Artificial Single-Crystal Diamond Detectors

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In High-Pressure High-Temperature processes, Single-Crystal Diamond (SC-HPHT-D) of hitherto unavailable large volume can now be synthesized. Samples of exceptionally good mosaic spread are obtained by controlled precipitation of carbon from solutions in molten metals and alloys (typically cobalt, iron, nickel) [1]. According to the presence and form of the major atomic-scale impurities, which is nitrogen and boron, diamond has been classified into four main types: Ia, Ib, IIa ,IIb. Stimulated and guided by Professor Friedel Sellschop, who has very unfortunately past away in last summer, we started to test HPHT diamond. We are striving on one hand for radiation-hard particle detectors suitable for time- and energy resolution, investigating on the other hand the suitability of the material for electronic devices.

In 2002, the work was focused on the investigation of Ib type material produced in Johannesburg. There are indications that this type of diamond has the best crystalline structure, although it contains hundreds of ppm nitrogen but in a single-substitutional form (P1 centres) only.

Three samples of a homogeneous transparent dark yellow color have been characterized.

1 Photoconductivity

In order to compare the defect-state concentrations, photo-conductivity measurements have been performed. In Figure 1 the Photo-Current (PC) obtained irradiating the samples with different lamps is plotted against the energy of the incident photons. The PC is normalized to the number of photons and to the thickness of the diamond probes.

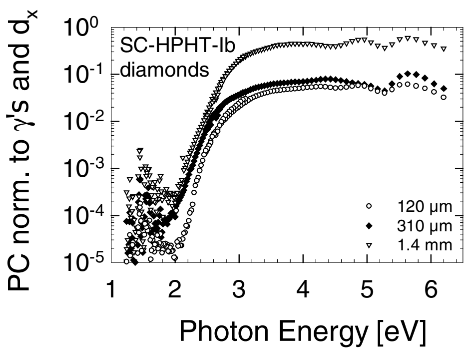

Figure 1: Normalized photoconductivity spectra. The PC saturates at a level corresponding to the nitrogen concentration.

The spectra are dominated by the onset of the well-known nitrogen-induced photo absorption at E = 1.7 eV [2]. The PC saturates according to the nitrogen content of each probe. The thickest sample shows the highest N_2 concentration.

2 I-U Characteristics

Intense and careful work has been spent to fabricate ohmic contacts and to study the influence of the contacts to the IU characteristics of HPHT-SC-Ib Diamond Detectors (DD). Different metal combinations (Cr-Au, Ti-Pt-Au, pure Al) and various evaporation protocols have been applied. The dark current measured at room temperature over a wide bias range is usually below 1 ns. The break-down field is comparable to that of PC-CVD-DD (PolyCrystalline CVD-DD) [3].

3 Charge Collection Properties

The Charge-Collection Efficiency (CCE) and the pulse-height resolution ($\Delta A/A$) have been studied with traversing electrons (^{90}Sr, E_e^{max} = 2.3 MeV), resp. with α particles of discrete energy (^{239}Pu, ^{241}Am, ^{246}Cm, 5.1 MeV < E_α < 5.8 MeV) with a range of 12 µm in diamond. The response to very heavy ions has been tested with ^{238}U of 380 MeV/amu.

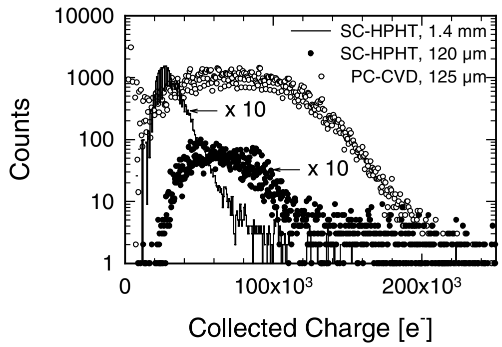

Figure 2: Mixed-nuclid-α-spectra measured with SC-HPHT- resp. with PC-CVD-DD. The data of the HPHT-DD are multi-plied by a factor of 10 for comparison on a same scale.

In Figure 2 α-spectra obtained from the HPHT-Ib-DD of 120 µm resp. 1.4 mm thickness are compared to an α-spectrum which has been measured with a PC-CVD-DD of 125 µm thickness. The pulse heights of the HPHT-DDs are multiplied by a factor of 10. The mean values correspond to a CCE of only 7.4%o for the HPHT-1.4 mm DD, 1.6% for the HPHT-120 µm DD and of 18.8% for the PC-CVD-DD. The pulse-height resolution is unexpected broad as for the PC-CVD-DDs, i.e. in the order of $\Delta A/A \geq 1.0$.

The investigations are not yet finished. However, the preliminary results indicate that the superior lattice quality of SC-HPHT-Ib does not mask the disadvantages of the N_2 impurities.

Outlook

A new Single-Crystal CVD diamond material is now available with a CCE of nearly 100% [4]. It is grown on 5x5mm² SC-HPHT-Ib diamond substrates. Novel techniques developed at Wits deliver large-area (1x1cm²) substrates with surfaces optimized for this purpose. Thefore, a substantial improvement of SC-CVD-DDs is expected in the near future.

References

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