EPJ Web of Conferences **103**, 10004 (2015)
DOI: 10.1051/epjconf/201510310004

Energy Relaxtation and Hot Spot Formation in Superconducting Single Photon Detectors SSPDS

I.N. Florya[1], Yu.P. Korneeva[1], M.V. Sidorova[1], A.D. Golikov[1], I.A. Gaiduchenko[1], G.E. Fedorov[1], A.A. Korneev[1,2], B.M. Voronov[1], and G.N. Goltsman[1,2a]

[1]Moscow State Pedagogical University, 1 Malaya Pirogovskaya, 119991, Moscow,
[2]National Research University Higher School of Economy, 20 Myasnitskaya, 101000, Moscow

Abstract. We have studied the mechanism of energy relaxation and resistive state formation after absorption of a single photon for different wavelengths and materials of single photon detectors. Our results are in good agreement with the hot spot model.

Keywords: superconducting single photon detectors, optical and IR wavelength radiation.

Superconducting Single Photon Detector (SSPD) is a nanostructure which is made of ultrathin film with nominal thickness about few nanometers. The meander covers an area of $7 \times 7\ \mu m^2$. SSPD demonstrated subgigaherz photon counting rate, picosecond time resolution, high quantum efficiency in visible and IR range, and negligible dark counts [1]. The maximum quantum efficiency of 93% is achieved at 120 mK temperature on SSPD fabricated from amorphous W_xSi_{1-x} film and integrated with optical cavity [2]. Single photon detectors have many applications due to their high performance: research into single-photon sources, quantum cryptography (quantum key distribution over 260 km), testing of integrated circuits.

The operating principle of SSPD is based on the occurrence of a resistive area in a small part of the superconducting strip after photon absorption. The SSPD works at temperature below the critical temperature, but at the bias current close to critical [3]. The photon absorbed by the strip breaks down Cooper pairs and forms an avalanche of quasiparticles. The superconductivity is suppressed and so called "hot spot" is formed.

In this work we have studied the evolution of the hot spot after absorption of a photon in SSPDs fabricated from two materials NbN and NbC which have different diffusivity D and electron thermalization time τ_{th}. In hot spot model the photon is detected if hot spot is large enough compared to the strip width (w). We used as a criteria the transition from single-photon regime to the multiphoton regime.

In order to determine the regime of the detector we measure dependence of counts rate vs incoming light power [3]. For mean number of photons per pulse m the probability $P(n)$ of absorption of n photons from a given pulse is given by Poisson distribution:

$$P(n) \sim \frac{e^{-m} m^n}{n!} \tag{1}$$

---

[a] Corresponding author: girusy@mail.ru

For strongly attenuated photon flux incident on the SSPD ($m \ll 1$), the detection probability $P(n)$ for one, two, and three photons are respectively equal $P(1) \sim m$, $P(2) \sim m^2/2$, $P(3) \sim m^3/6$ etc.

NbN detectors demonstrate single-photon regime in the entire wavelength range from 633 nm to 1550 nm. NbC detectors demonstrate in the same range only two- and three-photon regimes as shown in Fig. 1.

We performed a theoretical estimate of the hot spots size according to [4]:

$$R = \sqrt{\zeta \frac{h\nu}{\Delta}} \sqrt{\frac{1}{2D\tau_{th} d N_0 \Delta}} \left(\frac{1}{\pi^4 N_0 \Delta} \right)^{\frac{1}{3}} \ln\left(1 + \zeta \frac{h\nu}{\Delta} \frac{\pi^2}{D\tau_{th} d N_0 \Delta} \right), \qquad (2)$$

where R is the radius of hot spot, Δ is superconducting gap, D is diffusivity, τ_{th} is electron thermalization time, N_0 is electron density of states at the Fermi energy, d is film thickness, $h\nu$ is photon energy, ζ is the conversion efficiency, which defines the portion of energy from absorbed photon transferred to quasiparticles. We used the experimentally measured values of the diffusion coefficient in this estimate. Diffusivity of NbN is 0,45 cm^2/s and NbC is 0,38 cm^2/s.

Fig. 2. shows dependence of hot spot diameter vs wavelength of incoming light and film thickness for NbN and NbC SSPDs.

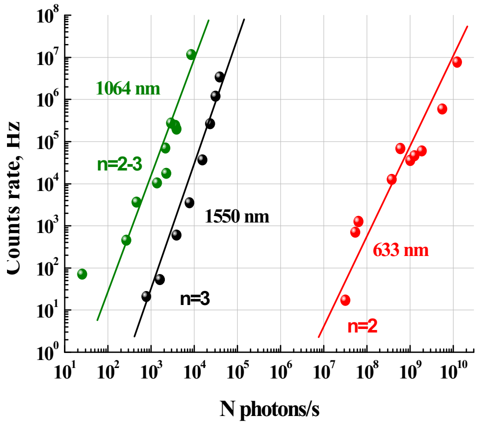

Figure 1. Dependence of SSPD count rate vs incoming light power for NbC at wavelengths 633 nm, 1064 nm and 1550 nm

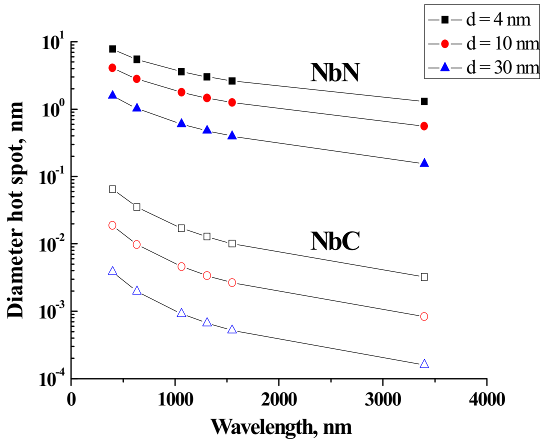

Figure 2. The dependence of the size of the hot spot vs wavelength and film thickness for NbN SSPD (closed symbols) and NbC SSPD (open symbols). Diffusivity of NbN is 0,45 cm^2/s and NbC is 0,38 cm^2/s

One can see that the hot spot diameter for SSPD from NbC film is two orders of magnitude less than that of NbN SSPD, which qualitatively explains the results.

The work was supported by The Ministry of Education and science of Russian Federation, project No. 14.586.21.0003, unique identifier for Scientific Research (project) RFMEFI58614X0003.

References

1. G.N. Goltsman, et.al., IEEE Trans. Appl. Supercond **17**, 1, 246-251 (2007)
2. F. Marsili, et.al., Nature Photonics **7**, 210-214 (2013)
3. G.N. Goltsman, et.al., Appl. Phys. Lett., **79**, 7, 705-707 (2001)
4. A. Semenov, et.al., Eur. Phys. J. AP **21**, 171–178 (2003)