

## Superconducting single photon detectors for near infrared wavelength with high sensitivity, low noise, and high timing resolution

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**Abstract.** *We present high performance fiber-coupled niobium titanium nitride superconducting nanowire single photon detectors fabricated on thermally oxidized silicon substrates. The best device showed a system detection efficiency (DE) of 74%, dark count rate of 100 c/s, and full width at half maximum timing jitter of 68 ps under a bias current of 18.0  $\mu$ A with a practical Gifford-McMahon cryocooler system. We also introduced six detectors into the cryocooler and confirmed that the system DE of all detectors was higher than 63% at the dark count rate of 100 c/s.*

### Introduction

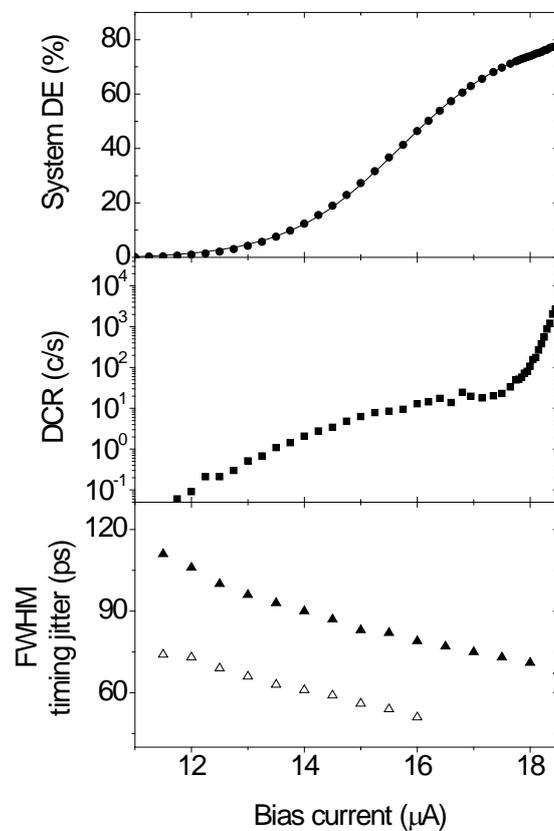
Superconducting nanowire single-photon detectors (SNSPDs or SSPDs [1]) have emerged as promising photon detectors that can be applied in various types of applications because of their broadband sensitivity that ranges from the visible to the near-infrared wavelengths, high detection efficiency (DE), low timing jitter, high count rate, and low dark count rate (DCR) [2]. Ongoingly, significant effort has been expended to further improve the system performance of these detectors. In particular, a primary objective is to identify a method to simultaneously achieve high system DE, low DCR, and low timing jitter in a practically available SSPD system, which is expected to significantly influence various SSPDs applications. Niobium titanium nitride (NbTiN) can be viewed as an adequate candidate for use in SNSPDs because its  $T_c$  is lower than that of NbN films, thus enabling higher sensitivity of the SNSPD system to incident photons [3]. The  $T_c$  of films is sufficiently higher than 2.3 K, enabling stable operation in GM cryocooler systems. In this paper, we report on the performance NbTiN-SSPDs with a practical GM cryocooler system. We describe the fabrication of SSPD devices based on NbTiN nanowire on thermally oxidized Si substrates, as well as the simulation results of our device's absorptance. Then, we verify the system DE, DCR, and timing jitter of our devices that are installed in a practical multichannel system.

### Results

For the device fabrication, thermally oxidized Si substrates were used. The 5-nm-thick NbTiN thin films for the nanowire were deposited by DC reactive sputtering and formed to a 100 nm wide and 60(100) nm spaced meandering nanowire that covered a square area of 15  $\mu$ m  $\times$  15  $\mu$ m. A 250 nm thick SiO and a 100 nm thick Ag mirror covered the nanowire to enhance the absorption efficiency,  $P_{\text{absorb}}$ , of photons to the meandering area of the nanowire. The simulated  $P_{\text{absorb}}$  of this structure

was estimated to be ~97% at 1550 nm wavelength according to the modeling of the electromagnetic behavior of single-period multilayer gratings [4]. The fabricated devices were mounted on fiber-coupled packages and installed into GM cryocooler system to verify their performances.

Fig. 1 shows the system DEs, DCR and full width at half maximum (FWHM) timing jitter of fabricated SSPD device with 100 nm wide and 60 nm spaced nanowire, as a function of bias current. The  $I_{sw}$  of a device was 19.2  $\mu A$ , which was sufficient to achieve stable operation and relatively short timing jitter. Although the system DE reached maximal values of 77.3% when the bias current was introduced near  $I_{sw}$ , this bias condition may not be suitable for practical use because the DCR increased to over  $10^4$  c/s. In the meantime, the device could achieve high system DE, low DCR, and short timing jitter simultaneously even for lower values of bias current. For example, the device showed a system DE of 74.0%, DCR of 100 c/s, and timing jitter of 68 ps at a bias current of 18.0  $\mu A$ .



**Figure 1.** System DE, DCR, and FWHM timing jitter as a function of bias current for fabricated device with 100 nm wide and 60 nm spaced meandering.