Contributions to CMS Phase II tracker module assembly

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Abstract

This report details the work I completed on the research and development of assembly methods for the modules of the phase II upgrade tracker of the CMS experiment. First, the effect of epoxy bleeding on electrical performance of sensors is measured. Second, UV cured glue as method of decreasing assembly time is investigated. Finally, the development and construction of a system to provide power and control to a motion stage used to control a plasma cleaner is described.

1. Introduction

1.1. Compact Muon Solenoid

The Compact Muon Solenoid (CMS) is a cylindrical particle detector designed to measure a wide range of particles produced in the collisions of Large Hadron Collider (LHC). The size of the detector is around 28 m long and 15 m in diameter. It is the heaviest detector in the world and weighs approximately 14000 t. The name "CMS" originates from the three key characteristics of the detector: its relatively *compact* size, its excellent capabilities in the detection and measurement of *muons* and its central feature, a superconducting 3.8T *solenoid* magnet. [1]

The CMS detector consists of many separate detector layers, each of them playing an individual role in detecting and measuring the traversing particles. A cross-sectional overview of the layers and its tasks in reconstructing tracks of particles is shown in the Figure 1.1.

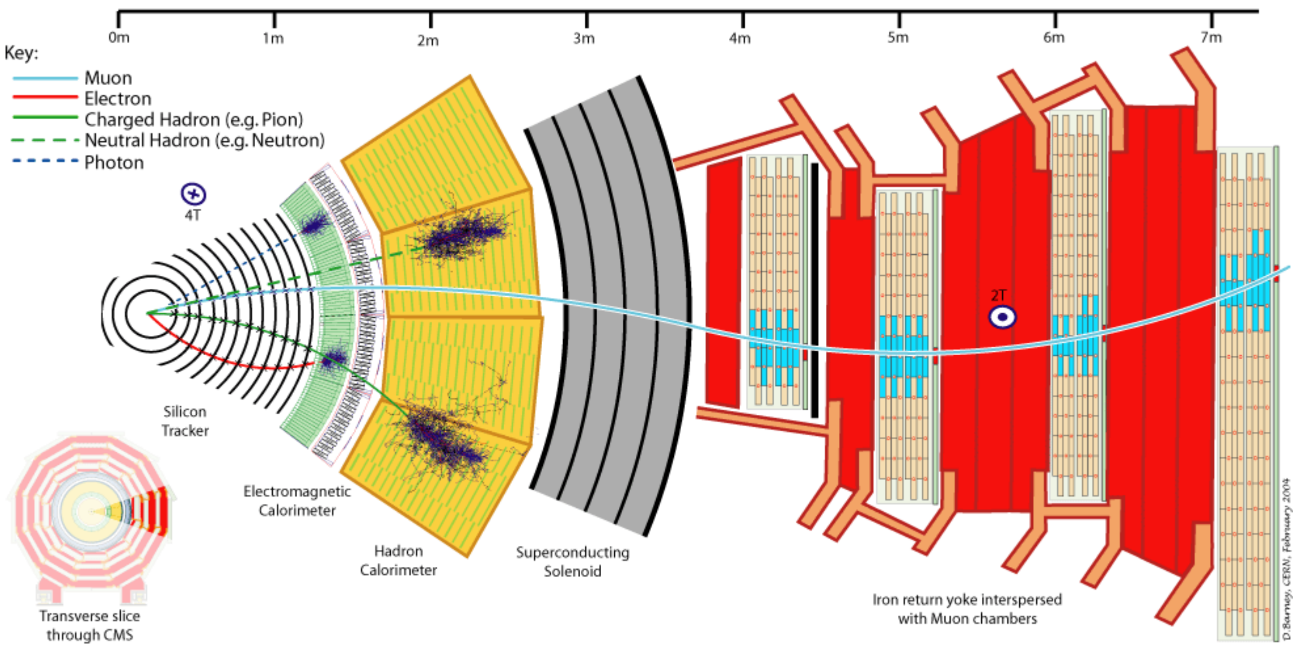


Figure 1.1. A cross-sectional view of the CMS detection layers.

1.2. CMS Phase II tracker Upgrade

After *Phase II* Upgrade, the LHC will provide a much higher luminosity. This regime is known as the High Luminosity LHC (HL-LHC). A serious problem presented by these conditions is the enormous data readout rates that exceed far beyond the bandwidth foreseen for the readout electronics [2].

However, the vast majority particles produced in the HL-LHC conditions are not of direct interest for new physics searches and are characterized by low transverse momentum. Thus rejecting tracker “hits” related to low transverse momentum particles can significantly reduce the amount of data to be readout. In order to provide momentum discrimination at the hardware level, a 2-layer module design was created. The central idea of the new modules is to provide fast discrimination between low and high momentum particles by estimating the track curvature caused by the magnetic field within the volume of the module itself. For example, particle with high transverse momentum after hitting some pixel/strip at the first sensor layer would hit on of neighboring pixels/strips of the respective pixel/strip on the second layer. While a particle with low transverse momentum would have a more curved trajectory an hit pixel/strips at a displaced position from the first hit. By varying the distance between sensors and number of neighboring pixel/strips required to match hits in adjacent sensors, (2 neighboring strips in the Figure 1.2) it is possible to set the transverse momentum threshold for a hit.

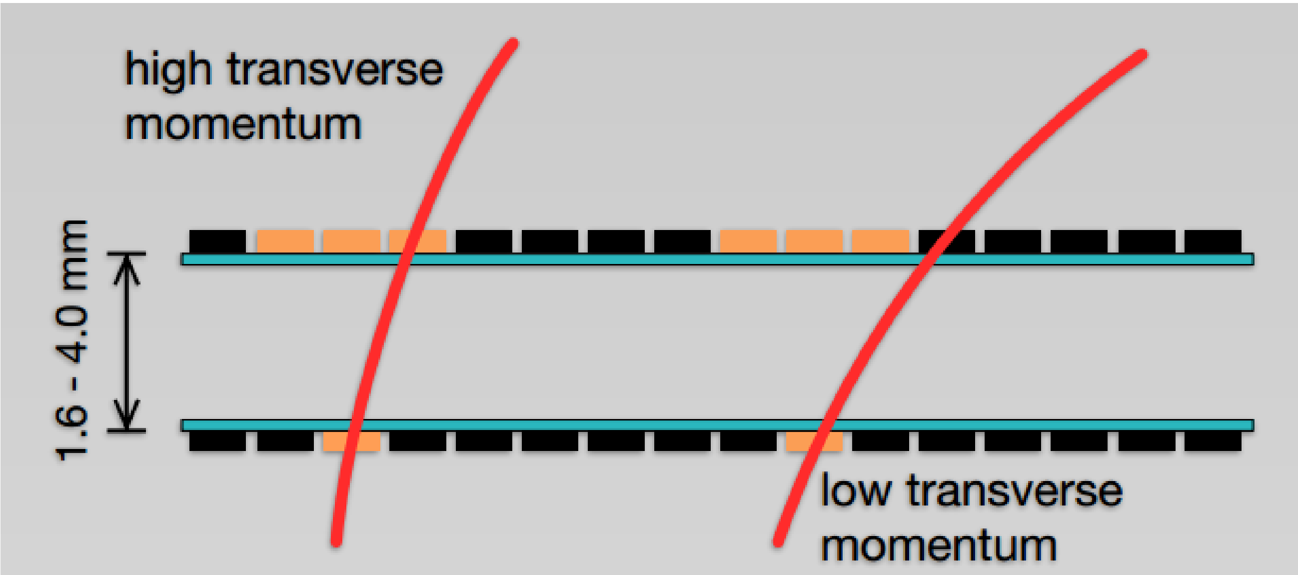


Figure 1.2. An example of distinguishing high and low transverse momentum. Particles, which hit any of two neighboring strips or the respective strip itself, would be record as high transverse momentum particles.

An exploded view of one type of 2-layers modules is shown on the Figure 1.3.

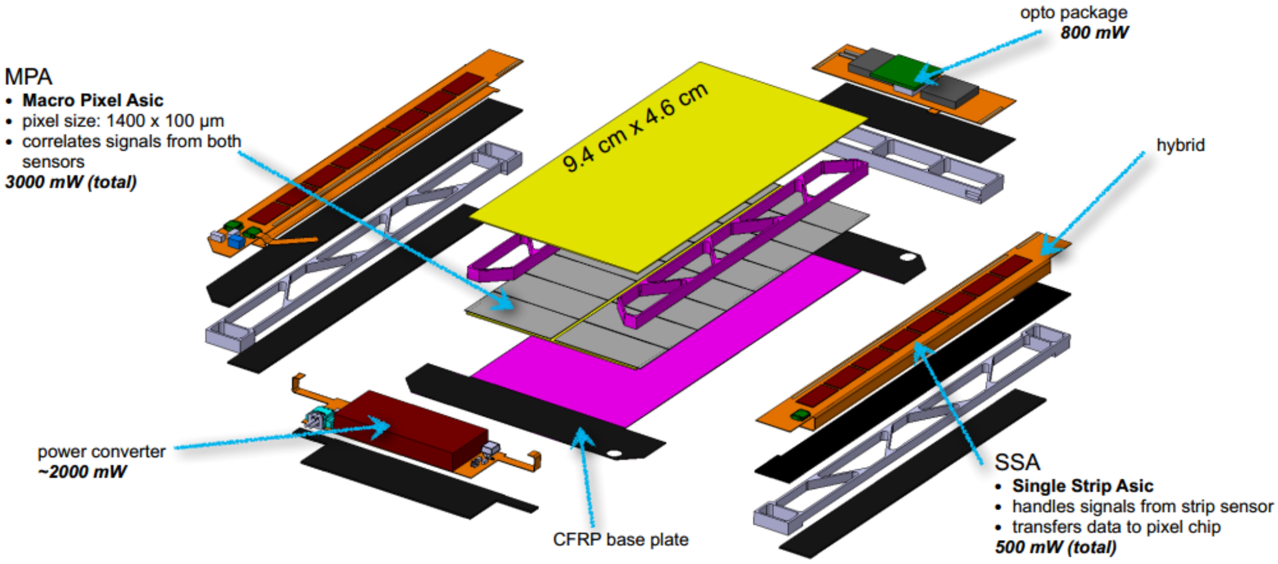


Figure 1.3. Exploded view of a one type of 2-layer module.

On the figure the yellow component represents the strip sensor, while gray rectangle-shape components under it are pixels of a pixel sensor. The purple structure between them is an Aluminum Carbon Fibered (AlCF) supported bridge. Purple and black component in the bottom is a supporting carbon fiber base plate. Brown-red part in the left-bottom corner of the picture is a power connector. Brown components on the sides and on the top-right corner represent read/out electronics of the module. Other black and gray parts are mechanical supported structures.

2. Contributions to CMS Phase II tracker module assembly.

In this section my personal work as a Summer Student in DESY will be described.

2.1. Epoxy bleeding

Precise relative alignment of components is crucial for transverse momentum discrimination. The most stringent requirement on the relative position of the two sensors where a precision of approximately 20 um is required. All components of the module need to be mechanically joined with glue. A suitable glue bond can satisfy a strong need for good thermal conductance across the module.

The glue should fulfil lots of requirements, e.g. radiation resistance, thermal conductivity, minimal mass, high transition temperature, low coefficient of thermal expansion and long life time. The chosen glue is *Epotek 301*. However, initial tests with this glue carried out by a group at CERN show that after curing a deposit is observed on the nearby surfaces. This effect is henceforth referred to as “epoxy bleeding”. Epoxy bleeding can be observed even on the opposite side of the sensor. A cross-sectional view sketch of the module is shown in the Figure 2.1. Yellow components represent sensors, while orange ones – kapton. Purple parts are AlCF support structures between sensors. Blue layers represent glue, while blue arrows schematically show how the epoxy bleed “gas” can go around the edge of the surface.

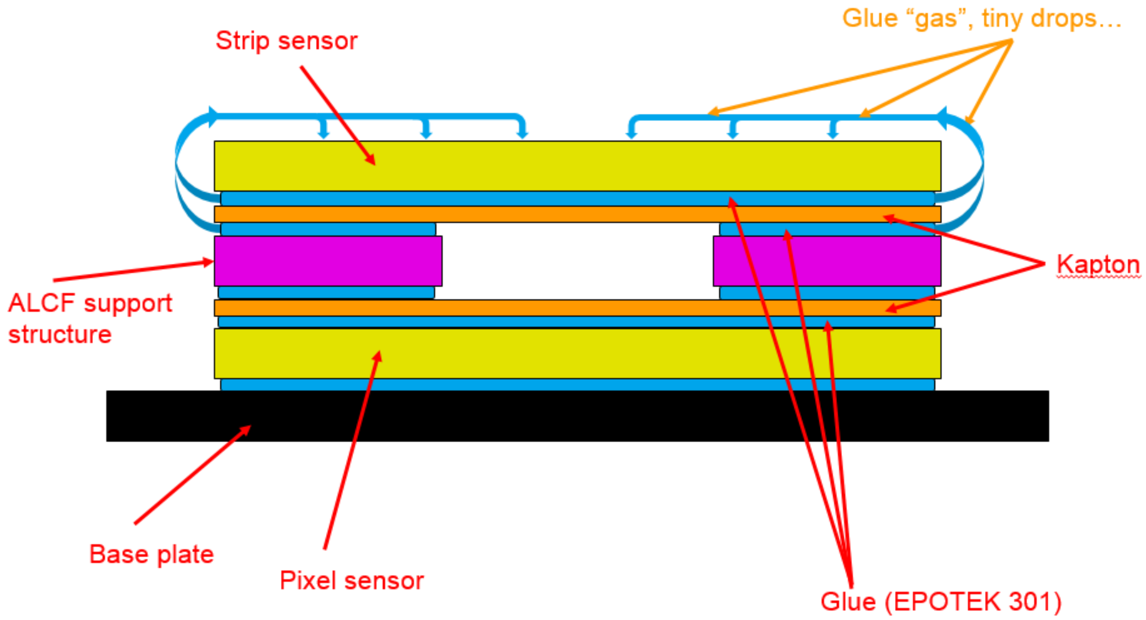


Figure 2.1. Cross-sectional view sketch of the module.

In order to assess the potential problems to posed by Epoxy bleeding, its effect on the electrical performance of a silicon sensor must be measured. In lieu of the final sensors, test pieces of silicon were used. These test samples act as realistic electrical models of the final CMS tracker sensors.

Firstly, to reconfirm the epoxy bleeding effect, a glue drop was deposited on a surface and after some time the expected coloured stain appears around the glue drop (Figure 2.2).

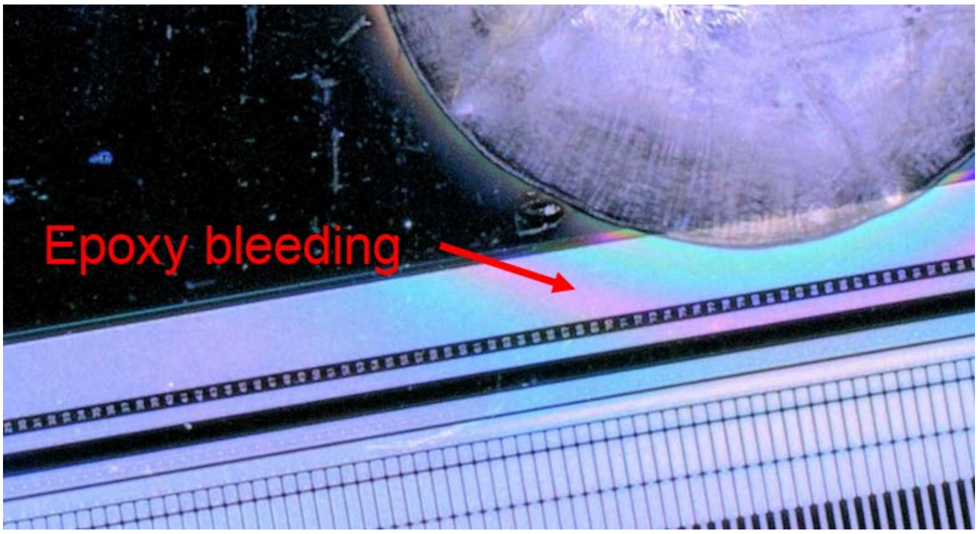


Figure 2.2. Epoxy bleeding observation around a glue drop.

2.2. Used facility and samples

In order to investigate the epoxy bleeding effect on the electrical properties of the sensors, we want to measure the IV curves of the samples using an electrical testing station. Several samples were made to simulate the glue joint of the module assembly. One of the samples is shown in the Figure 2.3.

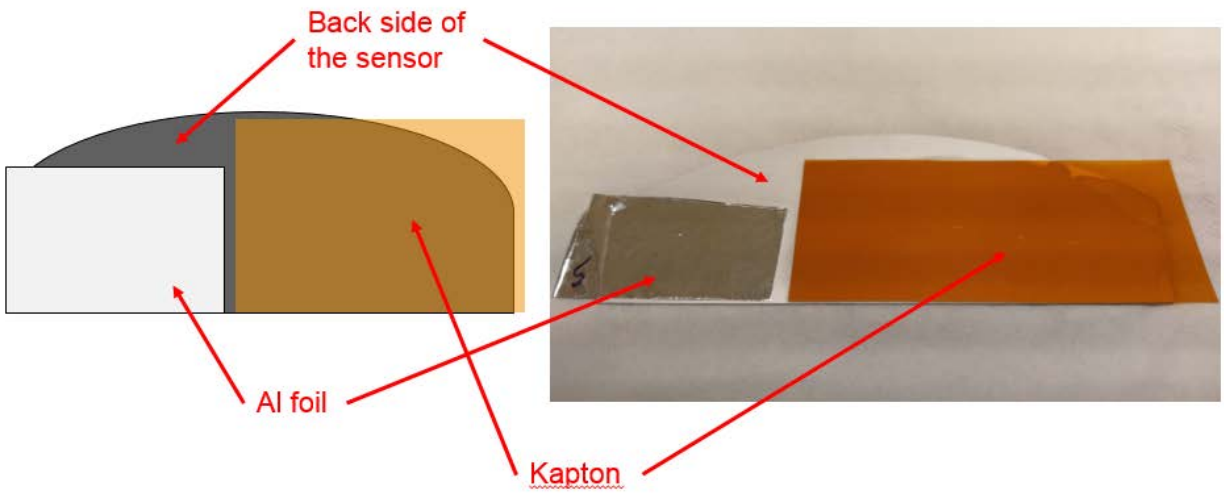


Figure 2.3. Tested sample.

Kapton is glued directly under the sensor strips on the other side. Aluminum foil is glued with a silver paste in order to provide the electrical connectivity.

The probe station, which was used to measure IV curves, is shown on the Figure 2.4. Large potential difference was applied across the sensor. In particular, high positive voltage (up to 500V) was applied to the back side of the sensor and a needle with zero voltage was connected to the bias ring of the sensor. The bias ring connects via resistors the individual strips to a defined potential, in our case to 0V of the needle. [3]

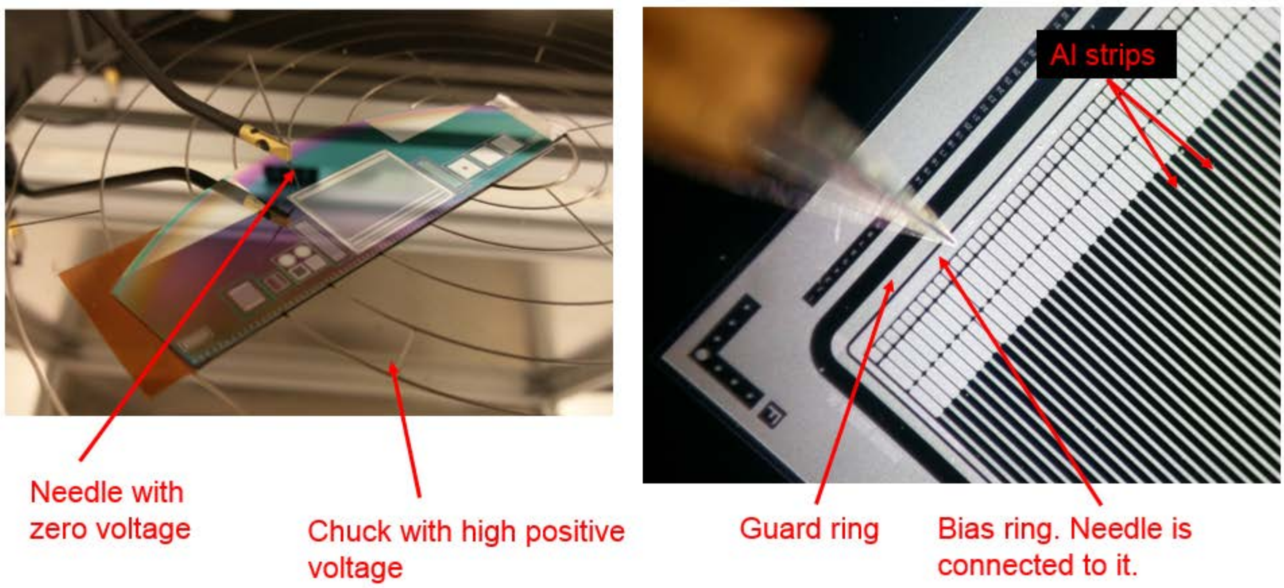


Figure 2.4. Probe station.

A number of gluing scenarios were explored:

- 2 samples (300um) with glue drops on top. One has a glue drop beside sensor strips, another has a glue drop, which partly cover sensor strips.
- 2 same samples (300um) with small amount of glue between kapton and back side of the sensor.
- 1 sample (300um) with bigger amount of glue between kapton and back side of the sensor.
- 1 sample (300um) with another glue (Epotek 301-1) between kapton and back side of the sensor.
- 2 samples (500um) without glue for measuring statistical uncertainties.

2.3. Results of the tests

Before putting the glue or Al foil to samples we measured its IV curves. This scenario is referred to as “default” in the following plots. The same concerns Al foil: before gluing kapton the IV curve of a sample with Al foil was measured. The IV curve corresponds to it is called “with Al foil”.

Each of the following plots has the same structure. X-axes shows voltage applied to the sample, while Y-axes represents current through the sample. Different coloured curves corresponds to different periods of time after curing. Every measuring is shown in logarithmic scale of X-axes.

Here is the list of glue scenarios:

- Glue drops were put on sensor surface.
  A glue drop was put on sensor's strips (Figure 2.5).

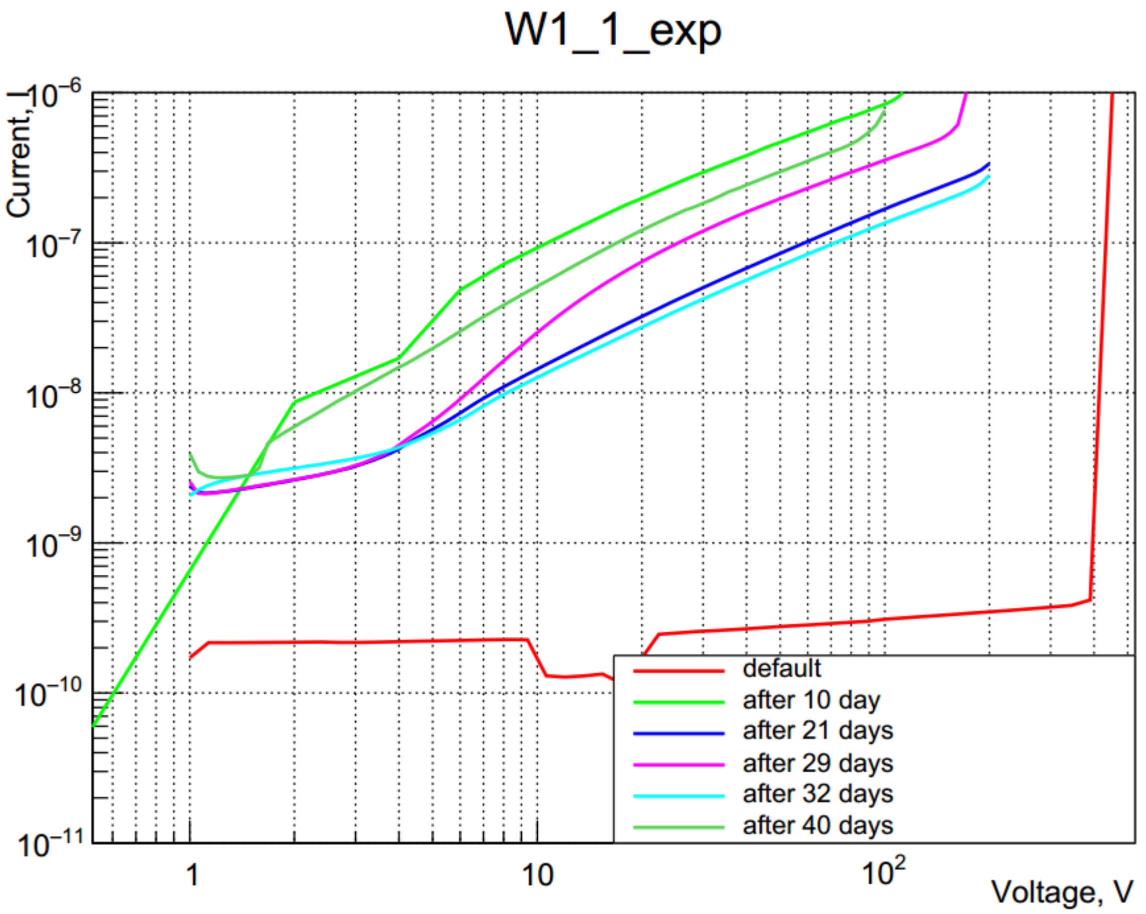


Figure 2.5. IV curve of a sample with a glue drop on sensor's strips.

After putting the glue drop one can see a breakdown effect at about 200V, which is crucial for sensor. Breakdown can be characterized by a sudden, rapid increase of the current under reverse bias. This effect confirms the effect of the glue on the sensor's electrical properties.

In another experiment the glue drop was put a small distance away from the strips from sensor's strips (Figure 2.6)

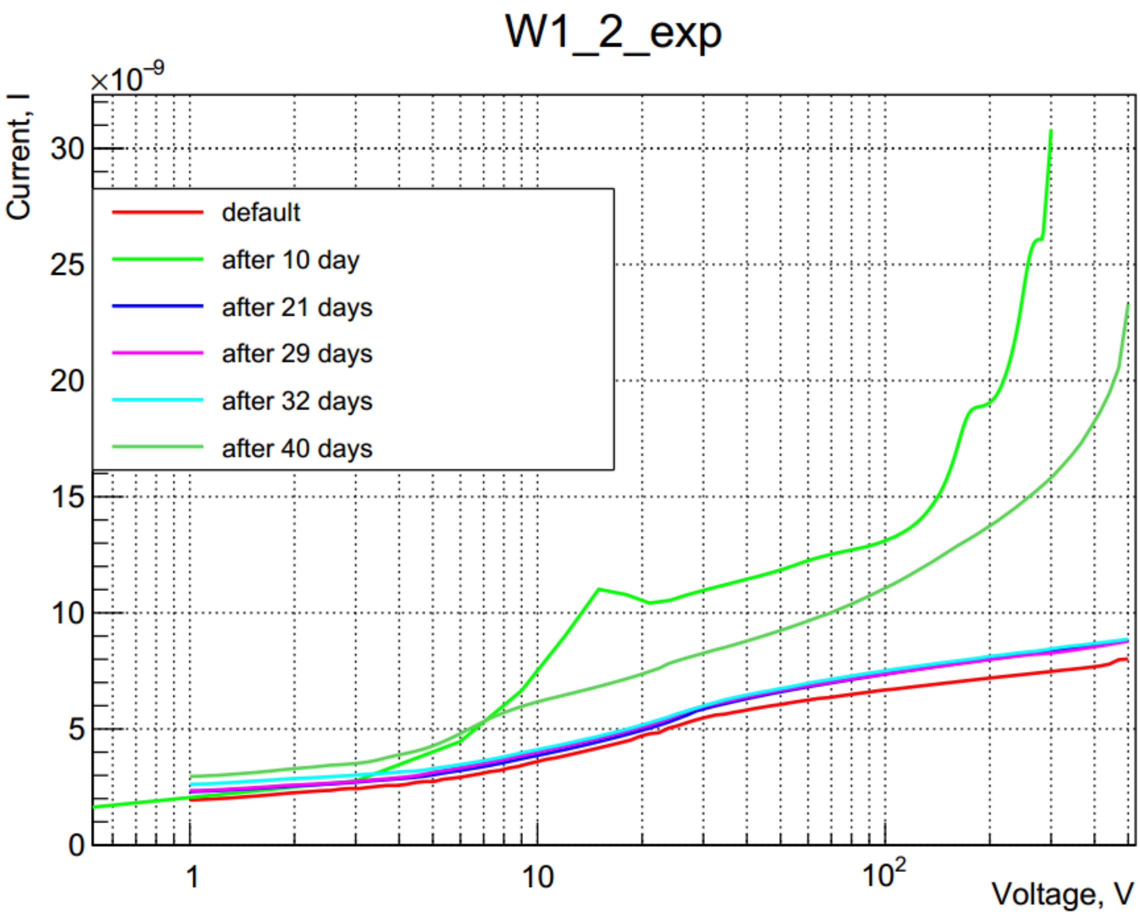
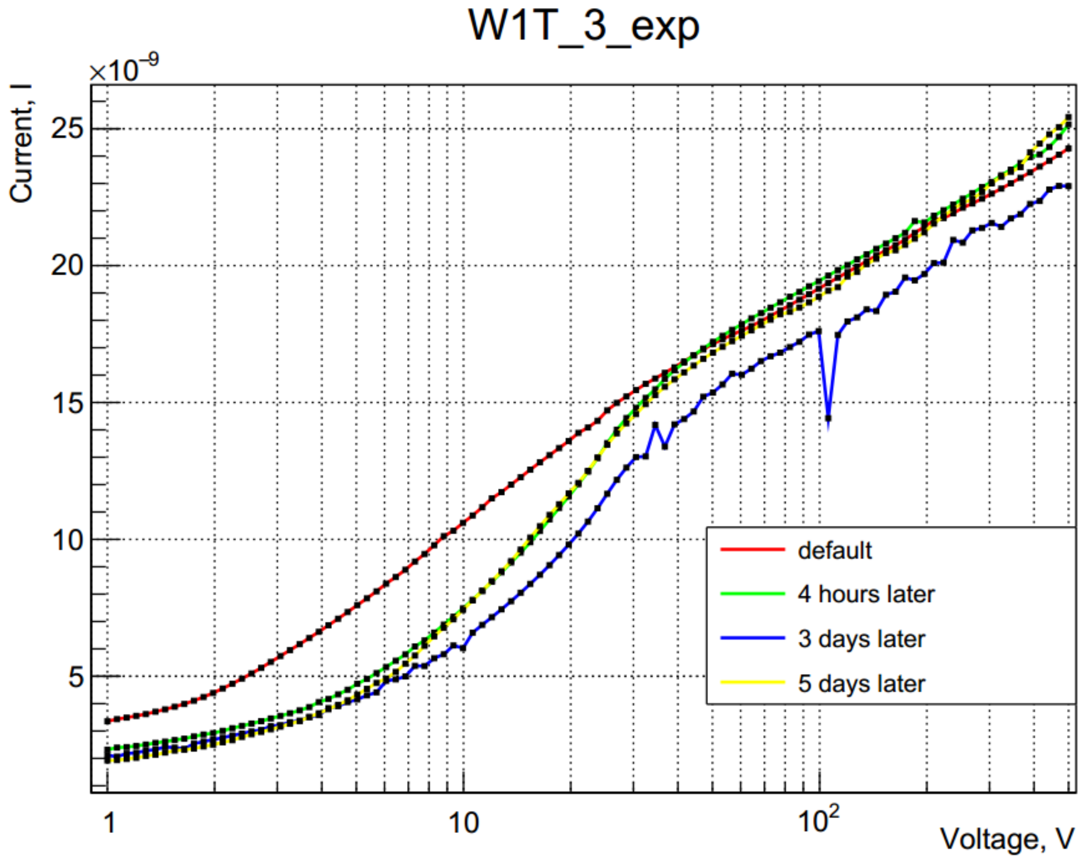


Figure 2.6. IV curve of a sample with a glue drop sensor's strips.

In this case the changes in IV curves are smaller, but still noticeable. There is a break down effect at about 300V after 10 days. Interestingly, the electrical properties seem to recover after some additional time.

- Different amount of glue.
  On 2 samples kapton was glued with small amount of glue (Figure 2.7)



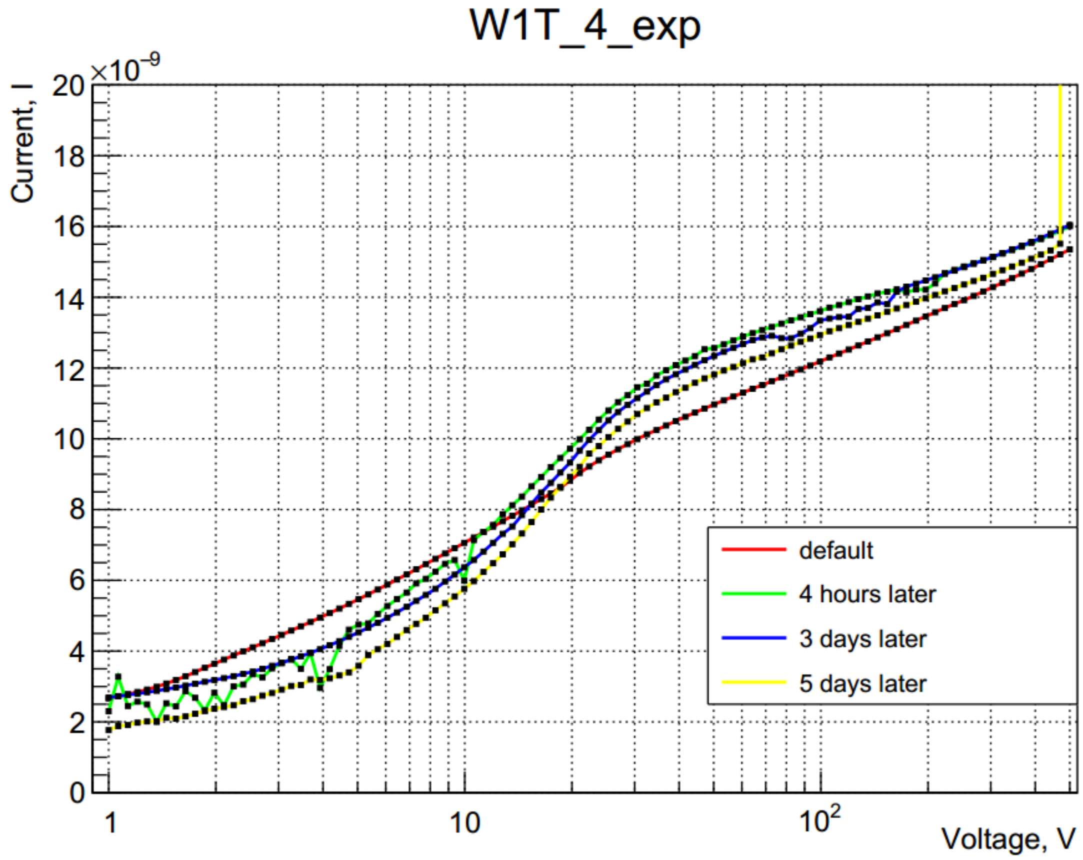


Figure 2.7. IV curve of a sample with kapton glued with small amount of glue.

There are almost no changes in IV curves having small amount of glue between kapton and sensor. That was the reason to make a test with larger amount of glue. On another sample kapton was glued with larger amount of glue (Figure 2.8)

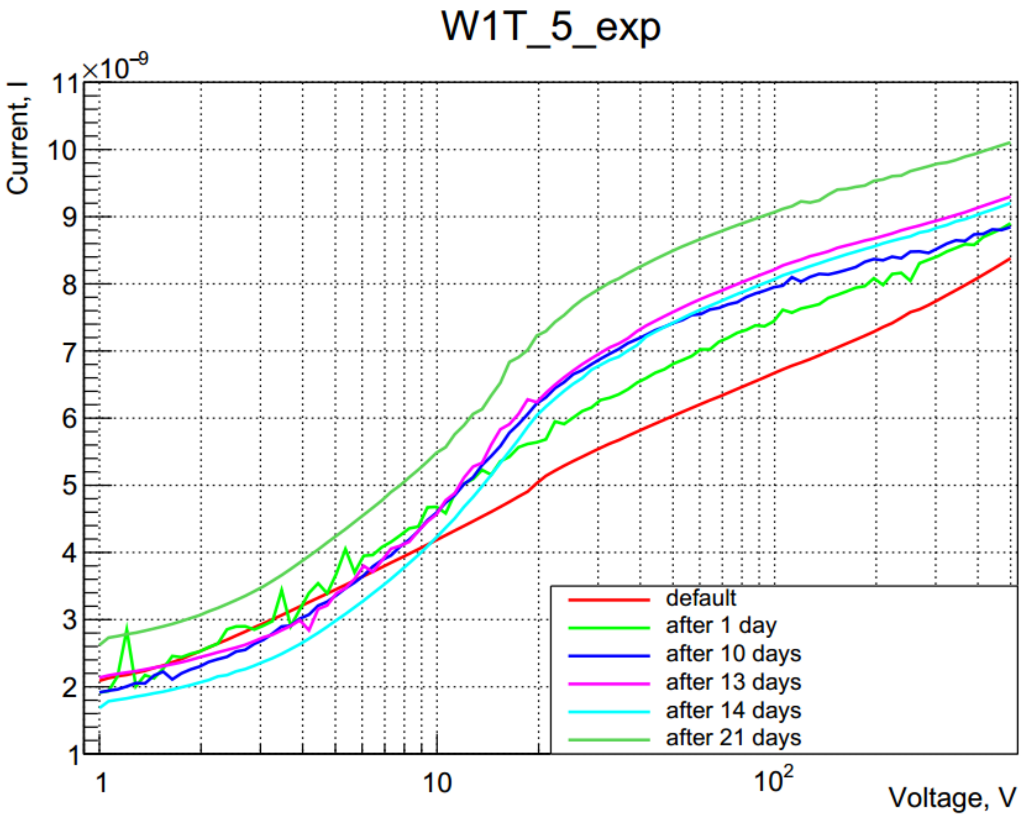


Figure 2.8. IV curve of a sample with kapton glued with larger amount of glue.

- Different kind of glue

On this sample kapton was glued with much lower viscosity glue - Epotek 301-1 (Figure 2.9).

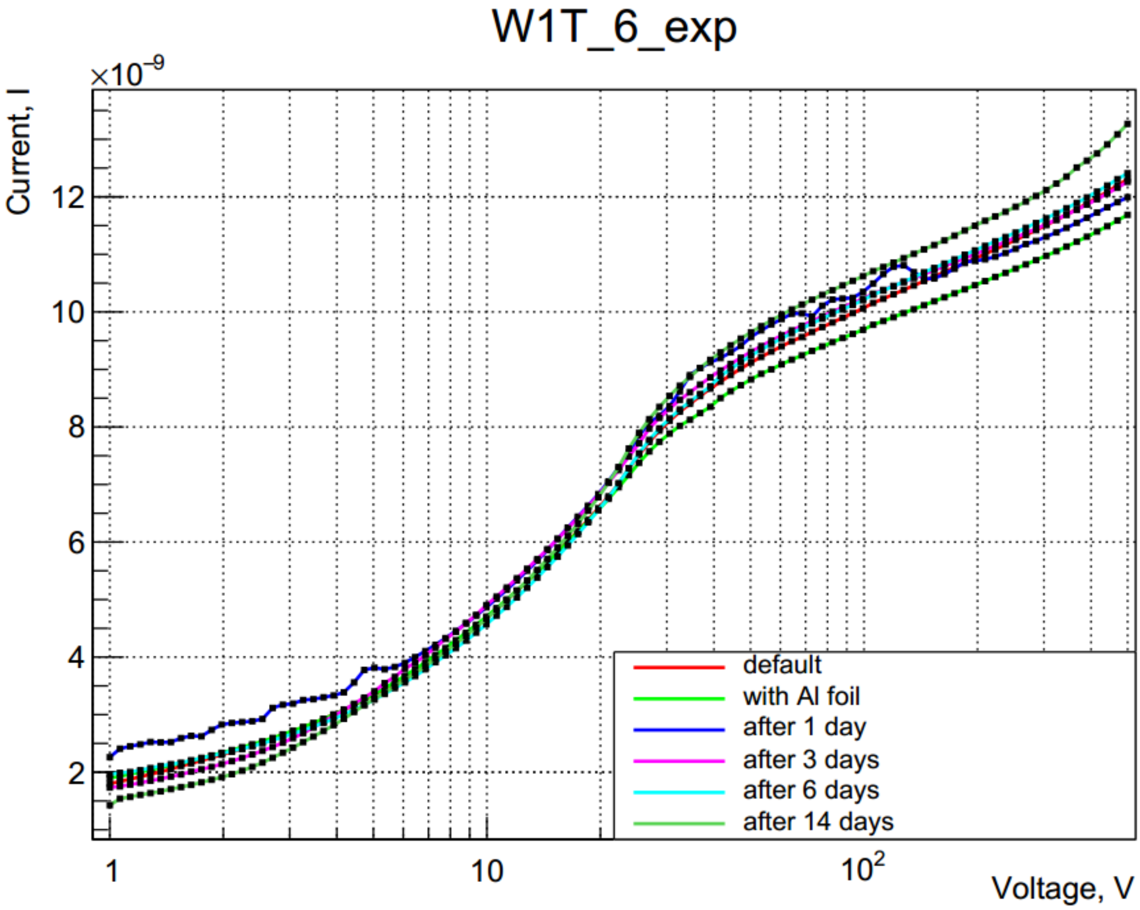


Figure 2.9. IV curve of a sample with kapton glued with much lower viscosity glue.

There are almost no differences between IV curves with this glue.

- Different needle position.

As soon as there were no significant changes in the IV curves, it was decided to find out what contribution was done to this changes by different needle position on the bias ring. Each sensor sample has 128 strips. Different coloured curves represent different needle position on the bias ring (Figure 2.10).

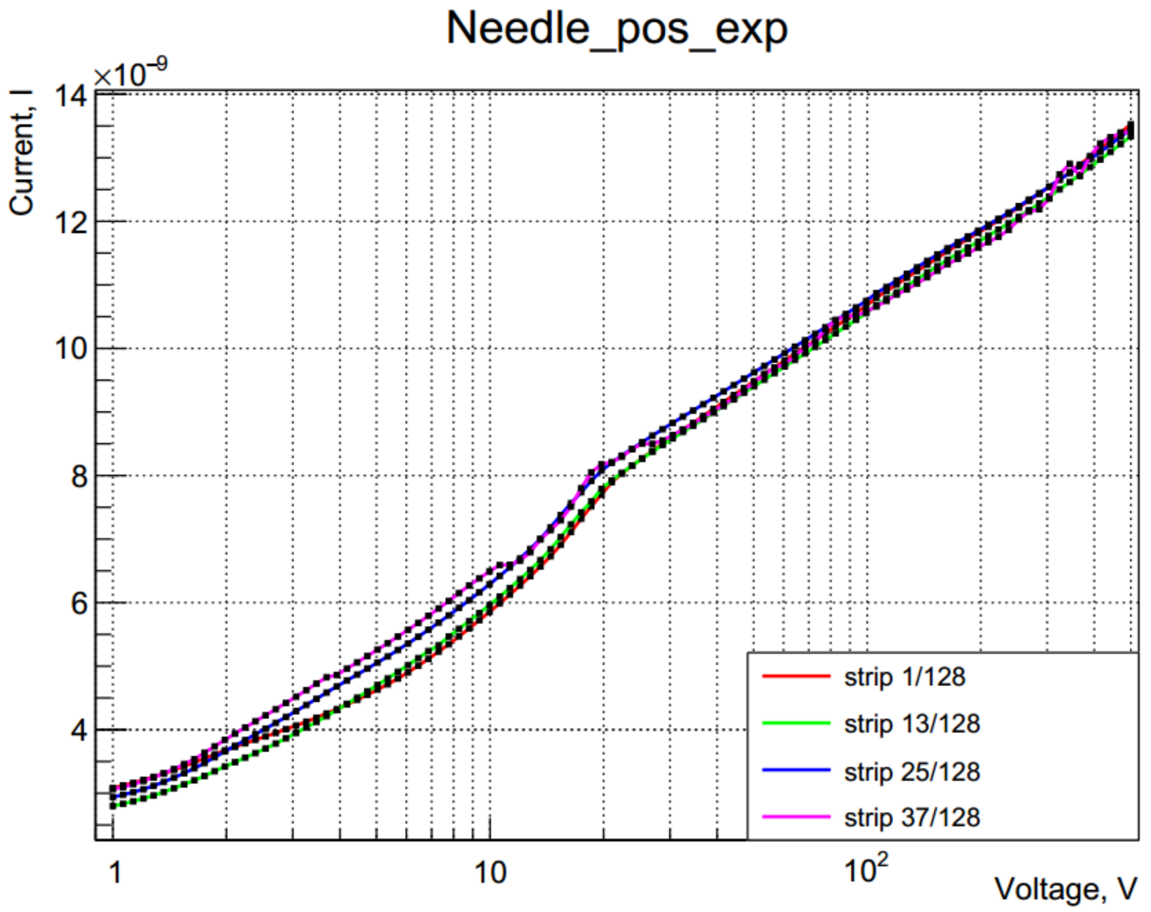


Figure 2.10. IV curve of different needle position on a sample.

The difference between IV curves representing different needles is negligible.

- Self-changing during the time.

The same as for needle tests it was decided to find out how IV curves of samples are changed during the time without gluing kapton and Al foil on it and can it be the reason of observing changes in glued samples. One of the samples was tested without the glue to see how IV curves changes during the time (Figure 2.11).

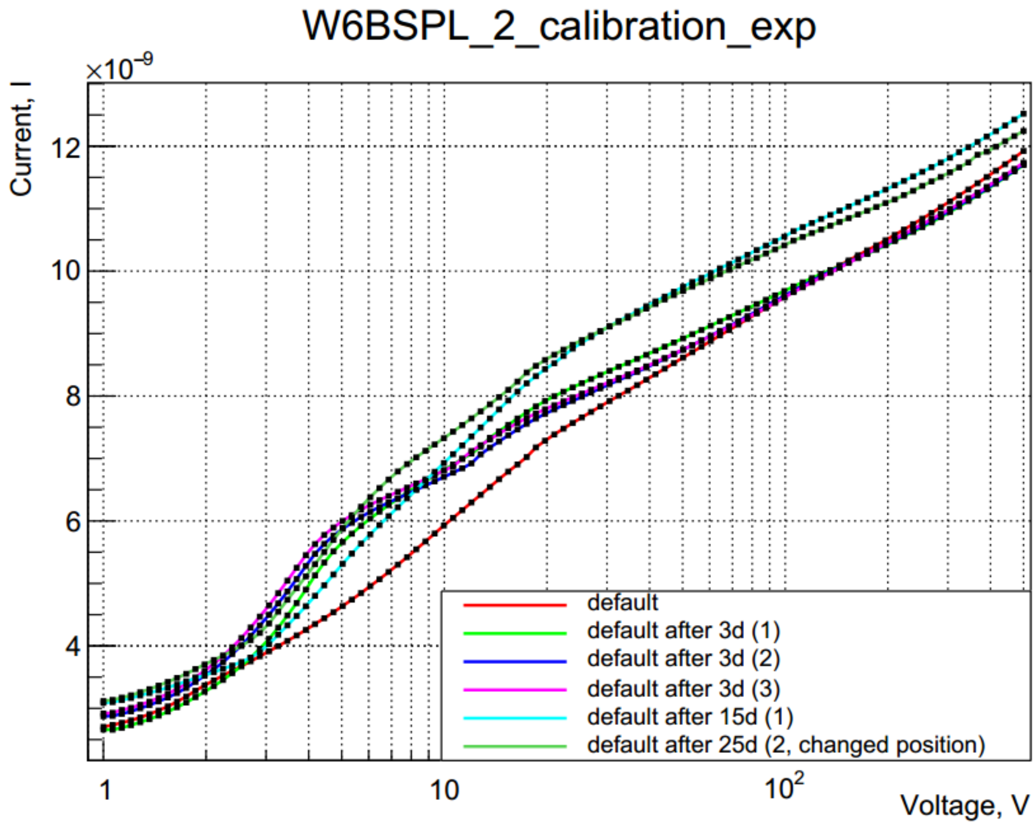


Figure 2.11. IV curve of an unglued sample depending on time.

Indeed, there are small changes in IV curves of the sample without the glue during the time.

- Statistical uncertainties.

To estimate the statistical uncertainties IV curves were measured several times with a sample with larger amount of glue. After each measuring sample was removed from the chuck and put back to the same position, as well as needle was connected to the same point. The result is shown in the Figure 2.12.

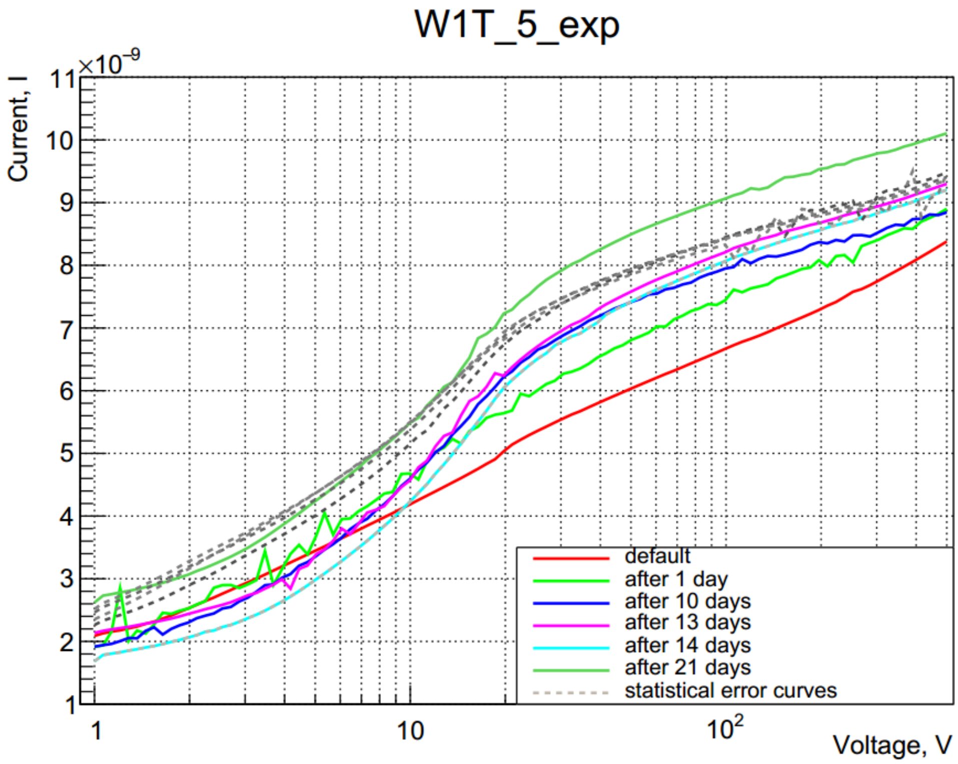


Figure 2.12 IV curve of a sample with larger amount of glue including statistical uncertainties.

To summarize, noticeable effects to the electrical performance related to epoxy bleeding are observed. However, if statistical uncertainties are included, the difference seems to be small in the most realistic gluing scenarios and there are no breakdown effects observed. There is some difference after one day, but it reduces after some more time. Thus we conclude that the Epoxy bleeding effect does not pose a serious problem to the electrical reliability of the sensors. However, in this experiment N-in-P sensor samples were used and P-in-N sensors will be used in future detector, so it would be worthwhile to investigate any differences in these sensors type with respect to epoxy bleeding.

2.4. UV gluing in module assembly.

The standard module glue (Epotek 301) takes 24 hours to cure. As this long curing time represents a bottleneck in the speed of the assembly process, we investigate glues that can be cured in a much shorter time. The idea is to use small amount of such glue in addition to the primary glue in order to make the module mechanically stable so it may be removed from the production chain to allow assembly of the subsequent module. One of the candidates was UV glue, which can be cured with UV light with curing times of the order of minutes.

With the experimental setup shown in the Figure_, we bonded aluminum to glass using a single UV LED positioned at the glue joint. Aluminum and glass were used to approximate AlCF bridge and silicon sensor of the CMS module respectively. After varying the current in the LED to achieve the maximum light intensity, we obtained a physically robust bond after about 5 minutes of curing time. Through trial and error, it was observed that it is crucial to have the UV LED no more than 1mm from the glue joint in order to achieve a strong bond.

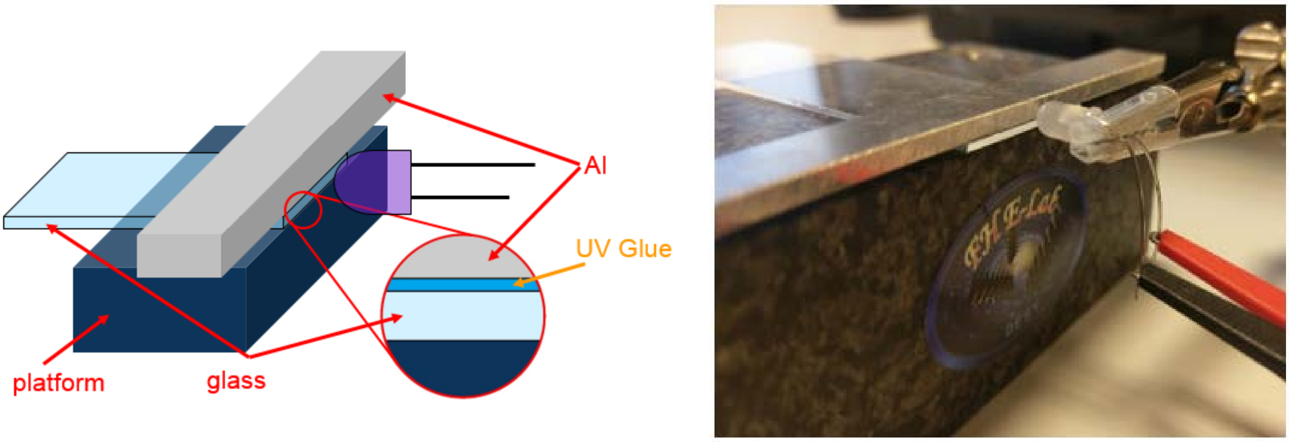


Figure 2.13. UV glue test setup.

The curing time of 5 minutes is sufficiently short to dramatically increase the efficiency of the assembly process. Thus it was decided to design a gluing and assembly platform (Figure 2.14) to allow integration of UV gluing in the assembly process.

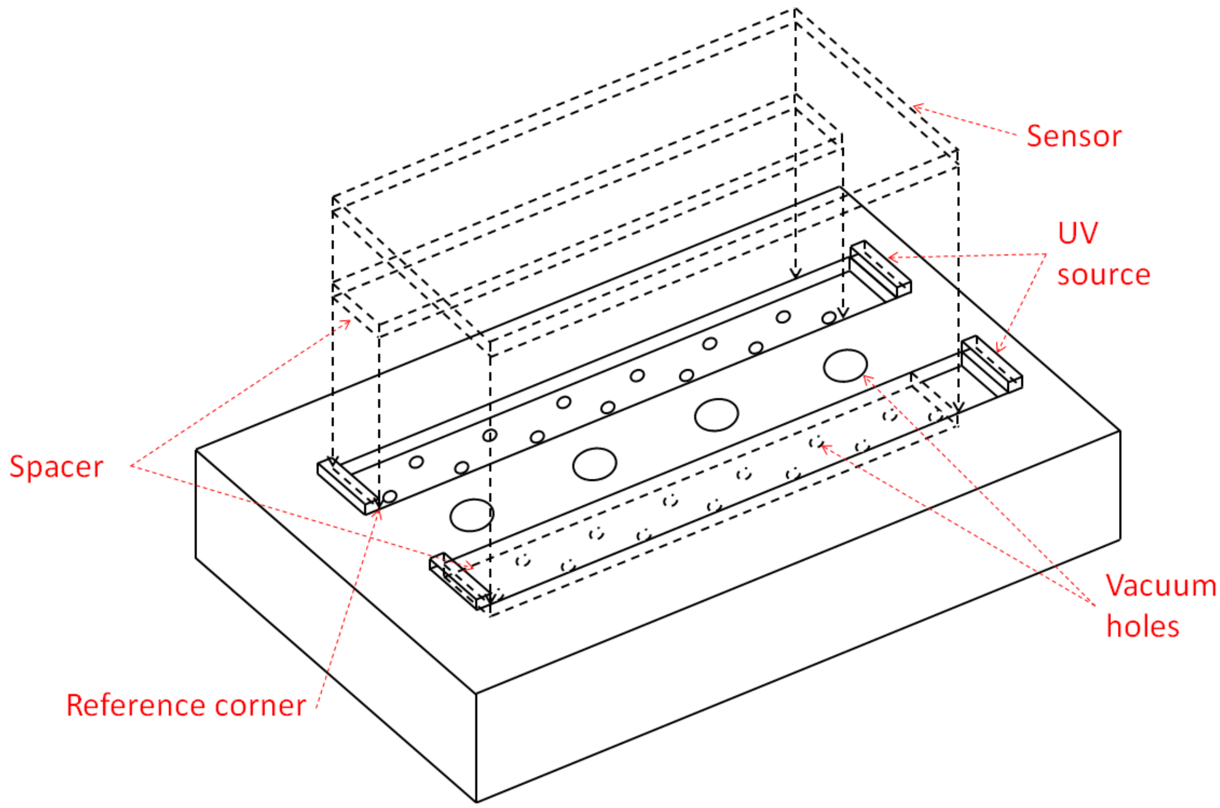


Figure 2.14. Assembly platform design.

The main task of assembly platform is to hold spacers and sensor in the precise position during UV curing. They are held by vacuum throw holes underneath them. There are two independent vacuum channels inside the assembly platform in order to have a possibility fix spacers and sensor independently.

The assembly process starts with placing supported AlCF bridges in two recesses. Subsequently they are gently pushed to the to the reference corner and fixed in place by vacuum holes. Then we can put primary glue on top and small amount of UV glue on the narrow edges close to UV light sources. Next, the sensor is places on the spacers and is held in position by vacuum through the middle larger holes. Now all the components are fixed in the correct positions and curing of the UV glue can be started. The LED UV lights sources are placed within 1mm of the glue joint in order to provide as much light intensity to the curing glue as possible.

To summarize, assembly platform plays an important role in the module assembly process. The design shown represents a first concept which will be improved and, finally used in real assembly. Next step of developing this platform could be creating a pushing mechanism of precise spacer position at the reference corner. Another improvement is the integration of optics to focus the UV source in order to provide maximum luminosity at the glue joint.

2.5. Development of motion stage for plasma cleaner

One of the way to improve adhesion of module components is to clean their surfaces with plasma before assembly. Thus a test facility was designed and built in order to allow testing of the plasma cleaning of module components. A sketch of a facility is shown in the Figure 2.15.

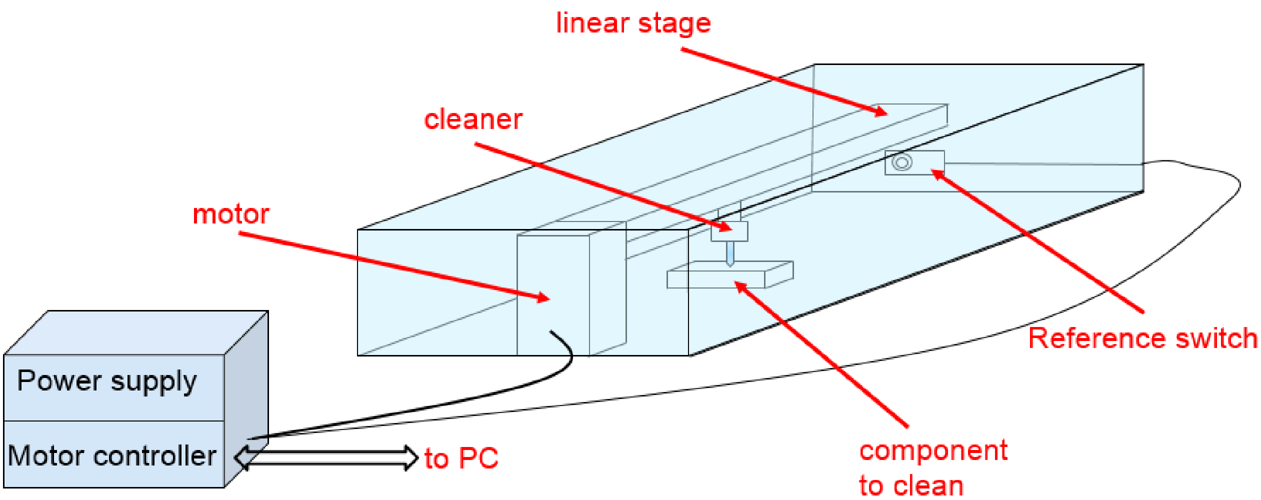


Figure 2.15. A sketch of a plasma cleaning facility.

The facility consists of:

- Linear motion stage. It provides motion in one dimension and is driven by motor.
- Stepper motor. It drives linear stage.
- Reference switcher. It plays an important role in the facility. It uses both to provide a possibility of physical reference and for safety reasons to protect the cleaner of crushing to the wall.
- Separate box with electronics.

This box includes:

- Power supply.
- Protection capacitor.
- Stepper motor controller. It also operates with reference switcher.
- Reference switch power circuit. Reference switcher by itself give a very high voltage output signal, which can't be directly connect to the stepper motor circuit. In order to solve this problem, I soldered a voltage regulation circuit and tested the stability of the voltage output with an Arduino to make sure it worked and was stable. It was installed between the reference switch and controller providing the controller with a stable input voltage of 0 to 5V from the larger (0 – 40V) voltages of the reference switcher.

The prototype of the facility was constructed and tested. On the Figure 2.16 the photo of assembled box is shown.

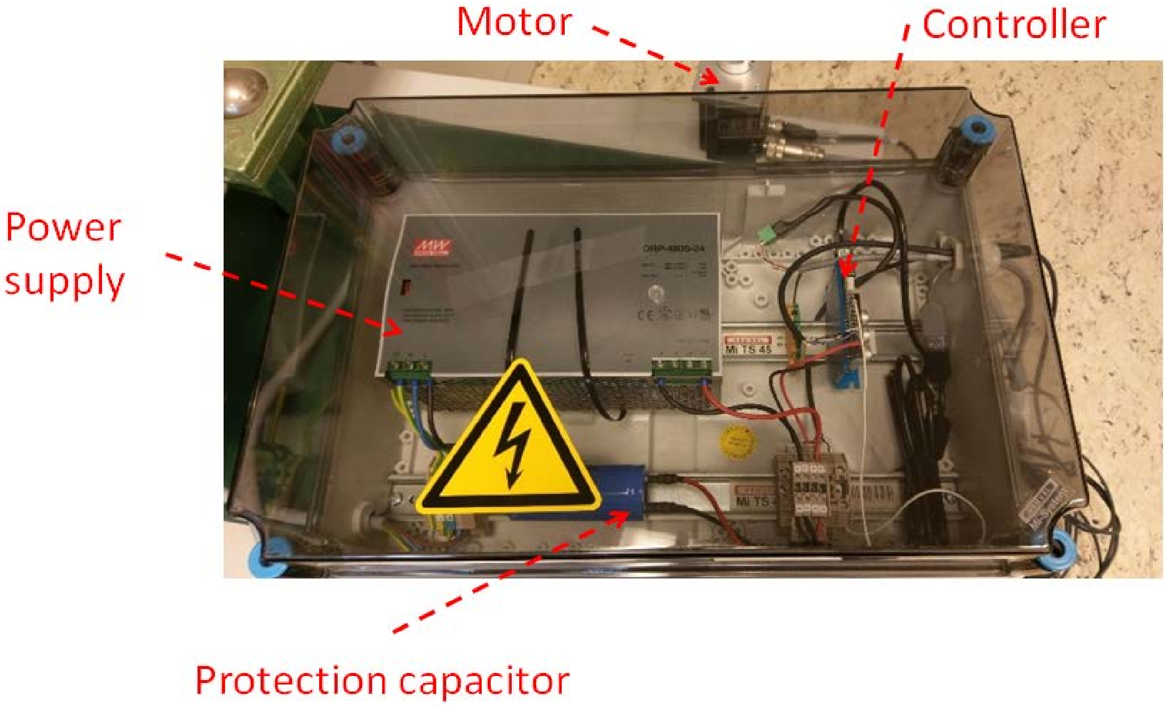


Figure 2.16. Assembled box with electronics for plasma cleaning facility.

3. Conclusion

1. Epoxy bleeding

   Noticeable effects to the electrical performance related to epoxy bleeding are observed. However, if statistical uncertainties are included, the difference seems to be small in the most realistic gluing scenarios and there is no breakdown effects observed. There is some difference after one day, but it reduces after some more time. Thus we conclude that the Epoxy bleeding effect does not pose a serious problem to the electrical reliability of the sensors. However, in this experiment N-in-P sensor samples were used and P-in-N sensors will be used in future detector, so it would be worthwhile to investigate any differences in these sensors type with respect to epoxy bleeding.

2. UV gluing in module assembly

   a. UV glue was tested and confirmed as a feasible option for fast curing. The curing time significantly depends on the intensity of the UV light.
   b. First design of assembly platform for integration of UV gluing into assembly process was created. It will be improved and, finally, used in the assembly process. Next steps of developing can be creating a pushing mechanism of precise spacer position at the reference corner or integration of optics to focus the UV source in order to provide maximum luminosity at the glue joint.

3. Development of motion stage for plasma cleaner

   a. Built and tested power supply, motor controller box for plasma cleaner.
   b. Built and tested crucial reference sensor circuit.

4. Acknowledgements

I would like to thank my supervisor, James Keaveney, for guiding and supporting me during my research project. Because of his patience and invaluable help I have successfully completed my work. I also would like to thank Doris Eckstein, Andreas Mussgiller, Torsten Kuelper and Jens Hansen for their help and being ready to answer all of my questions.

It was a great pleasure working in DESY. I got a lot of useful and interesting experience and met many pleasant people from all over the world here.

5. References

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