Testing of a sCVD diamond detector for monitoring accelerator beam profile

Akhil Jhingan[1]*, A. Rai[1], S. Ghosh[1], M. Kumar[1], P. Patra[1], J. Karmakar[1], S. Pal[2], G. K. Chowdhury[1], B. K. Sahu[1], V. Nanal[2], R. Palit[2]
[1]*Inter University Accelerator Centre, P. O. Box 10502, New Delhi - 110067*
[2]*Department of Nuclear and Atomic Physics, Tata Institute of FundamentalResearch, Mumbai 400005*
** email: akhil@iuac.res.in*

Introduction

Application of single crystal chemical vapor deposited or sCVD diamond detector as a radiation hard heavy ion detector is well established. This detector provides very good timing as well as energy resolution. It is being used as a diagnostic for low energy buncher stability at TIFR Pelletron-Linac Facility [1]. We report its projected application in heavy ion beam diagnostics with the Pelletron-LINAC accelerator system at IUAC. This system provides ion species from ^{12}C to ^{48}Ti at energies ranging from 5-10 MeV/A. The RF accelerator (LINAC) boosts energy of pulsed beams, from Pelletron, with bunch widths around 250 ps. Suitable detectors are required to carefully monitor these bunch widths while tuning the RF phase of the accelerator. Energy information is also essential to monitor the acceleration (de-acceleration) or increase (decrease) in energy of the beam species. The diamond detector has been tested to determine, in time domain, the bunch width as well as the energy of the pulsed beams from the accelerator. As a standard practice, totally depleted thin (40 µm) surface barrier detectors or SBD have been used to determine the beam bunch width from the superconducting LINAC buncher [2] of IUAC. This is realized by detecting beam particles scattered by a thin gold foil. Thin silicon detectors do not provide good energy resolution owing to large capacitive noise and at the same time have a very short life, being very prone to radiation damage. Also, since full energy of the incoming particle is not deposited, thus energy resolutions in thin transmission type detectors are generally inferior as compared to thicker ones (~ 300 µm). Thick silicon detectors do provide very good energy resolutions but timing resolutions are very inferior. Thick sCVD diamond detectors (~ 300-500 µm) provide very good timing resolutions (~ 100 ps FWHM) and their energy resolutions are at par with the silicon detector. Since particle is stopped in these detectors, thus full energy information of the beam particles from the accelerator can be known.

Diamond Detector

Fig.1: Picture of the sCVD diamond detector assembly.

Fig.1 shows the picture of the model B1 sCVD diamond detector manufactured by Cividec Instrumentation GmbH. It has an area of 4.5 x 4.5 mm^2 and a thickness of 500 µm. It has a conducting layer of gold of thickness 250 nm for electrical contacts. The detector is housed inside a shielded aluminum box. An SMA connector is provided for signal processing. In comparison to silicon, diamond has higher electron (1.5 times) and hole (2.5 times) mobilities, and higher electric fields (~ 6 times) can be applied. These characteristics enhance the timing resolution of diamond detector. Diamond requires ~ 4 times more energy (13 eV) as compared to silicon (3.62 eV) for the generation of an electron-hole pair. At the same time diamond has much lower capacitance (~ 3 pF) as compared to silicon (~50 pF), thus capacitive noise and load will be minimum for the preamplifier. The energy required to remove an atom in diamond is 3 times higher as compared to silicon, which makes it more radiation hard.

Test Measurements

The detector was tested with alpha emitters ^{241}Am and ^{229}Th. An energy resolution of 44 keV was observed for 5.48 MeV alpha. Intrinsic resolution will be better since there is energy straggling in the entrance gold layer. Fig.2 is the alpha spectrum with ^{229}Th showing well resolved alpha peaks. Charge sensitive preamplifier (CSPA) unit [3] with sensitivity 5 mV/MeV (diamond equivalent) was used for energy measurements.

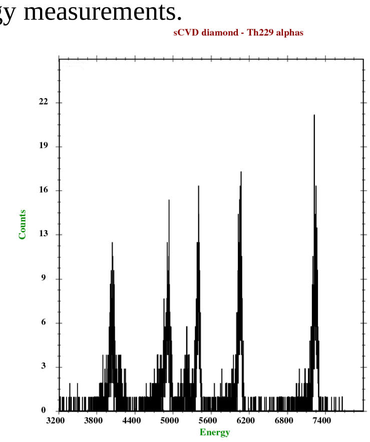

Fig.2: Alpha spectrum using ^{229}Th source.

Fast timing amplifier (FTA) unit, prepared at IUAC, was used to evaluate the timing performance. The design utilizes four stage common emitter amplifiers with an emitter follower at the output stage. The circuit is inspired by the earlier developed design of Beeskow [4]. Circuit diagram is shown in fig.3., and fig.4 shows an assembled unit which has detector bias network for providing bias voltage to the detector. These units have been widely used earlier with proportional counters [3], and more recently with silicon detectors [5].

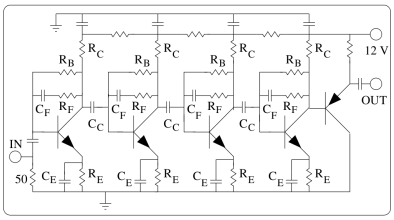

Fig.3: Circuit diagram of FTA

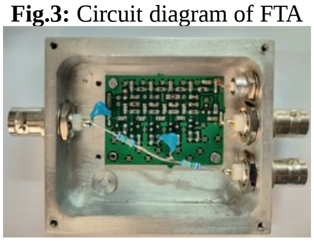

Fig.4: Assembled FTA unit with bias network.

A rise time of about 1.5 ns and gain of ~ 25 mV/MeV was observed for alpha particles. This performance, in terms of gain and rise time, is almost identical to the broadband amplifier unit provided by Cividec company.

Detector was tested in beam using 90 MeV ^{28}Si beam scattered from 150 μg/cm^2 gold foil. The pulsed beam had a repetition rate of 250 ns and a bunch width of ~ 1ns. Diamond detector was mounted at an angle of 20° *w.r.t.* beam direction in the beam diagnostic chamber for LINAC. For comparison, one silicon detector (300 μm thick) was also placed at 20° on the other side of the beam axis. Time of flight (TOF) was generated between RF pulse and diamond detector. Timing resolution of ~ 1ns was observed, consistent with the bunch width. Fig.5 shows the signal output from FTA for the scattered ^{28}Si particles with rise time ~ 2 ns and amplitude 1.8V, at bias voltage of 180 V. Intrinsic resolution is estimated to be < 100 ps from the displayed signal characteristics.

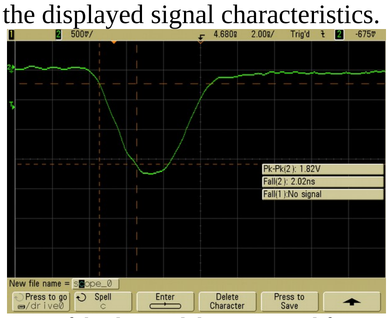

Fig.4: Trace of the diamond detector signal from FTA.

Diamond detector was also tested with Canberra 2003BT preamplifier which provides both timing and energy signals. Energy signal strength was 4 times less as compared to silicon detector. Rise times were 2 ns for the timing signal with amplitude ~ 200 mV. Additional amplification is provided with a Timing Filter Amplifier. Resolution achieved is ~ 1 ns. Energy resolutions were identical for both silicon and diamond detector ~ 1.6 MeV. In future we plan to perform measurements with the superconducting LINAC buncher, which can provide bunch widths of ~ 100 ps.

We acknowledge the support from A. Sarkar, S. Kumar and R. Joshi for providing good quality pulsed beams. We acknowledge the TIFR accelerator group for providing us the sCVD diamond detector for test measurements at IUAC.

References :

[1] S. Pal et al., DAE-BRNS InPAC-2013, 264
[2] S. Ghosh et al., Phys. Rev. ST Accel. Beams 12, 040101 (2009).
[3] A. Jhingan, Pramana J. Phys., Vol.85, 2015, 483
[4] Lynen et al., NIM 162 (1979) 657
[5] A. Jhingan et al., Proc. DAE-BRNS Symp. on Nucl. Phys. 61 (2016)964