Gain and Excess Noise Factor of an APD

EDIT Photo-detection

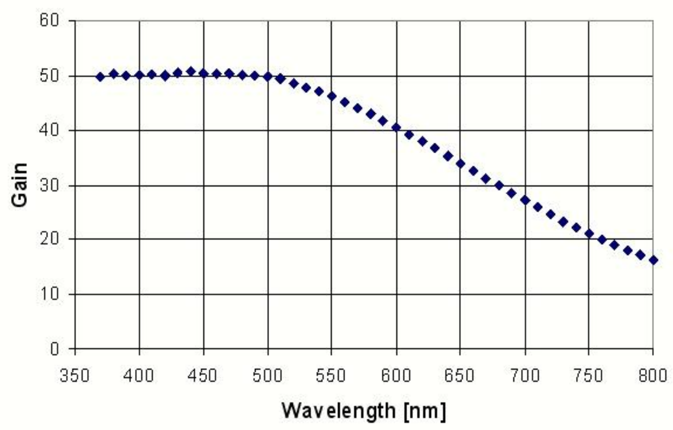
Gain:

We measure the gain of an APD with blue and red light.

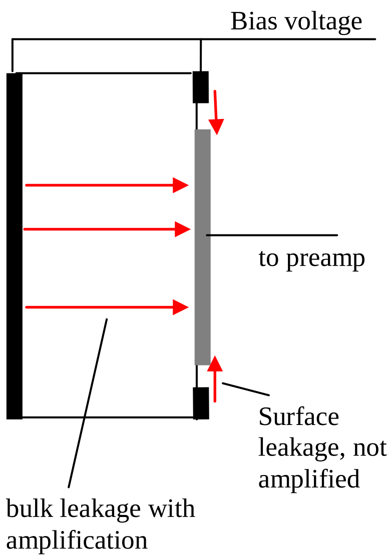
The currents are measured with and without DC light. Assuming that at low voltages (20 to 50 V) we have unity gain we get the gain at any voltage from the difference of the illuminated currents and the dark currents when we normalize to the low voltage difference. The APD gain M at voltage U should be calculated using equation:

$$M(U)=(I_{ill}(U) - I_{dark}(U))/(I_{ill}(20\ V)-I_{dark}(20\ V))$$

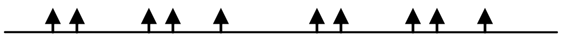
The gain measured with red light should be smaller than the gain at the same voltage measured with blue light. This is due to the shallow p-n junction location (~7 micron deep) and due to difference of ionization coefficients for electrons and holes in silicon (ionization coefficient for electrons is a factor of 100 higher than that for holes)



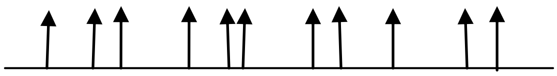
Excess noise factor:



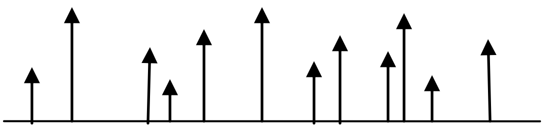
Surface leakage: RMS fluctuation = $\sqrt{qI_s}$



Bulk leakage: RMS fluctuation = M $\sqrt{qI_b}$



But the gain varies $\Rightarrow$ RMS fluctuation = $\sqrt{M^2+\sigma_M^2}\times\sqrt{qI_b}$



Energy resolution: $$\frac{\sigma(E)}{E}=\frac{\sigma_{intr}}{E}\oplus\frac{\sigma_{cal}}{E}\oplus\frac{\sigma_{photo}}{E}\oplus\frac{\sigma_{noise}}{E}$$

Photostatistics: $$\frac{\sigma_{photo}(E)}{E}=\sqrt{\frac{F}{N_{pe}\times E}}$$

Series noise: $$\sigma\sim\frac{C_t\sqrt{4kT\left(R_s+\frac{1}{g}\right)}}{N_{pe}M}\times\frac{1}{\sqrt{\tau}}$$

Parallel noise: $$\sigma\sim\frac{\sqrt{2q(I_s+(M^2+\sigma_M^2)I_b)}\times\sqrt{\tau}}{N_{pe}M}=\frac{\sqrt{2q(I_s+M^2F\times I_b)}\times\sqrt{\tau}}{N_{pe}M}$$

with $$F=\frac{M^2+\sigma_M^2}{M^2}$$

Measurements:

$$\sigma = A\sqrt{(i_s + (i_b + i_{ill})M^2 F) \times \tau}$$

$$\sigma_{ill}^2 = \sigma_{tot}^2 - \sigma_{dark}^2 = A^2 i_{ill} M^2 F$$

$$I_{ill} = i_{ill} M \quad , \quad I_{ill} = I_{tot} - I_{dark}$$

$$\sigma_{ill}^2 = A^2 I_{ill} M F$$

Calibrate with PIN-diode with $\mathbf{C_{pin} = C_{APD}}$ = 80 pF

For a PIN-diode **M = F = 1**

$$F = \frac{\sigma_{APD}^2}{\sigma_{PIN}^2} \times \frac{I_{PIN}}{I_{APD}} \times \frac{1}{M}$$

$$\sigma_{XXX}^2 = \sigma_{tot}^2 - \sigma_{dark}^2$$

We measure with an ADC the width of a line (generated by a signal on the test input of the amplifier) and the currents with a current meter with a PIN diode and an APD. We do this with and without DC illumination and at two different gains of the APD