<u>INTERSHIP REPORT</u>

Developpemnt of equipment and setup aimed at testing novel AC-LGAD silicon detector

Komlan Augustin Sokpor, University of Lomé, Togo

augustinsokpor@gmail.com / sokpor.komlan.augustin@cern.ch

INTODUCTION

LGAD are class of silicon sensors developed for the fast detection of minimum ionization particle. Built on thin silicon substrates and featuring an internal moderate gain, they provide fast signals, for excellent timing, performance, which are therefore useful to distinguish the different tracks. We distinguish several families of LGAD, namely: capacitively coupled LGADs (AC-LGAD), deep-junction LGADs (DJ-LGAD) and trench-isolated LGADs (TI-LGADs).

The following figure shows an example of an ultra-fast silicon detector with a highly doped p+ gain layer. The structure of LGAD is based on the standard PIN diode architecture with an n+ layer as the cathode and a p+ layer as the anode. A high bias voltage is applied across the anode and charge is collected at the n + cathode. The substrate p is the active volume where the electron-hole and the drift couples are located. Just under the n+ layer, a special gain layer, that is to say a multiplication layer, composed of silicon doped by a (p+) acceptor. The termination extension (JTE) made by an n+ dopant is added to the perimeter of the cathode to shape the electric field at the edge of the electrode and to protect the sensor from early failure [1]. In the figure 1, we can see an illustration of the structure LGAD.

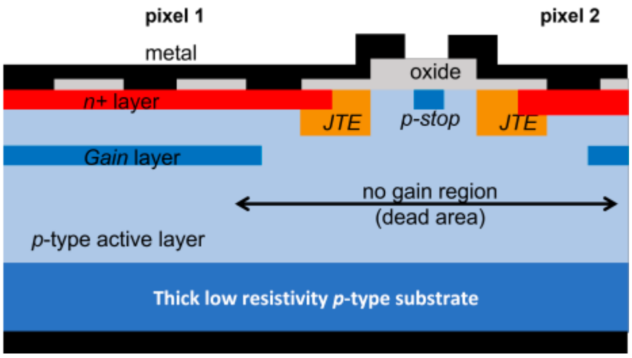


Figure 1: Structure of LGAD [2]

The LGAD sensor technology is used to build part of the ATLAS Detector of the Large Hadron Collider (LHC) at CERN to participate in new research and in making precise measurements of the properties of the Standard Model of Particle Physics. Indeed, nearly two million LGADs sensors will be assembled to build one of the very first high-granularity time detectors, which will be essential for the next phase of the LHC, where collisions will be so numerous that it will be impossible to distinguish them using only spatial information.

During our internship at Brookhaven National Laboratory, I worked on the electrical and thermal characterization of LGAD sensors and silicon diodes in order to compare the electrical properties between these two sensors.

I arrived at BNL on July 31, 2023. My internship took place in the Department of Physics within the Omega Group under the supervision of Dr Kétévi Assamagan and Dr Alessandro Tricoli.

I carried out the characterization tests in the Instrumentation Division department where Enrico Rossi was my main supervisor.

I- Electrical characterization (IV)

To carry out the electrical characterization of our sensors we used different devices and software. This characterization was made at probe station.

1- Electrical characterization methods

The following devices and software are used to perform the characterization:

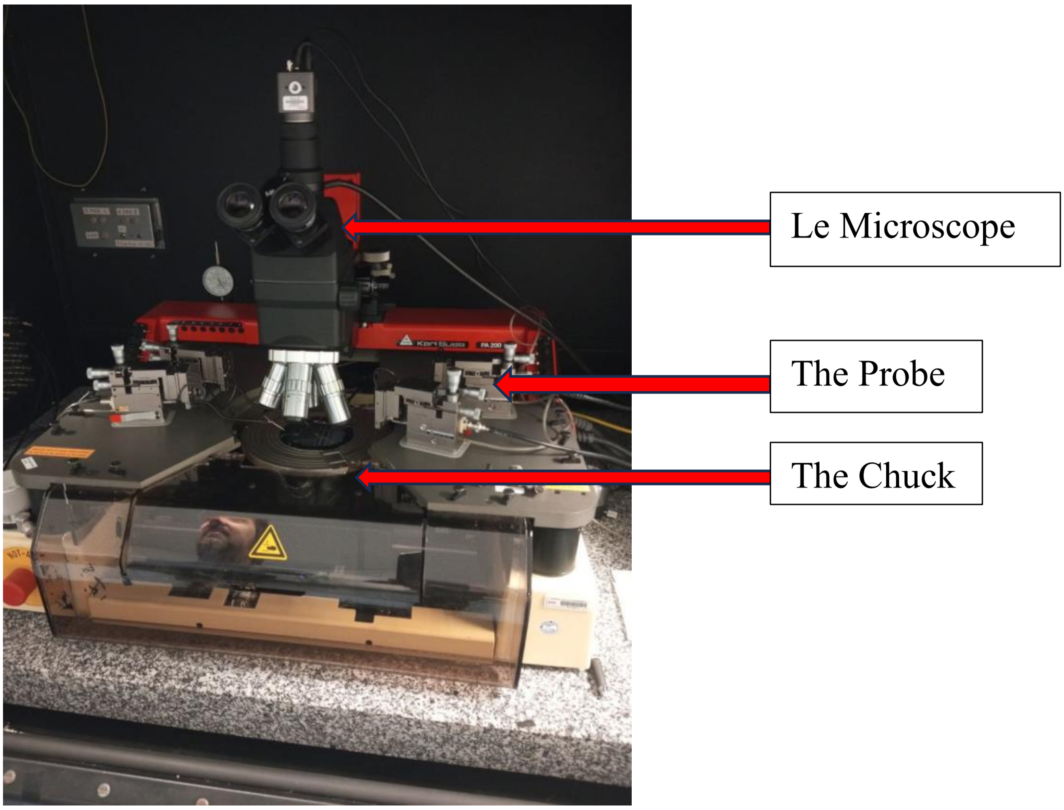


Figure 2: Probe station

The sensor is placed on the chuck. The probe is used to connect the pad and the guard ring to the sensors in order to perform the measurement. The microscope allows us to view the sensor in order to be able to connect the probe to the sensors we want to test. The figure 3 shows us how to connect the probe before taking the measurement.

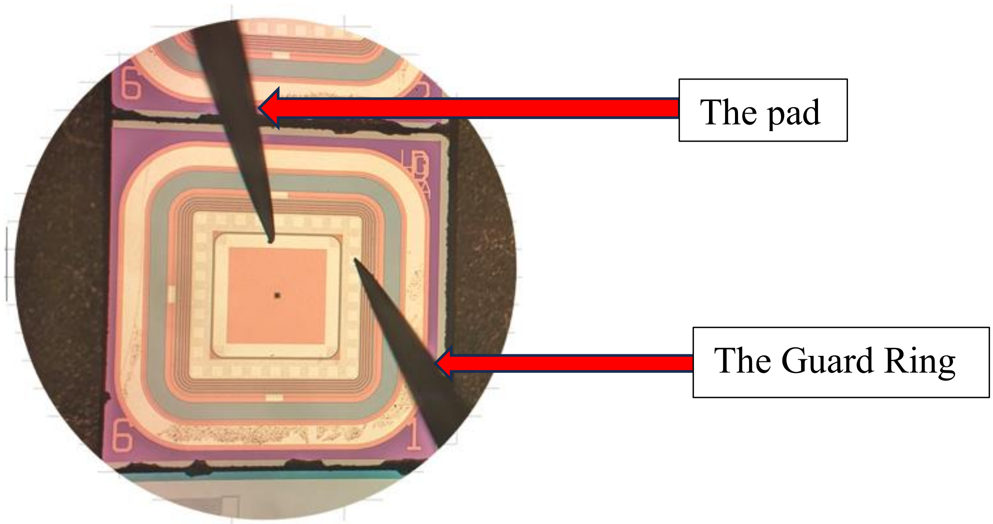
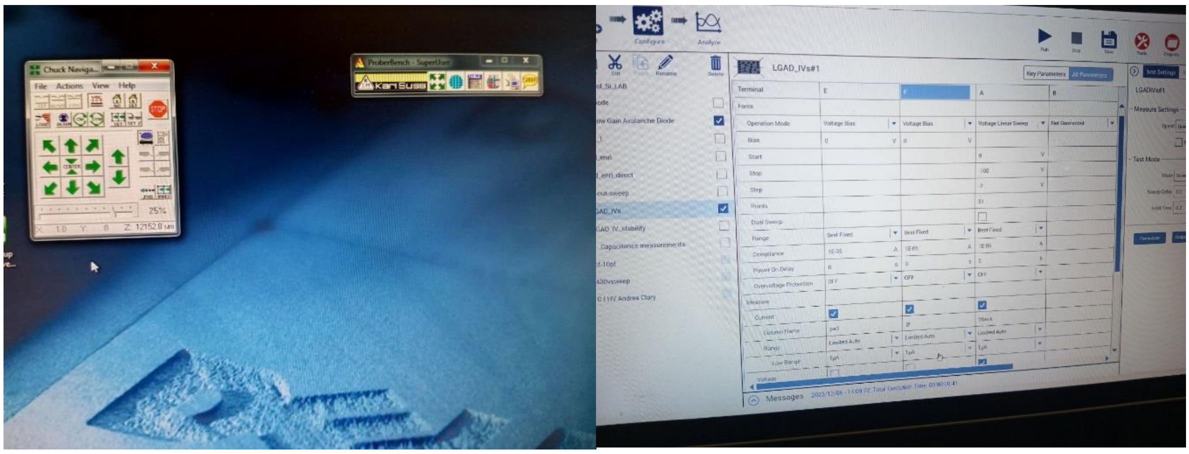


Figure 3: Measuring a sensor

This figure shows an example of a silicon sensor in full measurement.

Clarius software to run the program. After measuring the sensor the data is taken and analyzed.

In the following we will illustrate the software we used for this experiment.



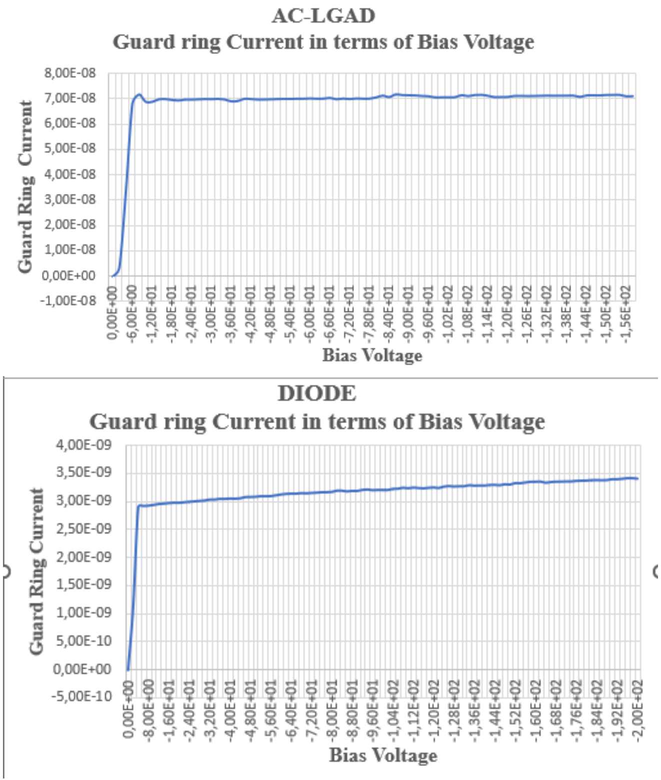
We use the software of ProbeBench and ChuckNavigation are used for moving Probe station's chuck

Clarius Software connected to the parameter's analyzer and power supply. It used for IV measurements, plotting data and saving data in a file.

Figure 4: Measurement Software

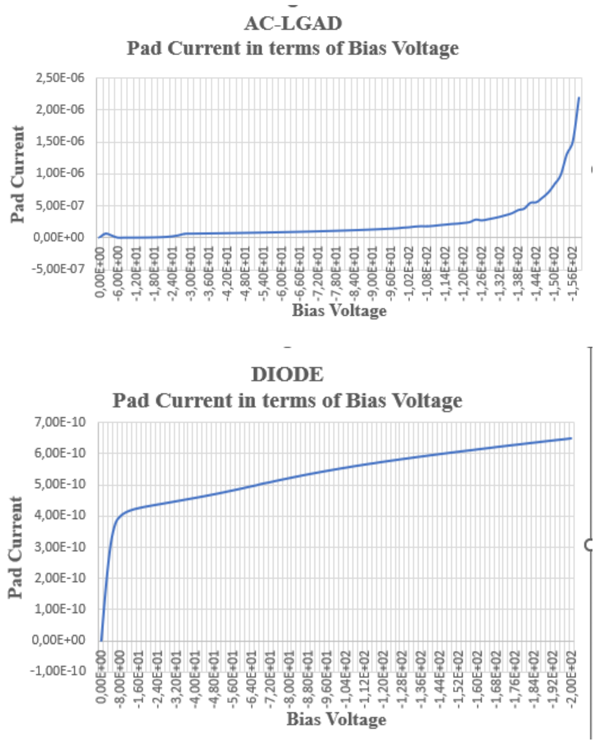
2- <u>Electrical characterization results</u>

The following figures show the results of the electrical characterization.



The plots show the guard ring leakage current (Amps) as a function of bias Voltage. It is important to ensure that there are no early failures or currents so high (above the milliamp range) that the device is damaged.
We can see early failure when the current reaches the instrument's compliance limit (usually around 0.1A) before the supposed breakdown voltage

Figure 5: Comparison of Guard Ring Current between diode and LGAD



The graphs show the difference of IV curves between a diode and an LGAD. The diode does not go in breakdown (until way after 200V) The LGAD does. The Break Down voltage is a function of thickness, doping and temperature.

Figure 6: Comparison of Pad current between diode and LGAD

II- <u>Thermal characterization</u>

1- <u>Thermal characterization method.</u>

We are commissioning a cold probe station in which we can perform electrical characterization, primarily IV scans on LGAD sensors at cryogenic temperatures. Initially we have been working on the thermal insulation of the probe station and identifying the optimum functionalities of instruments like the Chiller, Peltier which we use to cool down on the chuck on which sensors will be placed. We also worked on the Nitrogen supply to the station which is used to prevent condensation in the station when the temperature drops below 0C. This probe station will enable us to handle many sensors at a time to take IVs below -30 C.

To carry out this electrical characterization test I used the cold probe station indicated in the following picture:

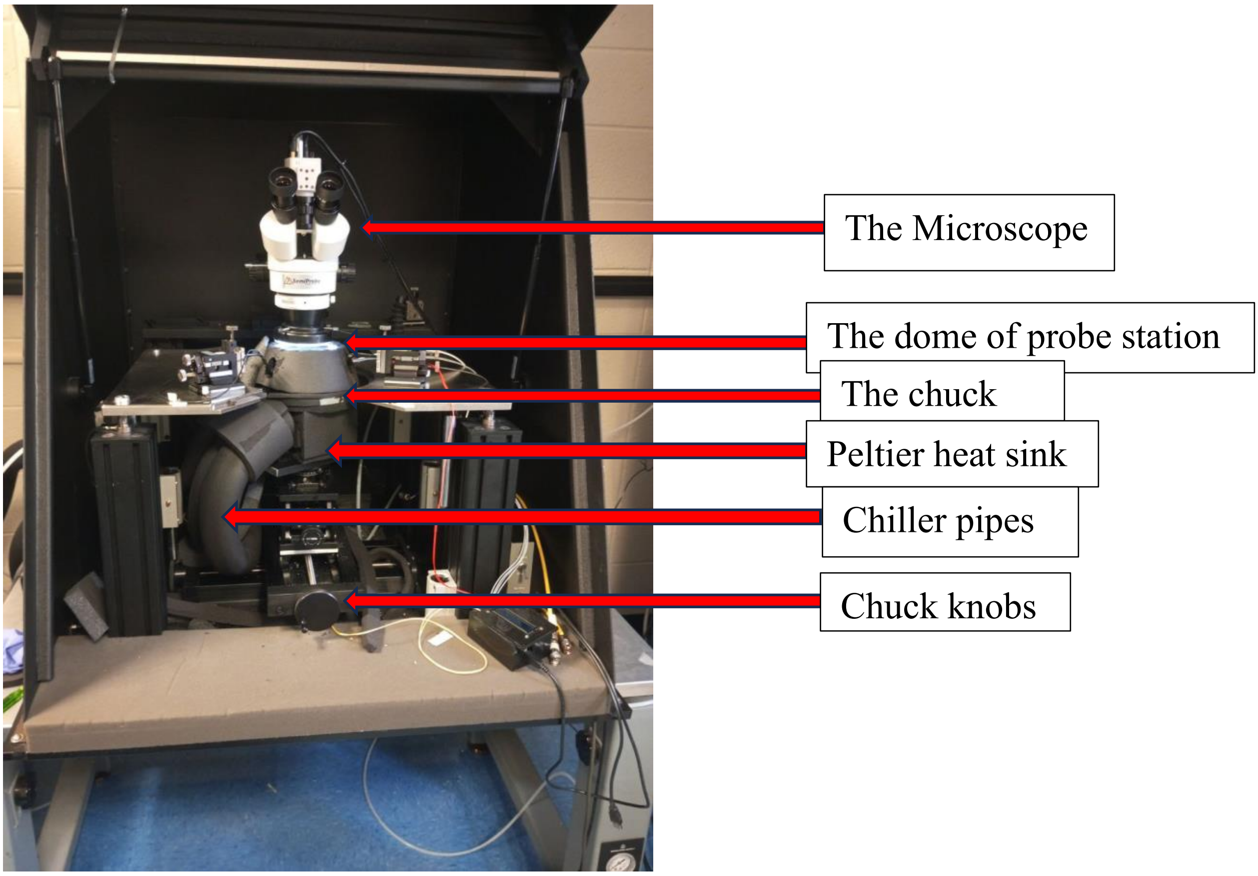


Figure 7: Cold Probe station

2- <u>Thermal characterization result</u>

The result of cold probe station test is obtained using as Python code which allowed us to obtain the plot in figure 8. This plot shows the evolution of humidity, the chuck temperature, of the ambient temperature as well as the dew point as a function of time. The dew point allowed us to know when condensation can occur. Nitrogen liquid is used to prevent condensation so that the sensor is not damaged.

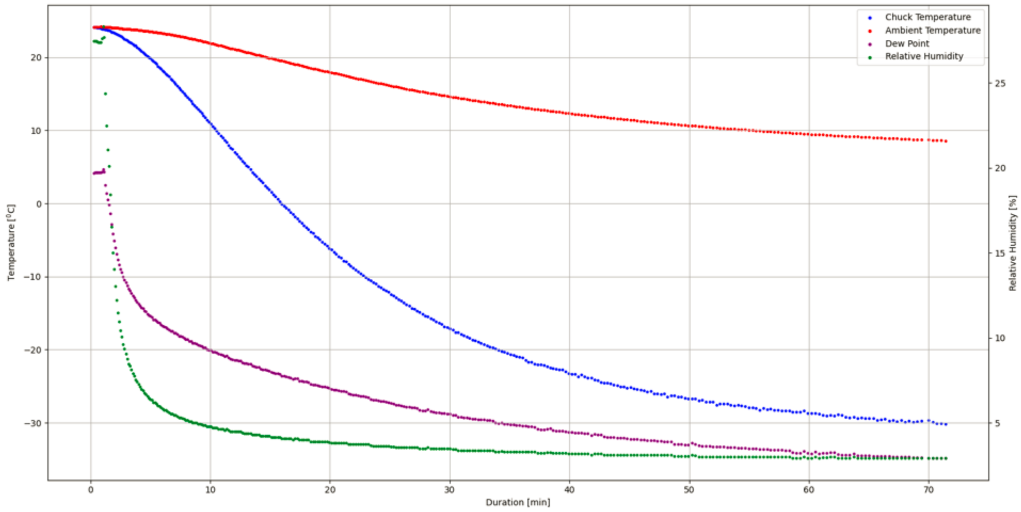


Figure 8: Cold probe station test result

The graph shows the temperature at which the cold probe station stabilizes and how long it takes.
The goal is to have a chuck temperature of -30 Celsius degrees. Therefore, we need good insulation.

CONCLUSION

This internship allowed me to acquire technical skills in the use of silicon sensor characterization devices. I also learned lessons about technology from LGAD.
The different results allowed us to compare the electrical properties between the LGAD and the silicon diode. Some LGADs will operate in a cold environment experiment. The cold probe station aims at simulating a cold environment while allowing us to test multiple devices together and faster, instead of just one or two a time like in the climate chamber. We operate the cold probe station at -30 degree Celsius because this is the temperature, we operate the detectors at the LHC after they are irradiated.

ACKNOWLEDGEMENTS

I express my sincere thanks to all the staff of Omega Group in the Physics department of BNL.
I thank the Department of Energy.

List of figures

Bibliographic References

[1] V. Raskina, Research and development of the High-Granularity Timing Detector (HGTD) for the ATLAS Detector as the preparation of the High-Luminosity LHC operation phase, 2023.

[2] G. Giacomini, «LGAD-Based Silicon Sensors for 4D Detectors».