Use of extremely thin 'LGAD' ultra-fast silicon detectors for fast timing and tracking in high radiation sections at future colliders.

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The recent development of silicon diode Low Gain Avalanche Detectors (LGADs) [1, 2]. has enabled the design of granular (∼1x1 mm^2) fast-timing layers for the ATLAS and CMS tracking systems at the HL-LHC. These systems will allow the determination of the time-of-passage of minimum ionizing particles to a precision of better than 50 ps [3].

The essential design aspects of the LGAD can be described as: a region "p++" with a dopant concentration significantly greater than that of the bulk "p" region. This leads, after depletion, to an electric field large enough to provide amplification (by as much as a factor of 70) through multiplication of the signal. Because of this amplification, the "p" region can be made very thin (50 μm or less), leading to a fast signal and, in turn, precise timing. A current limitation of classic LGAD technology is the granularity. However several new technologies are being studied to overcome the LGAD granularity limitation as outlined in these references [4, 5, 6].

1 Time resolution limit

As seen in this reference [7] ultra thin sensors, with thickness of 20 um, show a potential to reach 10-15 ps of time resolution. The time resolution in thin silicon sensors has two components:

- A jitter component that ultimately depends on the rise time (Tmax) divided by the signal to noise ratio (SNR). This component an be modeled as T_{MAX}/SNR and can be minimized by increasing the SNR (more gain) and reducing the rise time (thinner sensors).
- A Landau component that depends on the Landau fluctuations of the collected charge in the Silicon. This component depends on the sensor thickness and can be modeled as $\alpha_L T_{MAX}$.

The resulting time resolution can be modeled as $\sigma_T = T_{MAX}\sqrt{(1/SNR)^2 + \alpha_L^2}$. As the SNR increases with the gain the time resolution can improve only until the Jitter component becomes smaller than the Landau component which depends uniquely on the sensor thickness.

This model is fitted, as shown in Figure 1, on sensors of 35 um and 20 um of thickness showing the different trend of the time resolution with the thickness. The 20 um sensor shown is first prototype where the gain layer was not optimized, but the fit shows that with sufficient SNR increase the time resolution limit can be pushed down to 13 ps. Similarly for a 35 um the time resolution limit from the fit is around 20 ps and for a 50 um is around 35 ps.

Therefore very thin sensors shows the potential to reach the needs of 10 ps of time resolution per hit requirements of future HEP experiments.

2 Radiation hardness limit

An additional application of ultra thin sensors in very high radiation environment [8, 9]. In the late years a saturation of the charge trapping effect in silicon was observed [10]. However at a fluence of $10^{17} - 10^{18}$ a standard 300 um silicon detector would still need several thousand volts to deplete. For a thin sensor instead the full depletion at very high fluence can happen at much lower voltages: 500 V of full depletion for a 50 um sensor at 10^{17}. The collected charge for thin sensors would be too small to be efficiently detected by readout electronics. However thin LGADs can be used thanks to the intrinsic charge multiplication, it was shown that sufficient gain is observed until a few 10^{15} for time resolution measurements purposes but less gain is necessary for hit detection only. Furthermore at high fluences gain in the bulk "p" region of the sensor can be activated by increasing the bias voltage applied to the sensor [8, 9].

These statements gives an indication of the radiation hardness properties of thin LGADs even at extreme fluences for hit detection. A future application of thin LGADs would then be a tracking system very close to the interaction point in future hadron colliders.

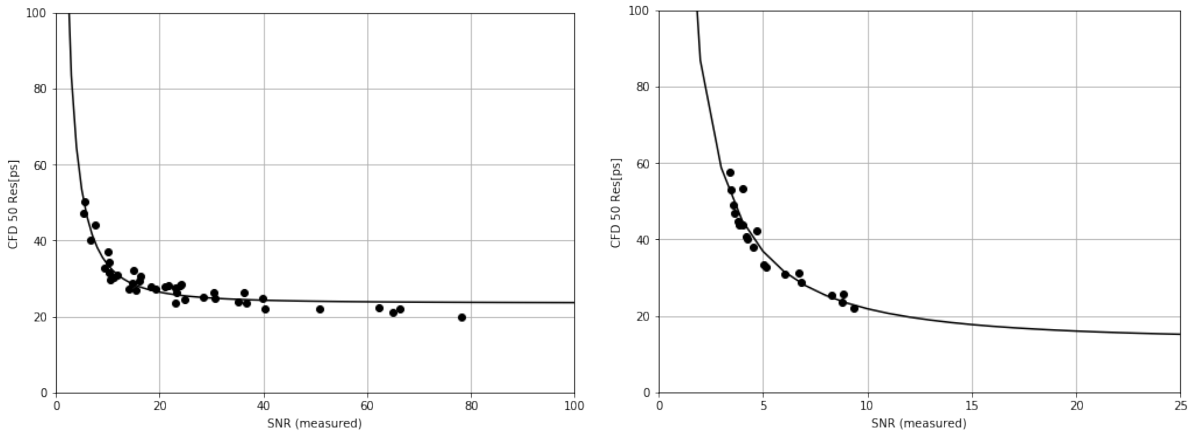

Figure 1: Time resolution versus SNR for 35 um (Left) and 20 um (Right) thick LGAD. Gain > 2.5 was required. The time resolution is calculated with a CFD (Constant Fraction Discriminator) algorithm of 50%. [7]

References

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