Time Resolution of Diamond Detectors for Relativistic Ions and Protons*

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The high pair production energy of diamond (ε_{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]:

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

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

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: 50Ω, 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 3σ deviation (dashed line), which is at least the amplitude required for good detection efficiency and time resolution with this FEE.

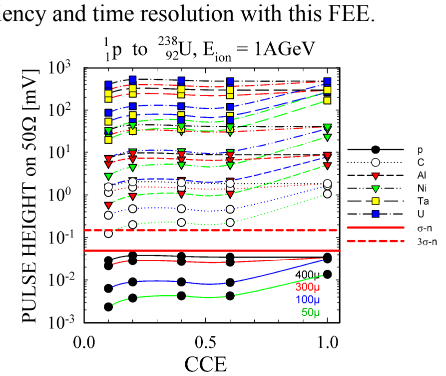

Figure 1: Expected amplitudes on 50 Ω vs. the CCE of diamond sensors of different d_D (line colours) (see text).

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

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

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

We tested the intrinsic time resolution of scCVDD quadrant sensors for relativistic ^{6}Li ions with two setups each consisting of two d_D = 400µm (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; 1MΩ, 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 σ_{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 σ_t = 77 ps (σ_{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 σ_{intr} = 32ps with a pure diamond contribution of 21ps 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).

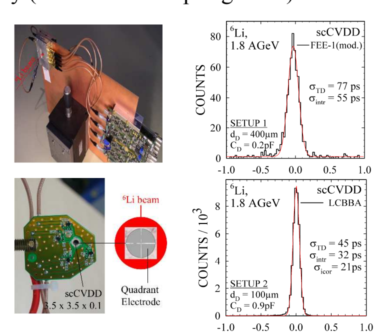

Figure 2: (left) The tested Setups, 1 (top) and 2 (bottom). (right) Time-difference spectra of two opposite sectors.

References

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