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Extensive studies of MRS APDs for plastic scintillator muon veto detectors of cryogenic experiments

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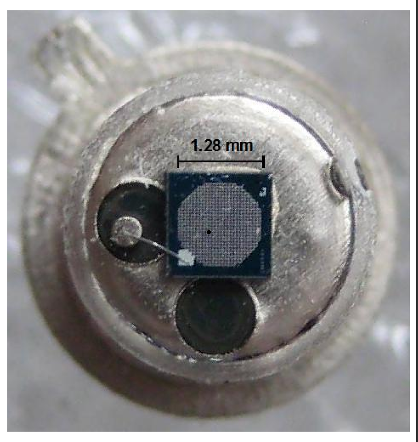
Introduction

Two low background experiments are located in the underground laboratory of the University of Tübingen. One is used for the test and operation of low temperature calorimeters. The second setup consists of a high resolution HPGe detector, which is used to screen materials for contaminants. In order to shield these experiments against cosmic ray muons, active muon veto detectors will be installed [1].
The muon veto systems for both experiments will be constructed by means of polystyrene based plastic scintillator panels. Each panel contains a wavelength shifting (WLS) fibre, embedded in a U-shaped groove. Both ends of the fibre are read out by multi-pixel Geiger-mode avalanche photodiodes (MRS APDs).

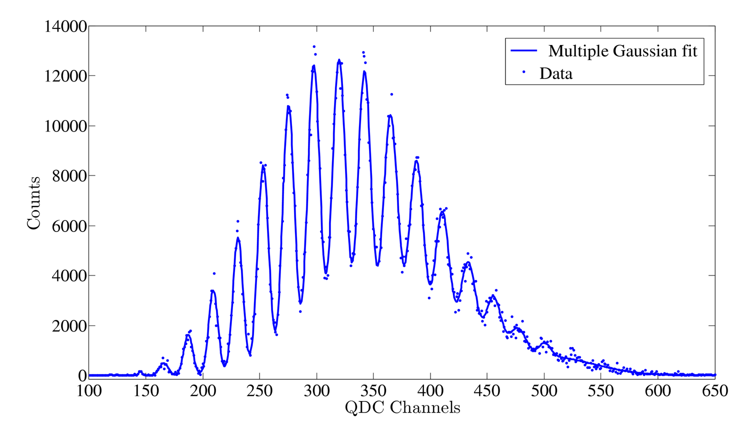
MRS APDs

The MRS APDs (CPTA 151-30 [2]) which are used in our projects are produced by the CPTA company. These devices consist of 796 pixels on the common substrate, which are connected in parallel. Each pixel has a sensitive area of 40x40 μm^2 and is quenched by its own quenching resistor.
The MRS APD has a **m**etal-**r**esistor-**s**emiconductor layer structure and is operated in the restricted Geiger-mode. The sensitive area of the whole device has an octagonal shape (see figure on the right) with 1.28 mm between opposed sides and is protected by an epoxy layer.
The pixels are divided by grooves, filled with an optical non-transparent material to suppress optical crosstalk between the pixels [3].

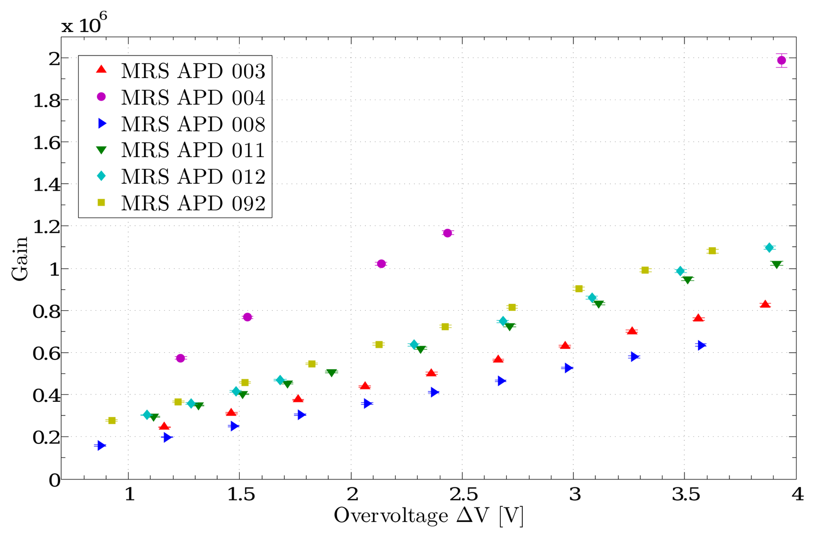


Gain

The internal gain of the MRS APDs was measured using short light pulses from a fast LED driver based on a green LED. On the right a typical multi p.e. charge spectrum of a MRS APD can be seen.

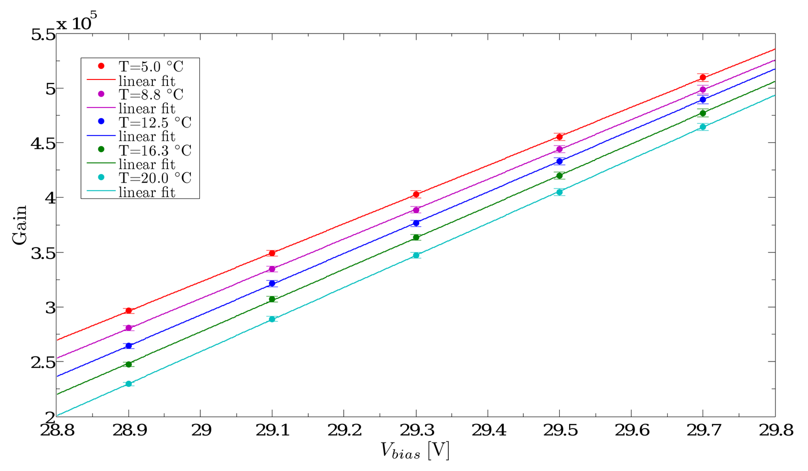


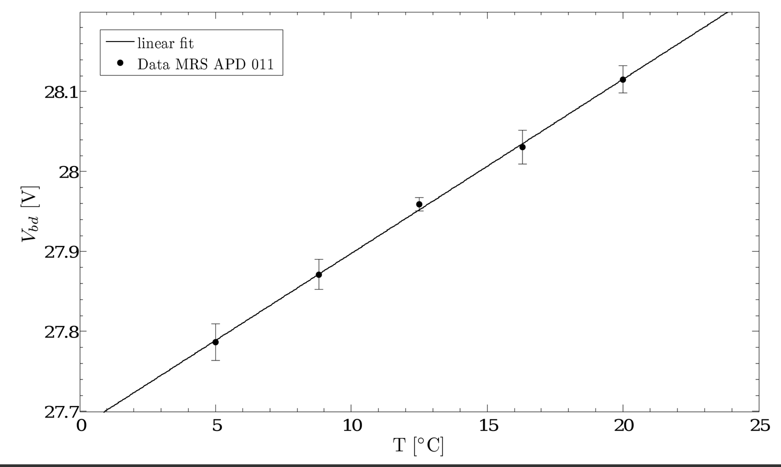
The gain depends linearly on the bias voltage or more precisely on the overvoltage $\Delta V = V_{bias} - V_{bd}$ as shown on the right.



Temperature dependence

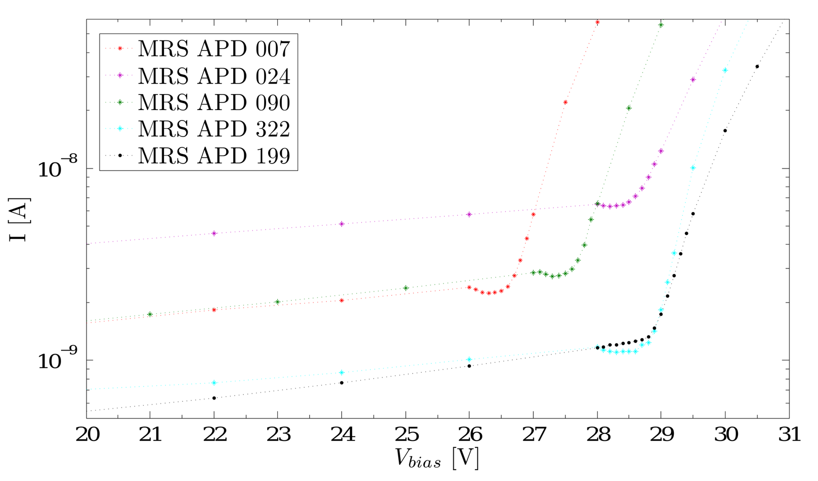
As can be seen below, the gain decreases with the temperature at a fixed bias voltage. This is because the breakdown voltage increases linearly with the temperature by ~ 0.02 V/°C for the tested MRS APDs.





Dips in the I-V curves

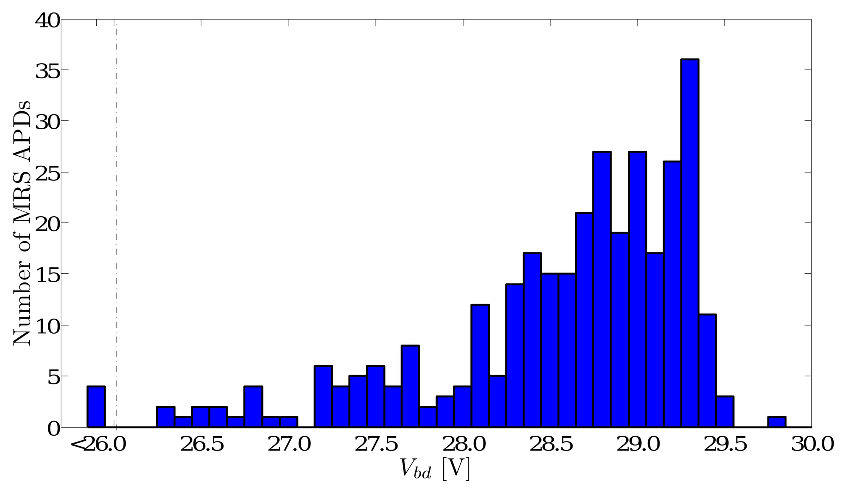
In a small fraction of the measured MRS APDs, a strange dip in the I-V curve just preceding the breakdown voltage point has been observed as shown on the right. The underlying reason for this effect is yet unknown.



References

[1] R. Falkenstein, Diploma thesis, 2011, University of Tübingen.
[2] http://www.cpta-apd.ru
[3] Yu.V. Musienko et al., Instrum. Exp. Tech. 51 (2008) 101.

Results and Conclusion

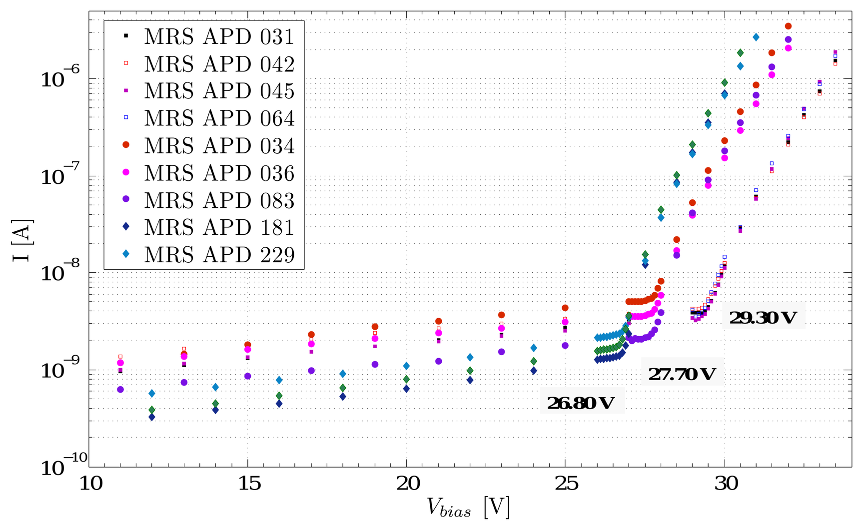


Extensive studies of the main parameters of MRS APDs have been carried out.
More than 80 % of the MRS APDs have breakdown voltages in a range of 1.5 V. All characterized MRS APDs are divided into subgroups with close operating voltages and gains which facilitates the whole muon veto detector control and adjustment.
The breakdown voltage increases linearly with the temperature by ~ 0.02 V/°C for the tested MRS APDs. The values of the quenching resistors between different MRS APDs vary considerably in a range of ~ 4 – 24 MΩ.
The measurements of the main parameters of MRS APDs revealed that these devices are suitable for the readout of plastic scintillator panels in our muon veto applications.

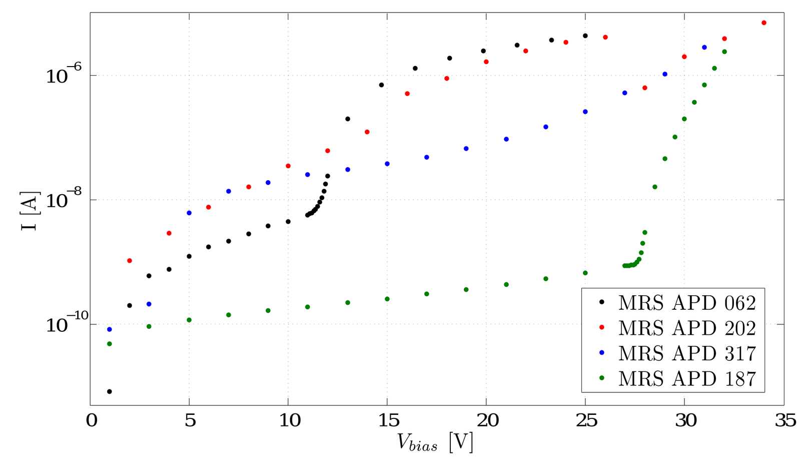
IV-Measurements

To determine the breakdown voltages, the values of the quenching resistors and the leakage current, I-V measurements were carried out. The setup consists of a light-tight metal box with an integrated Peltier cooling system. The MRS APDs are operated and readout using a Keithley 2400 SourceMeter and a computer based DAQ.

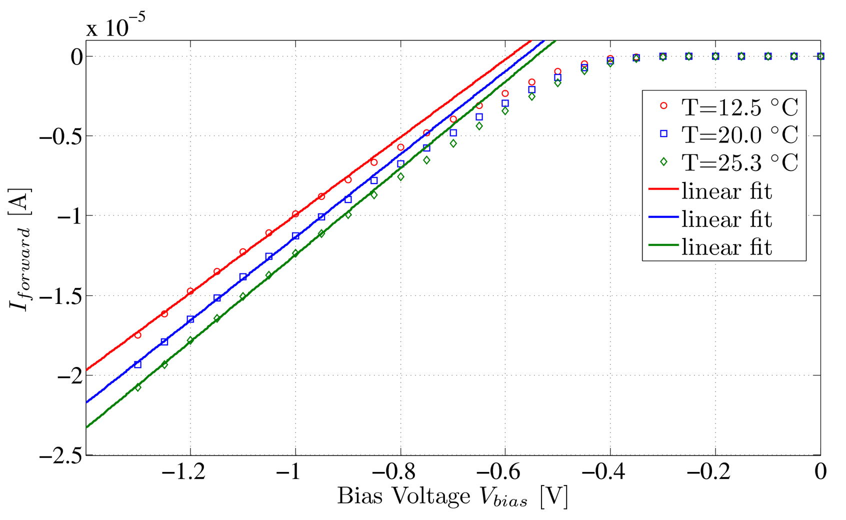
- **Reverse I-V characteristics**
  The reverse I-V curves are used to determine the breakdown voltage (V_{bd}) of the MRS APDs, which is an important parameter, since it defines the working point of the particular MRS APD, which is about 10-20 % above V_{bd}. More than 80 % of the MRS APDs have breakdown voltages in a range of 1.5 V (see results).



The reverse I-V measurements are also useful to identify damaged devices as can be seen below.

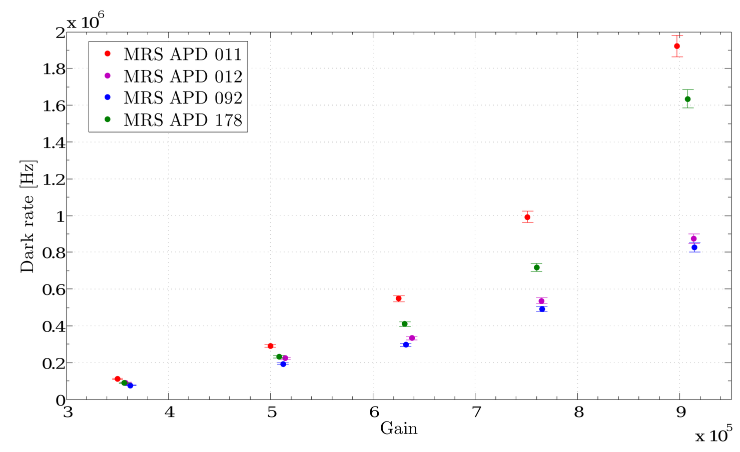


- **Forward I-V characteristics**
  If a forward bias voltage is applied instead of a reverse bias voltage, the value of the quenching resistor can be determined from the slope of the I-V curve.
  The values of the quenching resistors between different MRS APDs vary considerably in a range of ~ 4 – 24 MΩ.

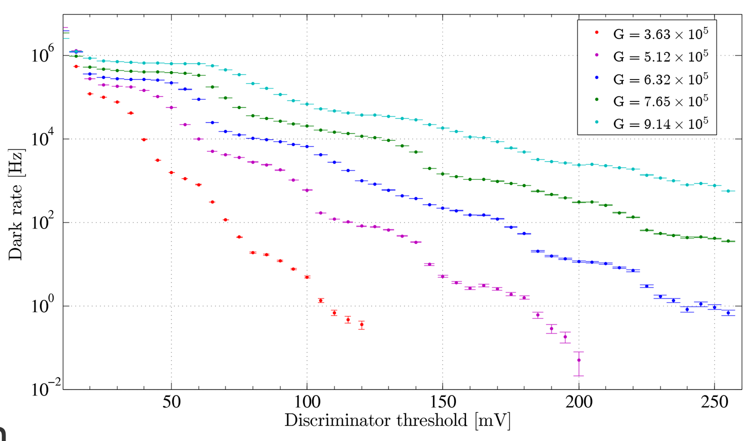


Dark rate

The dark rate is one of the main limiting factors of the performance of MRS APDs. The dark rate measurement was carried out for several MRS APDs at a temperature of 20 °C. The upper figure on the right shows the dark rate (0.5 p.e. threshold) as a function of the gain for four tested MRS APDs. As can be seen it increases significantly with the gain.



Since the dark events of MRS APDs are discrete pulses, mainly consisting of single p.e. pulses but also of multi-p.e. pulses, it is convenient to measure them as a function of the system threshold. The lower figure shows the test results for MRS APD 092 at different gain values. This plot is very meaningful, since a few properties of MRS APDs become apparent:



- The dark rate increases as a function of the gain.
- A step-like structure becomes evident due to the number of fired pixels.
- The sharpness of the steps reflects the uniformity of the gain among the pixels on the one hand, and furthermore the variations of the gain connected with the Geiger discharge development in one pixel on the other hand.