Silicon PhotoMultiplier cryogenic operation down to 77 K

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Introduction

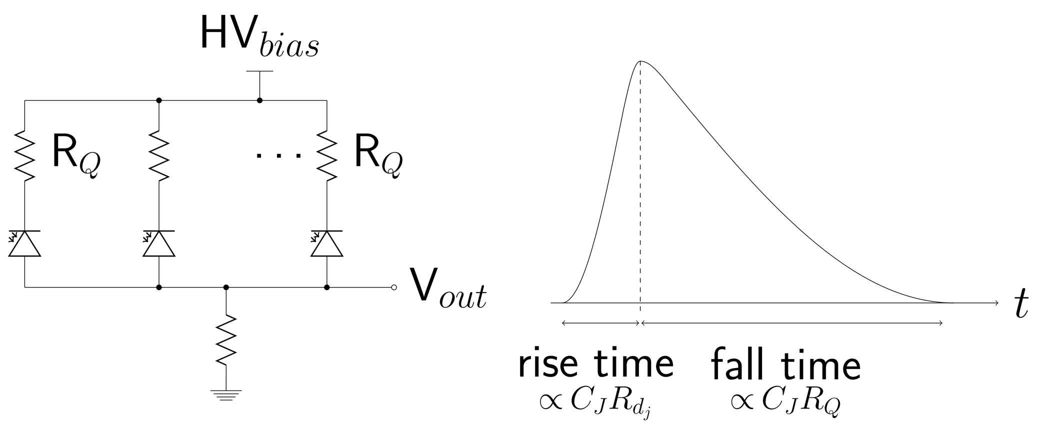
Silicon PhotoMultiplier (SiPM) are extremely sensitive photosensor based on the use of Geiger Mode **Avalanche PhotoDiode** (GM-APD) sensitive to one photon. Many people **cool down SiPM** close to 0 °C to reduce the Dark Count Rate (DCR). Moreover, liquid xenon or argon [1] is used as a scintillation liquid to detect Weakly Interacting Massive Particles (WIMP) (candidates for the universe dark matter explanation). The use of SiPM in such **cryo. environments** is plan.

Liquid nitrogen SiPM test setup.

A study of the evolution of SiPM parameters from **room temperature to 77 K** is presented and cover a large part of the possible uses of cooled SiPM. We present cryogenic measured parameters (breakdown voltage, junction capacitor, quenching resistor ...) of a commercial SiPM. Evolution of these parameters between room temperature and 77 K is discussed.

Silicon PhotoMultiplier :

SiPM is an assembly of Geiger Mode Avalanche PhotoDiode (GM-APD). Geiger mode provides internal gain as large as 10^6 carriers/photon. Indeed, a unique electron-hole pair generated by a single photon absorption (photogenerated) leads to million carriers. The increasing current crosses also a **quenching resistor** R_Q [2] which turns-off the avalanche process in few 10 ns (fall time).



Main parameters of GM-APD, and thus of SiPM, are the quenching resistance R_Q, the junction capacitor C_J (which limits the rise and fall time) and the breakdown voltage V_{BD}. The differential resistance of the junction R_{d_j} during the avalanche process is also an interesting parameter allowing to determine this rise time.

References

[1] DarkSide Collaboration 2008, *DarkSide-50 Proposal: A Direct Search for Dark Matter with New Tech. for Reducing Background*

[2] Cova S. et al 1996 *Avalanche photodiodes & quenching circuits for single-photon detection* (Ap. Optics, Vol. 35 No 12)

[3] HAMAMATSU datasheet, *MPPC (multi-pixel photon counter) - S10362-11 series*

[4] Otono H. et al 2007 *Study of MPPC at Liquid Nitrogen Temperature* (Int. Workshop on neaw Photon-Detectors, Kobe, Japan)

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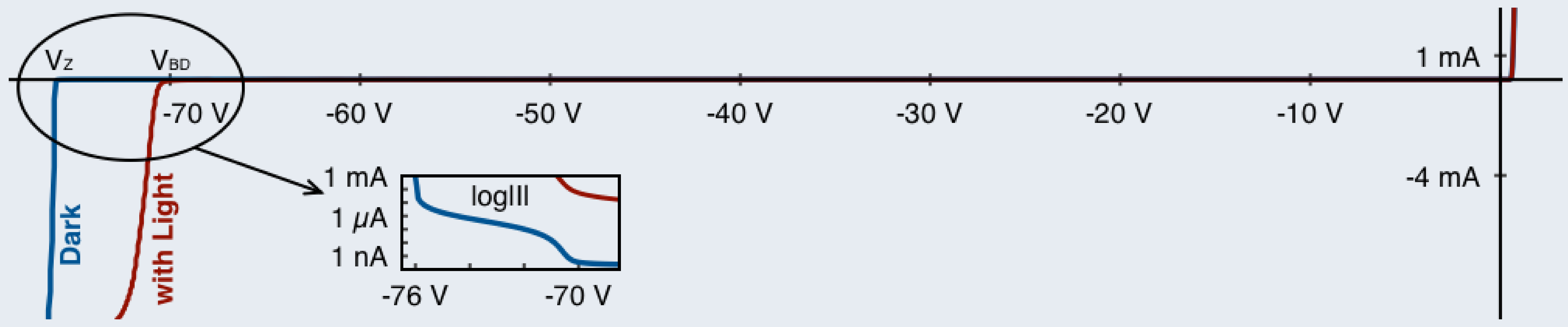
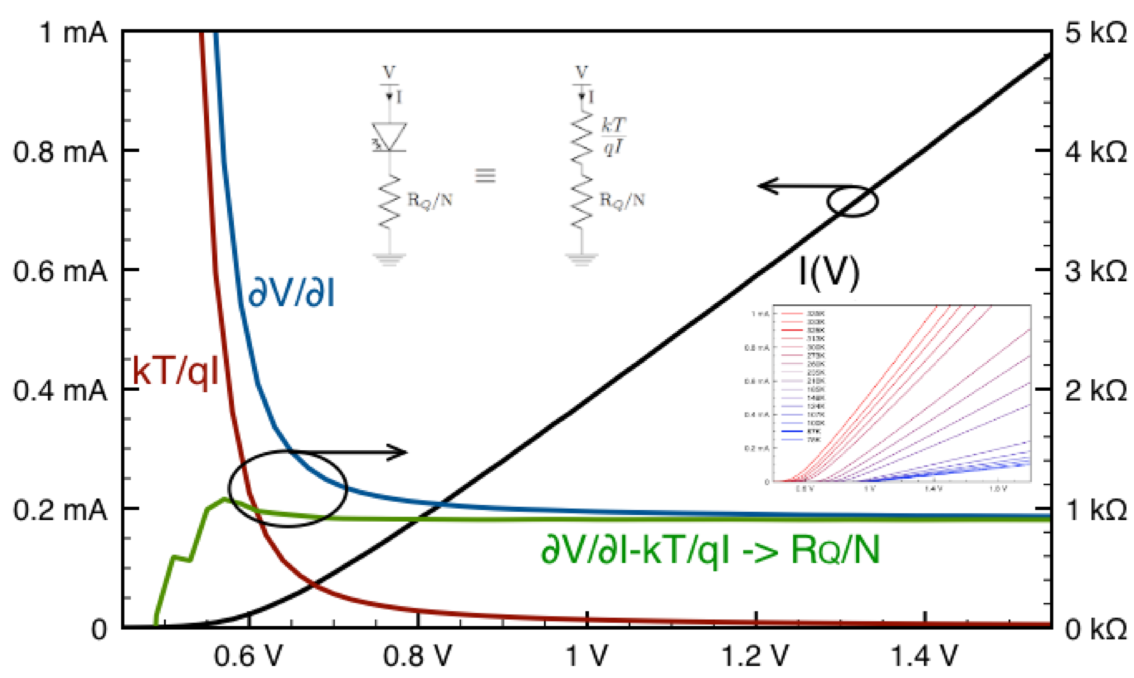
The use of I(V) curve to extract SiPM parameters

I(V) measurement is an easy way to extract lot of parameters of SiPM as Breakdown voltage V_{BD}, Zener voltage V_Z and Quenching resistance R_Q. Moreover, at **cryogenic temperatures** this method may be more precise than the dynamic one.

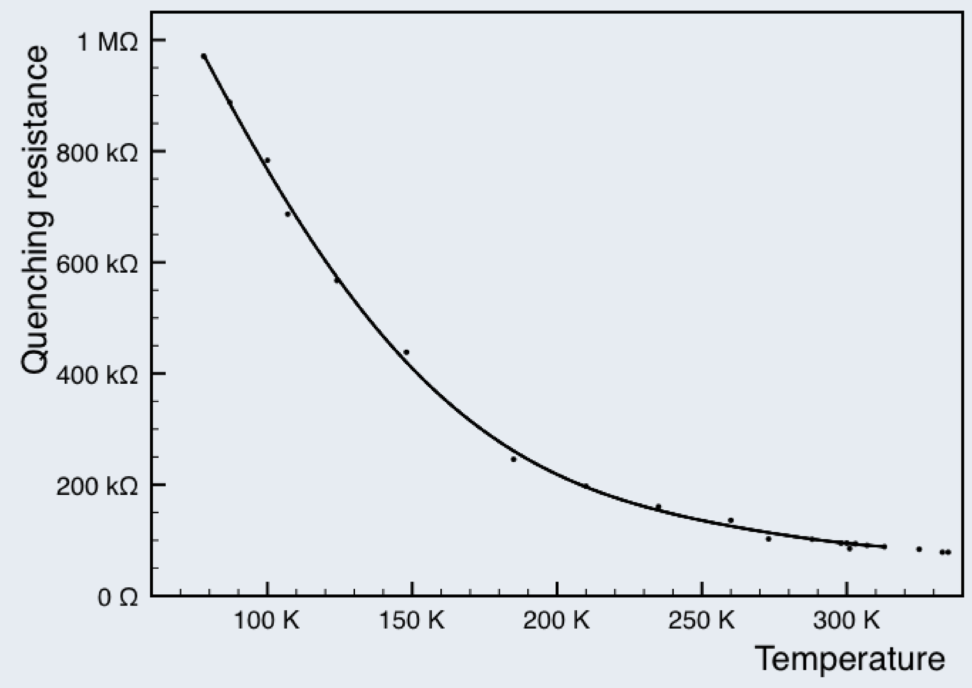


R_Q from the forward part of the I(V)

Using the forward bias characteristic of the SiPM, it is possible to extract the value of the **quenching resistor** R_Q, assuming that N cells **forward bias** is similar to a single diode in series with a R_Q/N resistor.

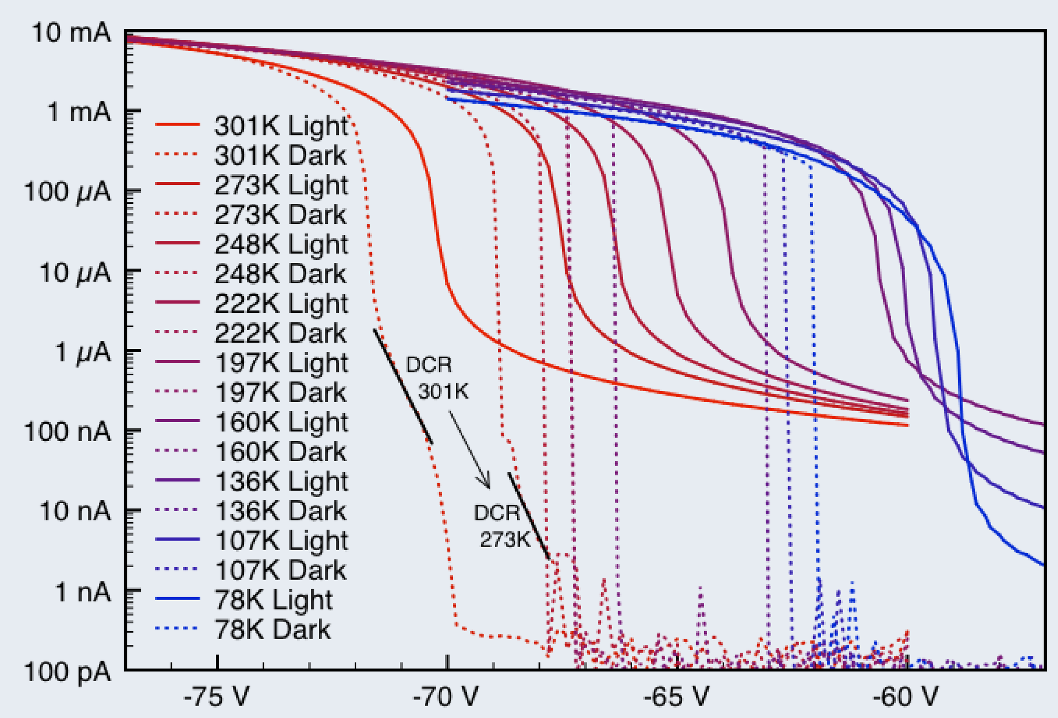


R_Q as a function of the T



R_Q goes from 100 kΩ at 300 K to 1 MΩ at 77 K. The **fall time increases**. This enhance the after pulse phenomenon at low temperatures and Joule heating.

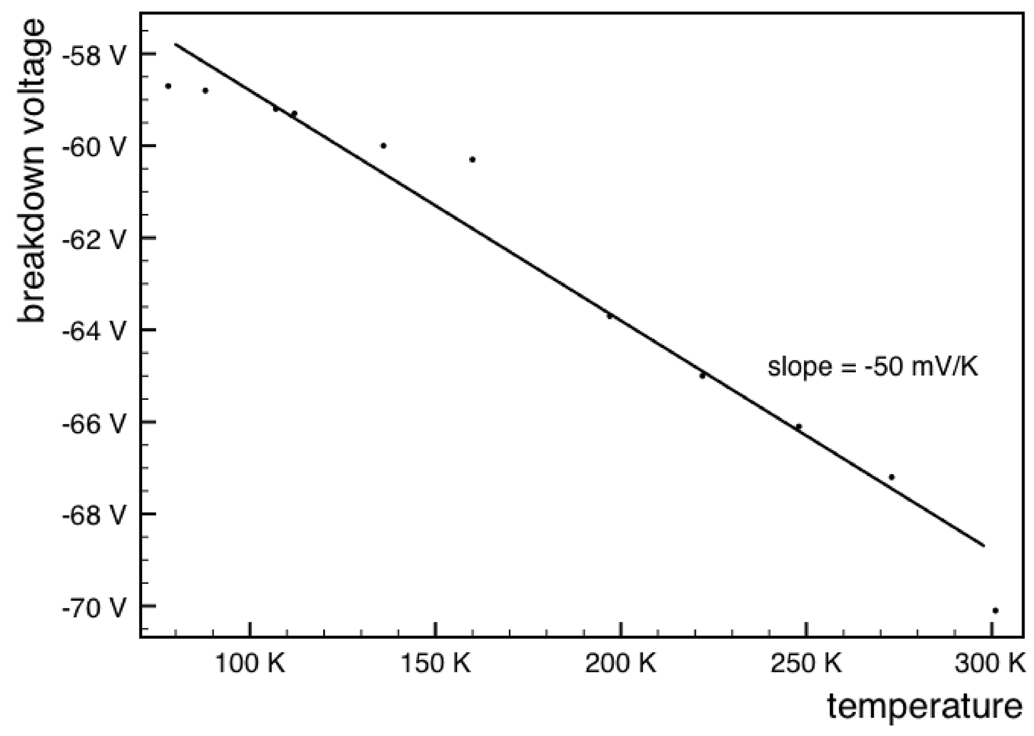
V_{BD} from the reverse part of the I(V)



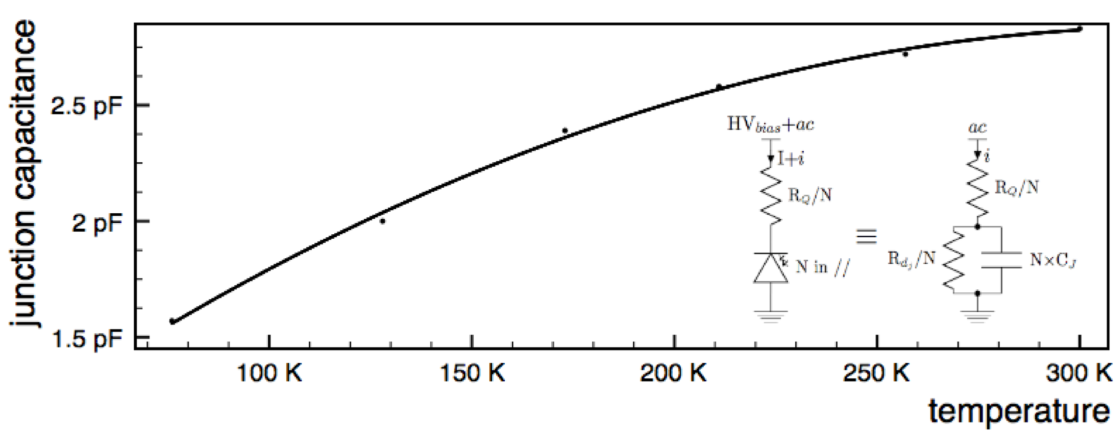
Decrease of DCR (Agilent B1500A noise floor ≈ 100 pA). **Full latching** unexpectedly above the V_{BD}. Different phenomenon than the "Zener" threshold.

V_{BD} as a function of the T

Light source to trig the overall SiPM ⇒ breakdown voltage. **Linear function with a temperature coefficient equal to -50 mV/K**. V_{BD} decreases of more than 10 V (in absolute value) from 300 K to 77 K.

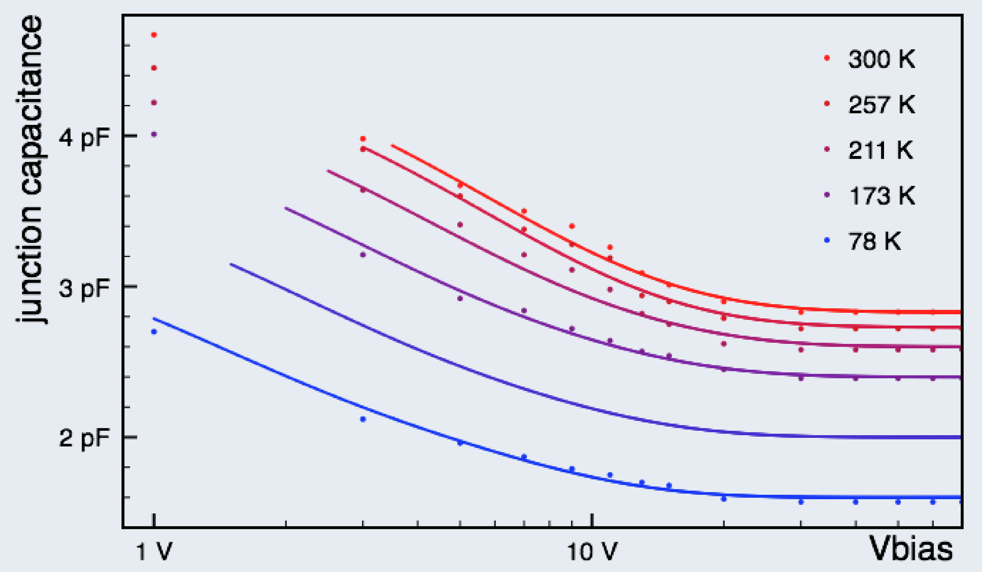


junction capacitance as a function of the T



Decreasing of the junction capacitance at low temperature. However, this decreasing is smaller than a factor of 2 between room temperature to liquid nitrogen temperature.

C_J as a function of the bias



Discussion

V_{BD}, R_Q and C_J has been measured from 300 K to 77 K on a commercial **SiPM MPPC S10362-11-100C** [3]. It appears a quasi-linear decreasing of the breakdown voltage with a temperature rate of -50 mV/K. Quenching resistance is multiplied by a factor of 10 between 300 K to 77 K. Finally, junction capacitor decreases less than a factor of 2 in the same temperature range. These experimental results give a good idea of the voltage biasing required for MPPC cryogenic operation. Furthermore, they predict an increasing by a factor of 5 of the SiPM fall time at liquid nitrogen temperature. Most of these results has been obtained by using **"simple" I(V) measurements and are fully compatible with similar measurements using time response** [4].

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