Detectors for Smart Lighting Systems

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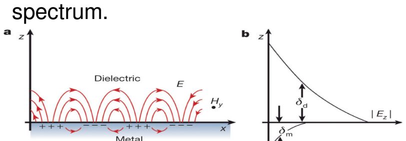
Project Overview

- Modeling, design and characterization of plasmonic detectors developed in collaboration with Boston University.
- Design and modeling of CMOS compatible avalanche photodiodes (APDs) and integrated plasmonic detectors for smart-lighting systems.
- Expected advantages of plasmonic and APD detectors:
  - Simple spectral filtering
  - Simplicity of design
  - High sensitivity
  - Low power consumption
  - Low cost
- Applications: Light intensity measurement, spectral and directional sensing, calibration, and control for smart lighting.

Basic Concept

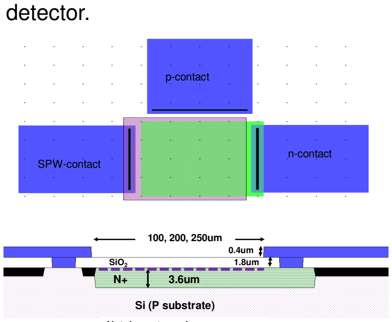
- Surface plasmons (SPs) result from the interaction between light waves and oscillating free electrons on the metal surface.
- The efficient control of photon-plasmon-photon conversion at subwavelength scale gives rise to high-resolution color filtering within the visible electromagnetic spectrum.



Basics of surface plasmon polaritons [1]

Proposed Structures

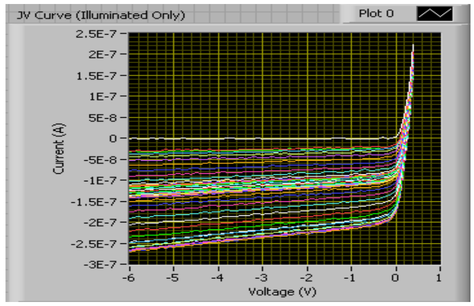
- Plasmonically enhanced CMOS compatible APD device structure.
- Plasmonic structure atop the silicon detector.



CMOS Compatible Plasmonic PN Photodetector

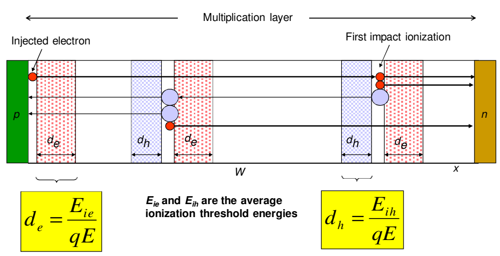
Design and Modeling

- Characterization results:



- Modeling

- Commercially available Sentaurus technology-computer-aided-design (TCAD) tool was used on the APD structure to:
  - simulate I-V characteristics
  - simulate band profile and electric field distribution along the length of the junction.
- Dead-space multiplication theory (DMST) is used to predict avalanche gain, excess noise factor, and breakdown voltage.

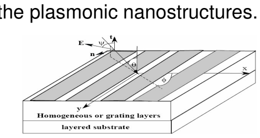


$$d_e = \frac{E_{ie}}{qE} \qquad d_h = \frac{E_{ih}}{qE}$$

Avalanche multiplication: dead space model [2, 3]

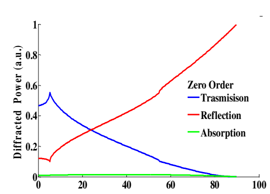
- Rigorous coupled-wave analysis (RCWA) code was undertaken to analyze integrated plasmonic pn-junction detectors. Predictions include:
  - plasmonic response
  - light transmission spectrum
  - electromagnetic field distribution
  - optical properties of the plasmonic nanostructures.

- Example: Application of RCWA to simple grating structure.



Gold grating atop glass substrate [4]

- UNM code is in good agreement with published results [4].
- Application to plasmonic PD is underway.



Conclusions & Future Work

- Characterization of the developed plasmonic detectors from BU (completed).
- Design and simulation of the plasmonically enhanced CMOS APDs.
- Modeling, design and characterization of different plasmonic PD structures (in collaboration with Prof. Brueck's team).
- Optimization of avalanche gain of CMOS-compatible APDs to improve high sensitivity and unification of responsively across the wavelength 500 nm – 1000 nm range.

Societal Benefits

- Energy sustainability
- Low power consumption

- Increased productivity
- High sensitivity

- Visible light communication
- Spectral calibration
- Wavelength selectivity
- Cost effectiveness
- Potential for time–correlated single-photon-counting for ultrasensitive sensing.

References

[1] O. Benson, "Assembly of hybrid photonic architectures from nanophotonic constituents," *Nature,* vol. 480, no. 7376, pp. 193–199, 2011.

[2] M. M. Hayat, Z. Chen, and M. A. Karim, "An analytical approximation for the excess noise factor of avalanche photodiodes with dead space," *IEEE Elect. Dev. Lett,* vol. 20, no. 7, pp. 344-347, 1999.

[3] M. M. Hayat, B. E. A. Saleh, and M. C. Teich, "Effect of dead space on gain and noise of double-carrier multiplication avalanche photodiodes," *IEEE Trans. Electron Devices,* vol. 39, pp.546-552, 1992.

[4] B. K. Minhas, "Numerical Modeling of Periodic Structures: Metalic Grids and Metamaterials," PhD dissertation, Electrical Engineering, University of New Mexico, 2003.

Acknowledgements

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