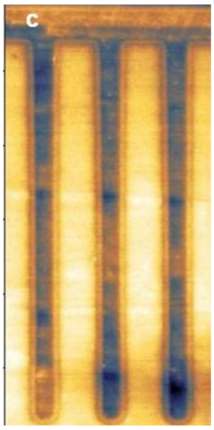

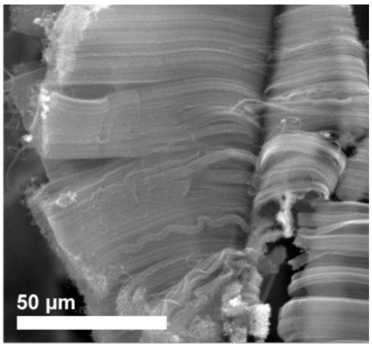

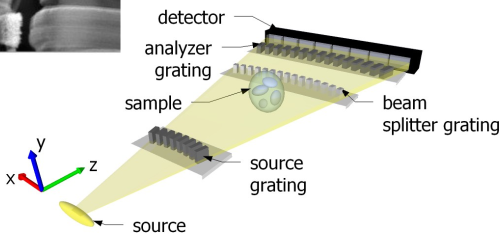

SLS Symposium on

Imaging

Tuesday, July 8, 2014

10:00 to 12:15, WBGB/019

10:00 Electronically active dopant profiling of power semiconductor structures by complementary Scanning Probe Microscopy (SPM) techniques
Harald R. Rossmann, U. Gysin, A. Bubendorf, T. Glatzel, H. Bartolf, T. A. Jung, and E. Meyer

10:30 Grating interferometry on a 160 kV lab source
Matteo Abis, T. Thüring, Z. Wang, C. David, and M. Stampanoni

11:00 Coffee

11:15 Fourier-Based Iterative Reconstruction Algorithms for Undersampled Tomographic Datasets of High-Pattern Complexity
Filippo Arcadu, M. Stampanoni, and F. Marone

11:45 Improved Fibre Strength of Carbon Fibres after CNT Growth by Application of Thin Alumina Interlayer
Samuel Vogel, C. Dransfeld, Ch. Schönenberger, M. Calame, and J. Gobrecht

Electronically active dopant profiling of power semiconductor structures by complementary Scanning Probe Microscopy (SPM) techniques

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Device functionality and performance of semiconductor devices strongly depend on the dopant profile, in particular on the spatial distribution of the dopant's electronic activity on the host material. In power electronics, the two main figures of merit are (i) a high blocking capability, which minimizes the reverse current in the OFF-state and (ii) a low ON-state resistance when the device is operated under forward conditions. In silicon technology the trade-off between these two quantities can be improved [1] by designs based on charge-compensated superjunction architectures at the cost of highly demanding manufacturing processes.

Due to the ongoing miniaturization, the lack of quantification or the nature of the underlying contrast mechanism, well-established dopant profiling techniques such as Scanning Resistance Probe (SRP), Scanning Electron Microscopy (SEM) or Secondary Ion Mass Spectroscopy (SIMS) proved unsuitable for precise monitoring the charge compensation during several epitaxial steps [2] and are challenged by low dopant concentrations. SPM derived methods however, which have been primarily used to provide complementary information, are able to assess electronically active dopant profiles even down into the low dopant concentration regime needed to control devices made from wide-band gap materials [3]. Nevertheless, quantitative dopant profile assessments are comparably challenging [4].

In this contribution we demonstrate that Kelvin Probe Force Microscopy (KPFM), Scanning Capacitance Force Microscopy (SCFM) and Scanning Spreading Resistance Microscopy (SSRM) can be used to assess dopant profiles in the low concentration regime. In our detailed study the three techniques are performed in the same measurement environment to map and quantitatively determine the electronically active dopant concentrations present at the surface region of the specimen. We show carrier distributions inside silicon trench structures mapped at high sensitivity and at concentrations as low as $7\cdot 10^{14}$ cm^{-3} [5]. Furthermore, first measurements on the wide-band gap material silicon carbide (SiC) will be presented.

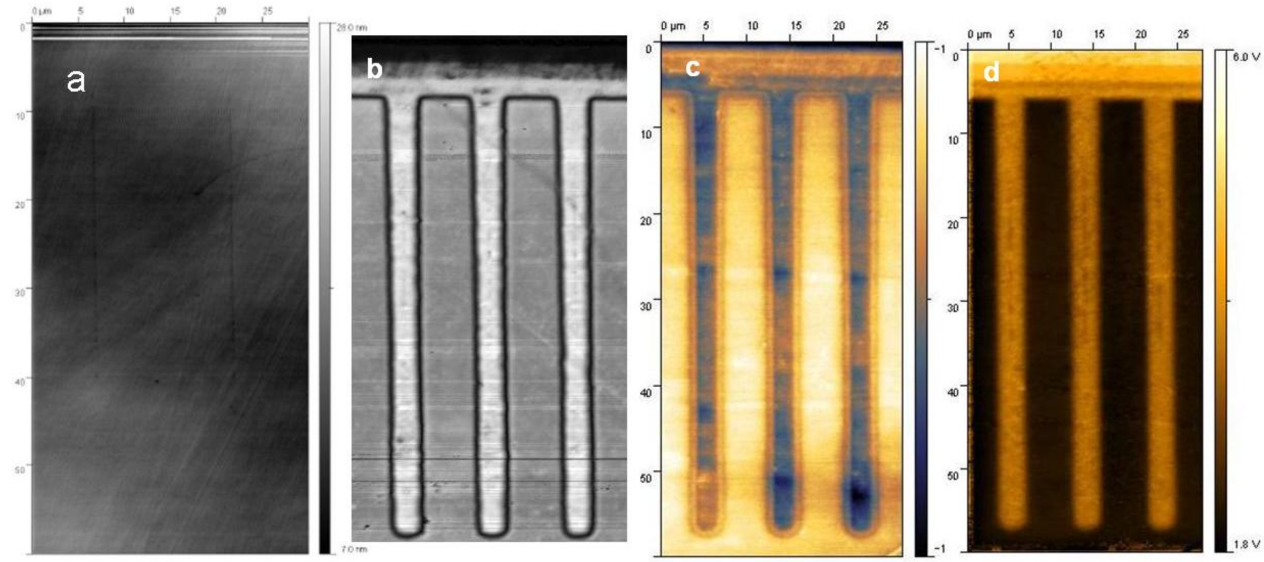

Fig. 1: The topographic signal (a) was simultaneously acquired with the SCFM (b) and KPFM (c) images. Since SSRM is a destructive technique the corresponding image (d) was taken at the end of each measurement series.

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Grating interferometry on a 160 kV lab source

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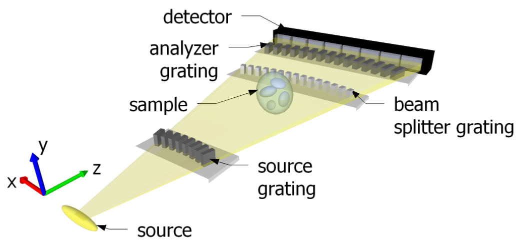
Grating interferometry is an imaging technique that allows the simultaneous retrieval of attenuation, phase and small angle scattering of X-rays. It was first demonstrated on synchrotron sources [1], then applied to conventional sources with a wide Bremsstrahlung spectrum and low spatial coherence [2].

Experiments on lab sources have been performed only for energies below 60 keV, while most applications in medicine and nondestructive testing require higher penetration power, with voltages above 100 kV. Absorption gratings suitable for high-energy interferometers would then need to be fabricated with a large thickness and a small pitch, in order to provide both enough blocking power and sensitivity. The necessary aspect ratios are thus outside of the reach of the most advanced microfabrication techniques.

In this presentation, an *edge-on* arrangement of the gratings is shown [3], where the gratings are not illuminated on the face but lay down in the beam plane, so that arbitrarily high aspect ratios can be achieved at the cost of one spatial dimension. With such an alignment, it is also easy to build curved structures that match the beam divergence on short setups.

The design of this kind of setup is shown, as well as the first images taken with two prototypes with a design energy of 100 and 120 keV realized at PSI [4]. The short length of the interferometer, under 60 cm, makes it also efficient from the point of view of the flux. The retrieval and meaning of the attenuation, differential phase and scattering signals is discussed, together with the possible applications available in this new energy range.



Edge-on arrangement for a high-energy interferometer.

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FOURIER-BASED ITERATIVE RECONSTRUCTION ALGORITHMS FOR UNDERSAMPLED TOMOGRAPHIC DATASETS OF HIGH-PATTERN COMPLEXITY

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ABSTRACT

The main problem in tomography is the reconstruction of an unknown image from its projections, acquired along a range of angles. In the usual practice, when the tomogram is sampled enough and with sufficient signal-to-noise ratio, Filtered Back-Projection (FBP) is used for the reconstruction, otherwise iterative algorithms are adopted.

Two Fourier methods are here presented as alternative ways to perform the forward and the backprojection operations, usually implemented in terms of Radon transform and its adjoint: the Regridding Method (GRIDREC) [1] and the Pseudo Polar Fourier Transform (PPFT) [2].

On one hand, GRIDREC is a fast algorithm which interpolates with an optimal kernel the Fourier samples of the projections, distributed in a polar grid, onto the two dimensional Fourier cartesian grid of the corresponding object. On the other hand, the PPFT is an application that maps an image into an oversampled Fourier grid defined "pseudo polar", because it shows properties of both a cartesian and a polar grid. These two approaches differ mainly in the fact, that GRIDREC performs interpolation in the Fourier domain, whereas the PPFT requires no approximation, but is tied to a precise constrained geometry.

The implementation of these two operators inside iterative reconstruction techniques [3], [4], [5], based on different functionals and different ways to exploit the a priori knowledge of the sample, is shown.

These iterative techniques are tested, in a first step, on phantoms showing increasing complexity, and, then, on real X-ray microtomography datasets [6], acquired at the TOMCAT beamline. An analysis framework, based on the combination of different metrics for image quality and fidelity assessment as well as for evaluation of the final achieved resolution, is also presented to determine the performance of the proposed iterative reconstruction algorithms in comparison with the standard FBP.

Finally, the advantages and disantavages of the presented algorithms are discussed in the context of the the future development of a Fourier-based iterative reconstruction algorithm capable of handling in a robust and efficient way undersampled tomographic datasets characterized by high structural content.

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IMPROVED FIBRE STRENGTH OF CARBON FIBRES AFTER CNT GROWTH BY APPLICATION OF THIN ALUMINA INTERLAYER

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The direct growth of CNTs on carbon fibres is a promising method to improve interfacial adhesion between fibre and matrix. However current approaches of CVD growth processes decrease the fibre strength remarkably. The application of a thin Alumina layer prior to CNT growth protects the carbon fibre from being attacked and the fibre strength is thereby preserved.

The growth of carbon nano tubes (CNTs) on high performance carbon fibres (CFs) provides means to substantially increase composite mechanical properties and bias thermal and electrical properties as well. The increased mechanical properties are attributed to the increased fibre matrix interphase surface and thereby increased fibre matrix adhesion. If radially aligned and overlapping with neighbouring CNTs, they may heavily increase the mechanical properties perpendicular to fibre direction. Furthermore, CNTs are reported to enhance composite toughness properties.

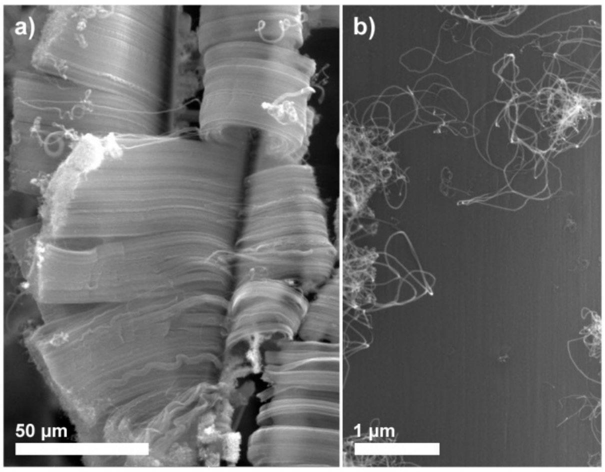

Figure 1: SEM images of CF after CNT growth: a) Long radially aligned CNT grown on Alumina coated CF, b) smooth Alumina surface after CNT removal

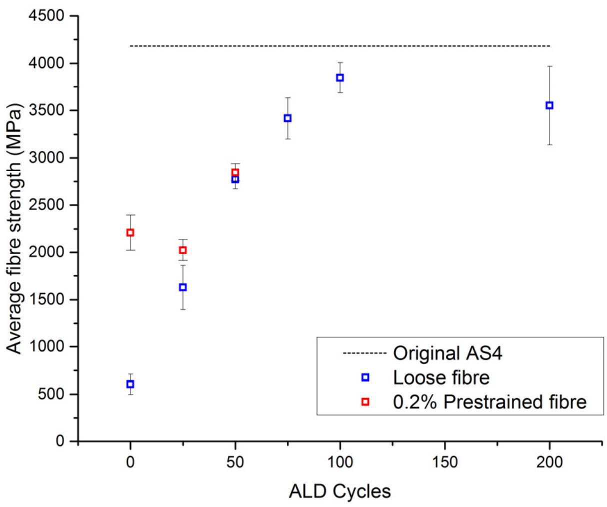

Figure 2: Protective effect of the applied Alumina layer thickness on the average fibre strength.

The common metal catalyst chemical vapour deposition (CVD) route to grow CNTs on CF degrades the tensile properties of the latter. This is attributed to oxidation of the fibre and second to etching of the CF surface caused by the metal catalyst [1].

Lachman et al. showed that ceramic fibre do not suffer any degradation during the CNT growth via the CVD route. In addition Alumina enhances the CNT growth in combination with iron catalyst particles [2]. However the high specific density of Alumina of 4g/cm3 and thereby reduced specific mechanical properties do not facilitate the application of such material for light weight composite applications i.e. aerospace construction or similar.

By applying a thin layer of Alumina around the carbon fibre, prior to the CVD processing, the advantages of the two materials can be combined. The thin layer around the CF provides protection from degradation during the CVD process, whereas the high specific mechanical properties of the CF can still be exploited. SEM images (Fig. 1 b) show a smooth surface of CNT grown CF after CNT removal, proving the protective abilities of the applied layer. Pretensioning the CF during CVD processing proved to be beneficial for the preservation of the tensile strength as well [3].

Single fibre tensile tests asses how well different Alumina layer thicknesses combined with different CNT growth parameters preserve the pristine CF mechanical properties. The strength distribution of the CF samples is approximated by a two parameter Weibull distribution. By doing so, the minimum layer thickness, preserving the initial CF tensile strength and thus providing the desired protection, is found to be 100 ALD cycles (i.e. roughly 10nm), as can be seen in Figure 2.

The effects of both the applied layer and the grown CNTs on the fibre-matrix adhesion are investigated by performing single fibre fragmentation tests (SFFT). In this method, one single fibre is embedded within a sample body of epoxy resin material. A tensile displacement is applied to the sample, leading to fractures in the single fibre (observable by cross polarised light) due to the lower strain to failure of the CF. At fracture saturation the fragment length is measured, whereby the interface properties can be calculated. To characterise the adhesion of the Alumina layer on the CF, SFFT are performed after application of the layer without any CNT growth processing.

Preliminary results show a good adhesion of the Alumina layer on the CF. However, both the opposite direction of thermal expansion of the combined materials and the crystallisation of the Alumina layer at the high processing temperatures during CVD, weaken the adherence of the protective layer on the CF. Increased Alumina application temperatures and low CVD processing temperatures can counteract these undesired effects.

After the single fibre fragmentation analysis, the specimens are tested to fracture. Thereby the embedded fibre is pulled out of the surrounding polymer matrix, revealing which layer interface (i CF-Alumina, ii Alumina-CNT, iii CNT-Matrix) is weakest.

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