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Comparison single- and double- spot detection efficiencies of SSPD based to MoSi and NbN films

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Abstract. In this work, we present results of quantum detector tomography of superconducting single photon detector (SSPD) based on MoSi film, and compare them with previously reported data on NbN. We find that for both materials hot spot interaction length coincides with the strip width, and the dependence of single and double-spot detection efficiencies on bias current are compatible with sufficiently large hot-spot size, approaching the strip width.

1. Introduction

The first observation of single- and double- photon modes of operation of a superconducting single-photon detector was demonstrated in [1]. When a photon hits a strip of superconductor a special area appears, called a hot spot. For estimation of hot spot dimensions in literature, a diffusion coefficient in normal state is used, which could lead to some inaccuracies. Direct method of hot spot sizes measurement, was introduced by Renema *et al.* [2]. They used nanowires with width from 100 nm to 400 nm. But nonuniform distribution of the current and absence of saturation of detection efficiency (*DE*) makes the interpretation difficult. After that Elezov *et al.* [3] used a nanowire with length of 500 nm, but the impact of double-photon counts was comparably small. Afterwards, in our work [4] a samples on waveguides with different width from 80 to 280 nm, were fabricated. Number of absorbed photons is known exactly (due to 100% internal *DE* and 100% absorption). But the total length of 80-280 nm, was yet too long. Previously we reported a usage of our protocol to specially fabricated samples of NbN [5]. The interaction length for hot spots was obtained and was equal to 70 nm. In this work we apply our method to the samples of made of MoSi films, and compare results with the obtained previously on NbN samples.

2. Experimental results

We have measured the dependences of the probability of count on the mean number of photons absorbed from the laser pulse for the sample made of MoSi film. The fabrication root was the same as described [5]. The sample has width (*w*) of 100 nm and length of 2 μ m. Then we processed the data using our protocol of quantum tomography [4], to extract the dependence of the internal double-spot detection efficiency (*IDE*₂) on the bias current *I* and the hot-spot interaction length *s*.



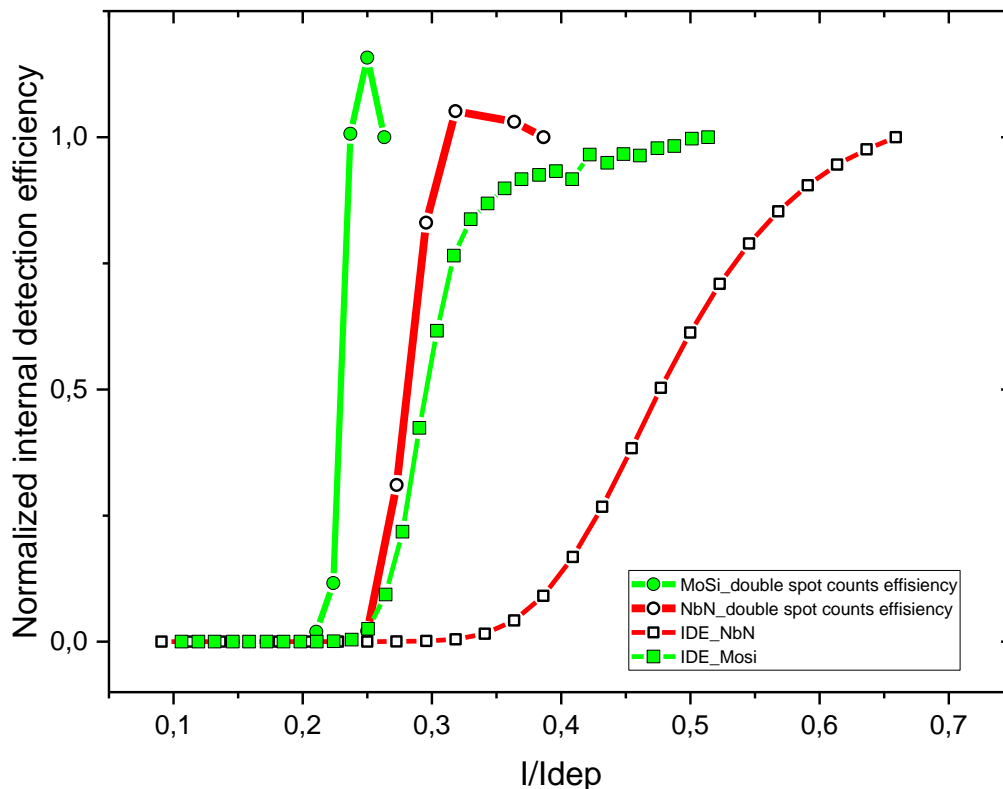


Figure 1. Single- and double-spot internal detection efficiency versus the critical current (I_c) normalized to the deparing current (I_{dep}). Red dots correspond to NbN, green dots to MoSi; squares correspond to single-spot counts, circles to double-spot counts.

Figure 1. shows plot of $IDE_2(I)$, together with the single-spot internal detection efficiency $IDE(I)$ for the same sample, measured directly at small mean number of photons, and the pair of IDE , IDE_2 for the NbN sample with the same dimensions measured in our previous work [5]. To facilitate comparison between IDE 's and samples, we normalized I to the deparing current I_{dep} calculated for MoSi and NbN samples using standard expression of the Usadel theory. Also, we normalized IDE 's to their values at saturation. One sees that the detector made of MoSi film show saturation of IDE and IDE_2 at a lower I/I_{dep} value than the detector made of NbN film, which is consistent with the idea that hot spots in MoSi are more efficient than hot spots in NbN, because of their greater size and 'depth' [6]. The value of s for MoSi sample turned out to be about 70 nm, which within the measurement accuracy coincides with s in NbN sample and with the width of the sample. These finding is consistent with the assumption that the size of the hot spot is not greater neither much smaller than the width of the sample, in which case one expects $s \approx w$ [5], and also with the estimate on the hot-spot size $d \approx 50$ nm [6].

3. Discussion

If we compare the behavior the $IDE(I)$ (green square for MoSi film and red open square for NbN film) and $IDE_2(I)$ behavior (green circles for MoSi and open red circles for NbN strips), then we can notice that for each of the samples its $IDE_2(I)$ grows steeper than $IDE(I)$.

Following [7], the finite width of the region where $IDE(I)$ turns from $IDE \ll 1$ to $IDE \approx 1$, is because of the dependence of the 'detection current' I_{det} on the position of the center of the hot spot with respect to the edge of the strip. The greater the hot spot compared to w , the slower the dependence. To give an insight why this is so, note that in the limit of the hot spot diameter greater than the w strip, the position and the shape of the hot spot depends very weakly on the position of its

nominal center (i.e. the point there the photon was absorbed), hence I_{det} is just independent on this position. At this, the dependency $IDE(I)$ would look like step function: at $I < I_{det}$ – probability of detection is zero, at $I > I_{det}$ - probability of detection is one. In the case when the hot spot is very small the dependence $IDE(I)$ is smeared and looks like sigmoidal function. The same argumentation can be applied also to double-spot counts and to $IDE2(I)$, with rough replacement of the single spot size to the size of two spots. Hence for the spot with the size $d \leq w$ one expects steeper growth of $IDE2(I)$ with current than of $IDE(I)$. Basing on this, we suppose that behaviour, which we can observe in the figure 1, correspond for the case, when the hot spot size is large enough but does not exceed the width of the strip.

4. Conclusion

In conclusion, our data on MoSi sample, in comparison with NbN sample, indicate that hot spot in NbN is big and the MoSi hot spot is even bigger but never the less is less than width of the strip. With the additional study obtained dependencies, it will be possible to compare the hot spot interaction length, obtained by our method, with the hot spot size.

Acknowledgments

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