Development of Heteroepitaxial Single-Crystal Diamond Sensors*

E. Berdermann[1], M. Ciobanu[1,2], M. S. Rahman[1,3], M. Träger[1], M. Fischer[4], S. Gsell[4], M. Schreck[4], and C. Stehl[4]*

[1]GSI, Darmstadt, Germany; [2]ISS, Bucharest, Romania; [3]Technical University and OncoRay, Dresden, Germany; [4]University of Augsburg, Augsburg, Germany

Recent CVD diamond (CVDD) samples grown by heteroepitaxy on 4-inch Ir/YSZ/Si001 substrates [1] showed for the first time a similar behaviour to that of homoepitaxial single-crystal diamond (SC) detectors. This improvement is attributed to the use of the upper part of a thick (~ 1mm) 'quasi single-crystal' Diamond-on-Iridium (DOI) plate for the detectors. We present the hole-drift characterization results obtained from a DOI sensor (DOI954, 290µm) grown in 2011 as well as the data of the best sample grown in 2010 (DOI886-2, 320µm). We compare the DOI characteristics to that of a commercial SC sensor (SC EBS-3, 393 µm) and to a polycrystalline (PC) sample (PC-PFX350, 350 µm).

The DOI sensors have been metallized with sandwich quadrant electrodes. The individual sectors showed similar results confirming a good area-homogeneity of the films. By applying the transient-current technique (TCT) with short-range α-particles we tested the homogeneity of the crystal structure, which controls the effective internal field. Figure 1 shows the TCT signals obtained. The applied electric field is noticed in V/µm. The triangular PC signals (blue lines) illustrate impressively the incomplete charge collection in PC sensors. Moreover, the increasing signal widths at increasing bias measured in the range 0.3 - 2.9 V/µm are in contradiction to the expected decreasing trend, as a consequence of the increase of the carrier drift velocity at higher fields. This behaviour is ideally demonstrated by the SC reference sample (inset, red pulses). The trapezoidal signal shapes obtained for every value of the electric field illustrate complete carrier drift at constant velocity in the absence of charge trapping (flat-top). In spite of the high CCE > 97% measured for the DOI 886-2 sensor [2], the width of the α-TCT signals was essentially independent of the electric field. We explain this behaviour by 'capture and release' of charge carriers by shallow traps. Their trapping time is supposed to be in the microsecond range, i.e. too slow for the DBA but within the shaping time constant of the charge-sensitive amplifiers used to measure the CCE. In contrast, the development of the signals recorded with the recent DOI 954 detector (black traces) reveals convincingly both features, the increase of the drift velocity and at E > 0.3 V/µm the arrival of the charge carriers to the opposite electrode. However, the slope of the 'flat-top' indicates significant charge trapping, which occurs most likely at residual crystal dislocations. A remaining puzzle is the observed improvement of the charge-drift and collection in case of differently biased neighbouring sectors (Fig. 1, dotted signal: Q1@1.4V/µm; Q2Q3Q4@1.0V/µm). This may be due to a discharge of a previously accumulated charge reservoir in the diamond-contact interface.

A rapid increase of the drift velocity at low fields (decreasing width of the TCT signals), causes a rapid increase of the CCE to high levels - as it is demonstrated in Figure 2 by the SC sensor (red dots, 99%) and by the recent DOI sample (black diamonds, 93%). The 2010 sample achieved even 97% but at higher fields, whereas the PC sensor (blue dots, - 20%) is simply worse and cannot be used for energy measurements. Interestingly, the energy resolution is improved for samples showing a 'steep' plateau but not the highest CCE. We measured (Fig. 3) 0.1% for SC-EBS3 (red), 1.8% for DOI954 (black) and 3.5% for DOI886-2 [2] (not shown here).

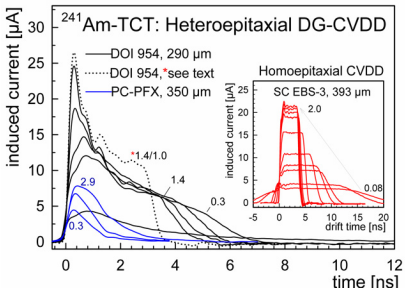

Figure 1: Averaged TCT signals at increasing field: DOI 954 (black); PC-PFX350 (blue); SC EBS-3 (red, inset).

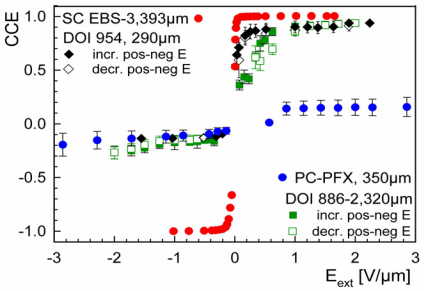

Figure 2: CCE at increasing electric field. (see text)

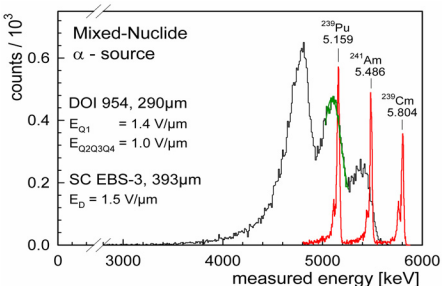

Figure 3: Mixed nuclide α-spectra of a recent DOI (black line) and of a SC diamond sensor (red line) compared.

References

[1] C. Stehl et al., GSI Annual Reports 2010, 2011.
[2] E. Berdermann et al., GSI Annual Report 2010

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