Overview of recent results for superconducting NbN terahertz and optical detectors and mixers

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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.**

Keywords— nanotechnology;HEB, hot-electron bolometer, superconducting single-photon detector, single-photon formatting; style; styling; insert (key words)

We discuss about hot-electron superconducting sensors: terahertz mixers, direct detectors and single-photon counters. These sensors have already demonstrated a performance that makes them devices-of-choice for many terahertz and optical applications.

The superconducting hot electron bolometer (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 [1] which make them suitable for most sensitive instruments being developed in the far IR region for astronomical and atmospheric studies.

Direct detectors made from NbN and MoRe films are operated in 0.3-3 THz range exhibit response time as low as 50 ps and 1 ns respectively with noise equivalent power (NEP) of $3x10^{-13}$ W $Hz^{-1/2}$ (NbN) and $5x10^{-14}$ W $Hz^{-1/2}$ (MoRe). Another versions of these detectors have a broadband sensitivity in 0.1-30 THz range with the same response time and exhibit higher NEP but much higher dynamic range.

A promising type of the photon counting detector is superconducting single-photon detector (SSPD). The SSPD is patterned from 4-nm-thick NbN film as 120-nm-wide and meander-shaped strip that covers a square area of 10 x 10 μm^2. At wavelength $\lambda \leq 1.3$ µm quantum efficiency (QE) of our best devices approaches 30% at 2 K with 35 ps timing jitter. The single-photon counting was observed at wavelength up to 5.6 µm with QE of ~1%. Simultaneously, at 2K the SSPD has negligibly low dark counts of $2x10^{-4}$ s^{1}. It provides NEP value of 10^{-20} $W/Hz^{1/2}$ at $\lambda \leq 1.3$ µm and 10^{-18} $W/Hz^{1/2}$ at 5 µm. Our recent investigations allowed us to develop an SSPD with photon-number resolving capability. Single-, two-, three- and four-photon absorptions were clearly observed [2].

Further development of SSPD was to form it as parallel-connected strips. Such SSPD has a new quality: the ability to resolve the number of simultaneously absorbed photons, because the amplitude of the detector response is proportional to the number of incident photons. Simultaneously duration of the photoresponse decreased to 200 ps, enabling up to 1GHz counting rate.

In an effort to move into the middle IR we managed to develop a SSPD with a strip width of 54 nm while preserving the superconducting properties. These detectors are more than an order of magnitude higher sensitivity at a wavelength of 5 µm. These results open the way to the development of the practical mid-infrared single photon detector.

SSPD can be efficiently coupled with a single mode optical fiber and thus can be easily integrated into a practical commercial dual-channel receiving system. High Speed Travelling Wave Single-Photon Detectors with near-unity quantum efficiency has been published very recently [3]. The system has already found a number of practical applications in experiments on optical coherence tomography, detection of radiation from the quantum dots with high temporal resolution, as well as in quantum cryptography.

THz direct detectors and HEB mixers are used in a wide range of applications ranging from THz imaging for security (observation of hidden drugs, explosives and weapon) and medicine (THz probing of human tissues) to radioastronomy observation of stellar formation (space observatories Herschel and Millimetron). SSPD due to their high quantum efficiency and picosecond timing resolution has already been successfully applied for non-destructive testing of CMOS integrated circuits, study of single-photon sources and quantum dot luminescence, and for quantum cryptography enabling quantum key distribution over 300 km distance.

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