep level transient spectroscopy (DLTS) on Schottky contacts. However, the quality, stability and reproducibility of the Schottky contacts have shown to be challenging[1]. Device performance can be estimated by charge carrier simulation using commercially available software (TCAD), but a reliable model of the transport properties of ZnO is needed.

In this study, Schottky contact on ZnO has been modelled and simulated for their electrical characteristics. The ZnO model was developed and investigated through experimental characterization of Pd Schottky contacts on ZnO using current-voltage (IV), deep level transient spectroscopy (DLTS) and admittance spectroscopy (ADSPEC). It is found that fitting of the large leakage current in the IV-plots can be achieved by implementing a highly n-doped interface layer which promotes tunneling effect.

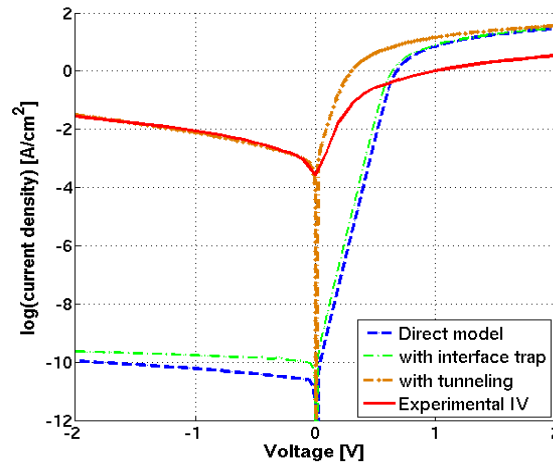


Figure 1: Experimental IV-curve and fitting with various effects implemented

References

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Emission channeling lattice location experiments in semiconductors

U. Wahl

Instituto Tecnológico e Nuclear, Unidade de Física e Aceleradores, 2686-953 Sacavém, Portugal

Email: uwahl@itn.pt

The principle of emission channeling is to dope single crystals with radioactive probe atoms that decay by the emission of charged particles such as α , β^- or β^+ particles or conversion electrons, which, on their way out of the crystal, experience channeling or blocking effects along low-index crystal directions. The resulting anisotropic particle emission yield from the crystal depends in a characteristic way on the lattice sites occupied by the emitter atoms and is recorded with the aid of position sensitive detectors. In comparison to conventional lattice location techniques by means of ion beam channeling, e.g. Rutherford Backscattering/Channeling (RBS/C), the main benefit of emission channeling is a roughly four orders of magnitude higher efficiency. This allows performing detailed lattice location studies with very good statistical accuracy at low fluences of implanted probe atoms, usually on the same sample as a function of post-implantation annealing temperature, which is not feasible by other methods.

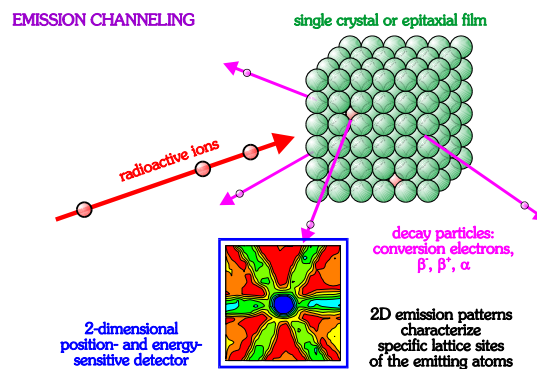


Figure 1. Schematic of an emission channeling experiment using radioactive probe atoms implanted into a single crystalline sample.

Apart from general features of the technique, some selected examples will be discussed, e.g. the lattice location of potential acceptors in ZnO and of transition metals in Ge. In ZnO, emission channeling experiments gave the first direct evidence that the potential group V acceptors P, As and Sb prefer to substitute for Zn instead of O. While the group Ib impurities Cu and Ag were found exclusively on substitutional Zn sites, the alkali metal Na also exhibited a large fraction on interstitial sites. By means of emission channeling, it was recently also found that in Ge, apart from the expected substitutional sites, considerable fractions of implanted Fe, Mn, Cu Ag, In and Sn are found on the bond-centered (BC) sites, which were attributed to the transition metals inside double vacancies in the so-called “split vacancy” configuration [1].

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Ferromagnetism and point defects in cobalt-doped ZnO

D. Seghier and H. P. Gislason

Science Institute, University of Iceland, Dunhagi 3, IS-107, Reykjavik, Iceland

Email: seghier@raunvis.hi.is

Transition metal (TM)-doped diluted magnetic semiconductors (DMSs) have become a highly desirable goal in the last years because of their potential applications in the field of spintronics [1]. In particular, the Co-doped ZnO system is promising for applications requiring room temperature ferromagnetism (RTFM) [2]. However, despite a great deal of studies focusing on the Co-doped ZnO system, there have been many contradictory reports on its magnetic properties. In some cases RTFM is thought to be intrinsic to the ZnCoO material, whereas in other cases the magnetism is thought to arise from secondary phases due the formation of cobalt clusters. Furthermore, paramagnetism and diamagnetism have also been reported.

In this work we report on optical and magnetic properties of ZnCoO materials grown using Molecular-Beam-Epitaxy (MBE). The cobalt mole fraction ranges between 2 % and 18 %. Our results show that the low Co-doped ZnO samples exhibit a clearer RTFM signal compared to those with higher cobalt mole fractions. The photoluminescence measurements show the presence of two luminescence bands in the range 400 till 600 nm which we attribute to the oxygen vacancy (V_O) and to an internal luminescence from the Co^{+2} ions. We show that the RTFM is stronger in the samples with lower Co concentrations because the cobalt ions substitute more efficiently for the zinc atoms and that the density of the V_O defects is higher in these samples. Our results suggest that the ferromagnetism is intrinsic to the Co-doped ZnO materials and that the V_O defects play a key role in the magnetic coupling.

References

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Paramagnetism of Fe^{3+} in $^{57}\text{Mn}^+$ implanted ZnO

T. E. Mølholt¹, H. P. Gunnlaugsson², R. Mantovan³, H. Masenda⁴, D. Naidoo⁴, W. B. Dlamini⁵, R. Sielemann⁶, K. Bharuth-Ram^{5,7}, G. Weyer², K. Johnston⁸, G. Langouche⁹, S. Ólafsson¹, H. P. Gíslason¹, ISOLDE Collaboration⁸

¹Science Institute, University of Iceland, Dunhaga 3, 107 Reykjavík, Iceland

²Department of Physics and Astronomy, Aarhus University, DK-8000 Aarhus C, Denmark

³Laboratorio MDM, IMM-CNR, Via Olivetti 2, 20041 Agrate Brianza (MB), Italy

⁴School of Physics, University of the Witwatersrand, WITS 2050, South Africa

⁵School of Physics, University of KwaZulu-Natal, Durban 4001, South Africa

⁶Helmholtz-Zentrum Berlin für Materialien und Energie, D-14109 Berlin, Germany

⁷iThemba LABS, P.O. Box 722, Somerset West 7129, South Africa

⁸PH Dept, ISOLDE/CERN, 1211 Geneva 23, Switzerland

⁹Instituut voor Kern-en Stralings fysika, University of Leuven, B-3001 Leuven, Belgium

Email: tem4@hi.is

Prompted by the generally poor understanding [1,2] of the nature of magnetic phenomena in 3d-metal doped ZnO, we have undertaken on-line ^{57}Fe Mössbauer spectroscopy. This was performed at the ISOLDE facility at CERN implanting a ZnO single-crystal at room temperature with a radioactive $^{57}\text{Mn}^+$ beam decaying to $^{57}\text{Fe}^+$ ($T_{1/2} = 1.5$ min.). The recorded Mössbauer spectra of the dilute Fe impurities (cf. Fig. 1), in an external magnetic field of 0.6 T, are dominated by sextets whose angular dependence rules out an ordered magnetic state, but are well accounted for on the basis of Fe^{3+} paramagnetic centres characterized by an unusually long relaxation times [3].

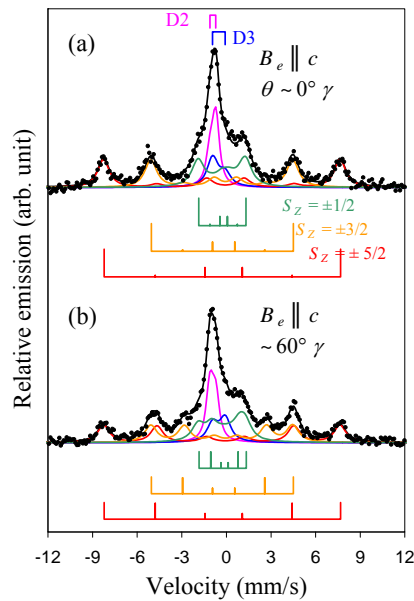


Fig. 1. Mössbauer spectra at 300 K in $B_c = 0.6$ T applied parallel to the c -axis and at two emission angles (θ) relative to the c -axis as indicated.

At higher temperatures, a line-broadening of the sextets is observed which can be related to a spin-lattice relaxation time (Fig. 2) comparable with the lifetime of the Mössbauer state [4].

In this contribution we will present ZnO Mössbauer data [3,6] and other relevant model-systems, such as MgO [4] and $\alpha\text{-Al}_2\text{O}_3$ [5].

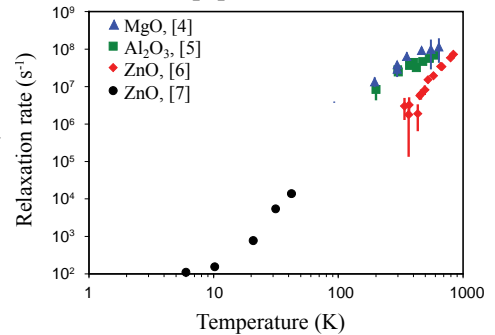


Fig. 2. Fe^{3+} spin-lattice relaxation rate of the labelled oxides vs. temperature.

References

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Monday 20 June 2011
Poster program

Defect annealing in Mn/Fe implanted ZnO

H. P. Gunnlaugsson¹, D. Naidoo², T. E. Mølholt³, R. Mantovan⁴, H. Masenda², K. Johnston⁵, K. Bharuth-Ram⁶, H. P. Gíslason³, G. Langouche⁷, S. Ólafsson³, R. Sielemann⁷, G. Weyer¹, and the ISOLDE Collaboration⁵

¹Department of Physics and Astronomy, Aarhus University, DK-8000 Århus C, Denmark

²School of Physics, University of the Witwatersrand, WITS 2050, South Africa

³Science Institute, University of Iceland, Dunhaga 3, IS-107 Reykjavík, Iceland

⁴Laboratorio Nazionale MDM CNR-INFN, 20041 Agrate Brianza (MI), Italy

⁵EP Division, CERN, CH-1211 Geneva 23, Switzerland

⁶University of KwaZulu-Natal, Durban 4001, South Africa

⁷Helmholtz Forschungszentrum, D-14109 Berlin, Germany

⁸Instituut voor Kern-en Stralings fysika, University of Leuven, B-3001 Leuven, Belgium

Email: hpg@phys.au.dk

ZnO single crystals have been implanted with radioactive $^{57}\text{Mn}^+$ ($T_{1/2}=1.5$ min) ions at the ISOLDE facility at CERN with 60 keV energy to fluences $<10^{12}/\text{cm}^2$. Mössbauer spectra for the 14.4 keV transition of the ^{57}Fe daughter atoms were measured with a gas-filled resonance detector equipped with a ^{57}Fe -enriched stainless steel absorber foil mounted on a velocity drive unit outside the implantation chamber.

At low fluences ($<5 \times 10^{10} \text{ cm}^{-2}$), the Mössbauer spectra are dominated by the line originating from Fe^{2+} on substitutional Zn site. For higher fluence ($>10^{11} \text{ cm}^{-2}$), the spectra are dominated by substitutional Fe^{3+} showing slow paramagnetic relaxations [1,2]. At room temperature, the Fe^{3+} fraction reaches saturation of approximately 70% for high fluences.

In this contribution we present the effect of annealing on ZnO crystals that have been pre-implanted to show dominantly a Fe^{3+} character. Five minutes of annealing at 660 K and storage at room temperature for approximately a day does not change the properties of the implanted crystals, i.e. the Fe^{3+} character is observed immediately at low fluences. Fifteen minutes of annealing at 711 K and storage at room temperature for approximately a day “resets” the crystal, in such a way that the Fe^{2+} character is observed at low fluence, and the Fe^{3+} character builds up subsequently as in fresh crystals. Storage for one year at room temperature likewise “resets” the crystal, while storage for approximately 2 days does not affect the Fe^{3+} character.

The dependence of fluence indicates that mobile defects must be involved in stabilizing the Fe^{3+} charge state, most likely the zinc vacancy. Assuming that the crystal is reset by out-diffusion of defects from the volume that is implanted allows us to estimate the activation energy for the diffusion of the defect. The data is consistent with values of the activation energy in the range from 0.35 eV ($D_0 = 1 \times 10^{-9} \text{ cm}^2/\text{s}$) to 0.55 eV ($D_0 = 6.6 \times 10^{-8} \text{ cm}^2/\text{s}$) in ZnO. The results furthermore suggest that binding of zinc vacancies to substitutional Fe must be very weak.

References:

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Optical transmission through arrays of β -Sn nanoparticles

B. Johansen¹, C. Uhrenfeldt¹, A. N. Larsen¹, T. G. Pedersen², H. U. Ulriksen²,
P. K. Kristensen², J. Jung², T. Søndergaard² and K. Pedersen²

¹Department of Physics and Astronomy, Aarhus University, Ny Munkegade 120, DK-8000 Århus C, Denmark

²Department of Physics and Nanotechnology, Aalborg University, Skjernvej 4A, 9220 Aalborg East, Denmark

Email: bj05@phys.au.dk

When particles are arranged in an ordered array anomalies in the optical spectra can appear. The first anomalies were observed for diffraction gratings by Wood in 1902 [1] and theoretically investigated by Rayleigh in 1907 [2]. The anomalies appear as the diffracted light becomes grazing to the plane of the grating.

We use electron beam lithography to produce well defined β -Sn nanoparticles arranged in a two-dimensional array on a fused silica substrate. The direct transmitted light through the array is measured. The optical measurements show that the anomalies only occur for large particles unless the particles are placed in an index matched environment. This observation is in agreement with the theoretical predictions in Ref. [3]. Furthermore we show by angle resolved transmission measurements that the positions of the anomalies do not follow the pure geometric prediction of horizontal diffraction. Instead the spectral position of the anomalies can be very exactly matched by calculating the lattice sum of the array. Figure 1 shows transmission measurements of light incident at different angles with S- or P-polarization. The vertical dotted lines show the peak positions in the theoretical calculated lattice sum and they match the features in the spectra precisely.

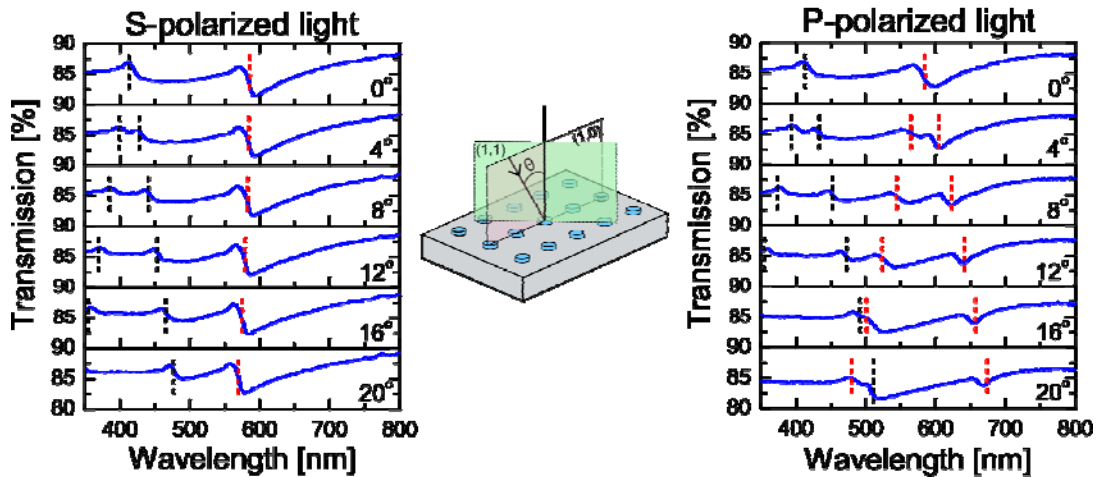


Figure 1 Direct transmission through an array of 120 nm β -Sn particles in an index matched environment with a refractive index of 1.46. The pitch of the array is 400 nm in both directions. The vertical dotted lines show peak positions in a theoretical calculated lattice sum.

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Time Delayed Mössbauer Measurements on Si single-crystals

H. P. Gunnlaugsson¹, D. Naidoo², T. E. Møllholt³, R. Mantovan⁴, H. Masenda², K. Johnston⁵, K. Bharuth-Ram⁶, H. P. Gíslason³, G. Langouche⁷, S. Ólafsson³, G. Weyer¹, and the ISOLDE Collaboration⁵

¹Department of Physics and Astronomy, Aarhus University, DK-8000 Århus C, Denmark

²School of Physics, University of the Witwatersrand, WITS 2050, South Africa

³Science Institute, University of Iceland, Dunhaga 3, IS-107 Reykjavík, Iceland

⁴Laboratorio Nazionale MDM CNR-INFN, 20041 Agrate Brianza (MI), Italy

⁵EP Division, CERN, CH-1211 Geneva 23, Switzerland

⁶University of KwaZulu-Natal, Durban 4001, South Africa

⁷Instituut voor Kern-en Stralings fysika, University of Leuven, B-3001 Leuven, Belgium

Email: hpg@phys.au.dk

In order to understand the vacancy kinetics in silicon-based materials, radioactive $^{57}\text{Mn}^+$ ($T_{1/2}=1.5$ min) ions have been implanted at the ISOLDE facility at CERN with 40 – 60 keV energy to fluences $<10^{12}/\text{cm}^2$ into Si single-crystals held at 300 – 770 K. Mössbauer spectra for the 14.4 keV transition of the ^{57}Fe daughter atoms were measured with a gas-filled resonance detector equipped with a ^{57}Fe -enriched stainless steel absorber foil mounted on a velocity drive unit outside the implantation chamber.

At the lower temperature range 300 – 450 K, the spectra are characterized by three components assigned to (i) interstitial Fe on tetrahedral sites (Fe_T), (ii) an asymmetric quadrupole doublet due to Fe in amorphous regions due to the implantation (Fe_D) and (iii) substitutional Fe (Fe_S). Above 475 K, the total annealing of the damage related defects leads to an increase in the substitutional fraction and the appearance of vacancy complexes.

The 1.5 min decay of ^{57}Mn offers a method to investigate the capture of vacancies in Si by the Mn atoms, which has been done by monitoring site fractions as a function of time. This technique, called “Time Delayed Measurements (TDM) [1]”, utilizes a short implantation ($\sim 6 \times 10^{10} \text{ }^{57}\text{Mn}/\text{cm}^2$), during which and after the collected spectra are stored at regular intervals. TDM measurements were performed immediately after the line-broadening of the interstitial line at seven different critical temperatures in the range of 509 – 712 K, in order to investigate the annealing behavior of the vacancy complexes on a minute timescale. For each temperature set, measurements were repeated six times in order to obtain sufficient statistics but also to monitor fluence dependence. New details on the kinetics, the stability, and the formation of Mn-vacancy complexes will be discussed.

References:

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FTIR analysis of oxygen dimers in heat-treated CZ-Si

B. Raeissi¹, A. Skogstad¹, L. I. Murin², E. Monakhov¹, and B. G. Svensson¹

¹Department of Physics, Center for materials Science and Nanotechnology, University of Oslo, B.O. Box 1048 Blindern, N-0316 Oslo, Norway

²Scientific-Practical Materials Research Centre of NAS of Belarus, P. Brovki str. 19, 220072 Minsk, Belarus

Email: raeissi@smn.uio.no

The oxygen dimer (O_{2i}) in Si is widely believed to have a crucial role in the formation of the recombination center responsible for the light-induced degradation of n^+p solar cells.¹ “staggered” and “ring” configurations with rather different migration abilities are predicted to exist for O_{2i} .² Evolution of O_{2i} with heat-treatment at different temperatures in the range 300-470 °C for n-type Czochralski grown silicon samples (resistivity $\sim 50 \Omega\text{-cm}$, oxygen and carbon concentrations $\sim (1.1\text{-}1.3) \cdot 10^{18} \text{ cm}^{-3}$ and $\leq 5 \cdot 10^{15} \text{ cm}^{-3}$, respectively) has been studied using Fourier Transform Infrared (FTIR) Spectroscopy. The samples were enriched with dimers due to a pre-irradiation with 2.5 MeV electrons at 350 °C.³ The intensities of the dimer-related vibrational bands at about 555, 1012, and 1060 cm^{-1} were investigated to study the evolution of O_{2i} upon heat-treatment and the O_{2i} diffusion characteristics. Additionally, developments of vacancy-oxygen-related radiation-induced defects (V_nO_m) and thermal double donors (TDDs) were monitored by FTIR (Fig. 1) measurements at low and room temperatures. The dimer kinetics was analyzed taking into account two main processes: a) the O_{2i} transformation into more complex defects like oxygen trimers, VO_4 and TDDs; b) the O_{2i} dissociation. An analysis of the data obtained has allowed determining the activation energies for the oxygen dimer migration and dissociation.

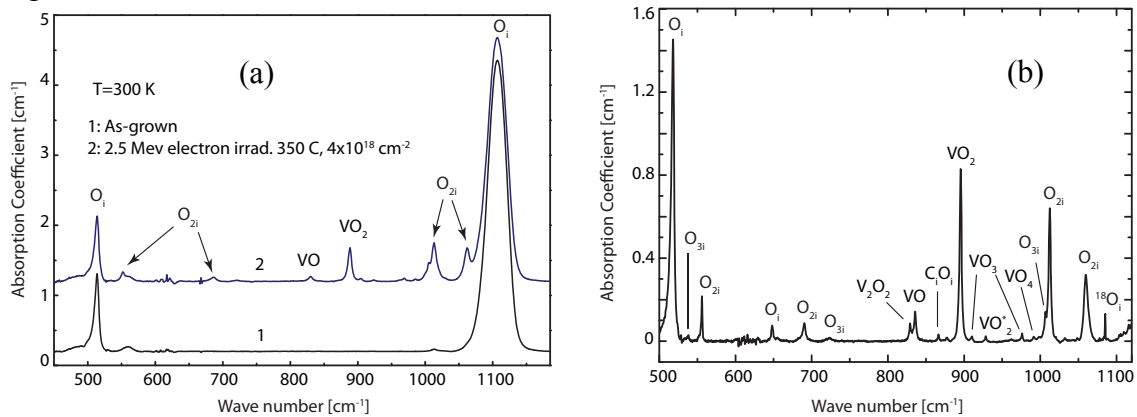


Figure 1. IR absorption spectra for a n-type CZ-Si sample (a) at 300 K before and after irradiation, 50 $\Omega\text{-cm}$ resistivity, $[O_i] = 1.3 \times 10^{18} \text{ cm}^{-3}$, $[C_s] < 5 \times 10^{15} \text{ cm}^{-3}$. (b) at 20 K after irradiation.

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Impurity Band Conduction in the Thermoelectric Material ZnSb

X. Song, O. B.Karlsen, J. Taftø, M. Böttger, T. G. Finstad

Department of Physics, University of Oslo, PO Box 1048, Blindern, Oslo 0316 Norway

Email: tgf@fys.uio.no

We report on low temperature electrical transport measurement in the semiconductor ZnSb. We have prepared bulk polycrystalline samples by melting, cooling and annealing in evacuated tubes, crushing into powder and hotpressing into pellets. This is one possible production technique for these materials for thermoelectrical elements. ZnSb is favorable from an environmental and global resource point of view. The related compound Zn_4Sb_3 of course also share these benefits. The latter also benefit from very favourable efficiency, which is mostly due to exceptionally low thermal conductivity and probably connected to a complicated unit cell and defect structure. The same phenomena may also be underlying the less favourable thermal stability of the material. ZnSb should not be bypassed because its earlier lower efficiency can be improved by reducing thermal conductivity by nanostructuring and the doping could be optimized. These tasks may require a better understanding of the material and particular the interplay between preparation techniques and material properties.

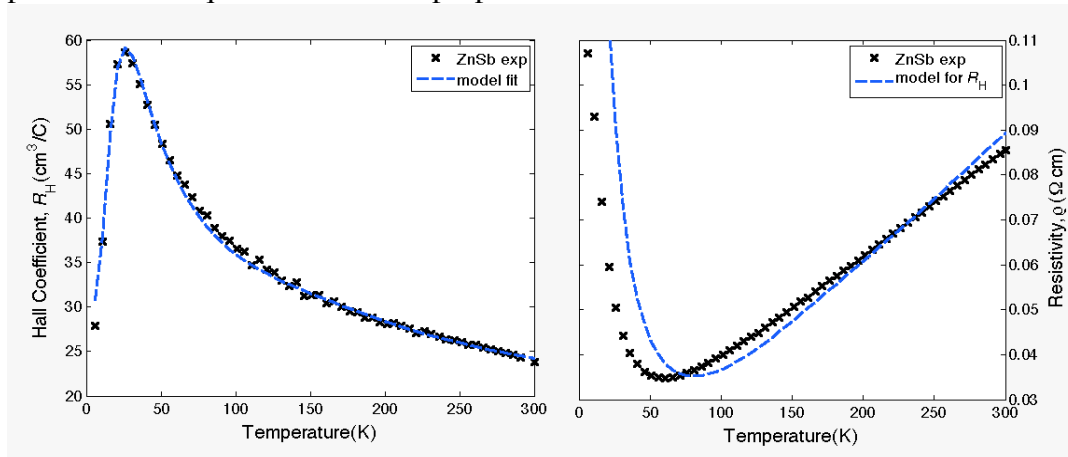


Figure 1. Hall coefficient(left) and resistivity(right).

The Hall coefficient, resistivity and magnetoresistance have been measured from 6K-RT. The data have been interpreted in terms of hole impurity band conduction; intrinsic acceptor defects creating bands which conducts when there are also compensating donors. Modeling of the transport using known scattering models give a qualitative good agreement but not a quantitative. We suspect the underlying models are incomplete or have uncertain parameters. The systematics of adding different amounts of Mn and Cr have been studied. Generally more acceptors are incorporated by both these elements, giving higher hole concentration both at low temperatures in impurity bands and at high temperatures in the valence bands, consistent with Seebeck measurements. The structure of the samples have been studied by XRD, SEM and electron microprobe identifying the compound ZnSb and with addition of Cr and Mn precipitated intermetallics and Sb.

Tuesday 21 June 2011
Oral program

Vacancies, divacancies and vacancy clusters in irradiated Germanium

J. Slotte¹, K. Kuitunen¹, S. Kilpeläinen¹, F. Tuomisto¹, I. Capan², A. N. Larsen³ and J. Räisänen⁴

¹Department of Applied Physics, Aalto University, P.O. Box 11100, FI-00076 AALTO, Finland

²Rudjer Boskovic Institute, 10~000 Zagreb, Croatia

³Department of Physics and Astronomy, Aarhus University, Ny Munkegade 120, DK-8000 Århus C, Denmark

⁴Department of Physics, University of Helsinki, P.O. Box 64, FI-00014 Helsinki, Finland

Germanium as an elemental semiconductor has been shadowed by silicon when it comes to the use of semiconductor materials in integrated circuits and devices. The supreme properties of silicon include a larger band gap, a stable oxide and an extremely low surface state density. However, electron and hole mobilities are much higher in germanium than in silicon, which has led to the use of strained Si_{1-x}Ge_x heterostructures to increase mobility in modern transistors. Even higher charge carrier mobilities could be pursued, if transistors were built out of germanium. Hence, a renewed interest in germanium research has been sparked in recent years.

In this presentation, we report on our recent work on proton and neutron irradiated germanium.

Weakly *n*-type germanium was irradiated with protons up to a fluence of $3 \times 10^{14} \text{ cm}^{-2}$ at 35 K and 100 K in a unique experimental setup. Positron annihilation measurements showed a defect lifetime component of 272 ps at 35 K in *in situ* positron lifetime measurements after irradiation at 100 K. This component was identified as the positron lifetime in a germanium monovacancy. Annealing experiments in the temperature interval 35-300 K revealed two annealing stages. The first at 100 K was tentatively associated with the annealing of the Frenkel pair, the second at 200 K with the annealing of the monovacancy. Above 200 K it was observed that mobile neutral monovacancies formed divacancies, with a positron lifetime of 315 ps.

In the second study, neutron irradiated Sb-doped germanium samples were annealed at 473, 673 and 773 K for 30 min. The positron lifetime was measured as a function of temperature (30-295 K). A lifetime component of 330 ps with no temperature dependence was observed in as irradiated samples, identified as the positron lifetime in a neutral divacancy and indicating that the divacancy is stable at RT. Annealing at 673 K resulted in an increase in the average positron lifetime and in addition, the annealed samples further showed a larger lifetime component of 430 ps at RT, which is due to larger vacancy clusters. The average positron lifetime in the samples annealed at 473 had a definite temperature dependence, suggesting that the divacancies became negative as the crystal recovered and the Fermi level moved up wards in the band gap. Annealing at 673 K, reduces the average lifetime and intensity of the defect component at RT indicating that the vacancy clusters started to anneal. Negative divacancies were still present in the samples after this anneal. Annealing at 773 K is enough to remove all observable vacancy defects.

Comparative study of hydrogen related defects in n- and p-type silicon

H. Malmbekk^{1*}, L. Vines¹, E.V. Monakhov¹, B.G. Svensson¹

¹*University of Oslo, Physics Department/Center for Materials and Nanotechnology,
P.O. Box 1048 Blindern, N-0316 Oslo, Norway*

The interaction between hydrogen (H) and irradiation induced defects, in silicon (Si), has been studied by many authors, but no consensus is yet to be reached for the most abundant H-related deep-levels in n- and p-type Si. At the present time, there seems to be ample evidence supporting the assignment of an electron trap located at about $E_c-0.32\text{eV}$ as an acceptor level of the VOH-complex[1,2], but the reported donor level of VOH is yet to be established. Consensus is also lacking for the levels related to partially saturated divacancies.

In this study, we have investigated the interaction between hydrogen and irradiation induced defects in p- and n-type silicon in order to shed more light on the nature of the hydrogen related defects. Deep level transient spectroscopy (DLTS), as well as minority carrier transient spectroscopy (MCTS) have been applied for the defect characterization of H implanted p and n-type pn-junctions. The n-type samples reveal two hydrogen related majority carrier levels at $E_c-0.32\text{eV}$ and $E_c-0.36\text{eV}$, which both have been reported to originate from VOH-complexes[3], as well as a minority carrier trap at $E_v+0.28\text{eV}$ (E_c and E_v denote the conduction and valence band edge, respectively). These levels have also been observed in the p-type samples, supporting the notion that they are related to intrinsic defects, and not to the dopants. In p-type samples, the reported levels show a substantial increase after a 15 min anneal at 150°C , which is the temperature region where hydrogen is released from the boron-hydrogen complex, while in n-type the level at $E_c-0.32\text{eV}$ and $E_v+0.28\text{eV}$ is already present in as implanted samples. A detailed study of the hydrogen decoration of the implantation-induced deep level defects will be presented.

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* Corresponding author: email: helge.malmbekk@smn.uio.no

Impurity migration in bulk and thin film ZnO

L. Vines¹, R. Schifano¹, M. Schofield¹ and B.G. Svensson¹

¹Department of Physics/Centre for Materials Science and Nanotechnology, University of Oslo, P.O. Box 1048 Blindern, N-0316 Oslo, Norway

Email: lassevi@fys.uio.no

Understanding diffusion processes in zinc oxide (ZnO) are important for the realization of ZnO-based devices within photovoltaics and light emitting diodes. However, diffusion coefficients of well-known impurities scatter by several orders of magnitude in the literature, and a possible source for this discrepancy is the ion induced defects and surface boundaries affecting diffusion studies using ion implantation and in-diffusion, respectively. Moreover, only the concentration of Li, Na and possibly H, change after thermal treatments up to 1500°C in bulk ZnO, while the concentration of other typical impurities like Al, Mg, Si, Fe, Mn, and Ni remain constant. This indicates very stable impurity complexes and/or reflective surface boundaries preventing out-diffusion.

Here we report on a diffusion study where a 300nm thin film of ZnO have been deposited by magnetron sputtering on bulk hydrothermally grown ZnO and heat treated at temperatures ranging from 500 to 1200°C. The thin film on bulk ZnO have been utilized to reduce surface boundaries and ion induced defects in order to investigate the diffusivity of typical impurities in ZnO. Secondary ion mass spectrometry (SIMS) have been carried out to obtain impurity versus depth profiles around the homojunction. Fig. 1 shows the chemical profiles of Li, Mg, Al, and Si in as-deposited, 800 and 1200C annealed samples. In contrast to bulk samples, where the concentration of Li is known to decrease after ~1000°C, Fig. 1 shows that Li is mobile at considerably lower temperatures. In addition, diffusion of Mg is observed, indicating reflective boundaries in bulk ZnO. The diffusion of Li, Mg and other typical impurities will be discussed.

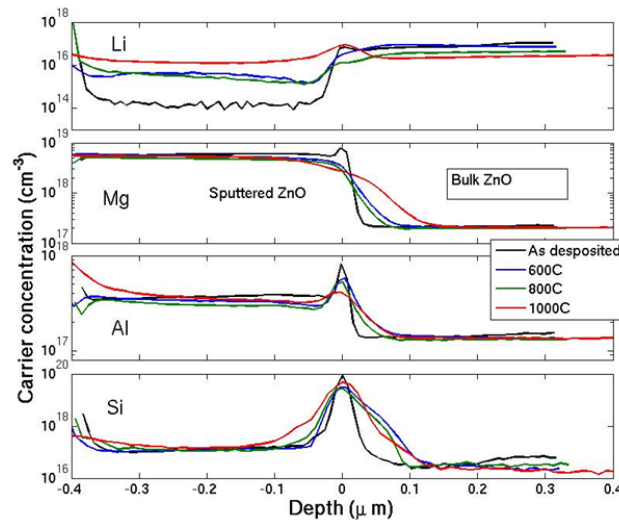


Figure 1: Concentration of Li, Mg, Al, and Si versus depth on a sputtered ZnO on bulk ZnO structure after thermal treatments up to 1000°C.

Modeling of plasmon-enhanced solar cells.

Thomas G. Pedersen, J. Jung, T. Søndergaard and K. Pedersen

Dept. of Physics and Nanotechnology, Aalborg University, DK-9220 Aalborg Øst, Denmark

A. Nylandsted Larsen

Dept. of Physics and Astronomy, Aarhus University, DK-8000 Aarhus C, Denmark

The cost of silicon solar cells would drop significantly if the thickness could be reduced into the few-micrometer regime. To maintain a reasonable efficiency, however, optical absorption in such thin layers must be optimized. This is challenging because of the intrinsically low IR/VIS absorption of silicon. One promising route to improved performance is via plasmon-enhanced absorption. By incorporating metal particles into the structure, sun light is scattered into new propagation directions favorable for absorption and, moreover, the enhanced near-field around the particles may be utilized. In this talk, various proposals for plasmon-enhanced thin-film solar cells are described. The tunability of plasmon resonances via choice of metal, shape, size and surroundings is discussed [1-3]. The angular profile of scattered light in a layered structure and the accompanying increased propagation distance is analyzed [4]. Finally, the possibility of directly increasing absorption through field-enhancement effects is critically examined.

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Novel light emitting and light controlled properties of ZnO nanostructures

V. Khranovskyy, M. Syväjärvi and R. Yakimova

Institute of Physics, Chemistry and Biology (IFM), Linköping University 58183 Linköping, Sweden

Email: volkh@ifm.liu.se

ZnO as a wide band gap semiconductor material (with $E_g = 3.3$ eV and $E_{BE} = 59$ meV at RT) is extremely prospective for optoelectronics and photonics due to the possible design of ultraviolet light emitting devices (UV LED) [1]. The nanostructures of ZnO undergo rapid growth of interest during the last decade, since nanostructures may relieve strain induced by allowing the material to relax and thus accommodate large lattice mismatches at heterointerfaces [2]. Moreover, the light extraction in nanostructured material may be enhanced due to a increased surface area and reduced reflection at the air/semiconductor interface; additional enhancements may be through photonic crystal effects in carefully arranged periodic arrays of nanostructures. Using of catalyst for the vapor-liquid-solid growth process results in degradation of the optical properties of ZnO nanostructures; therefore, it is important to grow high quality low sized ZnO nanostructures without additional contaminants. Here we present recent results on catalyst- and pattern- free growth of low sized ordered ZnO nanopillars/nanoneedles on Si substrates [3]. Light emitting and light mediated properties are reported.

The nanopillars (NPs) were of diameter ~ 35 nm and length ~ 150 nm. The growth evolution of the ZnO nanopillars, providing the $(0001)_{\text{NPs}}|| (0001)_{\text{ZnO grain}}|| (100)_{\text{Si surface}}$ epitaxial relationship is extensively studied by scanning and high resolution transmission microscopy. The approach of obtaining the low size ZnO 1D structures is explained in terms of selective homoepitaxial growth (SHG) via the crystallographic anisotropy of the seeding layer [3]. The grown ZnO NPs demonstrated advanced PL properties, which are related to their single crystalline nature within one pillar and most probably better stoichiometry and less contamination. Via applying the SHG technique, we obtained the assembly of ZnO nanoneedles. The grown nanostructures revealed that their wettability may be controlled by light: the UV irradiation with a $\lambda = 254$ nm changed the surface from superhydrophobic to superhydrophilic. The effect is related to the dissociative adsorption of water and oxygen on the defective states in ZnO surface. By the UV irradiation the hydrophobic behavior of ZnO nanostructures with a contact angle (CA) 124° can be changed into superhydrophilic state (CA $< 5^\circ$). The time of hydrophobic – hydrophilic transition was found to be dependent on the nanoneedles diameter: the fastest change of CA from 124 to CA $< 5^\circ$ was ≈ 5 min. Such an enhanced tunable wettability is due to the highly developed surface area and low needles diameters. The surfaces with controllable wettability are highly desirable, particularly for the effective control of micro or nano-fluid motion and respectively, enabling patterning the hydrophilicity/hydrophobicity with photolithography.

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Semiconductor Nanowire Based Solar Cells- A Nordic Top-level Research Initiative

Helge Weman

¹Department of Electronics and Telecommunications,
Norwegian University of Science and Technology (NTNU),
NO-7491 Trondheim, Norway.
Email: helge.wemanl@iet.ntnu.no

I will describe the goals and some initial results obtained in the Nordic consortium “NaNordSun” financed by the “Top-Level Research Initiative” program of the Nordic Innovation Center <http://www.nordicinnovation.org/> during 2010-2013.

The consortium targets research and development of radial p-n junction III-V semiconductor nanowire solar cells. The advantage of a radial p-n junction nanowire is that electrons and holes only have to move across a very short distance to reach the contacts. Good optical absorption is achieved since the light is mainly absorbed along the direction of the nanowire. The ability to collect carriers and light orthogonally is a unique feature of a radial p-n junction nanowire.

The nanowires are fabricated using bottom-up, catalyst-assisted and catalyst-free growth, as well as top-down methods. Processing of full nanowire solar cell arrays will be made, including the design of passivation layers and transparent contacts. Non III-V substrate growth as well as substrate-free methods will be tried out in order to find a substantial low cost advantage. The design of the solar cells will be accompanied by modeling of the nanowires unique light harvesting and anti-reflecting properties.

The objective is to find the most energy efficient nanowire solar cell with an optimum design solution for low cost.

Participants of NaNordSun:

H. Weman (project leader), NTNU, Norway.
L. Samuelson, Lund University, Sweden.
H. Lipsanen, Aalto University, Finland.
S. Anand, KTH, Sweden.
M. Magnusson, Sol Voltaics AB, Sweden.
B. Heidari, Obducat AB, Sweden.

Fluorescent SiC as new material for white LEDs

M. Syväjärvi¹

¹ Department of Physics, Chemistry and Biology, Linköping University, Linköping, Sweden
Email: mikael.syvajarvi@ifm.liu.se

Energy efficient lighting solutions will be a key figure in our homes, offices and industrial facilities. The transitional change from the light bulb to the white LED as lighting source will create new challenges in meeting users' demands while developing an environmental solution. A fluorescent material with such white LED solution is developed in a Northern European network [1] for an emerging white LED technology based on Silicon Carbide which has the possibility to adapt the color tone. The network is including cross-disciplinary fields ranging from materials, societal studies of new lighting and engineering energy savings in the society [2].

Recently it was shown that SiC can be an extremely efficient light emitting material [3]. The light properties can be tailored to produce a white LED for general lighting purpose by one or two layers doped with (i) Nitrogen and Boron, (ii) Nitrogen and Aluminium [4]. A warm white LED can be produced by the first layer while adding the second layer makes the light pure white. The efficiency of the light recombination is critically dependent on the growth method since defects will result in a decreased optical efficiency in the material for the white LED. We have applied a novel method to produce the material, the Fast Sublimation Growth Process [5] in which thick doped layers may be grown to produce a voluminous medium from which the dopants act to produce a donor to acceptor pair recombination mechanism. In this paper we evidence an enhancement of the room temperature photoluminescence by precise control of the dopant ratio. This opens an opportunity to explore new findings in the new materials energy research for new technologies.

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Passivation of interface traps at the SiO₂/4H-SiC interface by alkali ions

Pétur Gordon Hermannsson and Einar Ö. Sveinbjörnsson

Science Institute, University of Iceland, IS-107 Reykjavík, Iceland

Silicon carbide (4H) metal-oxide-semiconductor field effect transistors (MOSFETs) are predicted to outperform Si MOSFETs for high voltage high power applications. However, the main obstacle towards production of such devices has been poor quality of the SiO₂/4H-SiC interface due to a large density of electron traps. These traps are responsible for low inversion channel mobility in devices and thereby low transconductance. This has thus far limited the output power to a fraction of the predicted one. Recently SiC MOSFETs with a blocking voltage of 1200 V became commercially available but the operation gate voltage remains high and the transconductance is moderate [1]. The gate oxide in these devices is made by oxidation or post-oxidation anneal of 4H-SiC in NO or N₂O. There is still need for a further improvement of the SiO₂/4H-SiC interface. Of all the methods tested for making gate oxides on 4H-SiC, oxidation in the presence of sodium provides MOSFETs with record breaking inversion channel mobilities and two to three times more current output for a given device area than other methods [2]. However, the sodium ions are highly mobile within the gate oxide already at room temperature which makes such devices impractical. The mechanism responsible for the reduction in the density of interface traps in the presence of sodium is of interest and such information could aid in finding a more viable solution to this interface problem.

In this work we investigate the passivation of interface traps after oxidation of Si face 4H-SiC in the presence of potassium. A strong reduction in the density of interface traps, with energy levels near the SiC conduction band edge, at the SiO₂/4H-SiC interface is observed after dry oxidation in the presence of potassium [3]. These observations are similar to previously published work on oxidation of 4H-SiC in the presence of sodium [4]. In this work we examine the thermal stability of the passivation process after K-assisted oxidation. It is observed that if potassium ions residing at the SiO₂/SiC interface are moved towards the sample surface by exposing them to UV light under an applied depletion bias stress at high temperatures (> 520 K) the interface traps become visible again and are evidently depassivated. These findings are in line with recently published model of the effect of sodium on interface states [5]. The study predicts that sodium induces shallow donor states in the SiC close to the interface in which the electrons reside rather than becoming trapped in interface states. Then if the sodium ions are moved away from the interface the shallow donor states vanish and electrons are again trapped in the interface states. This behavior has not yet been clearly observed experimentally for sodium.

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Position dependent traps investigation in 4H-SiC bipolar junction transistors

Muhammad Usman^{a,1}, Muhammad Nawaz^b, Anders Hallén^a

^aRoyal Institute of Technology, ICT, Electrum 229, 16440 Kista, Sweden

^bUniversity Graduate Centre (UNIK), P.O.Box 70, N-2027 Kjeller, Norway

¹Contact author, email: musman@kth.se

Silicon Carbide material has attracted substantial attention during the last few years as a promising candidate for making power devices for high temperature operation and under harsh environments, i.e., applications at high radiation levels. To produce reliable power devices from SiC material, availability of defects free material is critical for utilization of this material up to its theoretical limits. While a significant improvement has been made recently in obtaining high quality SiC material, a number of manufacturing processes, such as deep reactive ion etching, ion implantation for the base contact, junction termination implant and high temperature annealing can induce defects that negatively affect the device performance. Moreover, a thick epi-layer (e.g. sub-collector drift region) is required to achieve high blocking voltage from SiC devices and defect free growth process presents another limitation to high quality thick SiC layers. Furthermore, the defects are also introduced during device operation in radiation rich environments [1].

It is the purpose of this work to theoretically investigate and quantify the effect of such defects located at different positions in a SiC bipolar junction transistor (BJT). We specifically study defect layers at different depths from the base-emitter region, in the base and underneath the base inside the collector. The paper presents a systematic theoretical investigation using the two-dimensional numerical computer aided design tool (TCAD: Sentaurus). The model of the device has been calibrated using experimental results from a recent study [2]. Trap concentrations ranging from $1 - 9 \times 10^{15} \text{ cm}^{-3}$ with 1×10^{-14} , 1×10^{-15} and $1 \times 10^{-16} \text{ cm}^2$ electron and hole capture cross sections are used. The device IV, leakage current and Gummel plots are then extracted for trap regions placed at different depths below the top surface. The results are discussed in relation to measured values of capture cross sections and trap concentration distributions resulting from ion implantation, as well as in relation to measured degradation of the electrical device performance.

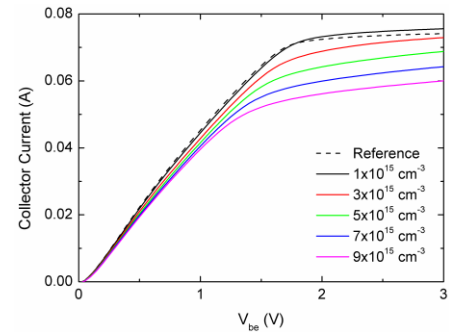


Figure 1: Simulated IV characteristics of a SiC BJT at different trap concentrations in the collector.

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Oral program

Sensors everywhere: An Electronic Patch

E. V. Thomsen, K. Birkelund

Department of Micro- and Nanotechnology, Technical University of Denmark, DTU Nanotech, Building 345 East, DK-2800 Kongens Lyngby, Denmark

Currently the field of distributed sensing is receiving a lot of attention. In this field sensors and wireless nodes are coupled into networks allowing measured data to be distributed and transmitted. Often, these systems need to have a low power consumption and are typically powered by batteries or by an energy harvesting device.

One such system is the Electronic Patch. The objective of the Electronic Patch project is to develop a new patient monitoring device where sensors and electronic is integrated into a sticking patch. In the Electronic Patch research is oriented towards design, clean room fabrication and integration of silicon based sensors for non-invasive measurement of physiological parameters. The Electronic Patch can measure heart beat rate and arterial oxygen saturation by pulse oximetry and measurements of other parameters like cardiac output, and blood pressure are investigated.



Figure 1. Silicon photodiode mounted on a printed circuit board. The photodiode has a hole in the center where two LED's are mounted..

The project relies on a strong collaboration between academic, industrial, and health care partners. In this multidisciplinary environment between physicists, electronic engineers, and medical doctors a new technological platform is innovated: Low-power sensors, electronics, and radio communication is integrated into an advanced adhesive material creating an “Electronic Patch”. It allows for continuous long term monitoring of chronic diseases in a discrete and comfortable way.

In conclusion, the Electronic Patch enables a new way of thinking about patient monitoring, personal health care, and health care infrastructure. The Electronic Patch has the potential to work in a body sensor network, passing information via gateways to central databases, intensive care units, and electronic patient journals.

High Power Impulse Magnetron Sputtering of TiN and TiO₂

S. Ólafsson¹, F. Magnus¹, B. Agnarsson¹, A. S. Ingason^{1,2}, K. Leosson¹ and J. T. Gudmundsson¹

¹Science Institute, University of Iceland, Dunhaga 3, IS-107, Reykjavik, Iceland

²Thin Film Physics, Department of Physics (IFM), Linköping University, Linköping SE-581 83, Sweden

High power impulse magnetron sputtering (HiPIMS) is a novel ionized physical vapor deposition (IPVD) technique that has shown great promise in materials processing [1]. By pulsing the target to a high power density with short unipolar voltage pulses at a low frequency and low duty cycle, a high electron density is achieved which leads to a high ionization fraction of the sputtered vapor.

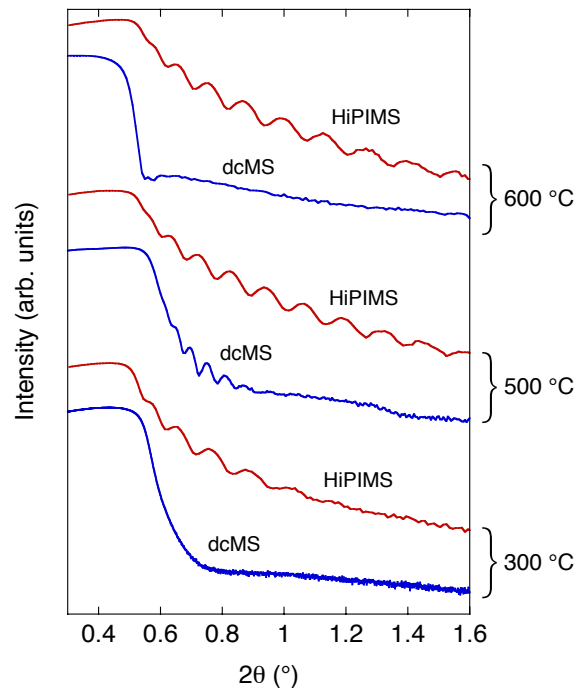


Figure 1. XRR spectra for TiO₂ films grown with dc sputtering and HiPIMS.

TiN and TiO₂ are important materials in the semiconductor industry due to their electrical properties. Here we report on the growth of TiN and TiO₂ on Si substrates using dc sputtering and HiPIMS in the temperature range of RT-700°C. The merits of HiPIMS over dc sputtering will be explored and quantified.

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Micro Hall effect - an emerging semiconductor metrology

D.H. Petersen¹, O. Hansen^{1,2}, F. Wang¹, F.W. Østerberg¹, H.H. Henrichsen¹,
P. Bøggild¹, R. Lin³, P.F. Nielsen³, T. Clarysse⁴, E. Rosseel⁴, W. Vandervorst^{4,5}

¹DTU Nanotech - Dept. of Micro and Nanotechnology, Technical University of Denmark,
building 345 East, DK-2800 Kgs. Lyngby, Denmark

²CINF - Centre for Individual Nanoparticle Functionality, Technical University of Denmark,
building 345 East, DK-2800 Kgs. Lyngby, Denmark

³CAPRES A/S, Scion-DTU, building 373, DK-2800 Kgs. Lyngby, Denmark

⁴IMEC, Kapeldreef 75, B-3001 Leuven, Belgium

⁵Inst. voor Kern- en Stralingsfysica, K. U. Leuven, Celestijnenlaan 200D B-3001 Leuven, Belgium
Email: dhpe@nanotech.dtu.dk

Driven by the aggressive scaling of semiconductor device dimensions, a small microprobe is presently entering semiconductor fabs worldwide for routine sheet resistance characterization of ultra-shallow junctions, since conventional metrology has become unreliable on ultra thin samples. In addition to sheet resistance measurements, recent development in micro four-point probe (M4PP) metrology now allow Hall effect measurements using the same M4PP with four equidistant collinear electrodes [1]. To extract the Hall resistance, the four electrodes are positioned parallel to an insulating boundary and the Hall resistance is measured as a resistance difference by configuration switching in a permanent magnetic field. Using a position error suppression method [2] and sample geometry correction [1,3], the carrier mobility and sheet carrier density can be measured in less than a minute with a standard deviation of <1% [2].

This review presentation covers the following topics: the micro Hall effect method, method validation (cf. Fig. 1 left), position error suppression method, sample geometry correction with conformal mapping theory (cf. Fig. 1 right), effect of sample non-uniformity, spatial sensitivity and vibration tolerant cantilever electrodes.

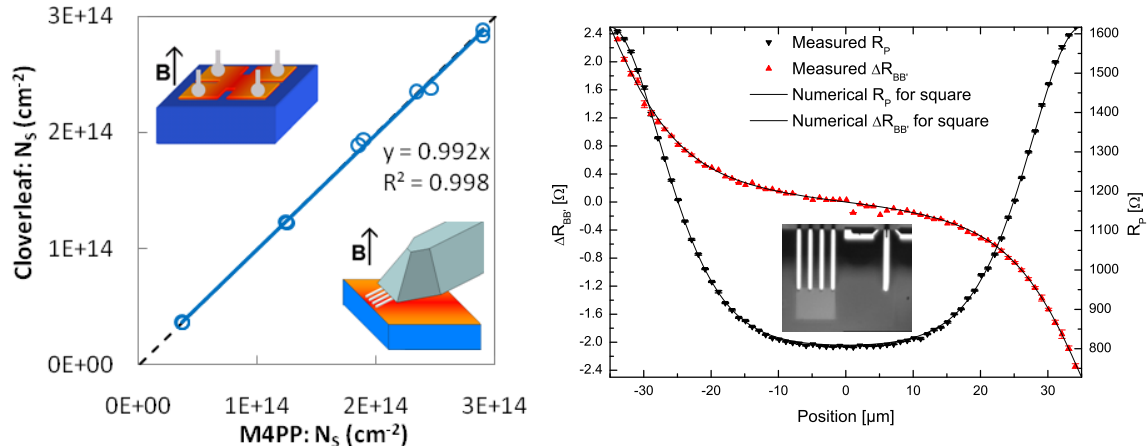


Figure 1. Hall effect measurements on laser annealed Si with ultra-shallow B implants. (left) Comparison of sheet carrier density measured using M4PP and cloverleaf patterned samples [4]. (right) Detailed Hall effect and four-point resistance scan on a $70 \times 70 \mu\text{m}^2$ test pad as illustrated in the insert [3].

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Group IV-based heterostructures for IR detection

H. H. Radamson, M. Kolahdouz and M. Östling

School of Information and Communication Technology, KTH, Royal Institute of Technology
Isafjordsg. 22-26, Electrum 229, 16640 Kista, Sweden

rad@kth.se

During recent years, single crystalline of composed group IV material has been recognized and employed as high performance thermistor material for infra-red (IR) detection in thermal detectors, specially in bolometers. The thermal detectors typically operate at room temperature. This class of detectors has modest sensitivity and temperature response but they are cheap and easy to use devices. This could be the reason that recently, they have attracted attention for both military and civil applications, specially for car industries. In bolometers, the thermistor material absorbs infrared radiation and changes the resistivity of these pixels which finally turns to an electric signal.

The figures-of-merit for high performance thermistor material are high signal-to-noise ratio and high thermal response which is expressed in Temperature Coefficient Resistance (TCR). The noise level in thermistors is mainly originated from the interactions between the carriers and defects or surface states of the thermistor material that is given by: $K_{1/f} = \gamma/N$, where N is the total number of free charges and γ is known as the Hooge's constant. The noise constant ($K_{1/f}$) is obtained by applying the line that best fits the decay part of the power spectral density curve. Today, commonly used thermistor materials such as vanadium oxide, amorphous, and polycrystalline semiconductors demonstrate moderate noise levels and TCR values around 2%–3% [1-2]. The recent studies have proposed single-crystalline (sc) SiGe as a thermistor material demonstrating a high signal-to-noise level [3-4]. This has been achieved by high epitaxial quality and smooth interfaces between the Si and SiGe layers. The simulations of the fully strained SiGe/Si quantum well structure indicate that the TCR performance can be improved to 6%–8% for 70%–100% Ge in sc-SiGe layers.

This study presents the effect of strain (Ge content), Ni-silicide in contacts and carbon-doping in SiGe/Si structures on thermal response and signal-to-noise ratio for high performance bolometer application.

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Characterization of donor-acceptor-pair emission in fluorescent 6H-SiC

Yiyu Ou¹*, Valdas Jokubavicius², Margareta Linnarsson³, Rositza Yakimova², Mikael Syväjärvi², and Haiyan Ou¹

¹Department of Photonics Engineering, Technical University of Denmark, DK-2800 Lyngby, Denmark

²Department of Physics, Chemistry and Biology, Linköping University, SE-58183, Linköping, Sweden

³School of Information and Communication Technology, Royal Institute of Technology, SE-16440, Kista, Sweden

*Email: yiyo@fotonik.dtu.dk

Boron (B)- and nitrogen (N)-codoped 6H-SiC epilayer exhibits strong donor to acceptor pair (DAP) band luminescence which makes it a promising candidate for the white light emitting diode (LED) [1]. To investigate the optimized dopant concentrations, five samples with the same B concentration level and varies N concentrations were grown by the fast sublimation growth process (FSGP) and analyzed by the photoluminescence (PL) and angle-resolved PL measurements. Secondary ion mass spectrometry (SIMS) and Raman spectroscopy confirm the increasing N concentration from sample #a to #e [2].

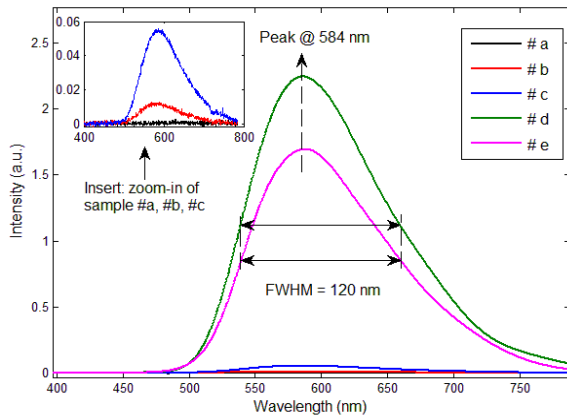


Figure 1. PL spectra of B-N-codoped 6H-SiC sample with emission angle of 0 degree (normal incidence, insert: zoom-in of sample #a, #b, #c).

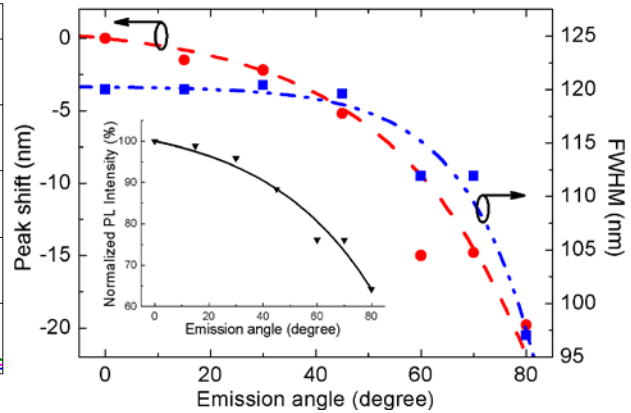


Figure 2. Variation of PL peak shift and FWHM with increasing emission angle in sample #d (Insert: change of normalized PL intensity).

The PL spectra are shown in Fig. 1. It is seen that high-level p-type sample (#a) exhibits extremely low DAP emission efficiency, while low-level p-type samples (#b, #c) have relatively stronger DAP emission but still at a low level. Intense DAP emission was observed in n-type samples (#d, #e) and the strongest DAP emission occurred in sample d with B and N concentration difference of $4.6 \times 10^{18} \text{ cm}^{-3}$. Despite the intensity difference, all the DAP emission spectra show the same peak wavelength at 584 nm and with a full width at half maximum (FWHM) of 120 nm. From Fig. 2, it is shown that the peak wavelength blue shifts with increasing emission angle in sample #d, and the FWHM starts to decrease and becomes more dramatic when the emission angle is larger than 45 degrees. Our results revealed that the optimized way to achieve intense DAP emission in B-N-doped 6H-SiC is to use low-level n-type doping with both B and N concentrations exceeding 10^{18} cm^{-3} . Also the their difference should be larger than $4 \times 10^{18} \text{ cm}^{-3}$.

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Microreactors for heterogenous catalysis

T. Pedersen¹, J. L. Olsen², P.C.K. Vesborg², I. Chorkendorff², O. Hansen^{1,2}

¹Department of Micro and Nanotechnology, Technical University of Denmark, Ørstedes Plads 345Ø, DK-2800 Kgs. Lyngby, Denmark

²CINF, Department of Physics, Technical University of Denmark, Fysikvej 312, DK-2800 Kgs. Lyngby, Denmark

Email: thomas.pedersen@nanotech.dtu.dk

In heterogenous catalysis discovery and optimization of catalysts require extensive and expensive testing. Traditionally such tests are carried out in macroscale chemical reactors. In recent years microfabricated reactors have shown great potential as an analytic tool for catalytic testing due to several advantages such as a high sensitivity and fast temperature response [1]. In this work we present a microfabricated reactor with an integrated heater element and temperature sensor. The reactor is fabricated using UV photolithography and Deep Reactive Ion Etch.

The microreactor chip is seen in Fig. 1. It consists of a channel system and a circular, central reactor chamber with a volume of 240 nL [2]. Gasses are fed into the inlet holes, the gas runs through the reactor chamber and out through a capillary outlet which is connected to a quadropole mass spectrometer. A suitable catalyst material is placed in the reactor chamber before the chamber is closed by bonding a pyrex lid to the chip.

As an example reaction we will look at photooxidation of CO on a P25 catalyst. Approximately 2.6 µg of catalyst is placed in the reactor chamber by a spin coating technique and a pyrex lid is bonded to the reactor. The reactor is illuminated by a 4 W Hg lamp and the evolution of CO₂ is monitored by measuring the mass 44 signal with the mass spectrometer. The recorded signal is seen in Fig. 2, it is clear that CO₂ is evolved when the catalyst is illuminated.

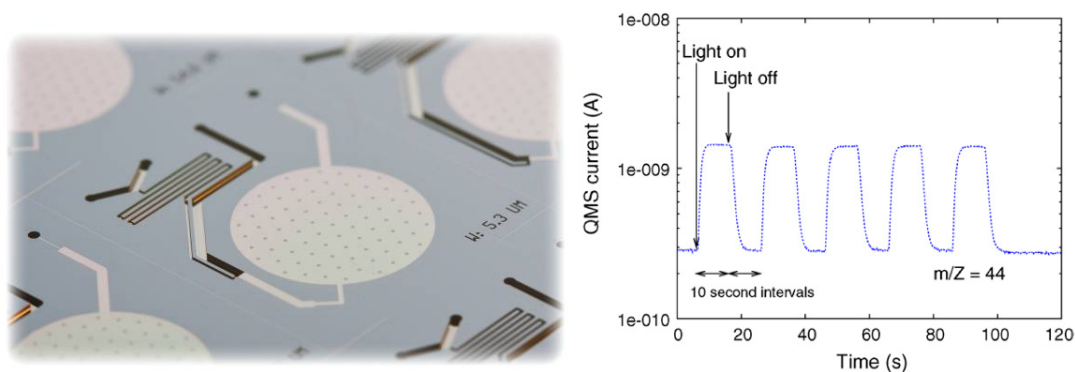


Figure 1. *Left:* Image showing the front side of the microreactor chip. The circular reactor area has a diameter of 10 mm and the depth of the reactor is just 3 µm. *Right:* Mass 44 signal recorded by the mass spectrometer as a function of time. It is clear that CO is oxidized to CO₂ when the catalyst is illuminated.

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