Modeling, Design and Characterization of CMOS Compatible Plasmonically Enhanced Avalanche Photodiodes for Smart Lighting

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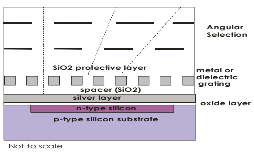
Project Code (S2.1.4)

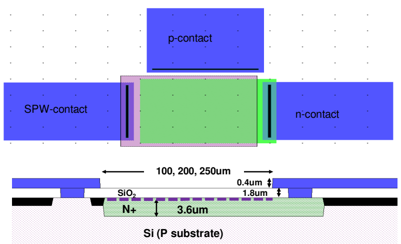
Project Goals

- Modeling and design of CMOS compatible linear mode avalanche photodiodes (APDs).
- Inclusion of the plasmonic effect to the APD structure to be used in smart-lighting systems.
- Expected advantages of plasmonic detectors:
  - Simplicity of design
  - High sensitivity
  - Low power consumption
  - Low cost
- Applications:
  - Color detection
  - Angular sensitivity
  - High resolution color filtering

Design:

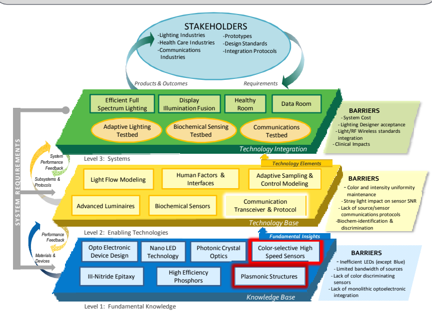
- Aperture of the plasmonic structure atop the silicon detector.





Not drawn to scale (courtesy to Prof. Payman)
CMOS compatible PN junction plasmonic APD

Project's ERC Role



Interactions with other ERC projects

- S2.1.1 Light Sensors with Integrated Communications
- S2.1.5 Integrated Plasmonic Photodetector Arrays
- T1.1.1 Distributed Light Field Control Systems
- T1.2.5 Improving Building Energy Efficiency through VLC Control Interface

Relevant Research

- C. Qin, W. Danial, D. Kirsty, D. Tim, S. Collins, Cumming, R. S. David, "CMOS Photodetectors Integrated With Plasmonic Color Filters," IEEE Photon. Technol. Lett., vol. 24, no. 3, pp. 197-199, 2012.
- M. Gu, P. Bai, H. S. Chu, Er-P Li, "Design of Subwavelength CMOS Compatible Plasmonic Photodetector for Nano-Electronic-Photonic Integrated Circuits," IEEE Photon. Technol. Lett., vol. 24, no. 6, pp. 515-517, Mar., 2012.
- S. Alkis, F. B. Oruç, B. Ortaç, A. C. Koşger, A. K. Okyay, "A plasmonic enhanced photodetector based on silicon nanocrystals obtained through laser ablation," J. Opt., v. 14, no. 12, pp. 125001-5, Oct. 2012.

Research Results

APD with high breakdown voltage:

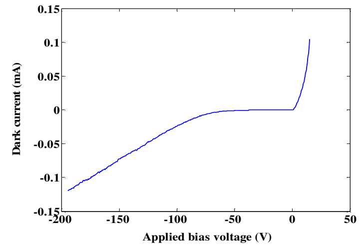


Fig. 1. Experimental dark current characteristics of the CMOS APD.

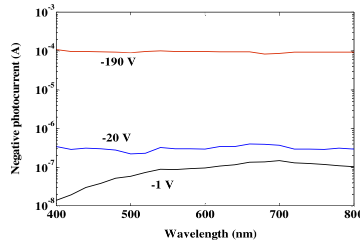


Fig. 2. Experimental spectral response of APD for different voltages.

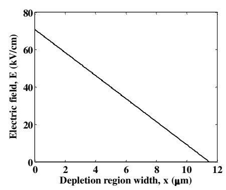


Fig. 3. Calculated electric field profile as a function of depletion width for Si.

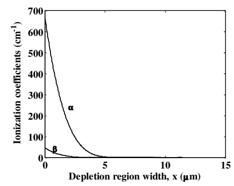


Fig. 4. Calculated ionization coefficients α and β for Si as a function of depletion width.

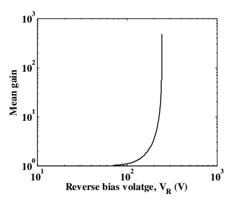


Fig. 5. Calculated mean gain (using the dead-space multiplication theory) as a function of the applied reverse bias voltage.

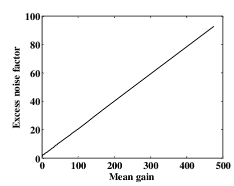


Fig. 6. Calculated excess noise factor (using the dead-space multiplication theory) as a function of mean gain for Si.

APD with low breakdown voltage:

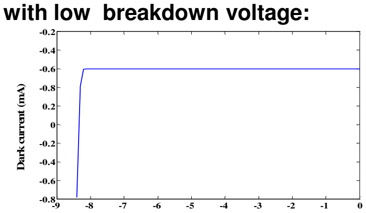


Fig. 7. Experimental dark current characteristics of the CMOS APD.

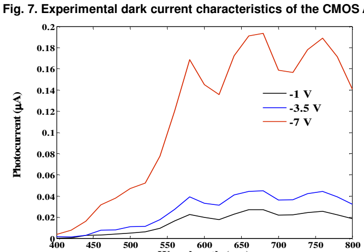
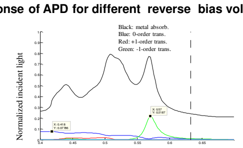


Fig. 8. Experimental spectral response of APD for different reverse bias voltages.

Plasmonic effect:

Fig. 9. Calculated light transmission and absorption profile for formalized incident light intensity as a function of wavelength.
(Courtesy to Alexander Neumann)



Future Work

Near term milestones:

- Characterization of the developed CMOS APDs is completed with Professor Payman's team.
- Modeling and initial design of plasmonically enhanced CMOS APDs have been completed.
- Characterization of the plasmonic device structure in collaboration with Prof. Brueck's and Prof. Payman's team is underway.
- Optimization of the APD design and operational gain for improved sensitivity and equalization of responsivity (across wavelength) is underway.

Long term milestones:

- Plasmonic spectral selectivity with resolutions of 25 nm and 10 degree
- Improve λ selectivity
- Improve directionality
- Improve dynamic range
- Develop wide dynamic range sensor
- Develop plasmonic-color sensor

Societal Benefits

- Energy Sustainability
- Low power consumption

- Increased Productivity
- High sensitivity

- Visible light communication
- Spectral calibration
- Wavelength selectivity
- Cost effectiveness
- Advanced time of flight
- Time-correlated single-photon-counting

Acknowledgements

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