

Characterization of CVD-diamonds for radiation detection

G. Gervino^{a,b}, S. Bizzaro^c, C. Palmisano^a, L. Periale^{d,b}

^aDipartimento di Fisica Università di Torino, Italy

^bINFN Torino, Italy

^cBrevetti Bizz, San Bonifacio (VR)

^dINAF Torino, Italy

Abstract

We report the results of our investigations on high quality Single Crystal Chemical Vapour Deposition (SC-CVD) diamonds to be used as ionizing radiation detectors. The unique properties of diamond makes it one of the most promising wide band-gap materials not only in the already established field of high luminosity X-ray detection for medical applications but also in modern high energy physics. Recent progress in growth of synthetic diamonds of very high purity and high homogeneity has opened perspectives to a new type of UV photosensors in order to work with large volume two phase liquid-Ar and/or liquid-Xe detectors, nowadays under design for next generation dark matter search. SC-CVD diamonds supplied by Brevetti Bizz firm of San Bonifacio (VR, Italy) were investigated and the results are presented and discussed.

Keywords: diamond properties and applications, MIS devices, UV detector

PACS: 72.40.+W, 81.05.Dz, 85.60.Gz, 95.55.Rg

1. Introduction

Application of two-phase radiation detection technique is currently highly investigated in hot topic areas such as WIMP dark matter searches [1, 2], neutrino physics [3] and double β -decay experiments [4, 5] placed in low background underground laboratories. In two-phase xenon or argon, a particle interacting in the liquid (LXe or LAr) target triggers prompt scintillation photons in ultra-violet (UV). At zero electric field ionization electrons created by the interaction will recombine, increasing the scintillation signal. By applying an external field to the liquid, some electrons can be extracted from the interaction site. Upon reaching the liquid surface electrons can enter the gas phase, once in the gas they are accelerated and collisionally excite atoms to produce secondary UV scintillation photons. To provide efficient background rejection in such experiments the electrons crossing the gas phase must be detected independently. Only few hundred photons per electrons are produced every cm of gas phase crossed. Such a poor number of UV photons needs to be collected with high efficiency in order to measure the single electron crossing the gas phase. But in the UV region quantum efficiency of photocathodes is falling down, it is much lower than for visible optical frequencies. One solution is the use of an appropriate UV-visible photon converter layer (thousand of Å) deposited onto the top side of the photocathode. In the present work we follow an alternative way and investigate the performance of CVD crystal diamonds as high efficiency UV photons sensors to work in association with next generation large cryogenic LAr/LXe detectors. CVD diamonds show excellent performances in UV and X-ray detection, its chemical inertness and mechanical robustness make them most suitable to operate in harsh environments.

Diamond detectors are blind to visible light and this property greatly helps reducing one of the most disturbing source of background. Several attempts have been made to build UV detectors from natural or synthetic diamonds. Detector grade natural diamonds are extremely rare and expensive, high-pressure high-temperature (HPHT) diamonds contain too many impurities and polycrystalline chemical vapour deposition (pCVD) diamonds have poor response times and very poor spatial homogeneity. As a result, persistent photoconductivity, undesirable pumping effects, very slow response time and low signal-to-noise ratios are some of the technological problems to be tackled in order to realize satisfactory diamond-based detectors. As first step, great effort has been therefore devoted to find high-quality single crystal diamond by CVD growth. Single crystal CVD diamonds (or SC-CVDs) were supplied by Brevetti BIZZ firm of San Bonifacio (VR, Italy), each crystal used for preliminary tests has the thickness ranging within $0.6 \text{ mm} \div 1.2 \text{ mm}$ with an area of $30 \text{ mm}^2 \div 40 \text{ mm}^2$. In order to have the chance to use successfully CVD diamonds as UV sensors in large volume two-phase LAr or LXe detectors, it is mandatory to realize detection set-up with the largest sensible area. One solution can be the realization of a matrix sensor prototype, each pixel made of a high quality SC-CVD.

2. Experimental

The SC-CVD diamonds have been investigated by SEM-EDS technique at CERN EN/MME Lab. in order to measure the quantity and the kind of impurities inside diamond lattice. Graphite, which is usually one of the most commonly found impurities and can seriously affect even destroy diamond excellent optical properties, was not seen by EDS. Other com-

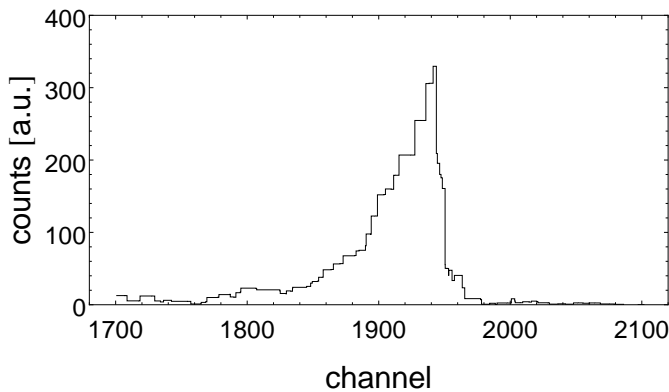


Figure 1: ^{241}Am α spectrum.

mon impurities in CVD diamond include nitrogen, hydrogen, tungsten and oxygen. They are due to growing condition and associated parameters. Nitrogen can be most likely found in the (111) face in a quantity three or four times higher than as in (100) face. EDS investigated both crystals faces: we conclude that the content of N or other impurities in the diamonds is below the detection limit of the technique. Silicon is found in particles in the diamond matrix along with C. EDS results suggest those are hard SiC particles that pinpointing contaminate at level just under 0.1 wt% (weight percentage). The presence of impurities and/or point defects in the crystal lattice can act as shallow, slow, high cross section trapping centers, giving rise to trapping-detrapping effect that could spoil the electric signal. All structure dishomogeneities induce the lowering of charge carrier collection efficiency. Polarization effects, due to trapping carriers, are responsible for time variations of charge collection efficiency. When a detector is irradiated with strongly ionizing particles as α , polarization phenomena can be observed. In order to investigate polarization effect together with memory effect produced by previous applied voltage, α spectra were acquired alternating positive and negative polarities.

The detector was placed in a vacuum chamber and exposed to a ^{241}Am calibrated α source. The source was collimated by a lead shield 5 mm thick with a hole of 1 mm diameter placed just in face of the diamond, the particles counting rate was around 500 pps \div 600 pps. The measurements were carried out in the darkness at 300 K with a vacuum of 10^{-3} mbar. The detector was linked to a CIVIDEC large bandwidth (up to 2 GHz) preamplifier that shows a gain of 20 dB and RMS noise of around 1 mV with the diamond detector in the dark connected and biased at +450 V (α spectroscopy conditions). From the preamplifier the signal enters a CAEN N968 Spectroscopy Amplifier and finally a 13 bit ADC. In Fig. 1 the ^{241}Am spectrum taken with positive bias is presented. Bias voltage was applied to the face of the detector exposed to collimated α -particles.

Comparing α -spectra taken with positive and negative bias we can notice that the negative one has a worse resolution, the peak is more asymmetric with a much bigger tail starting from

low energies up to the peak region. Also the tail at high energy region, after the peak, is much stronger and longer in the negative bias condition (holes collection). Evaluating the charge collection efficiency, with positive bias we get a value close to 98%, but with negative bias the efficiency has dropped of about a factor two (slightly over than 50%).

Carrying out subsequent measurements at positive and negative bias memory effects can be investigated. Memory effects are likely due to a progressive build up of internal polarization electrical fields, with the consequent time decay of counting rates or of charge collection efficiency and the appearance of pulses of opposite polarity on the analog detector chain. Memory effects have not been observed in both polarization bias, most likely because in both situations charge collection efficiency is large enough.

For UV applications, the detector was realized by depositing interdigitated Al contacts on the CVD diamond surface by standard photolithographic process. The interelectrode distance is 50 μm . We investigate the crystal response to different wavelength photons using a Hamamatsu Deuterium Lamp with dedicated stabilized power supply based on a constant-current circuit and a constant-voltage circuit that deliver stable and reliable lamp ignition in order to characterize the CVD diamond spectral response in the 190 nm \div 400 nm range. The highest current sensitivity of 0.15 A/W is achieved at $\lambda = 225$ nm, in agreement with theoretical prediction [6]. With an applied voltage of 100 V, the detector shows a photopeak response at 225 nm higher than 4 order of magnitude with respect to photocurrent measured at wavelengths just before 400 nm and a very sharp photocurrent drop is observed just after 245 nm. The detector optical response is stable in time and highly reproducible, so that undesirable effects such as memory effects under irradiation or pumping may be very weak. The main EDS spotted contaminant, hard SiC particles at level just under 0.1 wt%, seems to carry in low concentration trapping centers with low cross section as well.

3. Conclusions

Diamond based detectors have been produced from SC-CVD diamonds supplied by Brevetti BIZZ of San Bonifacio (VR, Italy). There are still open problems about the feasibility of UV diamond detector, among the ones we can quote the “memory effect” that could influence the readout. Building single crystals with a very high purity grade, reducing at the minimum point defects in the lattice, the charge collection efficiency would be high enough to solve the memory effect problem and tackling the trapping-detrapping effect. Good stability and reproducibility of the devices response were obtained, indicating that any undesirable pumping effects were under control.

- [1] Aprile E. et al., *New Astron. Rev.* **49**, (2005), 289.
- [2] Rubbia A., *Nucl. Phys. B, Proc. Suppl.*, **149**, (2005), 197.
- [3] Quarati P. et al., *Nucl. Phys. A* **261**, (1997), C345-C351.
- [4] Kubota S., Hishida M. & Nohara A., *Nucl. Instr. and Meth. A* **150**, (1978), 561.
- [5] Hitachi A. et al., *Phys. Rev. B* **27**, (1983), 5279.
- [6] Altukhov A.A. et al., *J. Com. Tech. Electr.* **52**(3), (2007), 360-363.