KFM 8: Diamond and related dielectric materials

In this session the basics of NV-centers and other defects in diamond were presented. The influence to applications in different fields are obvious. So, there is an influence on dielectric properties of diamond, used e.g. in high power microwave components for fusion applications in the GHz to THz frequency range. Biological diamond applications and applications in quantum photonics are also considered in this field of diamond and related materials.

Chair: Prof. Dr. Theo A. Scherer (KIT Karlsruhe)

Time: Wednesday 14:00–17:15 Location: POT 51

KFM 8.1 Wed 14:00 POT 51

Optimal Control for Quantum Sensing with NV Centers in Diamond — •Matthias Müller — Forschungszentrum Jülich GmbH

Diamond based quantum technology is a fast emerging field with both scientific and technological importance. The performance relies on unique features like superposition and entanglement and depends on sophisticated mechanisms of control to perform the desired tasks. Quantum Optimal Control (QOC) has proven to be a powerful tool to accomplish this task. I will give a brief overview on the use of QOC for quantum sensing with NV centers in diamond and report on recent applications.

[1] P. Rembold et al., AVS Quantum Sci. 2, 024701 (2020) [2] M.M. Müller et al., Sci. Rep. 8, 14278 (2018) [3] N. Oshnik et al., Phys. Rev. A 106, 013107 (2022) [4] A. Marshall et al., arXiv:2112.15021 (2022)

KFM 8.2 Wed 14:20 POT 51

Influence of N defects on dielectric properties of diamond — •Theo Scherer — KIT Karlsruhe

Atomistic structures and elastic and dielectric properties including first simulations of loss tangent, tan δ of diamond with small nitrogen impurities can be calculated using the first principles methods. The effect of a single nitrogen substitutional atom on the Raman and IR absorbance spectra is analyzed and compared with other calculations. It is shown that nitrogen defects do not affect tan δ at far IR region used in diamond windows in fusion reactors for plasma heating and stabilization.

KFM 8.3 Wed 14:40 POT 51

Technical application of CVD Diamond windows in fusion reactor heating systems. — •Peter Späh — KIT, Institute for applied materials, Karlsruhe

The application of CVD diamond windows in fusion experiments often comes along with challenging design requirements. Diamond windows and associated components must be protected properly from harsh environmental conditions. This is particularly the case for the future demonstration power plant reactor (EU DEMO), where sensitive applications shall operate under severe conditions in terms of heat, mechanical loads and radiation.

For the EU DEMO, an EC Heating and Current Drive System (ECH&CD) is under development, where CVD diamond windows together with microwave reflectors (mitre-bends and mirrors), corrugated waveguides, waveguide switches, shutter valves and confinement barrier feed-throughs, will be precisely integrated into a millimetre wave power transmission system. The entire system is installed into massive launching components and reactor building structures. The design takes into account mechanical integrity, dissipation of heat by powerful cooling systems, radiation shielding and the capability to be serviced and maintained by remote handling procedures.

This talk presents the conceptual design and integration of the ECH&CD launching system into the EU DEMO fusion power plant.

KFM 8.4 Wed 15:00 POT 51

Fabrication and Characterization of Thin Single-Crystal Diamond Membranes for Quantum Photonics — •Julia Heupel[1], Maximillian Pallmann[2], Johann P. Reithmaier[1], David Hunger[2], and Cyril Popov[1] — [1]Institute of Nanostructure Technologies and Analytics (INA), University of Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany — [2]Physikalisches Institut, Karlsruher Institute für Technologie (KIT), Wolfgang-Gaede-Str.1, 76131 Karlsruhe, Germany

Due to its exceptional physical and chemical characteristics, single-crystal diamond (SCD) in a form of thin membranes is a promising material for the fabrication of high-quality photonic devices and for envisioned applications in quantum information technologies (QIT). In order to structure SCD membranes with a good quality and thickness of few micrometer or below, it is important to minimize defects originating from polishing (e.g., grooves and pits) or etching procedures (e.g., micro-masking effect). Here we report on the fabrication of thin SCD membranes, exhibiting a low surface roughness down to 0.2 nm by means of inductively coupled plasma reactive ion etching (ICP-RIE). A significant roughness reduction was achieved by using distinct Ar/Cl2 etching recipes as a planarization step before the actual structuring process. These planarized SCD membranes are successfully bonded via van der Waals forces on plane cavity mirrors and optically characterized in a fiber-based Fabry*Pérot microcavity regarding their mode structure and finesse.

KFM 8.5 Wed 15:20 POT 51

Enhanced protein immobilization by nanostructuring of UNCD surface — •Daniel Merker[1], Daniela Bertinetti[2], Rolf Merz[3], Michael Kopnarski[3], Friedrich W. Herberg[2], Johann P. Reithmaier[1], and Cyril Popov[1] — [1]Institute of Nanostructure Technologies and Analytics (INA), Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), University of Kassel, Germany — [2]Department of Biochemistry, CINSaT, University of Kassel, Germany — [3]Institut für Oberflächen- und Schichtanalytik GmbH, Kaiserslautern, Germany

Investigations of molecular mechanisms related to the formation of the inner clock require detection of coupling factors, e.g. secreted neuropeptides, that mediate synchronization. In this work we study the application of ultrananocrystalline diamond (UNCD) as biosensor for detection of such coupling factors. The crucial part is the feasibility of protein immobilization on UNCD surfaces. From all investigated coupling routs only photochemical attachment of alkenes gave acceptable results when the green fluorescent protein (GFP) was immobilized. A process to create nanostructures was developed to increase the effective surface for protein immobilization. Both functionalization and structuring have beneficial effects on immobilization performance, but especially in combination the immobilization efficacy increases significantly. Lastly, the immobilization of different binding proteins against GFP - antibodies, nanobodies, DARPins - was investigated, with the last two showing promising results for high specificity and affinity capture of target molecules in a future UNCD biosensor.

15 min. break

KFM 8.6 Wed 15:55 POT 51

Numerical analyses of CVD diamond windows in high power microwave applications — •Gaetano Aiello[1], Andreas Meier[1], Heinrich Peter Laqua[2], Theo Scherer[1], Sabine Schreck[1], and Dirk Strauss[1] — [1]Karlsruhe Institute of Technology, Institute for Applied Materials, 76021 Karlsruhe, Germany — [2]Max Planck Institute for Plasma Physics (IPP), 17491 Greifswald, Germany

Nuclear fusion reactors require electron cyclotron heating and current drive (EC H&CD) systems for plasma heating and stabilization. Chemical vapor deposition (CVD) polycrystalline diamond windows on both the torus and gyrotron sides of the reactors act as confinement and/or vacuum boundaries allowing the transmission of high-power microwave beams. For example, the beam power scenarios of 1.5 MW and 2 MW are the current targets considered respectively in Wendelstein 7-X and European DEMO fusion machines. In this work, with reference to both reactors, the numerical analyses required to verify the thermal and structural performance of the windows are discussed. Experimental measurements of loss tangent in diamond provided inputs for the numerical analyses. Sensitivity studies of the windows with respect to loss tangent and other parameters were also carried out to check the temperature reserve margins of the design.

KFM 8.7 Wed 16:15 POT 51

Simulation study of LC superconducting microresonators for diamond characterization — •Francesco Mazzocchi, Dirk Strauss, and Theo Scherer — Karlsruhe Institute of Technology KIT IAM-AWP, Eggenstein-Leopoldshafen, Germany

The development of high optical quality, ultra-low losses single crystal diamond windows is paramount for the realization of future nuclear fusion facilities like DEMO, given the foresaw increase in power of microwave ECRH systems. Precise determination of the dielectric characteristics (ϵr and tanδ) of these innovative materials have so far relied on techniques involving Fabry-Perot microwave open resonators in various configurations. High Q, superconducting thin film resonators can be effectively used to determine dielectric characteristics of extremely low losses materials like single- and poly-crystalline diamond. Their extremely high-quality factors allow for a substantial increase in resolution in the determination of these parameters when compared to state-of-the-art Fabry Perot open resonators. We hereby report a detailed simulation study of the chosen resonators configurations (Lumped Elements and Circular) that lead to the final design of the devices.

KFM 8.8 Wed 16:35 POT 51

CVD Diamond Disks for ITER ECH windows - dielectric loss characterization and optical inspection — •Sabine Schreck[1], Gaetano Aiello[1], Pablo Estebnez[2], Andreas Meier[1], Theo Scherer[1], Dirk Strauss[1], Christoph Wild[3], and Eckhard Woerner[3] — [1]Karlsruhe Institute of Technology, Institute for Applied Materials, 76021 Karlsruhe, Germany — [2]Fusion for Energy, 08019 Barcelona, Spain — [3]Diamond Materials, 79108 Freiburg, Germany

Diamond disks with a diameter of 70 mm and a thickness of 1.11 mm will be installed into windows of the Electron Cyclotron Heating and Current Drive System (EC-HCD) of the fusion reactor ITER. The bare disks, manufactured by a microwave plasma assisted chemical vapor deposition process, need to ensure high mechanical stability, thermal conductivity and transmission of MW-class microwave beams. Factory acceptance tests of the disks produced by Diamond Materials include a check of dimensional properties and a determination of its dielectric loss. The loss characterization and the comparison with the respective specifications is performed at KIT using dedicated Fabry-Perot resonators, that allow the measurement of the loss tangent at the disk centre and a mapping of it over the disk area. An optical inspection with a digital microscope completes the examination. More than 60 diamond disks need to be qualified prior to their integration into the window assemblies and the application in the ITER EC-system. The disk qualification activities are performed within a contract between F4E and KIT and the talk will present the current status.

KFM 8.9 Wed 16:55 POT 51

CVD Diamond Windows for Electron Cyclotron Resonant Heating in Fusion — •Dirk Strauss, Gaetano Aiello, Andreas Meier, Theo Scherer, and Sabine Schreck — aKarlsruhe Institute of Technology, Institute for Applied Materials, Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany

Electron cyclotron resonant heating (ECRH) in nuclear fusion combines the injection of multi megawatt power with the possibility to focus the millimeter wave beam to small spot sizes of few centimeters. The ECRH allows efficient plasma heating as well as localized current drive for magneto-hydrodynamic stabilization of e.g. neoclassical tearing modes that create local magnetic islands with a fast loss of plasma confinement. One of the key challenges for high power ECRH systems is the provision of suitable confinement windows.

The low loss tangent, high thermal conductivity and outstanding mechanical properties qualify diamond as the state of the art material for high power millimeter wave heating systems in nuclear fusion devices. Artificial diamond disks are grown by CVD in diameters up to 180mm, sufficient for the usual waveguide diameters.

The principles of ECRH systems will be presented with a focus on the permittivity of diamond, which determines the loss tangent and suitable disk thicknesses. Further concepts and status for small and broadband windows for frequencies of 100-240GHz and beam powers up to 2MW will be discussed.