ESRF	**Experiment title:** Mapping of the transport properties of CVD diamond detectors by means of x-ray microbeam induced current measurements	**Experiment number**: HE-951
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Report:

The interest in the use of diamond as a ionising radiation detector stems from its unique combination of electronic, mechanical and thermal properties. The high band gap, small dielectric constant, chemical inertness and radiation hardness makes diamond an ideal candidate to operate as a vertex detector in high luminosity hadron colliders for a long time without significant degradation in performances [1].

For the past several years, the CERN-based RD42 collaboration has worked on improving diamond detector performances and on prototyping diamond based microstrip and pixel detectors. Radiation sensors are realised using diamond synthesised by means of the chemical vapour deposition (CVD) technique. CVD diamond is inherently polycristalline. This affects the electrical and transport characteristics and, as a consequence, the spatial resolution achievable through charge sharing in position sensitive (pixel or microstrip) detector (PSD).

MeV ion [2] probes with spatial resolution of the order of 1 micrometer have highlight the effects of grain boundaries on the electronic transport properties of CVD diamond. However, the not uniform carrier generation profile, plasma effects and ion induced damage do not allow the simulation of PSD response in high energy physics experiments. A much more direct technique to study the homogeneity of the response of diamond as observed with minimum ionising particles (MIP) consists in using x-ray photon microbeams from a synchrotron light source. Recently, Tromson et al. [3] used the scanning x-ray microscope (SXM) of the ID21 beamline at the European Synchrotron Radiation Facility (ESRF) in Grenoble (F) to map the photocurrent response of a CVD diamond detector. On the basis of the success of such an experiment (MI-347), we have used the same experimental set up to analyse the homogeneity of the response of a polished 5x5x0.6 mm^3 CVD diamond detector developed within the CERN-RD42 collaboration as a sensor for particle detection and tracking. The sample thickness was obtained by cutting “low quality” regions at the substrate side of the “as grown” diamond sample and by lapping/polishing both the surfaces; finally, circular, 3 mm diameter, ohmic contacts were realised using Cr and Au (total thickness about 500 nm). The electronic

quality of the sample was estimated by measuring the collection length (172 μm in the primed state) of charges induced by minimum ionising particles.
The measurements were carried out at the European Synchrotron Radiation Facility (ESRF) using the ID21 scanning x-ray microscope (SXM). The 5.5 keV monochromatic x-rays beam was focused into a submicrometer spot. The measurements were carried out in air, and the sample was mounted in the focus plane of the zone plate objective lens with the electrodes perpendicular to the incident beam. The x-ray beam irradiated the growth surface of diamond. The bias voltage was applied at the substrate side (non-irradiated surface) (Fig. 1). The sample was raster scanned perpendicular to the x-rays beam direction using a step of 1 μm and a pixel dwell time of 100 or 400 ms. The x-ray induced current was measured using a Keithley 617 picoamperometer. Synchronous acquisition of the photocurrent signal and of the sample position allowed image formation on a pixel-by-pixel basis.
Fig. 2 shows the general map of the sample. The photocurrents are encoded using a grey scale. High current are represented by light grey, regions of low signal are marked with dark grey. The circular luminous pattern corresponds to the electrode deposited on the polished surface (growth side) of the diamond. The black spot on the lower side is caused by absorption from silver paint, which has been used to contact the sample. This map clearly shows a non homogeneous response of the detector even if the sample appears at an optical inspection as perfectly smooth and transparent. The irregular response is attributed to the polycristalline nature of the material. The level of signal uniformity can be analysed by grouping pixels of the active region (i.e. the black area are excluded) in bins of different size and defining a “signal uniformity” term ν as follows:

$$(1)\quad \nu_j = 1 - \frac{1}{\langle s \rangle} \cdot \sqrt{\frac{\sum_{i=1}^{N_j} \left(s_{i,j} - \langle s \rangle \right)^2}{N_j}}$$

where <s> is the overall average signal, $s_{i,j}$ is the average signal of the i-th bin of bin size j, N_j is the number of bins of bin size j. Fig.3 shows the behaviour of the signal uniformity term as a function of the bin dimension. The decreasing behaviour of the uniformity vs. the bin scale confirms the results obtained with microstrip detectors at CERN.
Fig. 4 shows x-ray beam induced current (XBIC) maps relevant to this region carried out at different bias voltages. These maps highlight a substantial modification of the local photocurrent response. To interpret such an effect, we have to consider that x-ray photons probe the whole sample thickness and the diamond photoresponse is sensitive to bulk non-homogeneity. The charge collection profile changes when the applied bias voltage and polarity change. Hence, maps at different voltages involve both crystallites located at different depths and wider “active regions”. In this sense, the big concave crystal visible in maps relevant to high negative voltage should be located well below the irradiated surface, at a deeper position with respect to the small crystallites visible at +100 V. Other detailed analysis of the measurements can be found in [3].
In conclusion, XBIC technique has been proven to be a suitable technique to study CVD diamond detectors. Being the absorption length of the order of the sample thickness, ionisation profile extends through the whole detector thickness and, hence, the x-ray probe is suitable to simulate the response of the detector to MIPs. The use of scanning x-ray microscopes at synchrotron light sources allows a highly spatially resolved analysis of the non-uniformity of such CVD diamond, which limits the achievable resolution of detectors for charged particle tracking.

References

[1] S.Schnetzer for the RD42 collaboration, IEEE transaction on Nuclear Science, 46 (3) 193 (1999) and references therein.

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[3] D.Tromson, A.Brambilla, F.Foulon, C.Mer, B.Guizard, R.Barrett, P.Bergonzo, Diamond and Related Materials 9 (2000) 1850-1855.

[4] E.Vittone, A. Lo Giudice, C.Paolini, F.Fizzotti, C.Manfredotti and R.Barrett, submitted to Diamond and Related Materials.

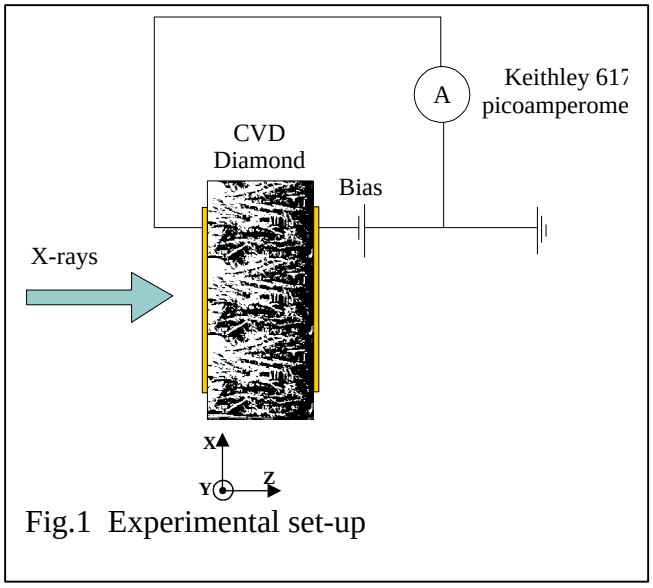

Fig.1 Experimental set-up

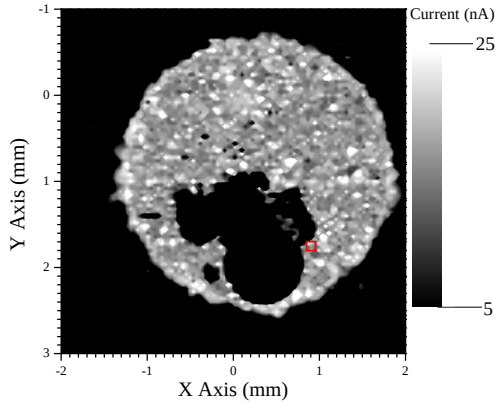

Fig. 2 XBIC map of the diamond detector;

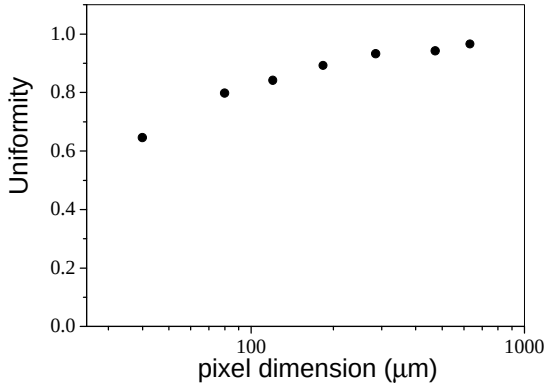

Fig.3 Behaviour of the signal uniformity term as a function of different beam size.

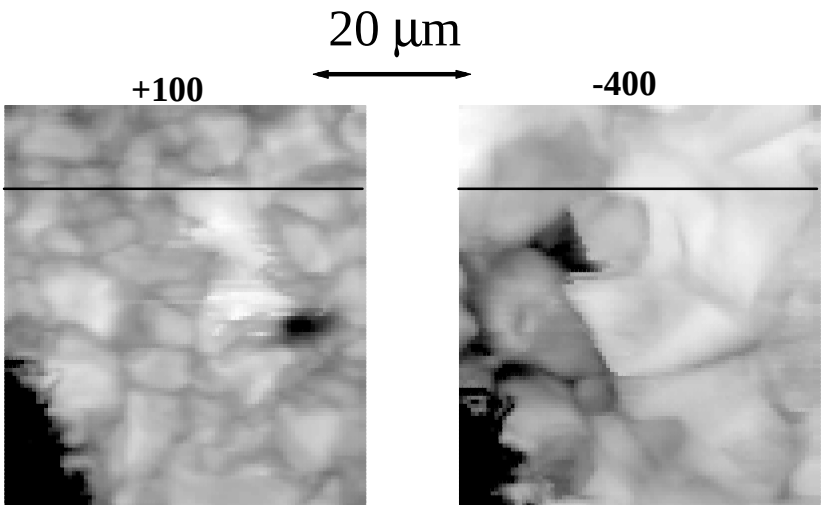

Fig.4 XBIC maps at different voltages carried out on the 90x100 μm^2 region indicated by the square at co-ordinate (1,2) in Fig.2.