Ge-on-Si Single-Photon Avalanche Diode Detectors with Low Noise Equivalent Power in the Short-Wave Infrared

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Single-Photon Avalanche Diode (SPAD) detectors are of significant interest for a range of applications [1], in particular for quantum technologies (e.g. quantum-key distribution, quantum information processing), and light detection and ranging (LIDAR) for defence, terrain mapping, and autonomous vehicles. These applications either require, or benefit from, operation at wavelengths in the short-wave infrared (SWIR). Previous SWIR single-photon LIDAR has typically used InGaAs/InP SPAD detector technology, which has relatively low efficiency and suffers from afterpulsing. Previously, a pseudo-planar design for a Ge-on-Si SPAD was demonstrated [2], yielding a huge improvement in performance for Ge-on-Si SPADs at 1310 nm and demonstrating the potential for Si foundry compatible SWIR SPADs. Furthermore, reduced afterpulsing was demonstrated compared to a commercial InGaAs/InP device when measured in nominally identical conditions. Here we present a further step change in performance, with reduced dark count rate (DCR), record low noise-equivalent-power (NEP) and low jitter by scaling the technology and developing 26 μm diameter pixels [3].

SPAD pixels were fabricated using standard photolithography techniques, and measured using Time-Correlated Single Photon Counting techniques, as described in [2,3]. The reduction in device volume by reducing the pixel diameter reduces the absolute number of defects within the device, and correspondingly there is a significant reduction in DCR, reaching as low as kilocounts/s at 100 K for excess bias up to ~ 5%. As demonstrated in Fig.1a), this improvement allows for higher temperature operation compared to the previously demonstrated 100 μm diameter detector [2], for a given DCR. For example, the 26 μm diameter device shown here has a lower DCR at 165 K (100s of kilocounts/s) than the 100 μm diameter pixel at 125 K. Single Photon detection efficiencies were found to be ~ 29 % at 1310 nm wavelength, at an excess bias of 7.5 %, with minimal temperature dependence across the measurement range of 77 to 175 K. The large improvement in DCR results in a record low noise-equivalent-power of 7.7×10^{-17} $WHz^{-1/2}$. Significantly, when compared to a comparably sized mesa device [4], the pseudo-planar design demonstrates approximately 2 orders of magnitude improvement in performance under the same conditions, Fig.1b).

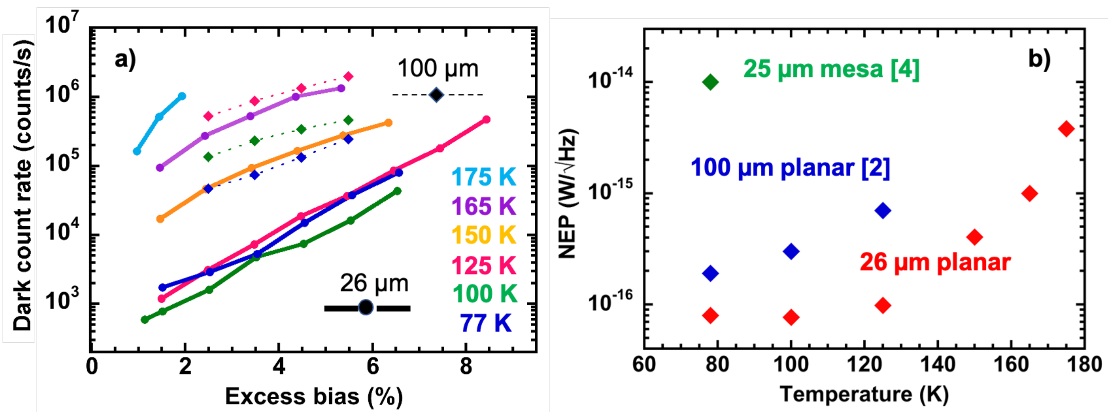

Fig. 1. a) Dark count rate versus excess bias for 26 μm and 100 μm diameter SPADs for a range of temperatures. b) Noise-equivalent power of various SPAD detectors at a wavelength of 1310 nm for a range of temperatures.

Scaling the detector diameter yields the further benefit of a reduction in temporal jitter, which is reduced to ~ 134 ps, full width at half maximum from the previous value of 300 ps for the 100 μm diameter detector. Future work will focus on further scaling the diameter of the device, with the goal of a sufficiently low DCR that enables operation at ~ 230 K, allowing for use of multi-stage Peltier coolers. This technology will potentially offer a low-cost, Si foundry compatible SPAD operating in the SWIR, with applications in autonomous vehicle LIDAR, ranging and quantum technologies.

References

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