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The primed state of CVD diamond under blue light illumination

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Abstract

The primed state of a detector grade CVD diamond sample has been investigated with respect to light illumination during alpha particles (5.5 MeV) detection. The measurements have been carried out as a function of elapsed time after beta-rays priming both in short term (1 h) and in long term (33 h) conditions. The contribution of holes and electrons to the average charge collection efficiency and to total number of counts above a threshold has been qualitatively separated by selecting bias polarity. The behaviour of electron collection after X-ray priming during blue light or UV illumination is improved while the hole one is worsened, confirming previous data. Linearity of the average collection efficiency for alpha particle is observed only at very low doses and in the hole case. Long term stability of both collection efficiency and of total number of counts is observed both in the primed state for holes and during blue light illumination for electrons.

Keywords: CVD diamond; Priming; Illumination; Stability

1. Introduction

There are several controversies about the effect of light illumination on the primed state of CVD diamond as obtained by X- or beta-rays irradiation at doses around 20–30 Gy: according to different authors, the effect could be either positive or negative, i.e. it can be used in order either to improve the performances of CVD diamond as nuclear detector [1] or to erase the improvement obtained by priming [2]. According to our experience, blue light illumination (around 400 nm) transfers the main contribution to charge collection from holes to electrons, and this conclusion has been largely demonstrated by using alpha particles in order to discriminate between electrons and holes contribution simply by changing bias polarity [3,4]. Illumination below 550–600 nm has been proved not to give rise to any effect on the primed state or at least to any improvement in holes and electrons collection. The investigation of primed state can be carried out also by Below Gap PhotoCurrent (BGPC) measurements [3] which can give some insight into transient or dynamic phenomena. In effect, the primed state is not stable under illumination for photon energies below 2.7 eV, but it decays probably because of an optically stimulated detrapping of trapped holes generated by priming, which are responsible [5] of what has been called Persistent PhotoConductivity (PPC). As a matter of fact, the integrated photocurrent is linearly proportional to the cumulated priming dose, as it was the case of ThermoLuminescence (TL) which starts to be used to measure X-ray doses. What is very strange, at least in our case, is that the linearity [5] is restricted to very low doses (below 1 Gy for instance) with respect to TL. Above 2.7 eV the situation changes because probably the main contribution to photocurrent is given by electrons and a good long_term stability is reached.

In order to throw some light on all these phenomena, we started a much longer investigation by using alpha particles spectra in the same way as BGPC as a function of time after priming and blue light illumination, which is a quite long and difficult task, but which gives a better understanding of electrons and holes behaviour. In order to follow the time behaviour, we extracted from alpha multichannel spectra both the centroid or the average value of charge collection efficiency (cce) and the total number of counts (ci), after subtracting the background. This latter parameter can in effect decrease in time because of polarization effects due to trapped charges that locally lower electric field and may cause charge pulses to fall below the electronic threshold. As a consequence, this

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parameter takes into a larger account regions of lower cce, which, according to our experience, should be more affected by blue light.

2. Experimental

The CVD diamond sample used for alpha spectroscopy measurements was grown by MWCVD and it was previously used as a strip detector for tracking purposes. With minimum ionising particles (mips), cce turned out to be about 10%. The total sensitive surface area is 5.5×5.5 mm^2 and thickness 600 μm. Strip contacts (width 19.8 μm and pitch 47.6 μm) were deposited on the growth side, while, in order to be illuminated, the sample was equipped with four parallel Cr/Au contacts (20 nm Cr, 100 nm Au, obtained by vacuum deposition) at the substrate side.

Fig. 1 shows a SEM micrograph of the growth side of the sample equipped with strip contacts. Alpha particles measurements were performed by using a calibrated Am-241 alpha source (mean energy = 5.48 MeV, penetration depth in diamond = 13 μm including contacts), placed in front of the growth surface at a distance of about 1 mm from the specimen. The alpha particles were suitably collimated to a 2-mm diameter spot. Pulses were recorded by means of a standard charge sensitive electronic chain composed by amplifier and preamplifier (Ortec mods. 142 and 572 respectively). The sample was primed with a strong Sr-90 beta source for larger doses and with a weaker one for lower doses, being the doses measured at the sample position by standard TLD100 dosimeters read by a mod. 3500 Harshaw reader. With respect to mips, cce measured with alpha particles is much lower, not only because of the much lower bias voltage used in our case, but also because of the strong polarization due to the short range of alpha particles and to the consequent space-charge build-up in front of the detector.

Before each measurement, the sample was annealed at 360 °C in order to completely recover the virgin state of the sample. Between the measurements and during the priming, the sample was kept in the dark.

As already mentioned, because of the short penetration depth of alpha particles, spectroscopy measurements allow to discriminate between electrons and holes by imposing a positive or negative bias voltage, in the assumption that the main contribution is given by the carrier having at its disposal a longer path. This assumption is quite understandable, even if the obtained charge collection distances (ccd) are of the same order of magnitude of the penetration depth of alpha particles. In effect, carriers moving towards front or irradiated electrode have a higher chance of recombination with the opposite charge carriers and because the plasma generated along alpha particle track shields and lowers locally the electrical field. In any case, it is obvious that all the quoted results referring to different carriers are to be assumed in a semiquantitative way. Since the main topic of the paper is the time behaviour of charge collection after priming and during illumination (or darkness), the applied bias voltage was fixed at 200 V, i.e. +200 V for electrons contribution and −200 V for holes contribution, even if the sample itself could support more than 600 V. In the following we will refer not to the voltage polarity, but only to the carriers that are mainly involved.

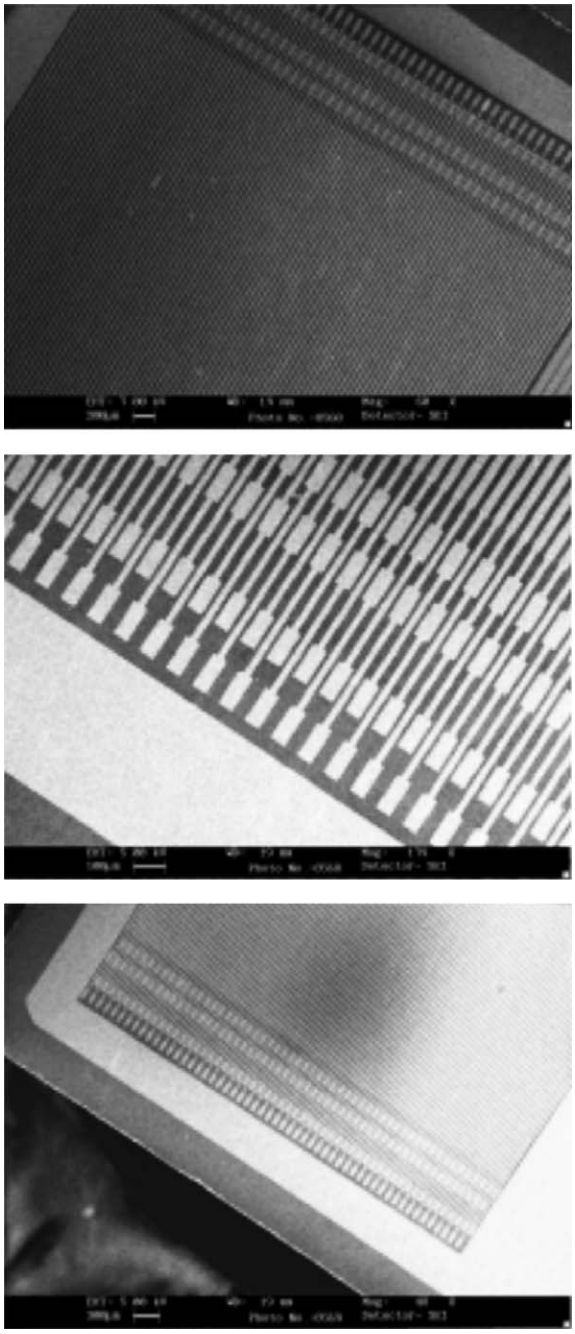

Fig. 1. SEM micrograph (7.0 kV, original magnification: 60×) of the growth side of the CVD diamond sample.

The sample was annealed and subsequently primed. The sample was placed in the experimental apparatus exactly 5 min after priming, in order to obtain the same starting conditions for all the measurements. A series of consecutive spectra was then acquired for a total time of about 1 h. The time required for each spectrum was 4 min. The electronic threshold was calibrated in order to eliminate the electronic noise. The average charge collection efficiency and the integral of counts of each spectrum were calculated. The charge collection