Application Note

Light from silicon and single-photon detection beyond 1550 nm

SINGLE QUANTUM
Excellence in photon detection

Silicon technology is the foundation of our modern lifestyle. It allows the fabrication of highly integrated circuitry which are used in almost every electronic device – from our kitchen's refrigerators to modern supercomputers. However, due to its natural diamond crystal structure silicon is an indirect semiconductor and, hence, cannot emit light efficiently.

Since the theoretical prediction[1] - more than 5 decades ago - that silicon would become a direct semiconductor if it is crystallized in a hexagonal crystal structure. Many scientists have tried ever since to achieve this goal. Finally, this dream became a reality through the revolutionary teamwork lead by Prof. Erik Bakkers from the University of Eindhoven[2] in 2020. The research team developed a silicon-based alloy *that can emit light*. To this end, they used a GaAs nanowire with a hexagonal shape serving as a seed crystal for the growth of a silicon germanium shell. In this way, the silicon germanium alloy also crystallizes in a hexagonal configuration and renders the silicon alloy into a direct energy band-gap semiconductor allowing light emission. Figure 1 shows a cluster of such nanowires.

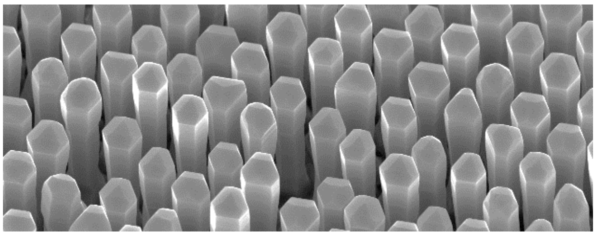

Figure 1*: Scanning electron microscopy image of a cluster of hexagonal crystallized silicon-germanium nanowires.*

Moreover, the research team managed also to master the purity of the silicon alloy resulting in *efficient light generation*. And their approach has yet another advantage, the nanowire's emission energy can also be vastly tuned by tailoring the amount of Germanium alloyed to the nanowire. This technique can tune the light's wavelength from the important telecom band at 1.55 microns until 3.5 microns.

Single Quantum's ultra-sensitive superconducting nanowire single photon detectors (SNSPD) allowed the researchers to study the dynamic evolution of the electron-hole pairs in their nanowires. Unlike other single-photon detector technologies, *Single Quantum's* SNSPDs provide a unique combination of time-resolution at the picosecond level with the outmost best signal-to-noise ratio. To promote further the work in this exciting field and many other potential applications, *Single Quantum* has recently optimized their SNSPD film composition and design to extend the sensitivity of our SNSPDs until 4 microns.

For example, at the wavelength of 2 microns, we developed a SNSPD system that can operate with a noise equivalent power in the order of 10^{-20} $WHz^{-1/2}$ corresponding to a dark count rate as low as 500 counts/s.

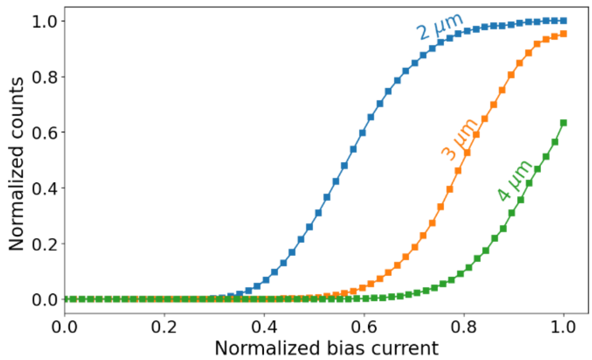

Figure 2: *Normalized counts as function of bias current for different wavelength at 2.5 Kelvin of single device optimized for long wavelengths.*

In figure 2, the presented SNSPD shows saturation of the photon count rate at 2 microns in bias current sweep which implies unity internal quantum efficiency. At 3 microns, it almost reaches saturation and at 4 microns has an internal quantum efficiency of 65%.

We foresee that single-photon detection above 1550nm with SNSPDs will benefit many applications such as material science and bio-imaging, due to the previous lack of sensitive detectors.

1- F. Herman, "The Electronic Energy Band Structure of Silicon and Germanium," in *Proceedings of the IRE*, vol. 43, no. 12, pp.1703-1732, (Dec. 1955).

2- Fadaly, E.M.T., Dijkstra, A., Suckert, J.R. *et al.* "Direct-bandgap emission from hexagonal Ge and SiGe alloys", *Nature* 580, 205–209 (2020).

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