

# Design of a superconducting nanowires single photon detector with dual broadband and high detection efficiency

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**Abstract:** In this paper, we propose a structure of a superconducting nanowire single photon detector (SNSPD) with a composite cavity. Compared with the SNSPD in previous studies, our device exhibits a property of high efficiency and dual broadband. Based on the transmission line theory, the structure is abstracted as an equivalent circuit model and a design method is presented. Taking  $\lambda=1310$  nm and  $\lambda=1550$  nm as an example, the structural parameters are calculated and verified by commercial software FDTD Solutions. The simulation results show that peaks of the absorption curve appear at both wavelengths and peak values are all larger than 97.5%. The influence of the upper half cavity on the full width at half maximum (FWHM) of the absorption peak is discussed. Our works provide a reference for designing a SNSPD with different FWHM.

**Index Terms:** superconducting nanowire single photon detector, high efficiency, dual broadband.

## 1. Introduction

In recent years, superconducting nanowire single photon detectors (SNSPDs) have attracted more attention because of those high detection efficiency in the near-infrared regime, low dark count, low time jitter and fast response speed[1-9]. In view of these advantages, SNSPDs have been widely used in quantum key distribution (QKD)[10-12], time-of-flight ranging[13], space laser communication[14], and so on. Especially in the application of QKD, photons are encoded and transmitted with different phase or polarization to achieve confidential communications. For this application, the efficiency of the detector has an effect on the bit error rate of the system directly. Therefore, the detection efficiency has been an important performance indicator for a SNSPD and also become an important research topic. In recent reports, F. Marsili et al[15] fabricate a high efficiency SNSPD with an optical cavity and the detection efficiency is larger than 90%. For this results, the optical cavities can be satisfactory for high-efficiency devices and have been widely used[16, 17]. However, this kind of the simple optical cavity can only improve the detection efficiency at the target wavelength and has an inhibitory effect at the other wavelength[18], which can lead to restrictions in certain applications. In fiber-based optical communications, both 1310 nm and 1550 nm are both technologically interested wavelength. Therefore, simultaneously optimizing the absorption of an SNSPD at these two wavelengths would expand SNSPDs' application space.

In this paper, we propose a device structure of the SNSPD with a composite cavity, which enables a high detection efficiency at two wavelengths, simultaneously. Based on the transmission line theory, a design method is proposed and verified by taking  $\lambda=1310$  nm and  $\lambda=1550$  nm as an example. Numerical simulations show that the peaks of absorption curve appear at the both wavelengths and the peak values are all larger than 97.5%.

## 2 Design of SNSPD

We first briefly describe the method of establishing the equivalent circuit model before our designing. Fig. 1 shows the schematic and the corresponding equivalent circuit diagram of the SNSPD with a composite cavity. From an optics standpoint, the superconducting nanowires can be approximately considered as sub-wavelength periodic structures. In each unit cell, the light transmits in the form of single-mode (TEM) and the higher order mode is cut off by the period boundary condition in our device. For this reason, we can express the SNSPD structure as an equivalent circuit model and complete our design by the transmission line theory. In the circuit model, each layer of the SNSPD is equivalent to a transmission line. The intrinsic impedance and the length of the transmission line are equal to the reciprocal of the medium refractive index and the thickness of the medium layer, respectively. The metal mirror (Au) is equivalent to a load impedance ( $Z_L$ ). It should be noted that the refractive index of gold is about 10 and does not tend to infinity in infrared band. Therefore, the load impedance is not

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