

# Superconducting Thin Film Nanostructures as Terahertz and Infrared Heterodyne and Direct Detectors

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**Abstract** — We present our recent achievements in the development of sensitive and ultrafast thin-film superconducting sensors: hot-electron bolometers (HEB), HEB-mixers for terahertz range and infrared single-photon counters. These sensors have already demonstrated a performance that makes them devices-of-choice for many terahertz and optical applications. HEB mixers based on ultrathin films of NbN combine the best sensitivity at the frequencies well above 1 THz and a gain bandwidth of about 6 - 7 GHz, which make them suitable for most sensitive instruments. Direct detectors made from NbN films are operated in 0.3-3 THz range and exhibit response time as low as 50 ps with noise equivalent power (NEP) of  $3 \times 10^{-13} \text{ W Hz}^{-1/2}$ . A promising type of the photon counting detector is the superconducting single-photon detector (SSPD). The SSPD is patterned from 4-nm-thick NbN film as 100-nm-wide and meander-shaped strip that covers a square area of  $10 \times 10 \mu\text{m}^2$ . At wavelength  $\lambda \leq 1.5 \mu\text{m}$  quantum efficiency (QE) of our best devices approaches 80% at 2 K with 35 ps timing jitter. The single-photon counting was observed at wavelengths up to  $5.6 \mu\text{m}$  with QE of  $\sim 1\%$ . Simultaneously, at 2K the SSPD has negligibly low dark counts of  $2 \times 10^{-4} \text{ s}^{-1}$ . It provides NEP value of  $10^{-20} \text{ W/Hz}^{1/2}$  at  $\lambda \leq 1.3 \mu\text{m}$  and  $10^{-18} \text{ W/Hz}^{1/2}$  at  $5 \mu\text{m}$ . In addition to the chip SNSPD with normal incidence coupling, we use the detectors with a travelling wave geometry design. In this case, a NbN nanowire is placed on the top of a  $\text{Si}_3\text{N}_4$  nanophotonic waveguide, thus increasing the efficient interaction length. Our approach is fully scalable and, along with a large number of devices integrated on a single chip can be adapted to the mid IR range where photon-counting measurement may be beneficial as well.

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**Keywords (Index Terms)**— Hot electron bolometer, HEB, NbN, ultra-thin film, NbN nanowire, THz mixer, superconducting single-photon detector, SSPD, infrared counter.

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