Photonics Research: Designing and Implementing a Single Photon Detector

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Abstract

A Single Photon Detector is an electrical circuit that reacts to a photon and produces a measureable voltage spike and can be used to sense and count photons. The ability to sense photons allows researchers to study fundamental physical concepts, such as entanglement and flame thermodynamics. Commercial versions of these circuits, however, are thousands of dollars. The possibility of fabricating one from components at a reduced cost was investigated. The main component of the system is an avalanche photodiode. Unless the voltage applied to the photodiode is larger than the breakdown voltage, current will not flow. However, when the applied voltage is slightly below the breakdown voltage, current can flow if light impacts the diode. Therefore, the photodiode can act as a switch, which is activated by one or more photons. There are two ways to improve the function of the Single Photon Detector. First, one can improve the reset time because it takes a while for the applied voltage to reset after being hit by a photon. Also, the temperature of the circuit rises due to current flow. A temperature control system is needed so that the sensitivity is constant. By applying all of the concepts above, it is possible to build a cheap but reliable Single Photon Detector.

Introduction

1. Single Photon Detectors are commercially available, but can cost thousands of dollars. Some smaller colleges or research facilities can find this cost prohibitive. It is possible to build one from scratch for a tenth of the cost.
2. The main component of the Single Photon Detector is an avalanche photodiode.
   - An avalanche photodiode is a light sensitive semiconductor. Like most semiconductors, there are situations in which current can flow and situations in which current cannot flow.
   - By applying a certain voltage potential to the diode, a single photon impact will allow current to flow. This applied voltage will be inside a certain breakdown voltage region.
   - Once current begins to flow, it will not stop until an outside influence lowers the applied voltage below the breakdown voltage region. If a resistor is connected in series with the photodiode, a drop in applied voltage will occur as a result of current flow.

Applications

Single Photon detectors can be used to view low light images such as those measured in combustion analysis.

Single Photon detectors can be used to detect photons in quantum optics.

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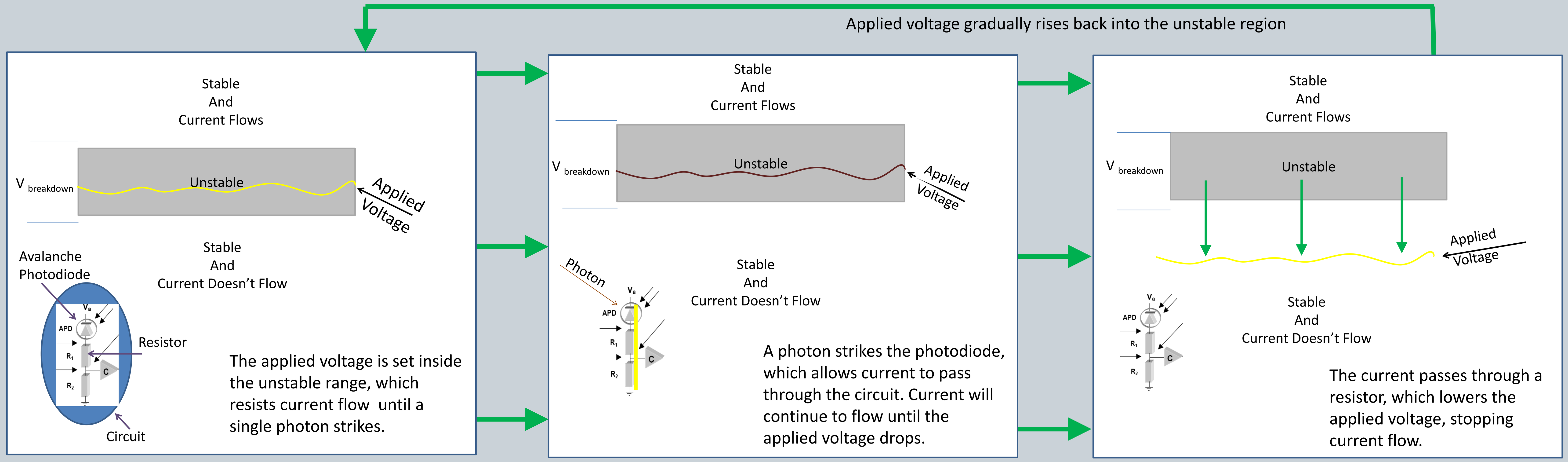
Experimental Design



Performance Issues and Improvements

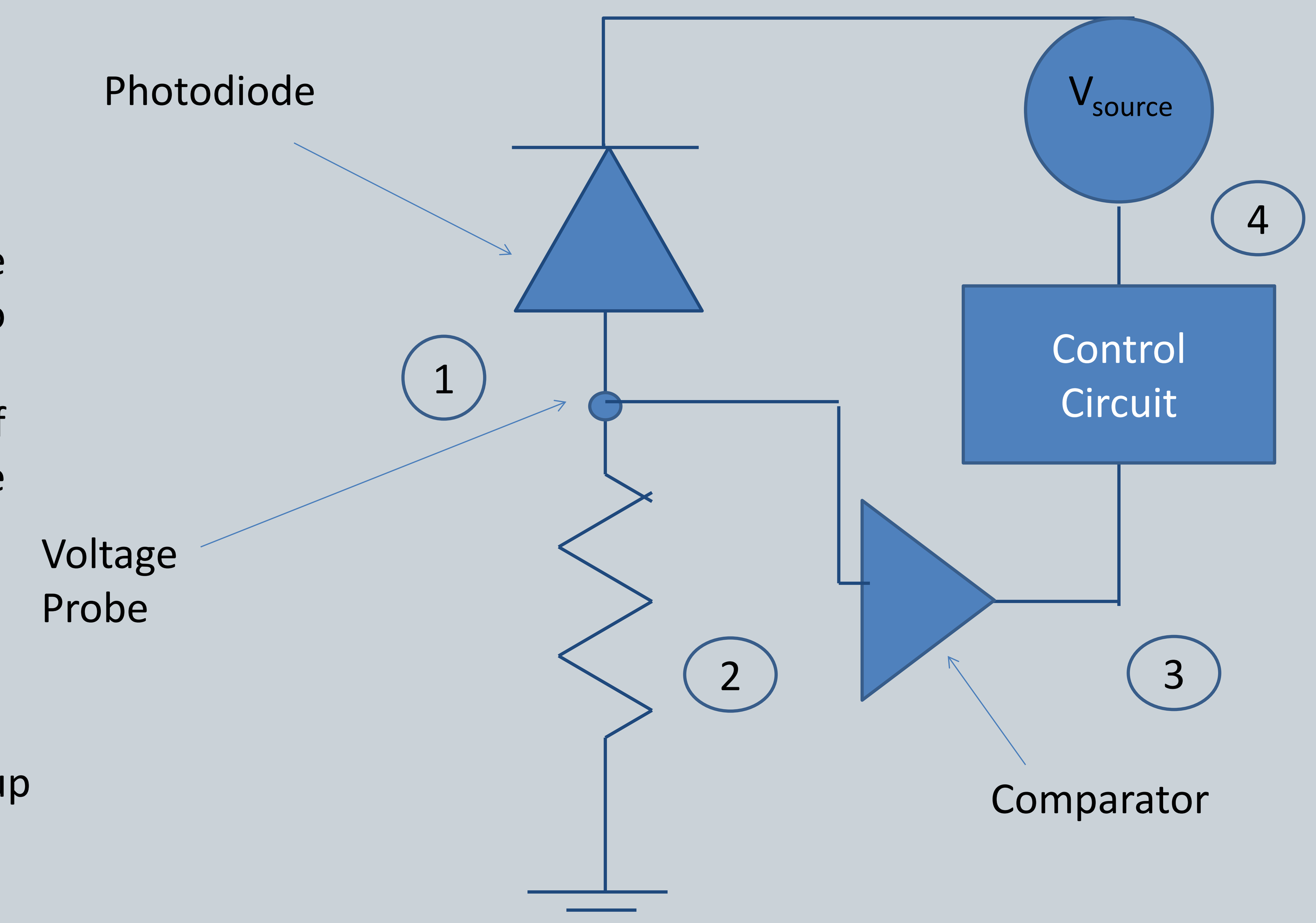
Performance Issues do not prevent the Single Photon Detector from functioning correctly.

- In order to improve the reset time of the avalanche photodiode, active quenching will be applied. This will allow a larger quantity of photons to be counted the same time interval.
- The avalanche photodiode is sensitive to fluctuations in temperature. If the temperature is maintained, the breakdown voltage region and the sensitivity will remain constant.

Temperature

- As current runs through the circuit there is an increase in temperature.
- This temperature affects the sensitivity of the avalanche photodiode.
- The unstable region where we keep the applied voltage will move either up or down.
- This will cause false detections of photons or miss photons all together.
- A temperature control circuit must be employed to combat the fluctuations in temperature.

Active Quenching



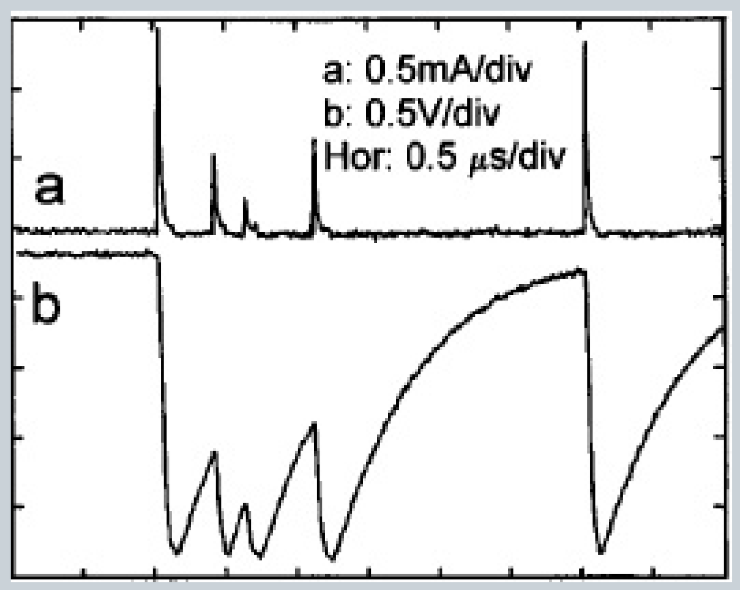
1) When a photon impacts the photodiode and current flows, this current passes through a resistor like above.

2) The current that passes through the resistor is then read by a comparator.

3) The comparator sends a signal to a control circuit that adjusts the voltage source to increase the applied voltage.

4) This forces the applied voltage back into the unstable region much faster than before.

Data from Literature

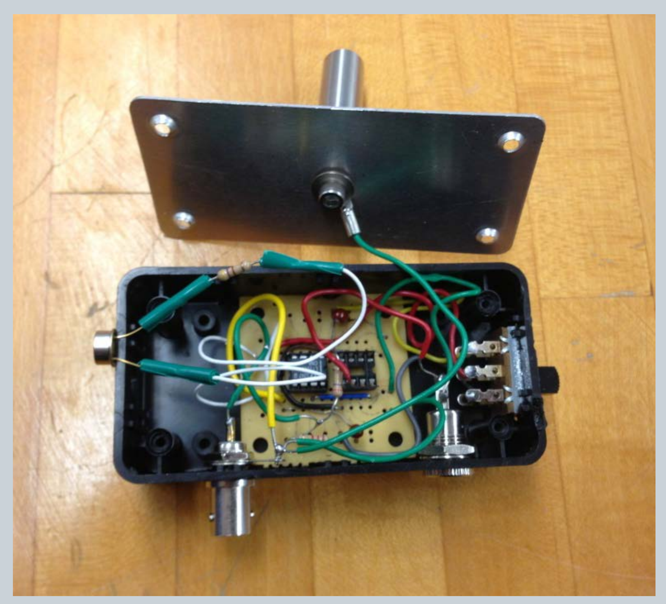


a. Current
b. Voltage applied

There is a current spike when a photon hits, but the voltage applied immediately falls, stopping the current. The voltage applied takes a while to reset.

Results taken from: Semiconductor optical single-photon detectors, pg.2 Zhang, 2006

Current Research



Two Photon Intensity Sensors were designed, fabricated, and implemented in order to gain related lab experience. These sensors were then tested for linearity.

Note: Please ask about sensors.

References

Zhang, Jie. 2006. "Semiconductor optical single-photon detectors." Workshop on Advanced Topics in Semiconductor Devices. University of Rochester. Available at: http://www.ece.rochester.edu/courses/ECE423/ECE223_423_MSC426%20Workshop06/term%20papers%2006/JZhang_06.pdf