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| ESRF | **Experiment title:**<br>**The influence of lattice defects on voltage breakdown in single crystal CVD diamond detectors** | **Experiment number**:<br>MI 885 |
| **Beamline**:<br>ID21 | **Date of experiment**:<br>from: 22 May 2007 to: 26 May 2007 | **Date of report**:<br>04 Sept 2008 |
| **Shifts:**<br>9 | **Local contact(s)**:<br>Murielle Salomé | *Received at ESRF:* |

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## Report:

**Samples and Experimental method.** Electronic grade, CVD diamond crystals were provided by Element Six Ltd, Ascot UK, selected from previously measured samples and new samples delivered to the GSI under a development contract. These samples were in the form of flat plates 50 … 350m thick and surface processed with various techniques. Our intention was to first image these samples with plane wave Laue topography to identify and localize threading dislocations in the samples (beamtime was requested for this in the original proposal, but shifts allocated only at ID21). However, we were able to access limited in-house research time at ID19 (courtesy Dr. J Härtwig, ESRF) and make topographs of a few selected samples, but this was only possible after the ID21 experiment.

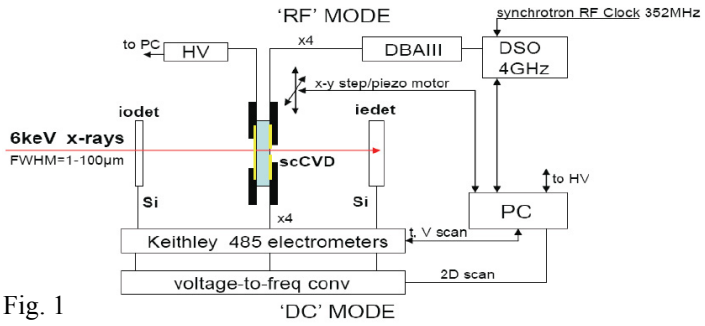


Fig. 1

To permit them to be operated as 'solid state ionization chambers' in the X-ray beam of ID21, all samples were contact metalized at the Target Laboratory of GSI Darmstadt. Each sample had four sputtered Al electrodes on one side, arranged as a quadrant detector, and a simple plane Al contact to the backside. The samples were mounted on special PCB boards at ESRF that were wired with electrical probes and which were mounted in the ID21 Scanning X-ray Microscope (SXM) scanning stage. A special vacuum feed-through flange was added to the SXM, this enabled sub-nA level current measurements to be made with the SXM under vacuum using electrometers. Diamond transient signal response measurements were made using 2.3GHz preamplifiers and a 50ps/sample digital storage oscilloscope (DSO) that was specially interfaced for this experiment to the SPEC beamline control environment (Fig. 1). A silicon diode with absolute X-ray calibration was inserted downstream of the diamond samples both to determine the beam flux and measurement of their X-ray absorption.

**Results.**

XBIC characteristics and image-maps were measured, varying the detector bias during the separate, individual irradiations of each of the diamond electrode quadrants. An incident X-ray flux ~4x10$^8$ photons/sec was used at 6.0keV. Two samples 100µm (SC8B) and 50µm (SC14B) thick that had ion-beam polished, near atomically flat surfaces, were found to be almost free of structural micro-defects, whereas a mechanically 'scaife' polished sample 300µm (s256-02-06) thick showed a high-density of structural defects. As shown in Fig. 2, the XBIC in the thin samples (red and blue curves) saturated at extremely low field of E=0.05 V/µm. Perfect operation stability was found for the sample SC14B up to a maximum applied field E=6V/µm. In contrast, the XBIC I-

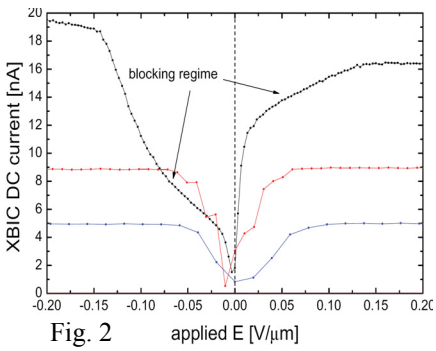


Fig. 2

V characteristics of S256-02-06 was highly asymmetric, showing unstable behaviour at negative bias, and with current increasing on a ~minute timescale reaching off scale values >200µA. Assuming the current plateaus shown in Fig. 2 correspond to complete, unity gain charge collection, the average energy needed for the creation of an e-h pair in the diamond was calculated from the absolute value of the incident X-ray beam flux, and the fraction of the beam intensity absorbed by the diamond sample, giving a value 13.05 ± 0.2 eV/e-h pair [1]

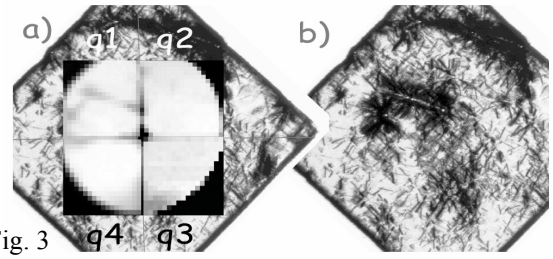

Fig. 3

In Fig. 3a the low resolution (50µ steps with a100µm unfocused beam) XBIC images of four quadrants electrodes (q1, q2, q3, q4) are 'overlaid' the on the Laue X-ray topograph (Fig. 3b) of the defective sample S256-02006. Regions of ~20% lower XBIC response (dark areas) are seen to correlate with the extended structural defects visible in the diffraction imaging, confirming charge-carrier trapping at the dislocation sites. Several other defective samples were mapped and the temporal evolution of defects recorded under various bias conditions. In this XBIC transmission mode of measurement, signal current consists of both electron and hole drift across the sample, so we were not able distinguish between electron and/or hole trapping. This would have been possible by lowering the ID21 beam energy to ~2keV (giving near surface X-ray absorption) and 'flipping' the bias polarity, but several hours are need to change the ID21 monochromator energy and refocus the beam etc, and this was considered prohibitive loss of available shift time. A high resolution (1µm step resolution with beam focused <1µm) XBIC map of the samples SC14B carried out at field 0.5µV/m is shown in Fig. 4. Near perfect homogeneity (σ =<0.3 %) of the XBIC response is found. The precision is limited by the beam intensity variations (using the ID21 $I_{odet}$ flux monitor to normalize beam intensity added noise at this level of precision, as shown by the increased σ value found for the vertical (slow) scan direction).

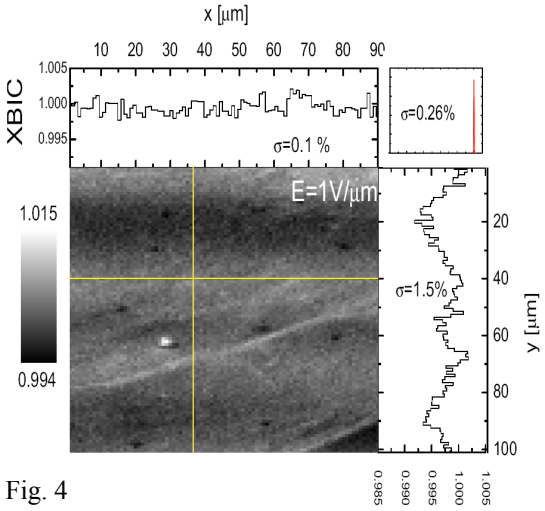

Fig. 4

The response of sample SC8B mapped at 4 V/µm with GHz wideband readout is shown in Fig.5. The collected charge from adjacent electrodes is plotted versus the beam position. The beam was scanned horizontally across the isolation gap of ~130 µm. The crossover response, corresponding to the charge diffusion is visible over a distance of 18µm (insert Fig. 5). The collected charge values of the left (L) and the right (R) quadrant, were obtained by 10ns triggered integrations of the XBIC signals recorded with the DSO. Despite the 130 µm gap between the quadrants, the sum of the signals of the L and the R quadrants indicate full signal charge collection in this area. This result is the first direct demonstration of using a diamond detector as an ultra-fast, position sensitive detector [2]. The measured beam size of σ = 0.42 µm, which is broadened by the thermalization of the hot photoelectrons in diamond to about $\sigma_{beam} \approx 0.85$ µm and the measured transit time of the induced charge carriers of ~2 ns, a rough estimate of the transversal diffusion coefficient $D_T \approx 16$ cm$^2$/s was derived. This value is much smaller than that predicted by the Einstein diffusion relation $D_T = \mu k_B T/q$, which gives a value ~ 90 cm2/s, confirming that the transversal carrier diffusion decreases significantly at high electric fields. This is favorable for the fabrication of high spatial resolution diamond strip- and pixel sensors.

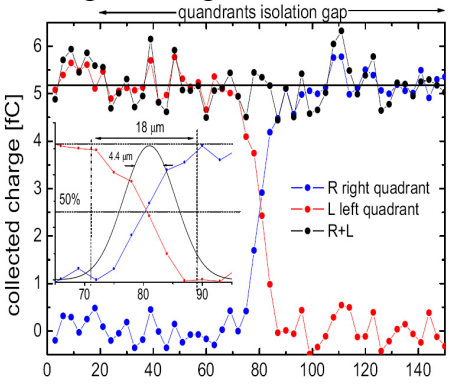

Fig. 5

**Resulting Publications:** [1] 'Single Crystal CVD Diamond Detectors: Position and Temporal Response Measurements using a Synchrotron Microprobe Beam", J Morse, M Salomé, E Berdermann, M Pomorski, J Grant, V O'Shea, P Ilinski, Mater. Res. Soc. Symp. Proc. Vol. 1039-P06-02; [2] PhD Thesis of M Pomorski, 'Electronic Properties of Single Crystal CVD Diamond and its Suitability for Particle Detection in Hadron Physics Experiments', Dissertation zur Erlangung des Doktorgrades der Naturwissenschaften vorgelegt am Fachbereich Physik der Johann Wolfgang Goethe-Universität in Frankfurt am Main, Aug 2008.