New empirical expression for APD gain vs voltage dependence

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Introduction

The gain vs. voltage dependence for avalanche photodiodes (APDs) is usually described by Miller's formula [1]:

$$M(V) = \frac{1}{1 - \left(\frac{V}{VB}\right)^n} \quad (1)$$

This formula works well at very high gains (when bias is close to APD's breakdown voltage (VB)). However agreement between (1) gain vs. voltage dependence is rather poor for APDs operating at moderate gains (10 ÷ 200).

In this presentation we propose a new empirical formula describing gain vs. voltage dependence of APDs in wide range of gains (20 ÷ 300)

[1] S. L. Miller, Avalanche breakdown in germanium, Phys. Rev. 99, p. 1234 (1955)

Method

Measuring gain vs voltage dependences of different APDs and SiPMs (before breakdown), we observed that relative change of APD gain can be approximated by linear function in wide range of gains:

$$\frac{1}{M} \times \frac{dM}{dV} = a \times M + b \quad (2)$$

The solution of this differential equations is:

$$M(V) = \frac{b/a}{exp(b \times (VB - V)) - 1} \quad (3)$$

where **VB** is APD's breakdown voltage, **a** and **b** are parameters depending on the APD structure. When V is close to VB eq. (3) coincides with the formula (1) for **n**=1: $M(V) = \frac{1}{a \times (VB-V)}$ (4)

In this presentation we compare the results of APDs gain measurements with the calculations using formula (3). APD gain was measured using blue LED continuous light illumination:
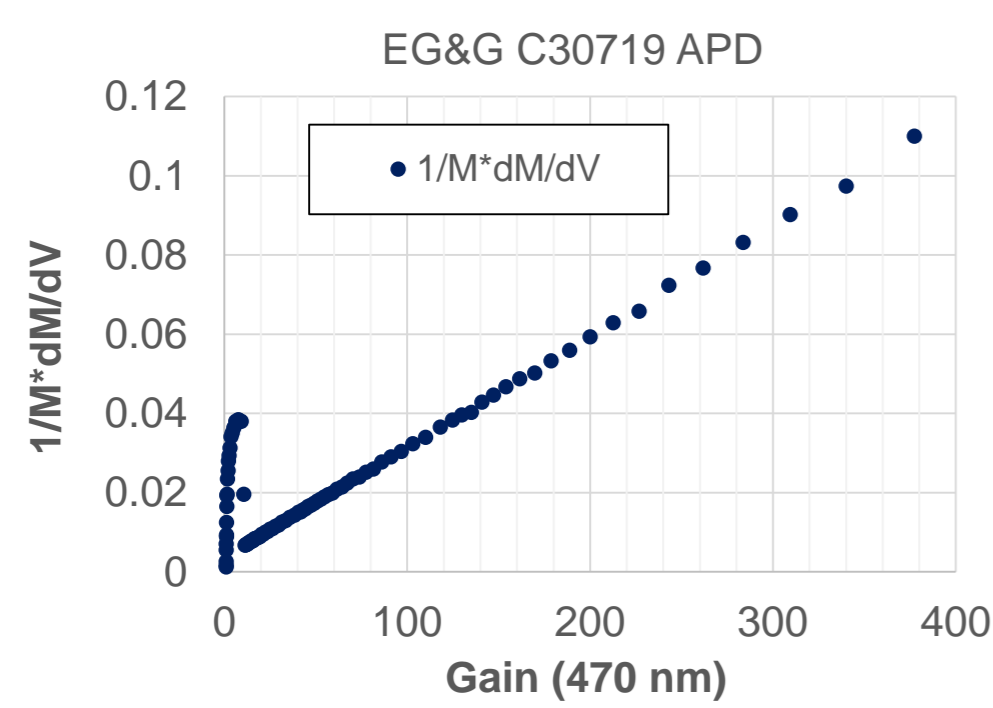
$$M(V) = \frac{Itotal(V) - Idark(V)}{Itotal(10V) - Idark(10V)} \quad (5)$$

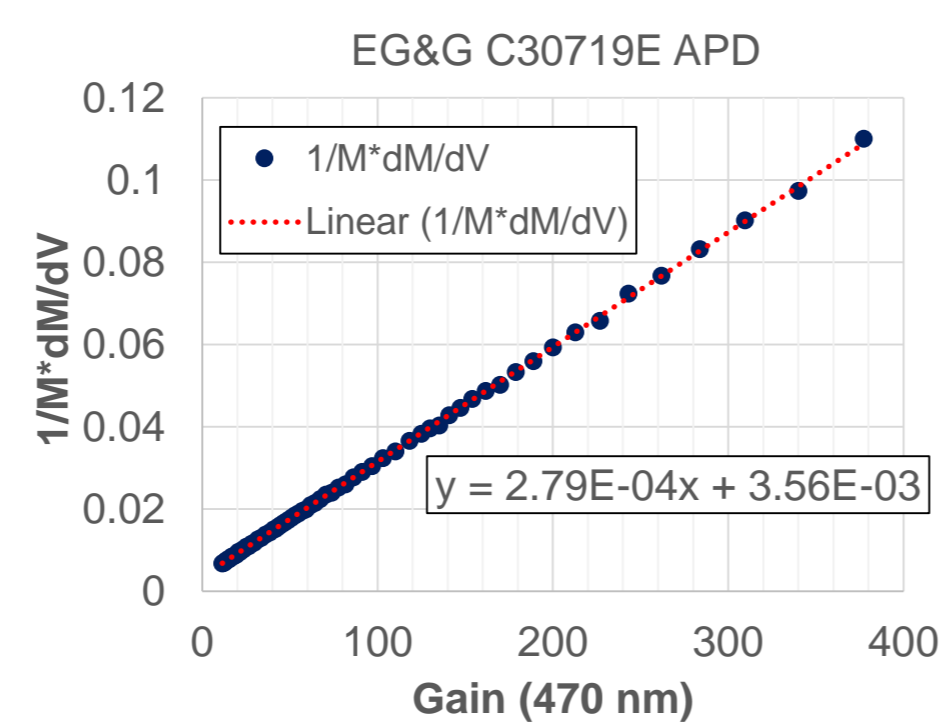## Gain vs. bias dependence for EG&G C30719 APD
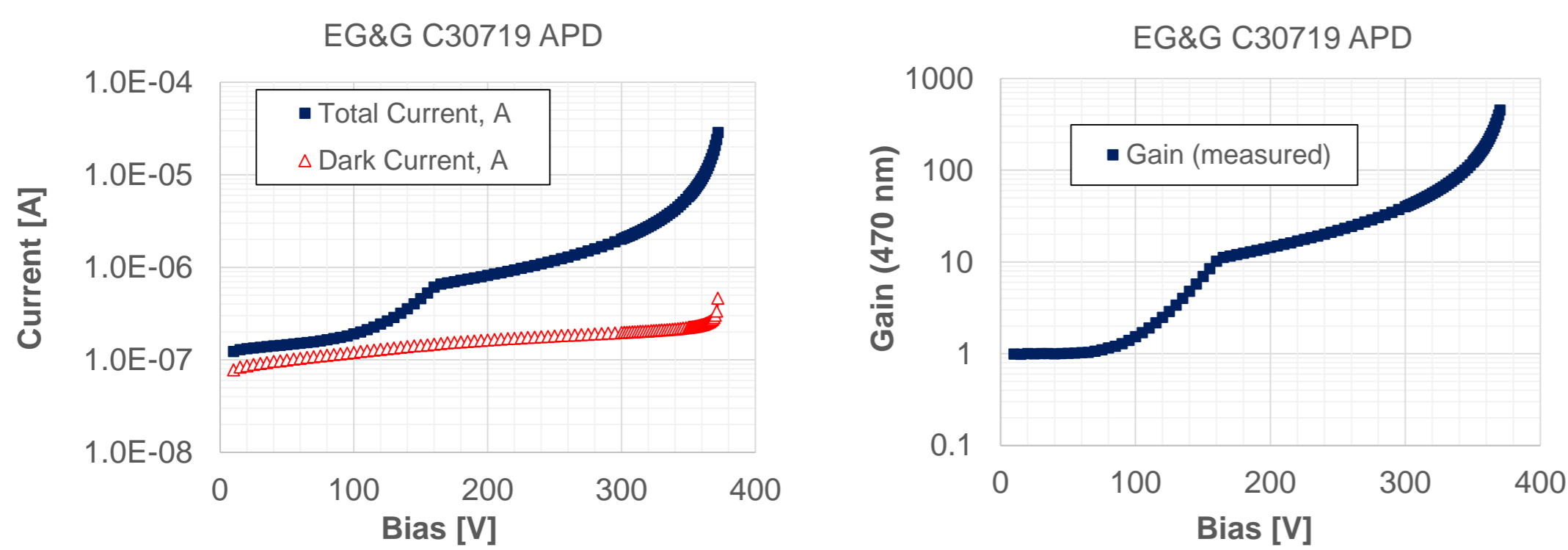
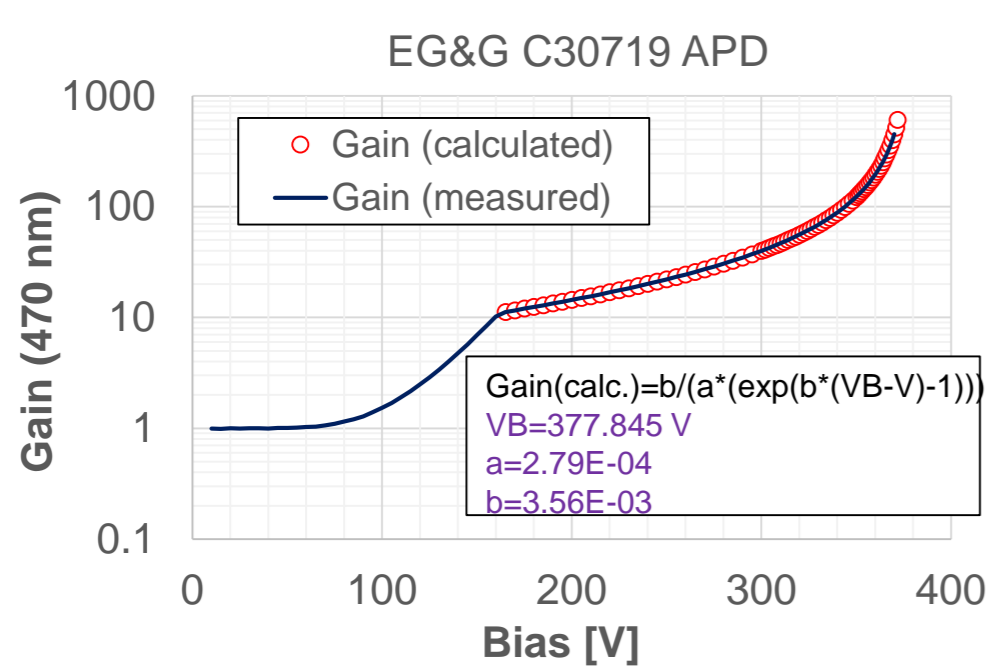Total current and dark current vs. bias measured for the EG&G APD at room temperature

Gain vs. bias dependence measured for the EG&G APD at room temperature
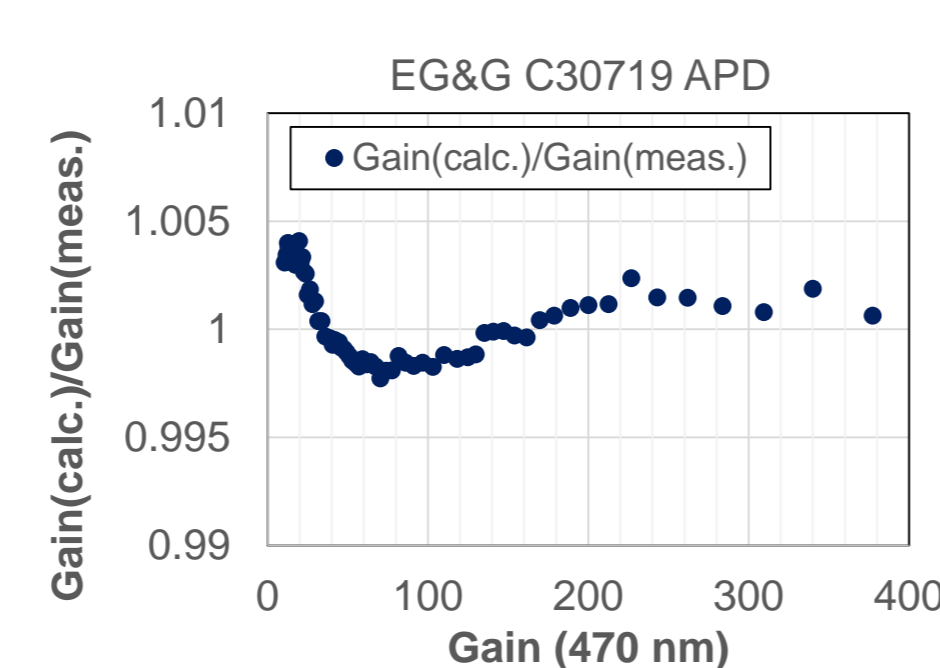

1/M*dM/dV vs. gain dependence calculated for the EG&G APD

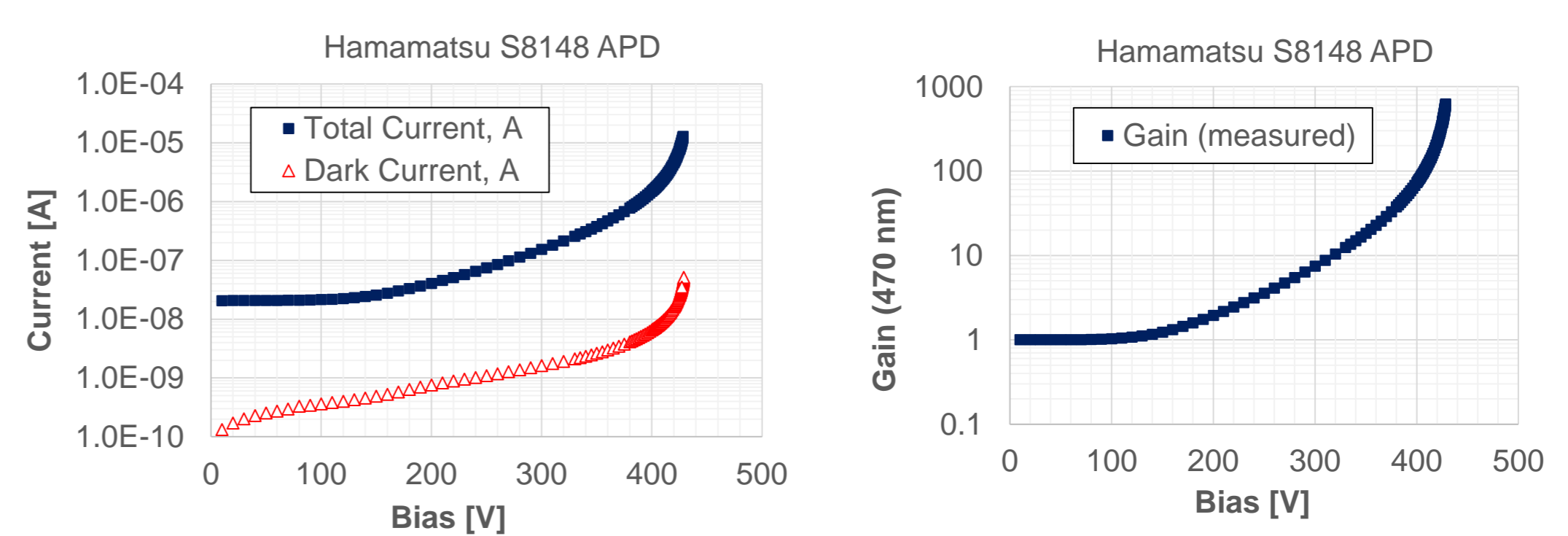Linear fit of the 1/M*dM/dV vs. gain dependence for the EG&G APD

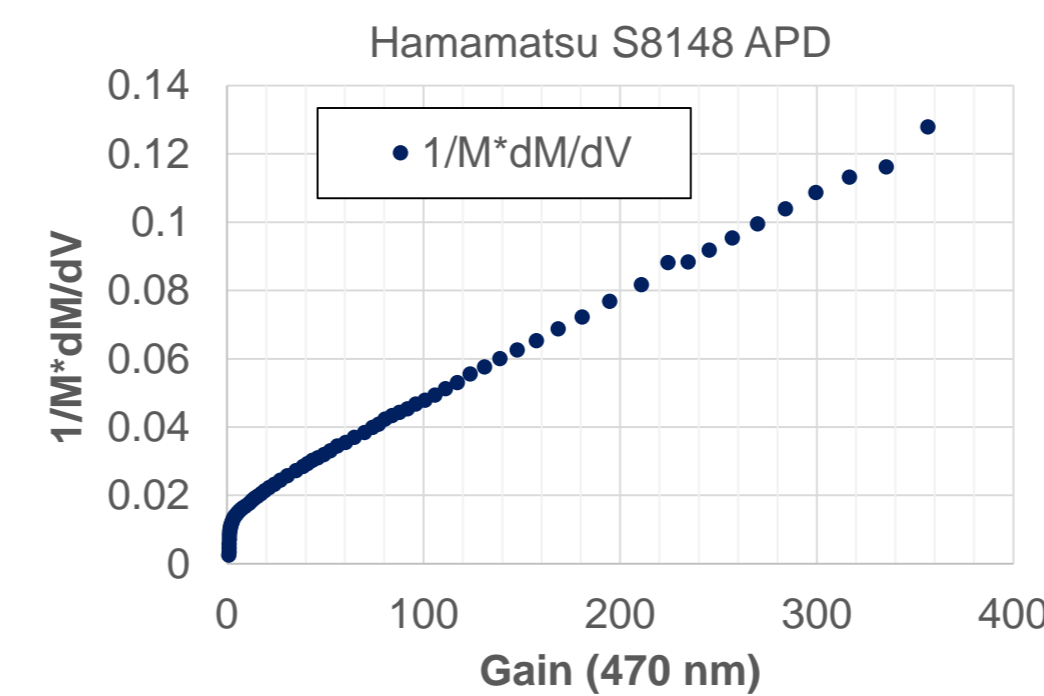Gain vs. bias dependence measured/calculated for the EG&G APD

Gain(calculated)/Gain(measured) vs. Gain(measured) for the EG&G APD

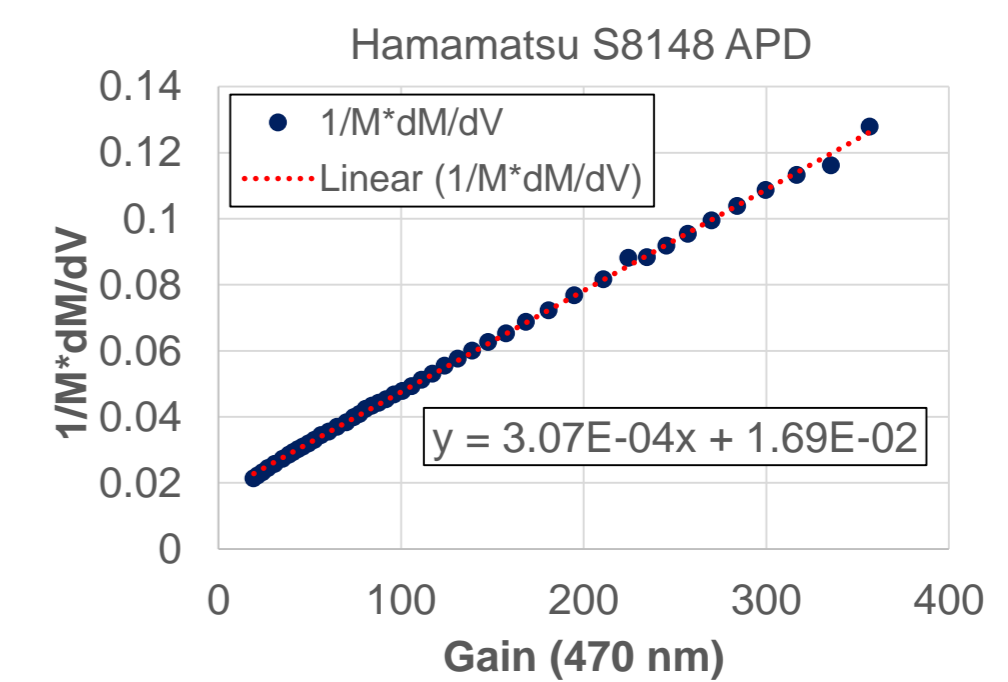## Gain vs. bias dependence for Hamamatsu S8148 APD

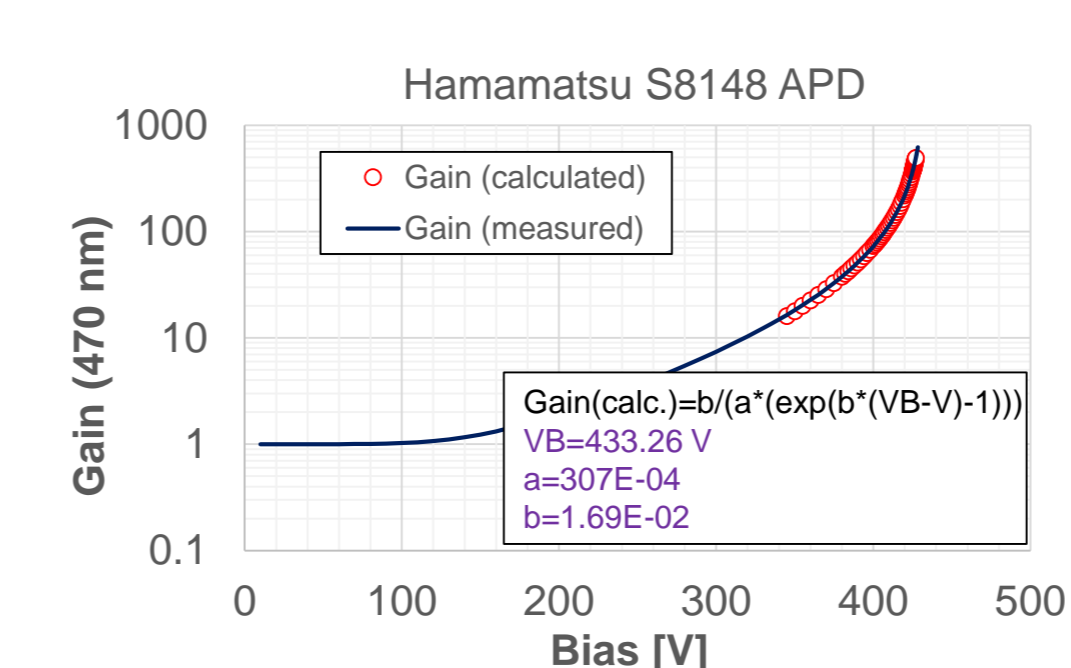Total current and dark current vs. bias measured for the S8148 APD at room temperature

Gain vs. bias dependence measured for the S8148 APD at room temperature
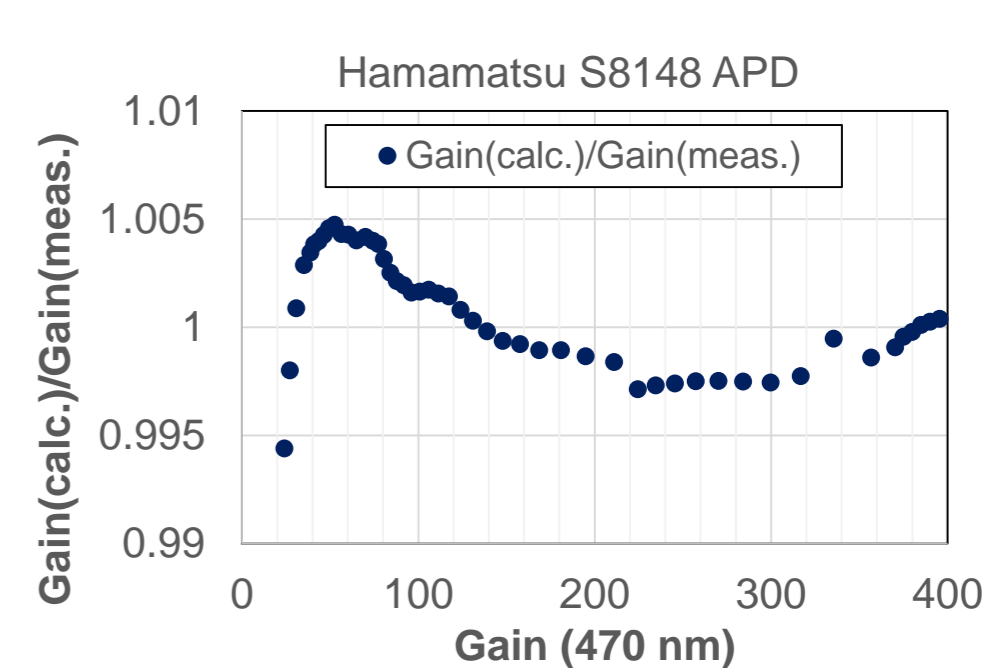

1/M*dM/dV vs. gain dependence calculated for the S8148 APD

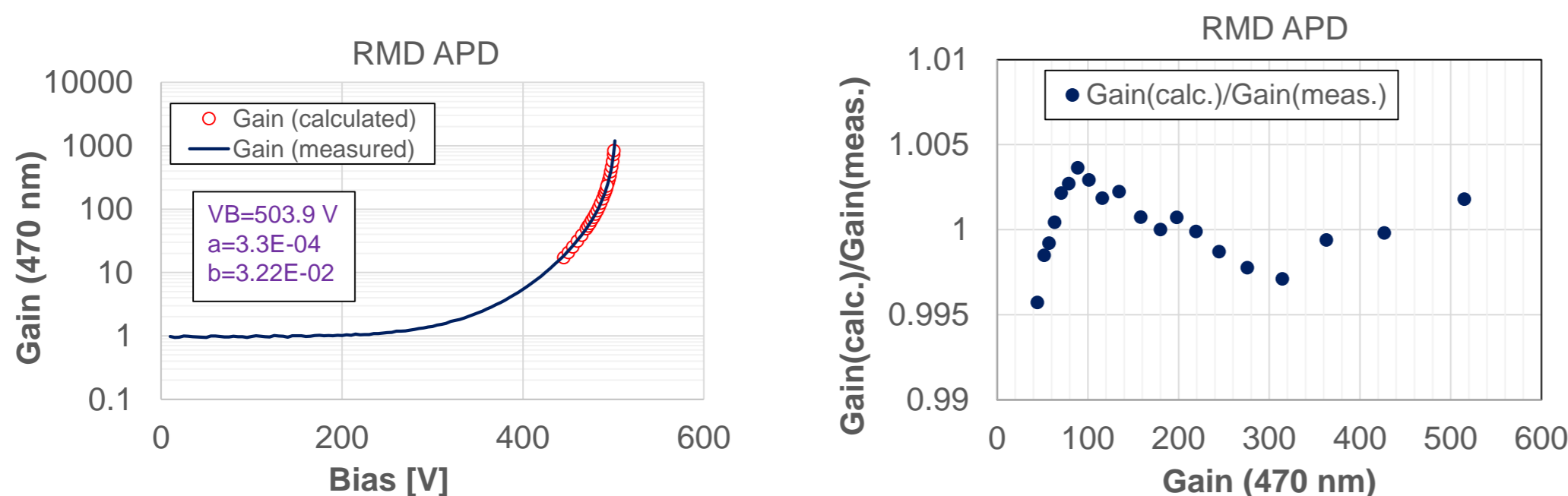Linear fit of the 1/M*dM/dV vs. gain dependence for the S8148 APD

Gain vs. bias dependence measured/calculated for the S8148 APD

Gain(calculated)/Gain(measured) vs. Gain(measured) for the S8148 APD
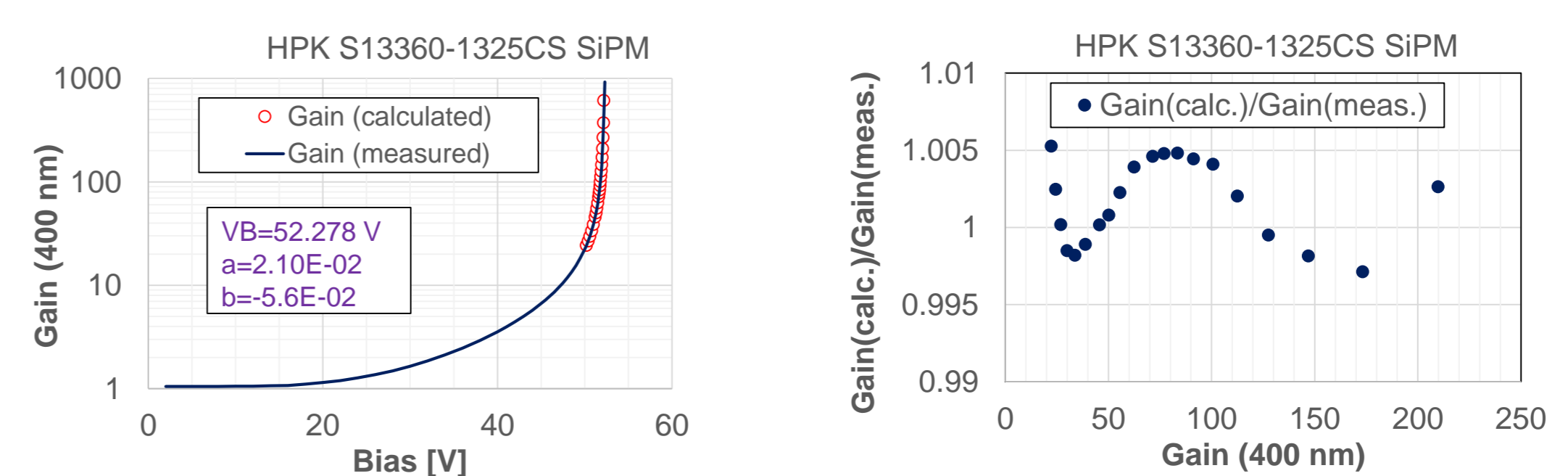
Gain vs. bias dependence for RMD APD

Gain vs. bias dependence measured/calculated for the RMD APD

Gain(calculated)/Gain(measured) vs. Gain(measured) for the EG&G APD

Gain vs. bias dependence for HPK S13360-1325CS SiPM

Gain vs. bias dependence measured/calculated for the HPK SiPM (before breakdown)

Gain(calculated)/Gain(measured) vs. Gain(measured) for the HPK SiPM

Summary

We proposed new empirical formula describing gain vs. voltage dependence of APD. Good agreement between this formula and real gain vs voltage dependence was found for several APDs/SiPMs used in HEP and medical applications.