

Time Resolution of Diamond Detectors for Relativistic Ions and Protons*

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The high pair production energy of diamond ($\epsilon_{\text{Dia}} = 12.84$ eV) is a challenging material property in timing measurements of relativistic light ions and Minimum Ionizing Particles (MIPs). The low amount of generated charge (Q_G) predicts reduced detection efficiency of assemblies, readout with broadband Front End Electronics (FEE). Eqs. (1) and (2) describe the time resolution σ_t and the Signal-to-Noise ratio (S/N), respectively [1]:

$$\sigma_t = \frac{N}{dV/dt} = \frac{\sqrt{k \cdot T \cdot (F-1) \cdot C_D}}{2.28 \cdot Q_C(e,h) \cdot BW_A} \quad (1)$$

$$S/N = Q_C(e,h) / \sqrt{k \cdot T \cdot (F-1) \cdot C_D} \quad (2)$$

with k , the Boltzmann constant; T the temperature; Q_C , the collected charge; C_D the detector capacitance; F and BW_A the noise factor and bandwidth of the FEE.

Accordingly the task is to maximize Q_C and BW_A and heights on the input impedance of a Diamond Broad band Amplifier (DBA: 50 Ω , 2.5pF, 2.3GHz), generated from ions of same velocity 1GeV/A in diamond sensors of different Charge-Collection Efficiency (CCE = Q_C/Q_G) and thickness $d_D = 50$ –400 μm (indicated by the line colours). Dot electrodes of 3 mm in diameter were assumed, and a thickness and quality dependent FWHM of the signals. The horizontal lines indicate the (rms) noise amplitude of the DBA (solid line) and its 3 σ deviation (dashed line), which is at least the amplitude required for good detection efficiency and time resolution with this FEE.

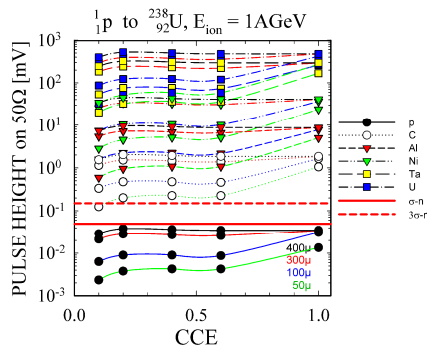


Figure 1: Expected amplitudes on 50 Ω vs. the CCE of diamond sensors of different d_D (line colours) (see text).

The data show that for $Z > 6$, polycrystalline diamond plates of $d_D \geq 50 \mu\text{m}$ and $CCE \geq 0.2$ are feasible, whereas MIP timing with DBA like FEE is prevented even for best single-crystal CVD Diamond sensors of $CCE \sim 1$.

Extended simulations confirm the best time resolution for low-capacitance broadband assemblies where both C_D and parasitic capacitances C_p are ≤ 1 pF; degradation up to a factor of three appears for $C_p \geq 2$ pF.

* Supported by EC Projects RII3-CT-2004-506078 and MC-PAD

Recent Results with ${}^6\text{Li}$ Ions of 1.8 AGeV

We tested the intrinsic time resolution of scCVDD quadrant sensors for relativistic ${}^6\text{Li}$ ions with two setups each consisting of two $d_D = 400 \mu\text{m}$ (Setup 1, top left) and 100 μm thick samples (Setup 2, bottom left), respectively. The corresponding single-sector capacitances were $C_{D,1S400} = 0.2$ and $C_{D,1S100} = 0.9$ pF. The modular Setup 1 was readout via capacitive buffers for each sector followed by modified FEE-1 cards [2] implemented as a 2nd stage analogue processing (MOS-follower; 1M Ω , 2.1pF, 1GHz). In Setup 2, the diamond sensors were mounted on the FEE boards with each sector wire bonded to an active impedance transformer of $C_i = 0.2$ pF. Subsequently, the signals were shaped with an external booster amplifier [3]. The best proton result with the former ‘low-Ci BBA’ used for the HADES Start Detector (SD) was $\sigma_{\text{intr}} = 117$ ps [3].

The time-difference spectra obtained with both setups are shown on the corresponding right graphs of Fig. 2. Note that for Setup 1 the data analysis is preliminary and incomplete. Resolutions $\sigma_t = 77$ ps ($\sigma_{\text{intr}} = 55$ ps) achieved by selecting prompt time coincident events of high signal amplitudes. No walk correction is performed at present. In contrast, the Setup 2 data are walk corrected and processed under the condition that no neighbour sectors have fired. Due to the new transistor implemented (SiGe:C; BFR705L3RH) an excellent $\sigma_{\text{intr}} = 32$ ps with a pure diamond contribution of 21 ps was achieved. Further improvement is expected by readout micro-patterned SDs with broadband ASICs (PADI [1]) modified for higher sensitivity (to be tested in spring 2010).

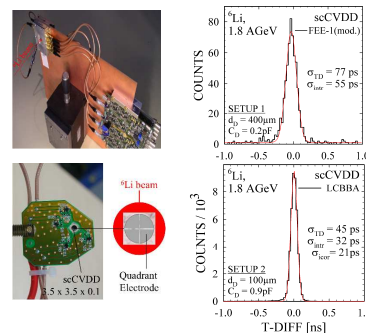


Figure 2: (left) The tested Setups, 1 (top) and 2 (bottom). (right) Time-difference spectra of two opposite sectors.

References

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- [2] M. Ciobanu et al, IEEE Trans. on NS, Volume 54, Issue 4, Pages:1201 – 1206, August 2007.
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