IL NUOVO CIMENTO **46 C** (2023) 104
DOI 10.1393/ncc/i2023-23104-0

COMMUNICATIONS: SIF Congress 2022

Timing performance of thin Low Gain Avalanche Detectors (LGADs)

S. STRAZZI

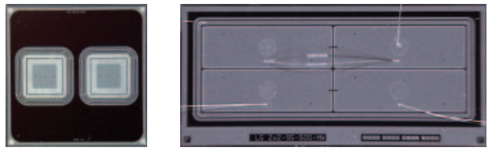
Dipartimento di Fisica e Astronomia, Università di Bologna - Bologna, Italy

received 30 January 2023

Summary. — The first very thin Low Gain Avalanche Detectors (LGADs) produced by Fondazione Bruno Kessler (FBK) were tested in a beam test setup at PS, CERN. The study focuses on LGADs with nominal thicknesses of 25 μm and 35 μm and an area of 1×1 mm^2. Several measurements were carried out and a summary of the timing performance is reported here. A time resolution of approximately 25 and 22 ps at voltages of 120 and 240 V was reached by 25 and 35 μm thick LGADs, respectively. These results demonstrate the potential of this new generation of LGADs.

1. – State of the art and study motivations

Low Gain Avalanche Detectors (LGADs), also known as Ultra Fast Silicon Detectors (UFSDs) [1], have been extensively studied in recent years and represent one of the most mature silicon technologies for timing applications. They are an evolution of the n-on-p planar silicon sensors, optimized to provide excellent timing performance by adding a heavily doped gain layer below the p-n junction to create a high electric field and exploit the impact ionization mechanism. The key point is the moderate internal gain between 10 and 70, keeping the sensor's noise under control and thus providing an excellent timing performance. Thanks to this, the LGAD technology is already used in several experiments and envisioned also for upgrades to those at the Large Hadron Collider (LHC), such as ATLAS [2] and CMS [3] in the HL-phase. However, future-generation experiments, like ALICE 3 [4] in LHC Run 5, have further increased interest in the R&D of high-resolution timing detectors, with the goal of achieving a time resolution of around 20 ps. This goal could be achieved using thinner LGADs. More details on the results presented here can be found in [5].



(a) (b)

Fig. 1. – Microscope photographs: (a) FBK25, composed by the tested LGAD on the left and a p-on-n detector with the same layout, but without the gain layer, on the right, used for characterization measurements; (b) HPK50 matrix, of which the bottom left pad was measured.

2. – Beam test setup and data acquisition configuration

The detectors under study, hereafter referred to as FBK25 and FBK35, with a nominal thickness of 25 and 35 μm, respectively, and an area of $1\times1\,\mathrm{mm}^2$, are the first thin wafers manufactured from Fondazione Bruno Kessler (FBK). In fig. 1(a), a microscope photo of FBK25 is reported (similar layout for FBK35). In addition, a $1 \times 3\,\mathrm{mm}^2$ LGAD with a standard thickness of 50 μm (HPK50, see fig. 1(b)) manufactured from Hamamatsu Photonics K.K (HPK), was tested for a comparison with the thinner layout. Prior to the beam test, a full electrical characterization was done on the samples at the INFN Bologna laboratories. All the main extracted parameters can be found in [5].

The thin FBK detectors were mounted on a single-channel Santa Cruz read-out board (V1.4-SCIPP-08/18) that contained a low-noise inverting amplifier (gain ~ 6) supplemented with an additional stage of amplification with a gain of 13 and 14 for FBK25 and FBK35, respectively. HPK50 was instead connected to a front-end board without amplification, followed by a Cividec amplifier with a gain of 190. Details can be found in [5]. The design of the beam test setup allowed for the simultaneous use of up to four sample boards. During each run, two or more read-out boards were arranged in a back-to-back configuration within a telescope frame. The entire setup was situated in a dark environment at room temperature.

The data for this study were collected at the T10 beamline at CERN's PS facility in November 2021. Using a 12 GeV/c hadron beam, the completed signal waveforms were recorded and analyzed with the use of an oscilloscope. The trigger for data acquisition was based on the coincidence of self-triggers from the DUTs (Devices Under Test), with data being acquired whenever all signals were simultaneously above a given threshold decided for each channel.

3. – Analysis and results

From the recorded events, after signals selection, the charge distribution was extracted for each LGAD, and it was then fitted with a Landau-Gaussian convoluted function to account for both signal shape and noise distribution. The collected charge for each sensor was defined as the Most Probable Value (MPV) from this fit. As an example, fig. 2 shows the charge distribution in the beam test setup for the three sensors considered at a similar gain of around 23 and for one sensor (35 μm) at different selected voltages. As expected, the amplitude of the distribution increases with both thickness and voltage, while the ratio between the width of the distribution and the MPVs decreases with increasing thickness. Additionally, fluctuations in the number of electrons-holes created in the silicon detector decreases with larger thickness, in accordance with previous measurements [6].

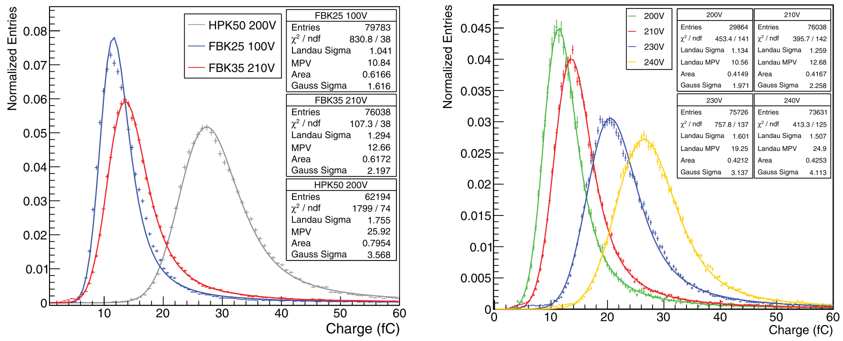


Fig. 2. – Charge distribution in the beam test setup fitted with Landau-Gaussian convoluted function (a) for the three detectors for a similar gain around 23 and (b) for one detector (FBK35) for different applied voltages.

The timing performance of the DUTs was extracted using the Constant Fraction Discriminator (CFD) method, after applying a four-points moving average smoothing to the signals to filter out the high-frequency noise. The time resolution of each LGAD was found considering a system with the differences between the threshold crossing time of each pair of detectors in the frame. The time difference distributions were fitted with an asymmetric q-Gaussian function to account for the Gaussian shape of the arrival time distribution with a small tail at late times. The sigma extracted from the fit is reported in fig. 3 as a function of the CFD threshold for all the applied voltages. As expected, at high CFD the time resolution is dominated by the Landau term, expected to be smaller for thinner detectors, while the trend reflects the higher jitter contribution for very low CFD [1]. Both these contributions depend on electronics, detectors and shielding against outer noise.

Considering a fixed CFD, in fig. 4 the time resolution is reported as a function of gain (a) and voltage (b), along with the intrinsic time resolution extracted taking into account the jitter of each DUT. Note that HPK50, which achieves a time resolution of

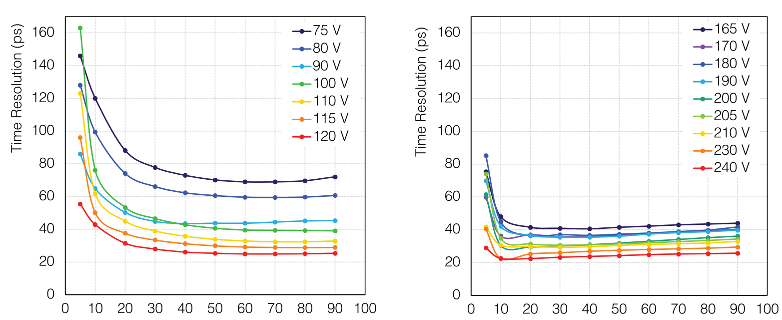
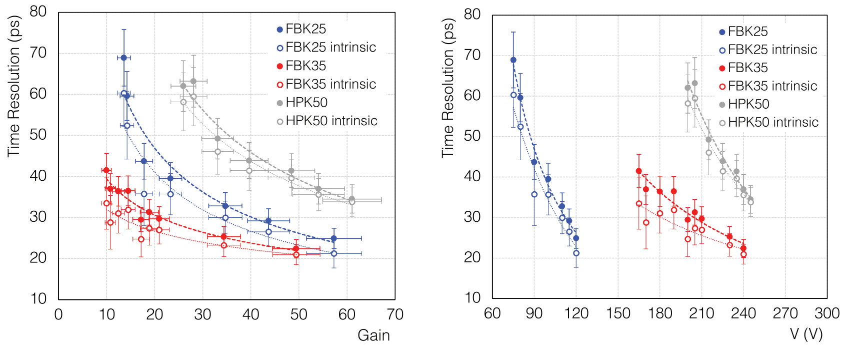


Fig. 3. – Measured time resolution of (a) FBK25 and (b) FBK35 as a function of the CFD threshold for different applied voltages. The errors, not shown in the plots, are about 10%.



(a) (b)

Fig. 4. – FBK25, FBK35 and HPK50 time resolution as a function of the (a) gain and (b) applied voltage, for a CFD of 60%, 20% and 50%, respectively. The full circles correspond to the measured time resolution, while the empty circles correspond to the intrinsic one. The errors, not shown in the plots, are estimated to be around 10% of the measurements.

$\sim$ 34 ps, has trends and values in agreement with previous results [7]. A better time resolution was found with the thinner LGADs, as expected. However, especially at low gains, FBK25 seems to perform worse, not in line with expectations. This could be due to a lower S/N ratio. Instead, the results of FBK35 were totally in line with expectations, reaching a time resolution of 22 ps for the highest applied voltage.

4. – Conclusions

Several results obtained with a new generation of LGADs are reported in this article. FBK sensors with a thickness of 25 μm and 35 μm were tested for the first time in a beam test setup with a 12 GeV/c beam at CERN PS. A time resolution of 22 and 25 ps at a bias voltage of 240 and 120 V was achieved from FBK35 and FBK25, respectively. FBK25 did not show any improvement in the time resolution over FBK35 due to its highly doped substrate not being optimized for timing measurements. However, all the results for the different thicknesses are consistent with simulations and demonstrate the potential for improved time resolution with thinner LGAD detectors.

REFERENCES

[1] Sadrozinski H. F.-W. *et al.*, *Rep. Prog. Phys.*, **81** (2018) 026101.
[2] ATLAS Collaboration, *Technical Proposal: A High-Granularity Timing Detector for the ATLAS Phase-II Upgrade*, Technical report, CERN, Geneva, CERN-LHCC-2018-023 (2018).
[3] CMS Collaboration, *A MIP Timing Detector for the CMS Phase-2 Upgrade*, Technical report, CERN, Geneva, CERN-LHCC-2019-003 (2019).
[4] ALICE Collaboration, *Letter of Intent for ALICE 3: A next generation heavy-ion experiment at the LHC*, arXiv:2211.02491.
[5] Carnesecchi F., Strazzi S. *et al.*, *Eur. Phys. J. Plus*, **138** (2023) 99.
[6] Meroli S. *et al.*, *JINST*, **6** (2011) 06013.
[7] Cartiglia N. *et al.*, *Nucl. Instrum. Methods A*, **850** (2017) 83.