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APPLICATION OF DIAMOND DETECTORS IN TRACKING OF HEAVY ION SLOWED DOWN RADIOACTIVE BEAMS*

P. Bednarczyk[a,b], E. Berdermann[a], J. Gerl[a], M. Górska[a]
I. Kojouharov[a], M. Pomorski[a], M. Rębisz[a], B. Voss[a], L. Acosta[c]
R. Berjillos[c], I. Martel[c], M.A.G. Alvarez[d], J.M. Espino[d]
J.L. Flores[d], I. Mukha[d], R. Wolski[b,e]

[a]GSI Darmstadt, Germany
[b]IFJ PAN Kraków, Poland
[c]University of Huelva, Huelva, Spain
[d]University of Seville, Seville, Spain
[e]JINR, Dubna, Russia

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Results of irradiation of thin Chemical Vapor Deposition (CVD) diamond detectors with low energy: p, α and ^{7}Li beams are presented. Energy resolution: $\Delta E/E < 1\%$ of a single crystal detector was achieved. A coincident measurement with two diamond detectors showed time resolution of 100 ps and efficiency above 70%. Despite a high beam flux reaching 10^9 particles/s cm^2 the tested detectors showed low dead-time and satisfactory radiation hardness. Perspectives of applying thin CVD diamond detectors in monitoring of a slowed down radioactive beam (RIB) are discussed.

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1. High resolution γ-ray spectroscopy at slowed down RIBs

Significant progress in prompt γ-ray spectroscopy of rare nuclei was achieved at the RISING setup in GSI due to availability of relativistic RIBs produced in flight [1]. In addition, delayed γ-decay studies of stopped fragments at RISING were successful [2]. However, use of RIBs slowed down to a Coulomb barrier energy would open a new perspective in in-beam γ-spectroscopy studies of nuclei far off stability accessible by transfer reactions, deep inelastic collisions and, in some cases, fusion–evaporation reactions.

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At the planned radioactive beam facility NUSTAR [3] we aim at high resolution γ-spectroscopy measurements with secondary RIBs at energies close to the Coulomb barrier limit of $5A$MeV. Relativistic radioactive fragments created in flight will be selected in the Low Energy Branch of the SFRS separator [4] and slowed down in a series of degraders. In turn, they will induce a nuclear reaction on a target. Due to the superior SFRS transmition, the secondary beam intensity can reach 10^8 particles/s. However, a significant spread in the projectile energy and position is expected. Detection of prompt γ-radiation emitted from the reaction target will employ novel techniques that incorporate pulse shape analysis and tracking of scattered photons. Nonetheless, for efficient Doppler shift compensation exact information about the velocity vector and the position of every projectile at the target has to be determined. Detectors suitable for the RIB tracking shall provide: *(i)* good energy resolution and minimum ion energy absorption, *(ii)* excellent timing properties, *(iii)* high efficiency and low dead-time, *(iv)* radiation hardness. In this context, thin diamond polycrystalline (PC) or single crystal (SC) CVD detectors [5] attract lots of attention. Recently, it was shown that SC CVD diamonds permitted of detection of α-particles from a ^{241}Am source with good energy resolution, comparable with Si detectors [6]. On the other hand, time of flight measurements of relativistic heavy ions demonstrated that a time accuracy of PC and SC CVD diamond sensors is significantly better than 100 ps [7, 8].

2. Performance of CVD diamond detectors in beam

Here, we report on an in-beam evaluation of a CVD diamond detector sensitivity on low energy and high intensity ion beams: p, α and ^{7}Li at energies of 5.8 MeV, 8.7 MeV and 11.2 MeV, respectively, delivered by the CNA-Seville 3 MV tandem accelerator [9]. SC and PC CVD diamond detectors of a size of 4×4 mm^2 and 1×1 cm^2 respectively, and various thicknesses were tested. The projectiles, were Rutherford scattered on thin Al, Pb and Au targets. A SC CVD diamond detector of 500 μm thickness was positioned at 70° with respect to the beam direction. Output signals were shaped in a standard charge sensitive preamplifier. The measured energy spectra of the scattered protons are presented in Fig. 1(A). The peak shift and broadening resulted from the target element composition and the energy spread due to the target thickness, as indicated in the picture. However, the spectrum measured for the 1μm Al target demonstrates rather narrow distribution of 50 keV at the FWHM, reaching the energy of 5.55 MeV. These values correspond rather well to the calculated energy spread and the maximum scattered proton energy. Therefore, one may conclude that the intrinsic energy resolution of the SC CVD diamond is better than 50 keV.

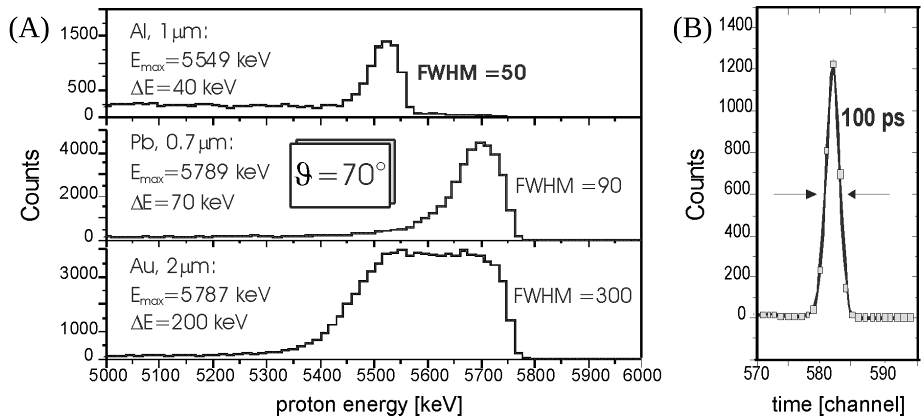

Fig. 1. (A) Energy spectra of 5.8 MeV protons elastically scattered from different targets, detected by a 500μm SC CVD diamond detector at 70°. The calculated maximum energy and the peak broadening are indicated. The intrinsic detector energy resolution is below 50 keV, thus better than 1%. (B) Time correlation spectrum of two SC CVD diamond detectors of 110μm and 300μm thickness, mounted in a stack, irradiated by the scattered proton beam. The time resolution of 100 ps at the full width half maximum and efficiency above 70% were measured.

A stack consisting of a 110μm and 300μm SC CVD diamond detectors was mounted at the angle of 90°. The protons scattered on the Pb target crossed over the thinner detector, loosing half of the kinetic energy and were stopped in the second diamond. Pulses from both detectors were fed into broad band voltage-sensitive preamplifiers DBA2 [10] that provided signals with a few tens ps rise-time. The coincidence rate was 70% of singles, in part due to the detectors misalignment. Leading edge discriminators were used to determine the signal timing. The telescope time correlation spectrum is shown in Fig. 1(B). One clearly sees a coincident peak of only 100 ps at the FWHM, even though a walk correction for such fast signals was not feasible.

The scattering setup was used to measure a time correlation between a PC CVD diamond detector of 13μm thickness and the 300μm SC CVD diamond, mounted in a stack. The ^{7}Li beam irradiated the Pb target. The projectile range in diamond was 16μm, the distance comparable with the PC detector thickness. Therefore, one expected high energy deposition of about 10 MeV in this detector. Indeed, despite low charge collection efficiency in a PC diamond, a signal of sufficient amplitude was generated. Although ^{7}Li ions entered into the second SC CVD diamond with energy below 1 MeV, one could clearly see coincident signals from the two detectors. As in the previous case, the PC and the SC diamonds exhibited very good correlation with the time resolution within the 10^2 s range.

To clarify the diamond detectors ability of detecting ions at high rates the 300 μm SC CVD diamond detector was exposed to direct proton and α-particle beams. The minimum stable current extracted from the accelerator corresponded to a beam flux of the order of 10^7–10^9 particles/s cm^2. Although the irradiation lasted several minutes, DBA2 preamplified signals monitored on a fast digital oscilloscope exhibited no signs of degradation or noisiness. Negligible leakage current was registered. The detector allowed for a clear distinction of two consecutive signals separated by 10 ns that would correspond to a continuous rate of 100 MHz.

3. Summary of obtained results and further perspectives

In the course of the described experiment SC and PC CVD diamond detectors were tested in low energy ion beams. The SC detectors showed excellent performance revealing the energy and time resolution being of 1% nad 100 ps respectively and efficiency above 70%, even at very low energies of the impinging particles. In this respect, PC detectors have comparable timing properties if the charge induced in the diamond was high. The tested detectors showed low dead-time and satisfactory radiation hardness allowing for effective operation even at 100 MHz charged particle rate. In the light of the current work use of SC CVD diamonds in low energy ion beam tracking is promising. However, availability of very thin single crystal diamond films of surfaces larger than 1 cm^2 is still limited. On the other hand, heavier ions may generate a charge in a PC diamond sufficient for measurements with satisfactory energy resolution. This issue needs a further clarification.

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