Development Of An In-Situ Magnetron Sputtering Plasma Monitoring Setup

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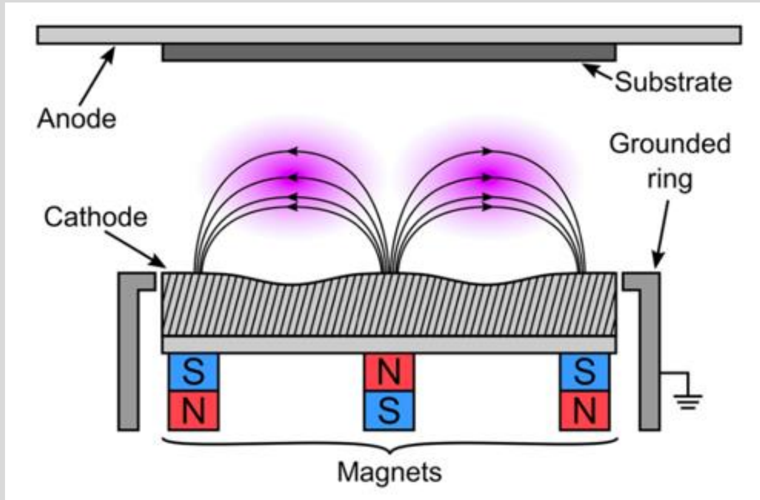
Description of the Magnetron Sputtering Technique - I

Physical Vapor Deposition (PVD) refers to the formation of a material that can be evaporated through physical mechanisms and the deposition of this material onto a substrate as a thin film or coating.

One of these techniques is sputtering, in which atoms are ejected from a solid or liquid source through momentum transfer.

Magnetron sputtering techniques are the most widely used methods in today's thin film coating and surface engineering processes. The biggest difference among existing magnetron sputtering applications lies in the power systems that generate the carrier plasma.

Description of the Magnetron Sputtering Technique - II



In the magnetron sputtering process, energetic ions from a plasma, usually created in an inert gas such as argon, bombard a solid target material, causing atoms (or molecules) to be ejected through momentum transfer. These atoms then travel through the vacuum chamber and condense on a substrate, forming a thin film.

The use of magnets behind the target enhances the process by trapping electrons near the surface, which increases plasma density and ionization efficiency. This allows for higher deposition rates, lower operating pressures, and improved film adhesion and uniformity Because of its versatility and reliability, magnetron sputtering is extensively applied in microelectronics, optics, energy technologies, and surface engineering to produce coatings with tailored structural, electrical, or mechanical properties.

Gudmundsson J.T.; Physics and technology of magnetron sputtering discharges, Plasma Sources Sci. Technol. 29 (2020) 113001.

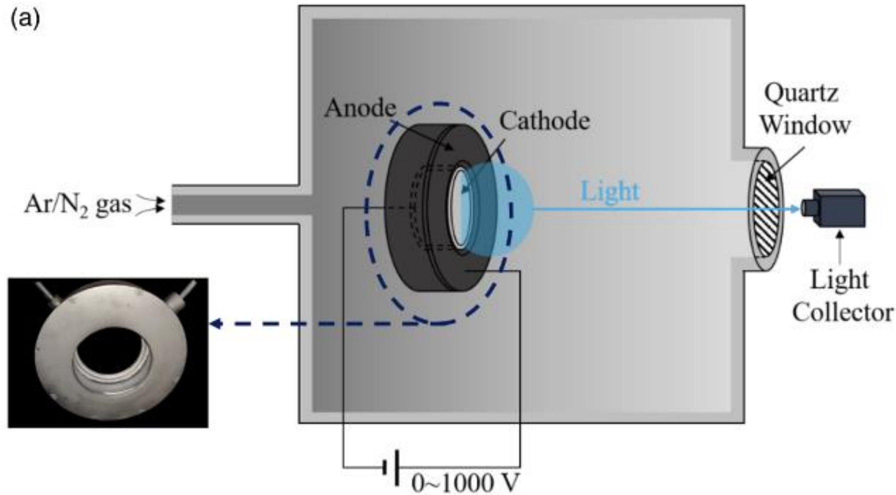
Dynamics of the Magnetron Sputtering Plasma - I

Understanding the plasma specifications is crucial in magnetron sputtering since the plasma directly governs how efficiently atoms are ejected from the target and how they are deposited onto the substrate. Moreover, controlling plasma characteristics allows us to optimize process stability, reduce defects, and fine-tune film properties such as hardness, conductivity, or optical behavior.

The best way to gain insight into the plasma characteristics is to inspect the spectral and timing properties of the plasma light.

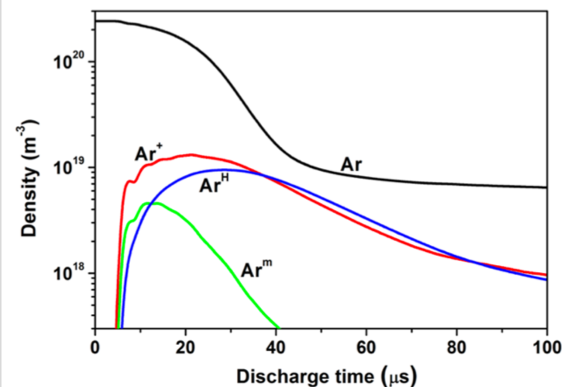
This has been tried a number of times by various teams worldwide by placing the optical detectors outside the vacuum chamber downstream a filtering optical medium such as a quartz window.

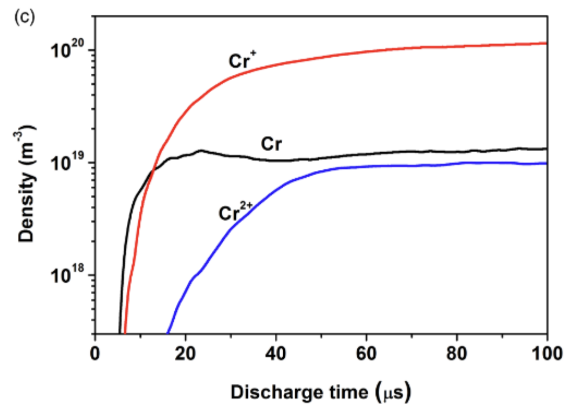
Dynamics of the Magnetron Sputtering Plasma - II

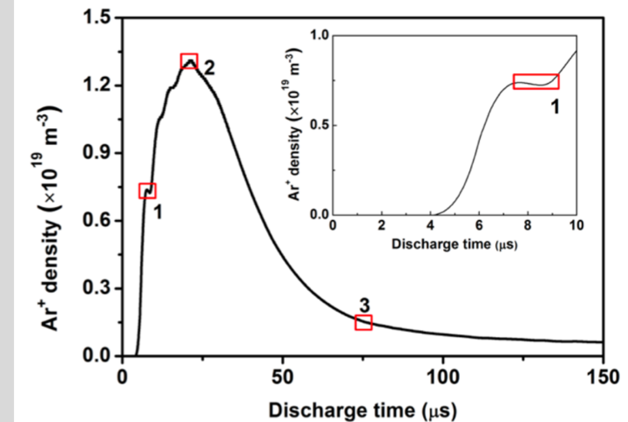


An example: Chromium coating in Ar/N_2 atmosphere with HiPIMS (High-Power Impulse Magnetron Sputtering) and measurement of light spectra with a fast spectrometer downstream a quartz window.

➔ Still several critical points to resolve.







Cui S. et al.; Nano-second temporal particle behavior in high-power impulse magnetron sputtering discharge in a cylindrical cathode, J. Appl. Phys. 127, 023301 (2020).

Outstanding Issues Related to the Sputtering Plasma

1. Plasma Instabilities and Process Control

•RF plasmas are prone to fluctuations in density and potential, leading to instabilities that reduce reproducibility.

2. Target Poisoning in Reactive Sputtering

•In reactive sputtering (e.g., for oxides, nitrides), reactive gases can form insulating layers on the target surface, drastically lowering deposition rates and causing hysteresis effects.

3. Limited Understanding of Plasma–Surface Interactions

•The detailed mechanisms of ion bombardment, secondary electron emission, and surface diffusion during sputtering are not fully understood.

➔ Initial parameters of the plasma can reveal valuable information on the progression of the plasma. Bridging the gap between plasma diagnostics, modeling, and experimental film properties is still ongoing.

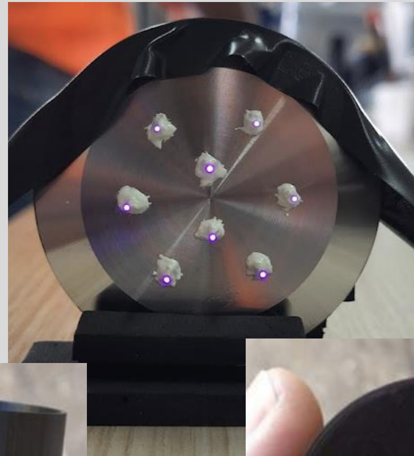
Construction of the In-Situ Plasma Monitoring Setup

In order to address these issues, we developed an in-situ plasma monitoring setup by installing optical fibers at critical locations of the plasma **inside** the vacuum chamber.

The setup consists of:

- 8 optical fibers with 600 μm diameter quartz core and 100 μm cladding
- A custom vacuum feedthrough for the fibers
- An electronics assembly to house 8 SiPMs (Silicon Photomultipliers)
- A waveform digitizer

Construction of the Vacuum Feedthrough



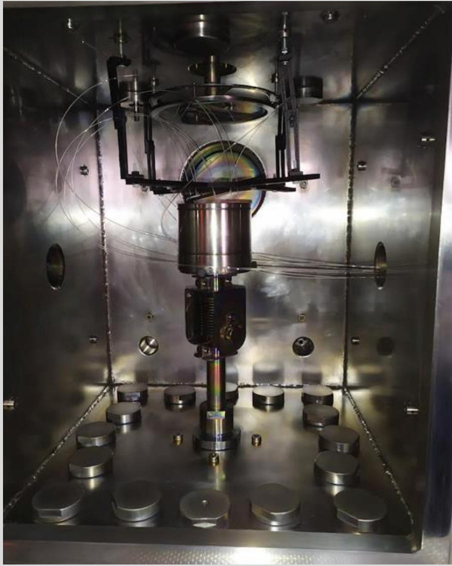
A KF40 blank flange was machined to produce 8 1-mm-diameter holes.

The 800 μm diameter quartz fibers were cut to size and polished on both ends.

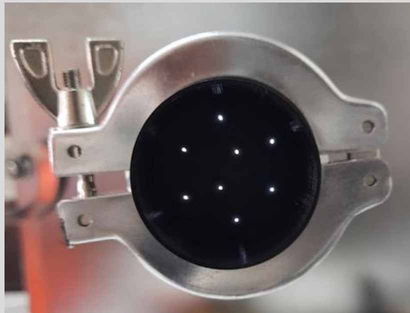
The fibers are coupled to the flange holes with TorrSeal.

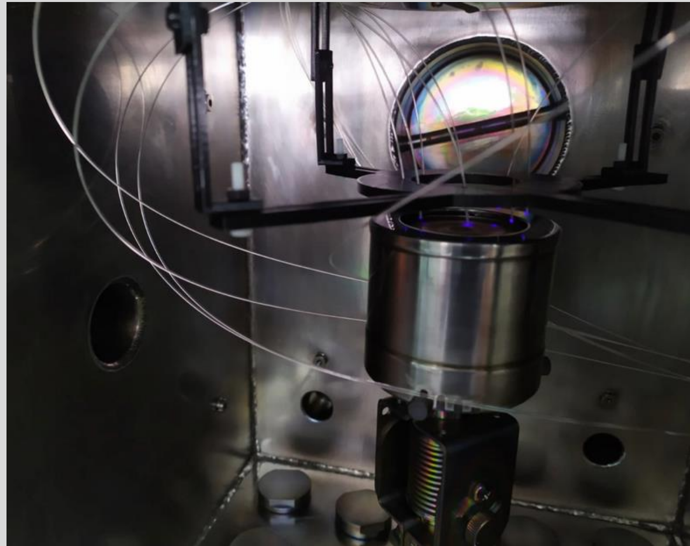
A structural assembly was 3d-printed to couple the fibers ends to the SiPMs.

Placement of the Quartz Fibers in the Vacuum Chamber

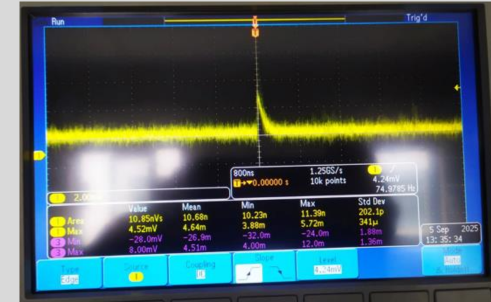


The special feedthrough was installed on one of the side walls and the fibers were routed inside the chamber and through a 3d-printed assembly to end up with a field of view around the rim of the target.





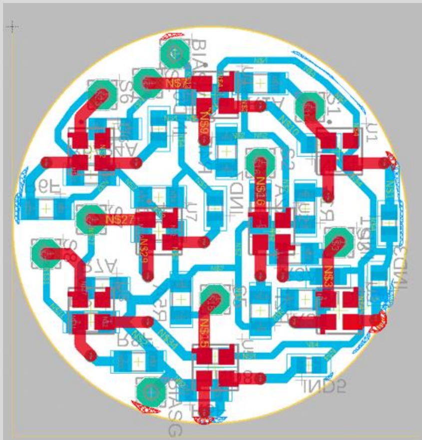
Desing and Assembly of the Readout Card

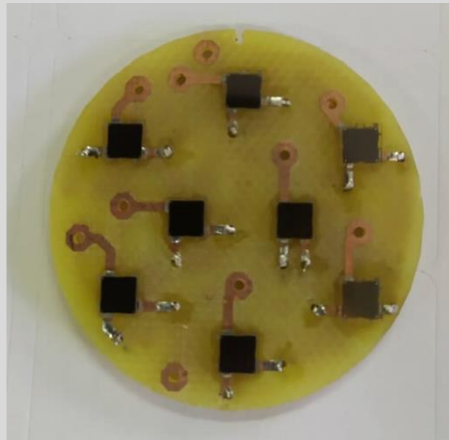


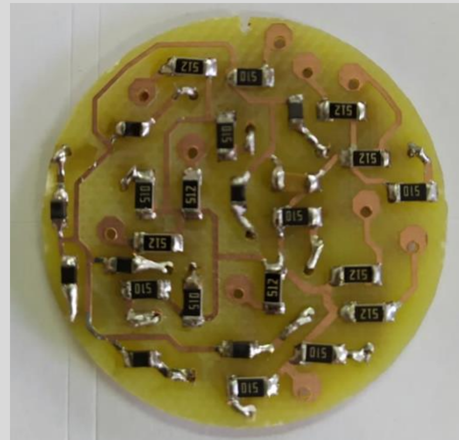
A custom PCB was designed and produced to house the 8 SiPMs (Onsemi MicroFC-30035).

The PCB was connected to an adapter board by CAT8 cables.

Eight RG-316 cables with MCX connectors are coupled to the adapter board, and the bias voltage connection was also made with an RG-316 cable.



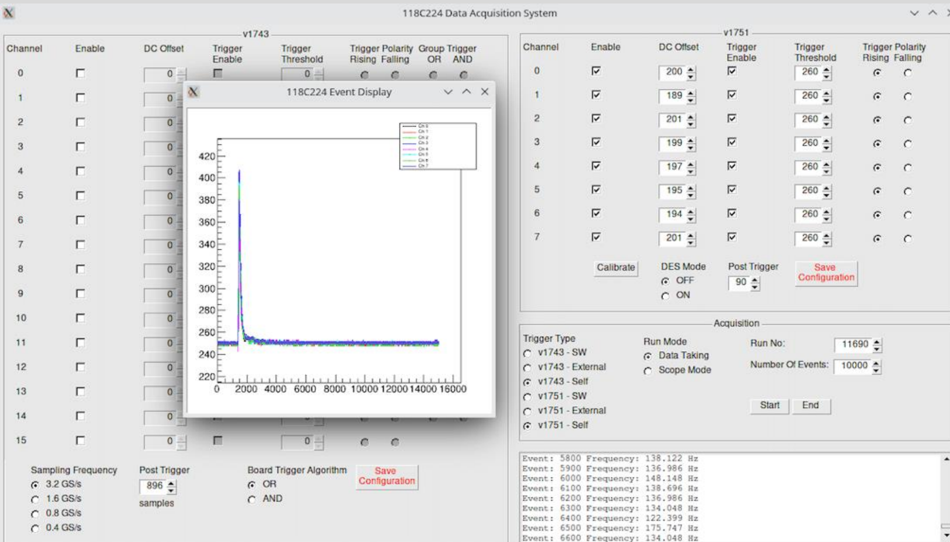




Calibration of the SiPMs - I

In order to obtain the single-photon response of the 8 SiPMs as a function of the bias voltage, the readout card was illuminated with white LED at 30 kHz and with varying intensities. The readout was performed with CAEN v1751 digitizer (15 μs readout window, 10 bits, 1 Gsps).

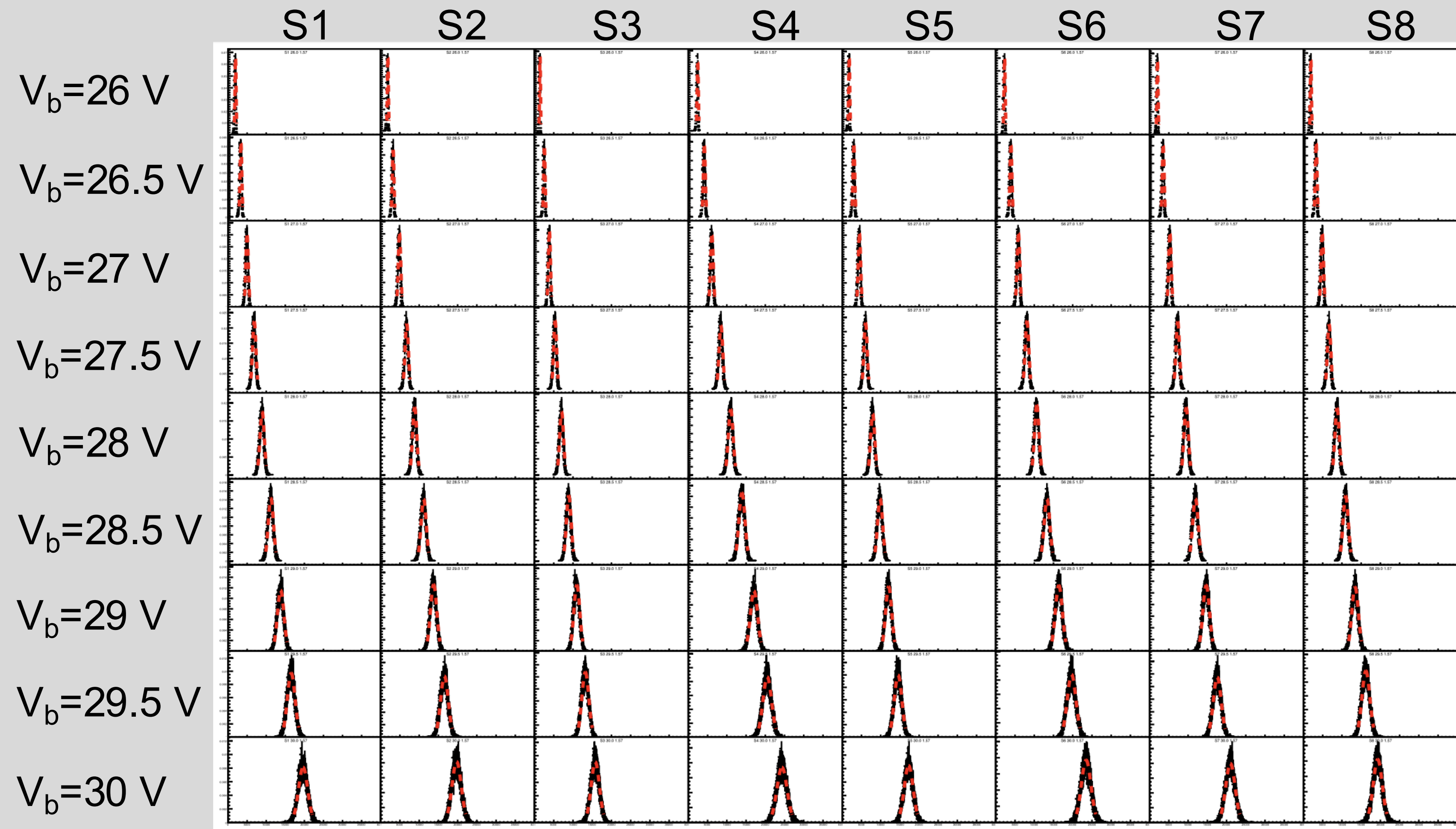
The bias voltage of the SiPMs was varied between 26 V and 30 V in steps of 0.5 V.



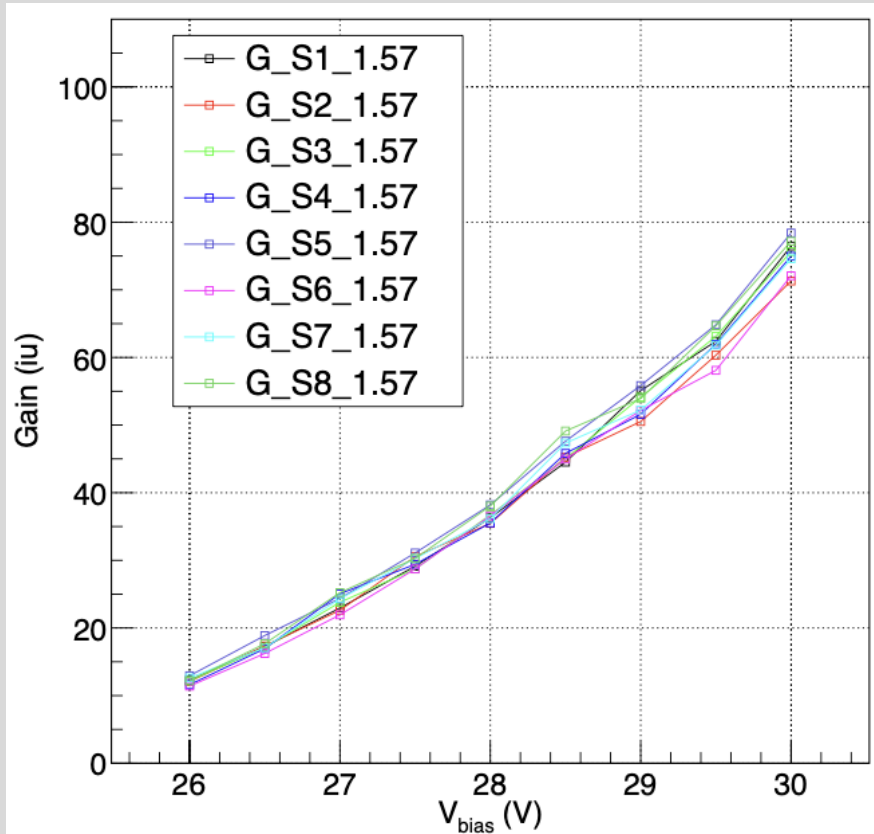
The pulse was integrated in a 500 ns window and the integral histogram was fit with a Gaussian. The gain can then be calculated as μ/σ^2 where μ is the mean of the Gaussian and σ is its standard deviation.

Calibration of the SiPMs - II

x axis is in integral units (mV x ns).



Calibration of the SiPMs - III

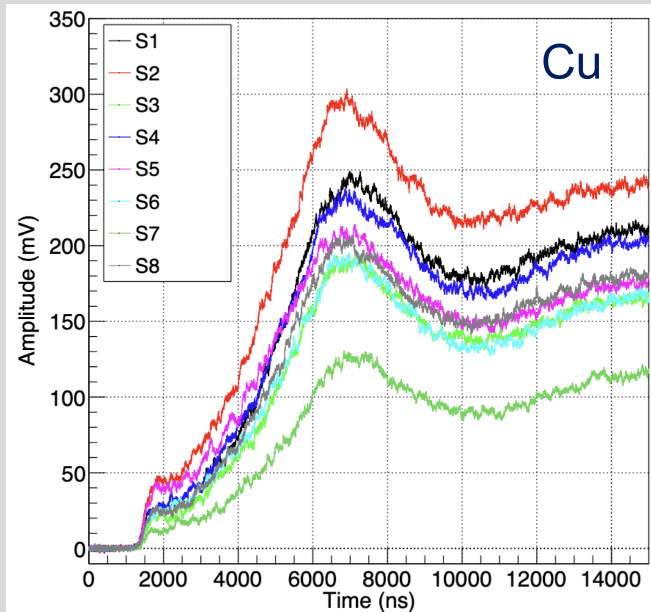


The gain variation across the SiPMs is acceptable and is better at lover bias voltages. Given the high amount of light produced in the plasma, the lower bias voltages are anticipated.

A gain value of 50 in integral units corresponds to 6 x 10^6.

First Measurements - I

We performed the first operational tests of the in-situ plasma monitoring setup with various targets. The chamber was put under vacuum down to 8.1 x 10^{-6} mbar, then circulated with Argon 6.0 at 15 cc/min rate. The readout was started with a trigger setup for the OR of the eight SiPM signals when 10 mV above the baseline. Therefore, the onset of the plasma is recorded with 1 ns time ticks.

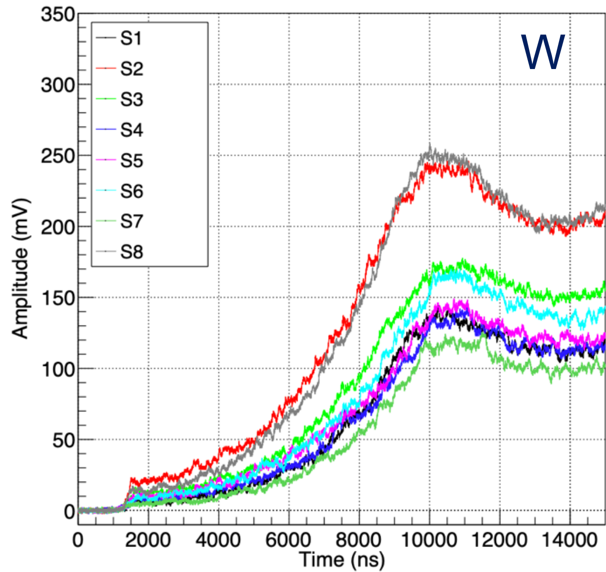


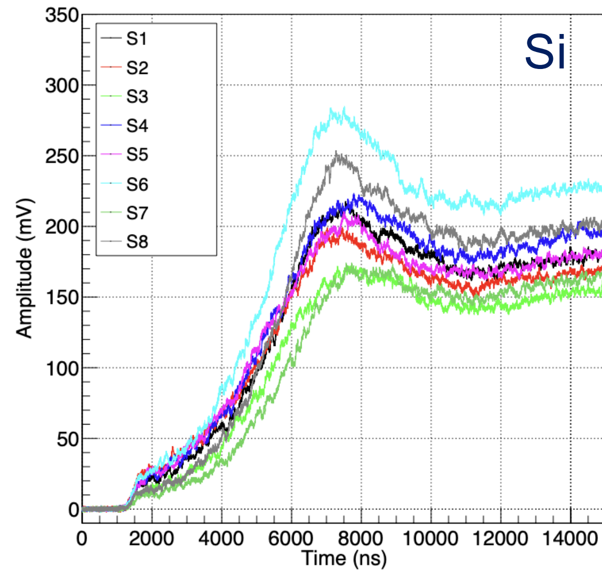
A common behavior among all fiber locations is observed.

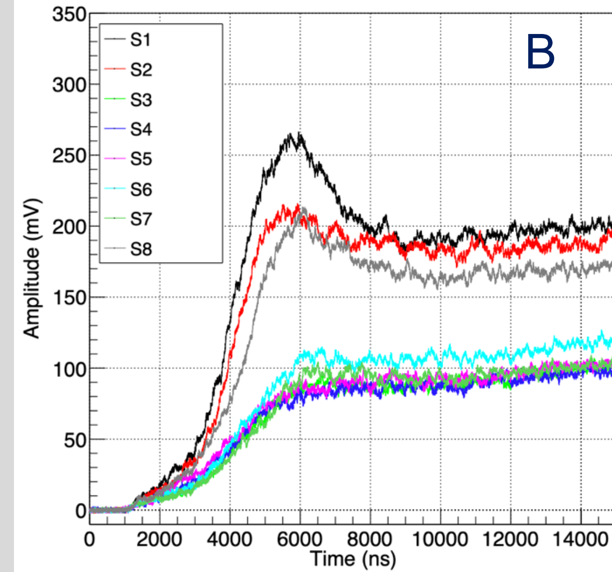
The peak intensity after ~ 6 μs from the onset of the plasma has different temporal specifications at different locations.

The pulses stay above 10 mV and mostly flat in later triggers.

First Measurements - II







Fiber ends are cleaned after each target change and the fibers are placed back in the assembly.

The onset waveform exhibits a common shape across all targets, while the timing structure shows distinct, target-dependent variations, which is the topic of the ongoing analysis.

Summary

- A special setup to measure the magnetron sputtering plasma was designed and constructed.
- The preliminary performance evaluation of this entirely custom system is completed.
- The data analysis is ongoing to investigate the critical timing signatures of the onset and progression of the magnetron sputtering plasma.
- The setup is one of a kind in terms of measuring the optical properties of the magnetron plasma **inside** the vacuum chamber.
- The TPB coating of the fiber ends will provide unprecedented insight into the plasma light.
- An integrated system to better quantify the specifications of the magnetron sputtering plasma has the potential to fine tune magnetron sputtering parameters in-situ to yield desired surface coating properties.