KFM 4: Focus Session III: Diamond

This focus session is dedicated to the growth of single and polycrystalline diamond. Applications for the use of diamond in nuclear fusion reactors as microwave transmission system for high power mm-waves will be discussed. New Diamond-based kinetic inductance detectors are described as well. Defects in diamond and their influence to microwave properties are described.

Chair: Theo Scherer (KIT Karlsruhe)

Time: Tuesday 14:15–16:15 Location: H2

Invited Talk KFM 4.1 Tue 14:15 H2

Single crystal diamond growth by chemical vapor deposition for high-end applications: Recent trends and state of the art
— •Matthias Schreck and Theodor Grünwald — Institut für Physik, Universität Augsburg, 86135 Augsburg, GERMANY

In order to profit from diamond´s unique material properties for demanding device applications, wafer size single crystals are needed. Currently, two alternative concepts based on chemical vapor deposition (CVD) are being explored. Crystals grown by homoepitaxy on seeds from the high pressure method excel in structural quality but suffer from severe size limitations. In contrast, heteroepitaxy on iridium using the multilayer substrate Ir/YSZ/Si(001) has recently provided the first real wafer with a diameter of 92 mm (155 carat). While dislocation densities of $7 \times 10^6\ cm^{-2}$ and mosaic spread values of 0.03° (polar) and 0.05° (azimuthal) document significant progress, the defect structure is still inferior to homoepitaxial diamond. After reviewing the current state of the art, recent and new attempts for further reduction of the dislocation densities are described. These comprise different variants of epitaxial lateral overgrowth (ELO) and metal assisted termination (MAT). Next, the electronic properties of threading dislocations in heteroepitaxial diamond have been investigated. Experimentally derived lifetime values enable estimations of capture cross sections for electrons and holes. In the final part, a new smart-cut technique is presented that facilitates a duplication of large area diamond wafers removing the need for new nucleation and elaborate dislocation density reduction procedures to be applied for every new wafer.

Invited Talk KFM 4.2 Tue 14:45 H2

Development of diamond based kinetic inductance detectors
— •Francesco Mazzocchi, Dirk Strauss, and Theo Scherer — KIT IAM-AWP

Kinetic Inductance Detectors (KIDs) have proven themselves as a very versatile cryogenic detector technology capable of applications in various fields due to their flexibility of design, sensibility and ease of production. We have recently proposed a polarization sensitive Lumped Elements KID as sensor for an innovative polarimetric diagnostics based on quantum cascade lasers (QCL) for application in the nuclear fusion. Each detector unit is composed by 4 pixels arranged at the vertices of a square, each pixels being sensible to only one polarization direction. The current system is based on niobium nitride (NbN) superconductor over High Resistivity Silicon (HRSi) substrate. Such material delivers good performances but its relatively high dielectric constant and loss tangent lead to increased substrate losses. Using a transparent substrate may improve this aspect and also the radiation resistance of such devices. Diamond is the substrate of choice, being a material already widely studied and used in the fusion environment as high power microwave window, due to its outstanding optical and mechanical performances. In this work we present the preliminary design study for a diamond based Kinetic Inductance Detector and subsequent characterization measurements of the first prototypes.

KFM 4.3 Tue 15:15 H2

MPA CVD diamond in nuclear fusion: dielectric characterization and influence of defects
— •Gaetano Aiello, Theo Scherer, Andreas Meier, Sabine Schreck, and Dirk Strauss — Karlsruhe Institute of Technology, Institute for Applied Materials, D-76021 Karlsruhe, Germany

Microwave Plasma Assisted (MPA) Chemical Vapour Deposition (CVD) diamond is used as window material in the shape of a disk in the heating and diagnostic systems for fusion reactors due to its combination of extraordinary thermal, mechanical and optical properties. CVD diamond polycrystalline disks with central loss tangent lower than 2E-05 allow for transmission of high power microwave beams (1-2 MW). However, the effect on the dielectric losses in diamond of defects like dislocations and nitrogen-vacancy centers introduced by the growing process and/or by subsequent neutrons and gammas irradiation has not fully investigated and understood so far. Investigations by several spectroscopic methods on non-irradiated and irradiated diamond samples are thus planned. In particular, first Elastic Recoil Detection Analysis (ERDA) measurements of small diamond samples have been carried out at the Tandem Laboratory in Uppsala, Sweden, aiming to calculate the sample composition with major focus on nitrogen content. The nitrogen plays an important role in the CVD process as it allows faster growth rates, but it causes greater dielectric losses in diamond.

KFM 4.4 Tue 15:35 H2

Defect structures related to dielectric properties in diamond
— •Theo Scherer, Gaetano Aiello, Sabine Schreck, Andreas Meier, and Dirk Strauss — KIT Karlsruhe (IAM-AWP)

State of the art windows used in high power electron cyclotron heating and current drive systems for large fusion devices such as ITER consist of a disk which is aligned perpendicular to the millimetre wave beam propagation. As reflection have to be kept on a minimal level, the window thickness restricts the allowed frequencies to a limited set defined by multiples of half wavelengths in the dielectric matter. Actual loss tangent values are several 1E-6 for the best polycrystalline materials. For frequency tunable systems in fusion reactors, corresponding to the gyrotron development, BREWSTER windows must be realized, where the elliptic cut diamond disk is inclined under the BREWSTER angle in the waveguide structure.

KFM 4.5 Tue 15:55 H2

Photoconductive gain in single crystal diamond detectors used for dosimetry
— •Theodor Grünwald, Christina Bestele, and Matthias Schreck — Institut für Physik, Universität Augsburg, D-86135 Augsburg, Germany

Diamond crystals equipped with metal electrodes can be used for the detection of energetic radiation, i.e., x-rays, γ-rays and ionizing particles. Operated as solid state ionization chamber, single α-particles are completely stopped generating e-h pairs which can be collected with a maximum efficiency of $\sim 100\%$. When the same device is used as dosimeter in high intensity beams of energetic photons or particles, photoconductive gain G with values from < 1 to $> 10^6$ have been observed by various groups. This contribution analyzes first theoretically the irradiation induced conductivity of perfect diamond single crystals containing nitrogen and boron as electronically active defects. A system of coupled rate equations is formulated for the charging states of N and B, the concentration of electrons in the conduction band plus the neutrality condition. Analytical solutions are obtained for the gain as a function of the impurity concentrations, the detector thickness and the excitation density. The theoretical predictions cover the full range of experimentally derived values in literature. Photocurrent measurements on three series of heteroepitaxial samples grown under nearly identical conditions yielded G values ranging from < 1 to $> 10^4$. All the data are interpreted in terms of the measured absolute boron concentrations N_B and the potential concentrations N_N of nitrogen. In addition, the role of the dislocations as charge carrier traps is discussed.