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Diamond detectors with electrodes graphitized by means of laser

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Summary. — In the last years there has been an increase of interest in diamond devices because of the promising applications in different field, such as high-energy physics, radiotherapy and biochemical applications. In particular, a new frontier is represented by the realization of full-carbon detectors characterized by graphite electrodes, which give to the devices considerable advantages like high radiation hardness, perfect mechanical adhesion and good charge collection properties. In this paper the manufacturing of full-carbon devices and their detection performances are illustrated and compared to a reference diamond detector characterized by traditional electrodes.

1. – Introduction

The conventional technique to realize ohmic contacts on diamond materials are based on metal deposition by evaporation or sputtering, requiring several process steps with well-controlled environment conditions sometime resulting in poor mechanical adhesion, low radiation hardness and polarization phenomena. A promising alternative technique consists in the realization of contacts by laser-induced "graphitization" of diamond. This technique is capable to fabricate good and mechanically robust ohmic contacts in a unique process step and in ordinary working conditions of temperature.

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2. – Laser graphitization of a diamond sample

The graphitization of diamond takes place when a laser beam, with an appropriate wavelength and energy density values, hits the surface of the diamond inducing a localized heating, which allows to overcome the potential barrier between diamond and graphite phases ($T_g \simeq 700\,^{\circ}\mathrm{C}$ in air) [1]. The experimental set-up is in principle quite simple. An ArF excimer laser beam ($\lambda = 193\,\mathrm{nm}$, $\tau = 20\,\mathrm{ns}$), attenuated and focused by a suitable optical system, is directed on the diamond surface which is fixed on motorized X-Y stages having bidimensional sub-micrometer displacements in the orthogonal plane to the beam direction with the aim to make 2D graphitic structures [2]. In order to study the diamond graphitization and find out the optimal experimental parameters to realize good contacts, the graphitization process has been studied varying the laser energy densities and number of pulses. Further, graphitic strips have been realized on a thermal grade CVD polycrystalline diamond surface for different combinations of laser fluence ($F = 3$, 5 and $7\,\mathrm{J/cm^2}$) and number of (C) laser scan cycles $C = 2$, 6, 8, 10, 12, respectively (1 cycle corresponds to one up and down laser scan). In this paper the interesting results of the micro-Raman Spectroscopy and of the nuclear characterization are briefly reported.

3. – Characterizations and discussion

The micro-Raman spectroscopy allows to investigate the physical evolution of the diamond graphitization process. In particular, in fig. 1 it is reported the most significant Raman spectra acquired on the graphitic strips realized with a laser fluence of $F = 7\,\mathrm{J/cm^2}$ and with a number of laser scan cycles equal to $C = 2$, 6 and 8. The micro-Raman spectra, obtained with a Raman excitation wavelenght of $\lambda = 514.5\,\mathrm{nm}$, show that with an increasing number of laser scan cycles, from $C = 2$ to $C = 6$, the characteristic peak of the graphitic phase (a broad peak at $1580\,\mathrm{cm^{-1}}$, G peak) increases while the peak relative to the diamond phase (a sharp peak at $1332\,\mathrm{cm^{-1}}$, d peak) progressively decreases. As the laser-material interaction proceed, the competitive process of partial ablation of the laser-induced graphite phase takes place, resulting for $C = 8$ in the appearance of the diamond sharp d peak (fig. 1). In table I the intensities of the d and G peaks are reported together with their ratio for the different realized graphite strips. Moreover, by means of detailed electrical investigations it was found out that all the graphitic strips had an ohmic behavior and in particular that the best estimated resistivity value, like expected from literature [1], was $(4.0 \pm 0.8) \times 10^{-3}\,\Omega\mathrm{cm}$ relative to the strip realized with $F = 7\,\mathrm{J/cm^2}$ and $C = 6$ [2,3]. Subsequently, a diamond device with graphitic electrodes was tested at the Beam Test Facility of Frascati (Italy). The detector was realized using a polycrystalline diamond of size $5 \times 5 \times 0.325\,\mathrm{mm^3}$, with 20 graphitic strips of $150\,\mu\mathrm{m}$ pitch on the front-side and a graphitic pad of $3.5 \times 3.5\,\mathrm{mm^2}$ on the back side. The device response was investigated in the testbeam by means of bunch of about 300 electrons with an energy of 500 MeV and compared to a reference diamond detector with metal strips as eletcrodes. The metallized device was realized using a polycrystalline diamond of size $10 \times 10 \times 0.5\,\mathrm{mm^3}$, with 4 metal strips of 1.5 mm pitch on the front-side and a metal pad of $9 \times 9\,\mathrm{mm^2}$ on the back side. Figure 2 shows the pulse response of the two detectors as recorder by the waveform digitizer after a fast charge amplifier of gain 5.4 mV/fC. Taking into account the different values of the covered active area and the expected charge collection distance (due to a different sensor thickness) the two detector responses are comparable.

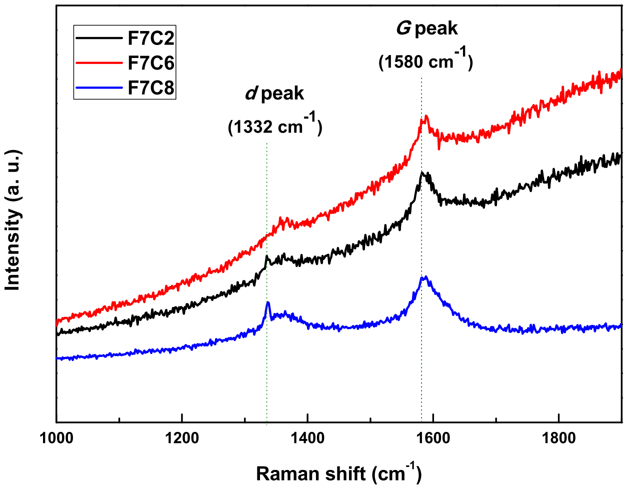

Fig. 1. – Micro-Raman spectra of three graphitic strips on diamond sample realized with fixed laser fluence at $F = 7\,\mathrm{J/cm^2}$ and different scan cycles: $C = 2$ (black line), $C = 6$ (red line), $C = 8$ (blue line) [2].

Table I. – *Intensities of the* d *and* G *peaks together their ratio for the graphite strips realized with* $F = 7\,\mathrm{J/cm^2}$ *laser fluence and* 2, 6 *and* 8 *laser scan cycles* [2].

Strip	d Intensity (a.u.)	G Intensity (a.u.)	d/G Intensity Ratio
$F7C2$	1.2×10^3	2.0×10^3	6.0×10^{-1}
$F7C6$	$\simeq 0$	2.6×10^3	$\simeq 0$
$F7C8$	7.5×10^2	1.0×10^3	7.5×10^{-1}

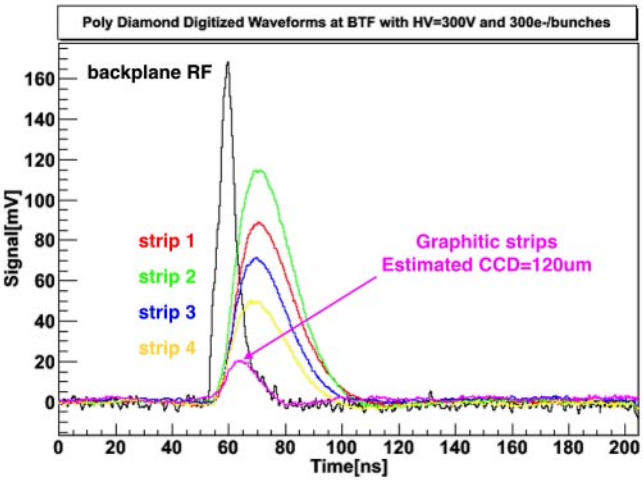

Fig. 2. – Measured pulse height of graphitic and metallized diamond detectores to 300 electron bunches. The waveforms refer to a group of about 10 strips for the first one and to single strip for the second one.

4. – Conclusion

In this work, a study of the laser-induced graphitization process of diamond has been reported in order to realize ohmic contact for full-carbon nuclear detectors. Changing the laser energy densities and laser cycles good and well adherent ohmic contacts have been realized on the diamond surface with resistivity values of $(4.0 \pm 0.8) \times 10^{-3}\,\Omega\text{cm}$. Finally, a prototype of full-carbon detector was tested with electronic beam of 500 MeV at the BTF of Frascati and compared to a reference diamond detector with metallized contacts, resulting in comparable performances. This work open the possibility to build full-carbon active target for nuclear physics experiment, such as the one recently proposed at DAΦNE Beam Test Facility to look for the hypothetical particle called "dark photon" [4].

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