Growth of Heteroepitaxial CVD Diamond Films on Ir/YSZ/Si(001) for Detector Applications: Scale-Up and Crystal Quality Improvement*

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In the framework of the "CARAT" collaboration, which executed work package 15 of the EU FP7 "HadronPhysics2" project, the diamond group at the University of Augsburg was responsible for the development and growth of heteroepitaxial diamond films, which shall be used in particular for tracking and ToF measurements of heavy ions and minimum ionising particles.

Motivation

For future particle accelerator experiments, e.g. at FAIR, we aimed at developing novel, advanced diamond sensors grown by chemical vapour deposition (CVD), capable of replacing the commonly used silicon tracking devices and being furthermore an advantageous alternative to polycrystalline or single-crystal diamond sensors used so far in beam diagnostics and timing applications.

During the reporting periods of 2010 and 2011, very promising α-particle and heavy ion tests were conducted at GSI, showing very high values of charge collection efficiency (> 95%) and excellent time resolution (< 20 ps) of our heteroepitaxial CVD diamond films grown on Ir/YSZ/Si(001). This encouraged the scale-up of the detector crystals to lateral dimensions beyond the reach of homoepitaxial diamond single crystals. More effort was made in order to characterise the heteroepitaxial material with respect to structural crystal quality, investigating especially the role of dislocations.

Scale-up

The growth of heteroepitaxial diamond films on the Ir/YSZ/Si(001) multilayer system by microwave plasma enhanced CVD was established at the University of Augsburg in 2004 [1]. A layer of YSZ (yttria-stabilised zirconia) is deposited on a 4-inch Si wafer by pulsed laser deposition. In a second step a film of Ir is deposited on top of the YSZ layer by electron beam evaporation.

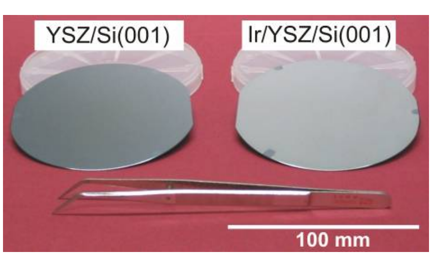

Figure 1: 4 inch silicon wafers after application of YSZ and iridium films.

The heteroepitaxial growth concept inherits the potential of being scaled up in order to synthesise wafer-size diamond films in the future [2]. At present, diamond nucleation and growth on large areas with high quality (i.e. esp. free of impurities and cracks) is still a huge challenge. Nevertheless, at the end of the "CARAT" project we were able to synthesise two large diamond crystals of 18 x 18 mm² lateral size (around four times the area of the largest available homoepitaxial diamond samples), one of which is shown in Fig. 2. The remaining dark spots on the sample originate from few non-epitaxial crystallites, which will be avoided in the future by further optimisation of the plasma growth parameters.

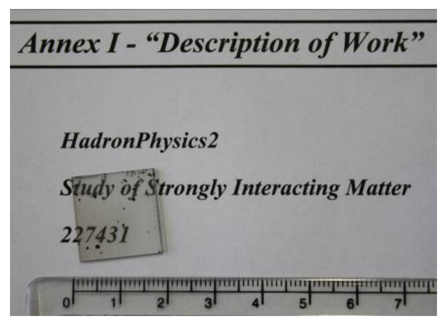

Figure 2: Large transparent heteroepitaxial diamond sample. Scale is in cm.

Crystal quality: the role of dislocations

So-called threading dislocations are the predominant crystal lattice defect in our heteroepitaxial films. Their density is assumed to decrease with larger film thickness. Indeed, the very high α-particle CCE values could only be achieved by using the upper part of a 1 mm thick diamond film for the detector. The quantitative evaluation of the dislocation density and the investigation of its evolution with increasing film thickness are in the focus of current work. First results have been obtained. This topic will be one of the main issues in the upcoming "ADAMAS" project, which is part of "HadronPhysics3" and will continue the collaboration between GSI and the University of Augsburg.

References

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[2] M. Fischer, S. Gsell, M. Schreck, R. Brescia, and B. Stritzker, Diamond & Related Materials 17 (2008) 1035.

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