Single photon avalanche diode operating at the wavelength of 2 µm

J. Bélec[1], O. Moutanabbir[1]

[1]*Department of Physical Engineering, Polytechnique Montréal, Montréal, Québec, H3C 37A, Canada*
jeremy.belec@polymtl.ca

Compact photonic platforms integrated on silicon and operating around the wavelength of 2 µm hare sought-after for a plethora of applications in quantum sensing, imaging, and communication. At this wavelength, the atmospheric transparency reaches its peak thus providing an attractive window for freespace communication. Moreover, silicon is known to suffer from significant linear and nonlinear loss around the canonical 1.55 µm. This loss can be drastically reduced if the operation wavelength is increased to 2 µm [1]. Furthermore, at this wavelength the threshold for eye-safe laser power becomes relatively high thus providing a clear advantage for applications such as LiDAR (Light Detection and Ranging). Exploiting the vast potential of 2 µm quantum photonic platforms calls for the development of key components such as integrated lasers, single-photon emitters, and single-photon detectors that are simultaneously compatible with silicon and capable of delivering the 2 µm operation. With this perspective, herein we introduce all-group IV single photon avalanche diode (SPAD) consisting of GeSn semiconductors on silicon. This emerging class of semiconductor offers a broader spectrum of absorption, extended from 1.6 to 8 µm [2,3] at a cheaper cost than the competitor semiconductors of group III and VI.

The main objective of this project consists of finding the optimal SPAD structure using: Ge, Sn and Si to operate at the wavelength of 2 µm.

To ensure a good performance of the device, it is essential to optimize the GeSn absorption layer to increase the detection efficiency while conditioning the device in an ingenious way given the possible triggering of the avalanche without illumination. The photodiode must be designed in such a way that this phenomenon caused by the tunneling effect and the Zener effect is limited while providing extreme sensitivity to illumination. In this regard, I will use band structure calculations using k.p theory to evaluate the composition and stress allowing effective absorption around 2 µm and thus better understand the properties of GeSn. Then, simulations using the TCAD tools of Synopsys Sentaurus will be conducted to obtain the optimal diode. So far, three models have been investigated: 1) Vertical SPAD using a vertical P-i-P+-i-N junction and GeSn as the absorber. 2) Horizontal device using a GeSn membrane over a horizontal P-i-N silicon junction separated by a thin layer of silicon dioxide. 3) Horizontal thin silicon junction SPAD with a GeSn membrane used as absorber incorporated on the top. Each device model is currently under investigation with ongoing modifications aimed at optimizing its performance. The main goal of these investigations is to find a way to have a high enough electric field in the GeSn absorber allowing to grab the carriers generated by the photon absorbed and drift them into the multiplication region using the excellent electrical properties of silicon and ensuring that the simulations take into account the current limitations of the growth of a GeSn layer to maximize the chances of success of the manufactured device.

The resulting optimal structures will have the potential to push the boundaries of LiDAR sensing with the ability to detect through haze, snow and water. In addition, everything can be manufactured using the standard microfabrication processes available in Polytechnique's clean room.

References

[1] Lawrence M. Rosenfeld, Dominic A. Sulway, Gary F. Sinclair, Vikas Anant, Mark G. Thompson, John G. Rarity, and Joshua W. Silverstone, Optics Express 28, 37092 (2020).

[2] Giunto, Andrea, GeSn as next-generation material for short-wave infrared single-photon detection, Lausanne, EPFL (2023), [en ligne] tire de: https://memento.epfl.ch/event/gesn-as-next-generation-material-for-shortwave--2/

[3] Q. Chen, S. Wu, L. Zhang, W. Fan and C. S. Tan, "Simulation of High-Efficiency Resonant Cavity-Enhanced GeSn Single-Photon Avalanche Photodiodes for Sensing and Optical Quantum Applications," in IEEE Sensors Journal, vol. 21, no. 13, pp. 14789-14798, 1 July1, 2021, doi: 10.1109/JSEN.2021.3074407.