I-V Characteristic and Dark Count Rate

Experiment 2

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1 Objectives

The objectives of this experiment are as follows:

- To measure current versus voltage for a photon counting detector and plot the resulting current-voltage (I-V) characteristic.
- To use the measured I-V characteristic to extract the photodiode parameters.
- To investigate the variation of dark count with temperature and excess bias.

2 Equipment

- 1 PC (not supplied)
- 1 Power supply (not supplied)
- 1 Ammeter (not supplied)
- 1 SensL Passive Quench Circuit (PQC) (supplied)
- Integrating sphere with filter holder (supplied)
- 1 PIN photodiode (supplied)
- 1 White light source (supplied)
- 1 SensL photon counter (supplied)
- SensL Integrated Environment software (supplied)

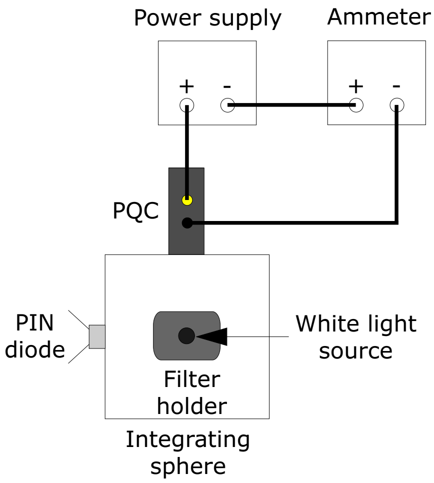

Figure 1: Experimental setup for measurement of the I-V characteristic.

3 Measurement of I-V Characteristic

- Set up the equipment as shown in Fig. ??. This places the photon counting detector, contained within the SensL PQC, in the dark. The room lights may be turned off when making measurements as this increases the darkness.

- In the circuit shown in Fig. 1 the PQC is forward biased. Initially set the voltage on the power supply to 0 V and set the current limit to 30 mA. Read the current flowing through the diode from the ammeter. Record the current and the voltage.

- Increase the power supply voltage in steps of 0.1 V until the current limit is reached. Read and record the voltage and the current at each bias.

- Reverse bias the diode by exchanging the power supply connections. Set the current limit to 0.1 mA.

- Starting from 0 V increase the power supply voltage in steps of 0.5 V until a current of ≈ 10 μA has been read on the ammeter.

- Plot current (y-axis) versus voltage (x-axis) to obtain a typical I-V characteristic (see Module 3 Section 2.2 for an example). **Note:** the part of the plot where the diode is forward biased is known as the forward characteristic and the part where the diode is reverse biased is known as the reverse characteristic.

4 Photodiode Parameter Extraction

4.1 Shunt Resistance

Using the setup shown in Fig. 1, exchange the power supply leads and therefore reverse bias the diode. Starting from 0 V increase the voltage on the power supply to 10 mV. Record the current on the ammeter. Using this current value, find the shunt resistance using:

$$R_{sh} = \frac{0.01}{current}\ \Omega \tag{1}$$

where R_{sh} is the shunt resistance and 'current' is the recorded current value in Amps.

4.2 Breakdown Voltage

Reverse bias the diode using the procedure outlined above for the shunt resistance. Starting from zero increase the power supply voltage until there is a current of $1\ \mu$A flowing through the circuit. Record the voltage, this is the breakdown voltage. Look back at the I-V characteristic plotted in Section 3. The breakdown voltage measured here should coincide with the point on the reverse characteristic where the current starts to increase rapidly.

4.3 Threshold Voltage

Look at the forward characteristic obtained in Section 3. Find the equation of the linear part of this characteristic. Find the x-intercept (value of x when $y = 0$ of this equation). This x-intercept gives the threshold voltage.

4.4 Ideality Factor and Saturation Current

The current flowing through a photodiode in the dark is governed by the ideal diode equation. The ideal diode equation is given by:

$$I_d = I_{sat}\left(e^{\frac{qV_d}{\eta kT}} - 1\right) \tag{2}$$

where I_d is the photodiode current, V_d is the photodiode voltage, I_{sat} is the saturation current, q is the charge on an electron (1.602×10^{-19} C), η is the ideality factor, k is Boltzmann's constant (1.381×10^{-23} JK^{-1}) and T is the room temperature (usually 300 K).

Under sufficient forward bias the ideal diode equation can be approximated as:

$$I_d \approx I_{sat}e^{\frac{qV_d}{\eta kT}} \tag{3}$$

which gives:

$$\ln I_d = 2.303\log_{10} I_d \approx \frac{qV_d}{\eta kT} + 2.303\log_{10} I_{sat} \tag{4}$$

This represents the equation of a straight line $y = mx + c$ where:

$y = \log_{10} I_d$,
$x = V_d$,
$m = q/(2.303\eta kT)$ = the slope,
$c = \log_{10} I_{sat}$ = the y-intercept.

Using the photodiode voltage and photodiode current obtained for the forward characteristic in Section 3, plot $\log_{10} I_d$ (y-axis) versus V_d (x-axis). Find the slope of the resulting graph and then proceed to find the ideality factor using:

$$m = \frac{q}{2.303\eta kT} \tag{5}$$

Note: The slope and hence the ideality factor is not constant for all forward bias voltages, but changes depending on the bias. At low bias voltages $\eta \approx 1$ while at higher voltages $\eta \approx 2$.

The saturation current is obtained by finding the equation of the linear part of the $\log_{10} I_d$ versus V_d graph. There will usually be two linear parts to the plot. Use the linear section that occurs at the higher bias voltages. The y-intercept of this equation (value of y when $x = 0$) will give the value of $\log_{10} I_{sat}$. I_{sat} can be found using:

$$I_{sat} = 10^{y-intercept} = 10^c \tag{6}$$

5 Investigation of Dark Count Rate

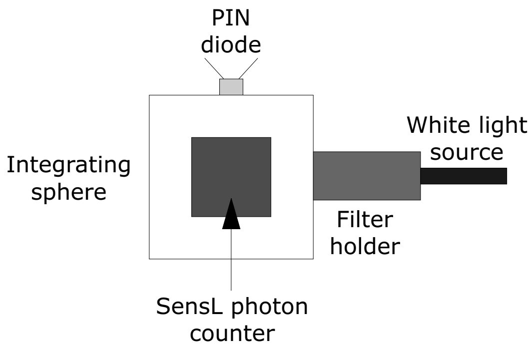

Figure 2: Experimental setup for measurement of dark count rate.

- Connect the SensL photon counter, PIN photodiode and white light source to the integrating sphere as shown in Fig. 2. This places the photon counter in the dark.
- Install the SensL Integrated Environment software onto the PC. Bias the photon counter paying particular attention to the biasing sequence, i.e. initially switch on V_{cc}, then the APD bias and finally the quench voltage, (see the supplied photon counter installation and user guide for further information).
- Connect the supplied USB lead to the photon counter and to the computer. Open the SensL Integrated Environment software. For information on the

photon counter GUI (graphical user interface) refer to the user manual supplied or select 'Help' on the software.

- When the start screen appears, navigate to the toolbar and select the option labelled 'Window' followed by 'Results'. Click 'PCDMini' followed by 'Channel' on the 'Results' window to view the diode temperature, the diode voltages and the count frequency.
- Navigate to 'Window' on the toolbar and open the 'Graphs' window by selecting 'Graphs'. Select 'This Computer', 'PCDMini', 'Channel', 'Counts' and 'Count Frequency'. Then press the 'Play' icon to observe the count rate. Fig. 3 shows the 'Graphs' window displaying a count rate of $27,500$ Hz or cps (counts per second).
- Turn the room lights off and observe that the count rate decreases significantly. This is the dark count rate.
- To investigate the variation of dark count rate with temperature, initially observe and record the count rate with the photon counter cooled to $-20°$C and operating in the dark.
- Remove the bias from the photon counter. Take the photon counter boards apart and remove the middle photon counter board, which contains the Peltier cooler. Replace the bottom board. Bias the photon counter and observe and record the dark count rate of the uncooled photon counter. (**Note:** shut down the software before removing the photon counter bias and restart the software when the photon counter is again biased, otherwise the software will not be able to detect the photon counter.)
- To investigate the variation of dark count with excess bias, unbias the photon counter, insert the Peltier cooling board and re-bias the photon counter.
- Set the APD bias to 30 V. Calculate the excess bias using the value of the breakdown voltage supplied by the manufacturer. Record the dark count at 30 V together with the excess bias.

- Increase the APD bias to 31 V. Measure and record the dark count rate. Calculate and record the excess bias.
- Repeat the procedure until an APD bias of 40 V has been reached. Plot a graph of dark count (y-axis) versus excess bias (x-axis).

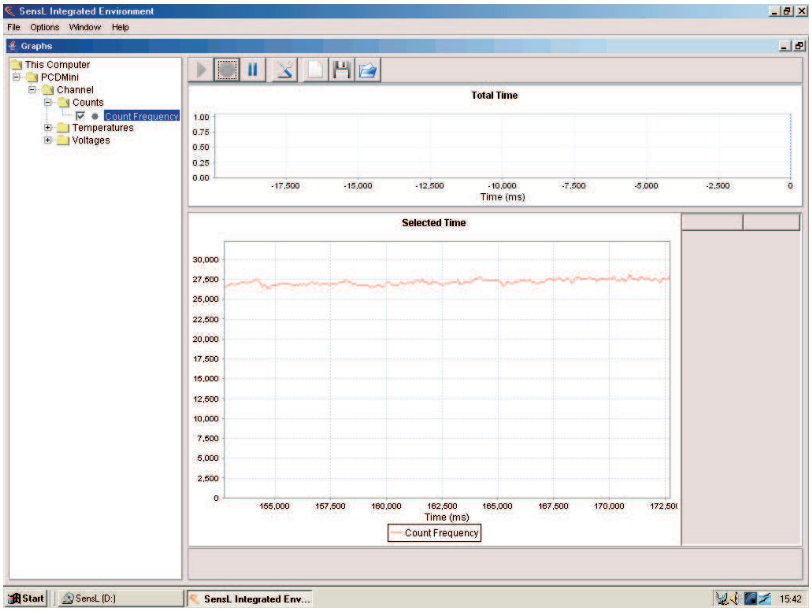

Figure 3: 'Graph' window of the photon counter.

6 Summary

After completing Experiment 2, the reader should be able to answer the following questions:

1. How is shunt resistance measured?
2. How is the breakdown voltage measured?
3. What is the expected value of the ideality factor for a silicon photodiode?

4. How does dark count vary with temperature?

5. How does dark count vary with excess bias?

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7 Acknowledgements

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