Dane Gentry

Thesis Prospectus

M.S. in Electrical Engineering

Avalanche photodiodes (APDs) are becoming increasingly useful in today's industry, especially for applications requiring high precision sensitivity to low light conditions.[1] In addition, a silicon photomultiplier (SiPM) is an analog device consisting of a parallel combination of single photon avalanche diode (SPAD) pixels[2] and acts as an efficient alternative to magneto sensitive photomultiplier tubes which are commonly expensive, high voltage, and large in area.[3] Furthermore, SiPMs have proven to be valuable in numerous applications including radiation detection and medical imaging as well as light detection and ranging (LiDAR).[3]

An in-depth experimental optimization study of APDs and SiPMs in all aspects of standard Complementary Metal–Oxide–Semiconductor (CMOS) and Bipolar CMOS (BiCMOS) processes will be explored for improvements to these types of photodetectors with no process modifications. This is important because it will allow for fully monolithic integration of electronics and photodetectors for a complete optoelectronic system on chip solution. This effort will be implemented in the AMS S35 0.35 um SiGe BiCMOS process and will be laid out using Cadence.

The Objectives of this study are to:

- Reduce dark count rates in Geiger-mode APDs and in SiPMs
- Reduce dark current of APDs
- Tailor the spectral response towards either the UV or towards the near-infrared portion of the spectrum through the selection of different process layers

- Reduce photodiode capacitance and consequently increase the bandwidth
- Reduce noise

The Objectives detailed above will be accomplished by using techniques such as:

1. Perimeter gating
2. N-well merging
3. Striped, buried N-wells

Experimental results will be determined using a variety of electrical and optical measurements including:

1. Capacitance-voltage (C-V) measurements
2. Current-voltage (I-V) measurements
3. Responsivity and quantum efficiency measurements using calibrated light sources and monochromators
4. Frequency response measurements using network analyzers

From the above, it is hypothesized that '*APDs can be implemented in standard CMOS or BiCMOS processes and possess electrical and optical performance sufficient to effectively replace commercial discrete photodetectors in LiDAR and laser range finding applications.*' The process undertaken will provide the opportunity to derive various alternative approaches from the described study in the design and layout of a variety of APD and SiPM test structures in order to optimize their electrical and optical performance. These alternative approaches will be pursued by experimenting with numerous different layout techniques in conjunction with semiconductor theory as well as utilizing the various layout layers provided in Cadence using the AMS S35 0.35 um SiGe BiCMOS process.

It is expected that removing the emitter layer will allow desired wavelengths of light to strike the photodiode and be absorbed and also that laying out the NTub layer in strips will decrease the NTub concentration and likely increase switching speed.[4] Furthermore, it is expected that dark current, dark count rate, and photodiode capacitance will be reduced and that, by experimenting with the various available layers, the spectral response will be shifted towards either the UV or towards the near-infrared portion of the spectrum, yielding APDs with improved optical performance, increased bandwidth, and reduced noise. Meticulous characterization of various APD and SiPM test structures will, undoubtedly, yield useful results and a thorough understanding of how their electrical and optical performance relates to numerous design considerations such as sizing and layout techniques.

Dane Gentry

References:

1. Montierth, D., Strand, T., Leatham, J., Linder, L., and Baker, R. J, “Performance and Characteristics of Silicon Avalanche Photodetectors in the C5 Process,” *Proceedings of the 55th Midwest Symposium on Circuits and Systems*, pp. 134, August 5-8, 2012.

2. M. H. U. Habib and N. McFarlane, “A Perimeter Gated Single Photon Avalanche Diode Based Silicon Photomultiplier as Optical Detector,” *IEEE 58th International Midwest Symposium on Circuits and Systems*, pp. 1-4, Aug. 2015.

3. M. H. U. Habib, M. S. A. Shawkat, and N. McFarlane, “Improved Signal to Noise Ratio Across the Spectral Range for CMOS Silicon Photomultipliers,” *2016 IEEE Sensors Conference,* pp. 1-3, Nov. 2016.

4. G. Meinhardt, J. Kraft, B. Löffler, H. Enichlmair, G. Röhrer, E. Wachmann, M. Schrems, R. Swoboda, C. Seidl, H. Zimmermann, "High-speed blue-, red-, and infrared-sensitive photodiode integrated in a 0.35 um SiGe:C-BiCMOS process," *2005 IEEE InternationalElectron Devices Meeting*, pp. 803-806, Dec. 2005.