Optical lithography of WSix superconducting nanowire single photon detectors

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In the fabrication of superconducting nanowire single photon detectors (SNSPDs) operating in the near-infrared, the most common method to define the nanowire pattern has been electron-beam lithography (EBL) because of the superior resolution of the technique. However, EBL is a serial-write lithography technique. As the active areas covered by superconducting nanowires in SNSPDs increases from the order of 10s of μm2 to mm2 to meet the needs of future deep space optical communication, quantum information, and astronomical applications, the time and cost to write nanowire patterns with EBL increases rapidly. Here we report on SNSPDs fabricated with optical

lithography, which allows faster, inexpensive patterning over large areas. The optically defined SNSPDs had similar performance to devices fabricated with EBL.
Among superconducting materials used for SNSPDs, amorphous WSix shows great promise to realize devices covering areas up to mm2 in the near future. The amorphous nature of WSix has greatly simplified the fabrication of SNSPDs and allowed reliable manufacture of devices covering larger active areas than granular superconductors based on nitrides, such as NbN. A pertinent advantage of WSix is that efficient detection in the near-IR has been shown to occur with nanowire widths between 120nm to 220nm for ~5nm thick films; films of this thickness have superconducting transition temperature TC=3.1K [1], [2]. Such nanowire widths become amenable to optical lithography patterning using deep-UV (DUV) steppers where KrF excimer light (λ=248nm) is utilized. Optical lithography is a parallel-write lithography technique that would circumvent and greatly reduce the time and cost to produce nanowires using the traditional EBL method.

The relevance of optical DUV steppers for patterning WSix SNSPDs is apparent when considering the patterning resolution possible with these tools. The conventional illumination mode of DUV steppers has a critical dimension (CD) patterning resolution given by CD=k1 λ/NA. Here, k1 is a constant dependent on process related factors, typically k1~0.6 for DUV processes, and NA is the numerical aperture, which is typically available up to ~0.65 in DUV steppers. Thus, a CD of 220nm is readily achievable in DUV steppers. However, so-called resolution enhancement techniques (RETs) are typically employed in the semiconductor manufacturing industry to push below the conventional illumination CD, and KrF DUV steppers have been shown to produce lines with widths at or below 130 nm in both isolated line and dense line formats.

In this paper, we report our ability to reliably pattern and produce meandered, dense nanowire structures with widths down to 160 nm using the RET known as off-axis illumination in both a Canon EX3 and EX6 DUV stepper, when combined with a backside anti-reflection coating (BARC) layer below our DUV sensitive photoresist. As a test of the technique, we have also fabricated single-pixel SNSPD test structures, and we compare the performance of these structures fabricated with optical lithography to those made with EBL. We achieved maximum system detection efficiency (SDE) of 30.5% and minimum SDE of 21.3%, with system dark count rates ~100cps. A bias plateau was observed with saturated SDE in current bias versus SDE characterization measurements, indicating saturated internal quantum efficiency. Future incorporation of optically defined SNSPDs into optimal optical cavities promises to produce results similar to Ref. [1], with SDE exceeding 90%.

[1] F. Marsili, et.al., "Detecting single infrared photons with 93% system efficiency," Nature Photonics 7, Feb. 2013, pp. 210-214.
[2] B. Baek, et.al., "Superconducting nanowire single-photon detector with saturated internal quantum efficiency from visible to 1850 nm," Appl. Phys. Lett. 98, June 2011, Art. No. 251105.