Selective nanowire fabrication in niobium nitride using sacrificial proximity-effect-correction features in HSQ

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Superconducting nanowire single-photon detectors (SNSPDs [1]), based on ~80-nm-wide 4-nm-thick niobium nitride (NbN) nanowires, offer an unmatched combination of high detection efficiency [2] and low timing jitter [3] in the near-infrared wavelength range. These properties have made SNSPDs an attractive choice for integration with photonic integrated circuits [4, 5]. One integration scheme is shown in Figure 1: the hairpin-shaped SNSPD, overlapping with a waveguide, absorbs light travelling through the waveguide. We fabricated the SNSPD and waveguide separately, and integrated them in a subsequent step by releasing the SNSPD on a membrane and placing it on top of the waveguide [6]. This micrometer-scale flip-chip process allowed for testing and pre-selection of high-performance SNSPDs before integration with waveguides.

We fabricated the SNSPDs via e-beam exposure of HSQ at 30keV. We developed the exposed resist in TMAH (25%) at 27 ºC and transferred the detector pattern into the underlying NbN via CF_4 RIE. In order to achieve high uniformity in the mean nanowire width (crucial to the detector performance), we had to ensure a uniform exposure dose. Typically, to correct for the proximity effect and to achieve uniform dose in the side regions of the detector, dummy structures are exposed outside the active region of the device [7]. However, we had to avoid solid proximity effect correction (PEC) features outside the side regions enclosed by dashed lines in Figure 1, as these features would overlap with the waveguide and absorb some of the incoming light before it can reach the hairpin-shaped detector. Figure 2 shows a detector fabricated without any proximity effect correction features in the side regions, resulting in narrower nanowires in the side regions.

We compensated for the dose inequality in the side regions by exposing sacrificial PEC features that did not result in solid HSQ features after development. These features consisted of 2-nm-wide lines (single-pass line exposure) arranged in a 20 nm pitch. Figure 3 shows that these features compensated for the lower dose on the edges of the detector and resulted in a uniform mean nanowire width.

While we have applied the sacrificial proximity effect correction method to SNSPDs, it could be applied to other cases where solid PEC features have to be avoided in specific regions.

[1] G. N. Gol'tsman et al, Appl. Phys. Lett. 79, 705-707 (2001); [2] F. Marsili et al., Nat. Photon. 7(3), 210-214 (2013); [3] E. Dauler et al., IEEE T Appl Supercon 17(2), 279-284 (2007); [4] W. Pernice et al., Nat. Commun. 3 : 1325 (2012); [5] J. Sprengers et al., Appl. Phys. Lett. 99, 181110 (2011); F. Najafi et al., CLEO 2013, paper QF1A.6 [7] F. Marsili et al., Nano Lett. 11(5), 2048-2053 (2011).

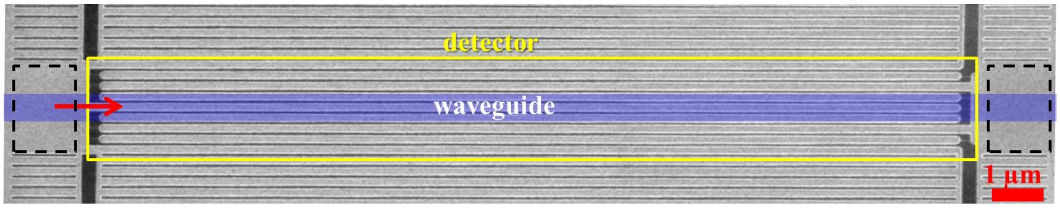

Figure 1: SEMs of a detector based on ~80-nm-wide superconducting nanowires. The yellow line encloses the active area of the detector. The contact area between waveguide (to be added in a later fabrication step) and detector is highlighted in purple. The red arrow indicates the travelling direction of light coupled into the waveguide. The detector and waveguide are integrated in a subsequent step by releasing the detector on a mambrane and placing it on top of the waveguide.

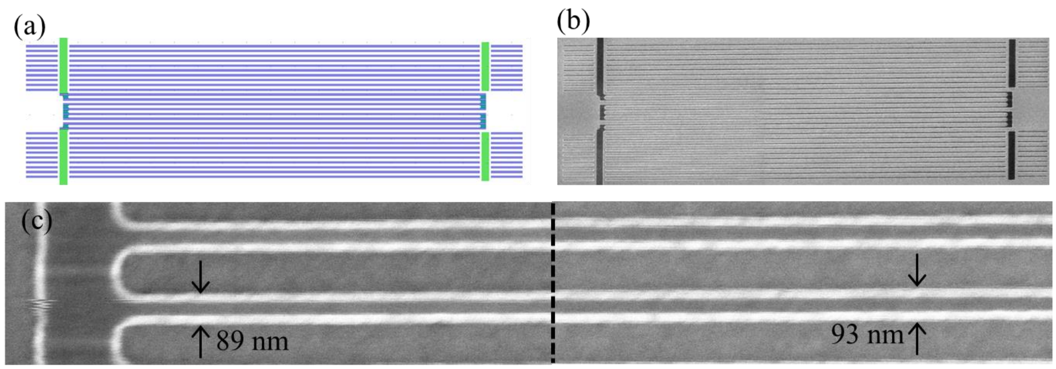

Figure 2: Detector fabricated without proximity effect correction features in the side regions. (a) Illustration of the detector pattern exposed via e-beam lithography. (b) SEM of resist structure (HSQ) resulting from exposure of the pattern shown in (a). (c) SEM of nanowires at the edge (left) and in the center (right) of the structure shown in (b).

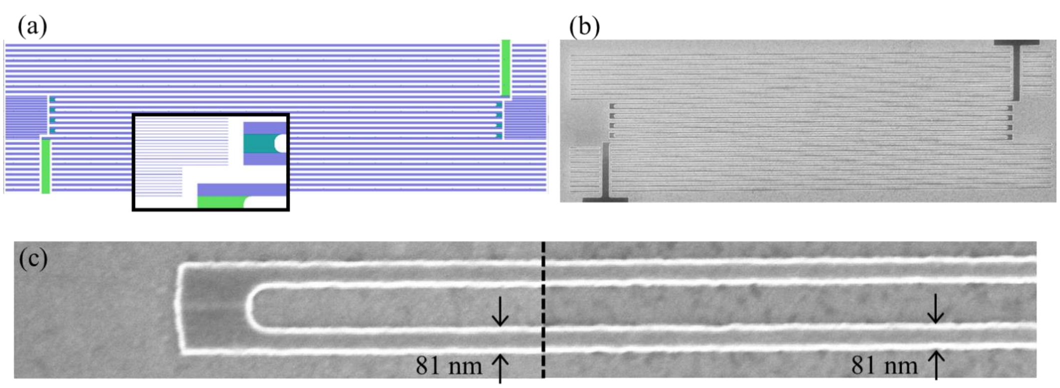

Figure 3: Detector fabricated using sacrificial proximity effect correction features in the side regions. (a) Illustration of the detector pattern exposed via e-beam lithography. The inset shows the proximity effect correction features consisting of 2 nm-wide lines in a 20 nm pitch. (b) SEM of resist structure (HSQ) resulting from exposure of the pattern shown in (a). (c) SEM of nanowires at the edge (left) and in the center (right) of the structure shown in (b).