Broadband Metamaterial-Based Single-Photon Detectors with Near-Unity Absorption

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The ability to detect single photons has opened doors for applications in quantum information, quantum ranging, and medical imaging. The near-infrared light range known as the “valley of death” (800-1000 nm) is a desirable optical window for imaging biological tissues and for automotive LiDAR; however, falls outside the efficient detection range of commercially available silicon (Si) and indium gallium arsenide (InGaAs) photodetectors [1, 2]. Here, we show that using semiconductor-nanowire metamaterials as a photodetector’s active area can enhance optical absorption and improve overall efficiency across an unprecedented bandwidth that not only covers the “valley of death” but extends far beyond.

Our approach is three-fold: First we show the merit of exploiting the unique arrangement of tapered nanowires to manipulate the properties of incoming photons. With our fabricated InGaAs nanowire metamaterial, we show near-unity absorptance (93%) across a bandwidth of 900-1500 nm (Figure 1) [3, 4]. Second, we have designed an avalanche photodiode material stack that utilizes a separate absorption-multiplication region. Lastly, our approach culminates in patterning the active area of our avalanche photodiode layer stack with the nanowire metamaterial design. By harnessing the tapered nanowire design to funnel the optical absorption into the nanowire core along with the strategic placement of the p-n junction, our metamaterial photodetector is shown to overcome the shortcomings in detection efficiency of conventional photodetectors.

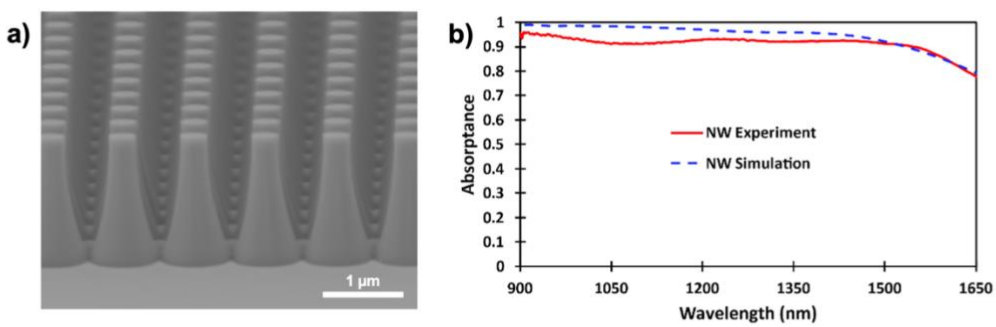

Figure 1: Optical characteristics of a conical InGaAs nanowire metamaterial. a) Scanning electron micrograph of tapered InGaAs nanowires. b) Comparison of simulated and experimentally measured absorptance spectra of the material showing near-unity absorption efficiency from 900 to 1500 nm [3 ,4].

References

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