Initial Studies of GaInP Based Geiger Mode APD Arrays

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Geiger Mode Avalanche Photodiode (GAPD)

- Photodetectors work by converting light signals into electrical current.
- When a photon hits a semiconductor material, it may get absorbed and create an electron-hole pair.
- In an avalanche photodiode (APD) the electron-hole pairs are accelerated using a high voltage gradient, creating a cascade and larger current for detection.
Silicon Photomultipliers (SIPMs)

- Commonly used due to small size and mechanical robustness, and insensitivity to magnetic fields
- Simple Readout: set to operational bias and measure current
- Each microcell (or SPAD*) consists of a Geiger mode photodiode and a quench resistor which shuts down the avalanche process

*Single Photon Avalanche Detector
Characteristics of Geiger Mode APD Arrays

- Initial: breakdown voltage ($V_{\text{br}}$) and whether device responds to light found using I-V curves
- A microcell enters Geiger mode when its voltage is above breakdown voltage, which is when the electric field is strong enough to create a cascade of current
- Leakage: the current before breakdown voltage
- Gain: $G = C_d \times V_{\text{ex}}$, photon detection efficiency, and noise
- We also studied the pulse shapes of the produced avalanches, which are affected by the quench resistance of the cell
GaInP Devices

- GaInP has a wide band gap and low carrier concentration, which makes it (theoretically) more radiation hard than silicon devices.
- Radiation hard light detectors have applications in high particle flux environments (e.g., high energy and nuclear physics, space-based applications).
- We present data to show a first proof of principle that large detection area devices can be made to work with this alternate semiconductor.
I-V Curves and Breakdown

0.05 × 0.1 mm² array
11 µm pitch, 50 SPADs in parallel

1.0 × 1.5 mm² array
25 µm pitch, 2400 SPADs in parallel
Dark Counts v. Voltage

• Dark Counts are avalanches that are produced by thermal excitations generating e-h pairs instead of generation by photon absorption

• The Dark Count Rate (DCR) is dictated by $V_{\text{ex}}$ and temperature

• $V_{\text{ex}}$ also affects detection efficiency

• Ideal operational voltage is often a compromise between the amount of gain, efficiency, and DCR because all of them increase with $V_{\text{ex}}$
Gain

- Gain is defined as the ratio of the output charge to the charge of an electron.
- Below breakdown, the gain is approximately unity.
- After breakdown, the gain increases linearly with excess voltage.
- However, increasing dark count rates eventually lead to saturation at large $V_{ex}$. 
Quench Resistance (Rq)

- Each of the SPAD’s has a quench resistor which cuts off avalanche current and allows the cell to recharge
- Fall time = $R_q \times C$
- $C = \frac{G}{V_{ex}}$
- Pulse produced from illumination of array with ~200ps laser pulse
- Measurement of quench resistance ~1.5e5 Ohms
Quantum Efficiency Measurement

- QE is the ratio of the current to the light intensity.
- This measurement was taken at Vbias = 28 V, about half of the breakdown voltage, where gain is 1.
- Because it was measured at unity gain, it does not account for the creation of an avalanche.

![Graph showing QE measured in unity gain region]
Multiphoton Peaks

- Every time a SPAD breaks down, the avalanche creates a quantized amount of charge, making the amount of charge per photon constant, when other variables such as $V_{ex}$ are kept the same.

- The quantized amount of charge released per avalanche allows us to see multiphoton peaks.
Conclusion

- SPAD arrays with good photon detection properties can be made using GaInP, 25 and 11 μm pitch demonstrated.
- Noise signals can be kept < 1MHz/mm^2 for operation with O(10^5) gain.
- Quantum efficiencies on the order of 10’s of percent have been measured for visible light around 500-650 nm.
- These prototype devices are comparable to earlier generations of SIPM devices, but not at the level of modern SIPM performance.
- GaInP devices are still far from optimized based on theoretical performance expectations involving band gap, carrier concentration, etc.
- Additional properties and tests of these prototypes will be discussed in the following talk by G. Cummings.