Superconducting Nanowire Single Photon Detector Integrated with optical cavity on Au Reflector

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Abstract

Superconducting nanowire single photon detectors with an optical resonant cavity structure are fabricated directly on the single crystal SiO_2 substrate. In order to enhance the photons absorption of incident light and improve system detection efficiency (SDE) efficiently, the structure of SNSPD with Au mirror on SiO_2 substrate was designed and optimized by the finite-difference time-domain analysis. We obtained an optimized thickness of cavity Si_3N_4 and fabricated the NbN-SNSPD. Measurement of SDE under free space coupling shows saturated detection efficiency at the wavelength of 1064nm by illuminating from the front-side of the device through single mode optical fiber.

0. Background and Motivation

- Development of superconducting material and fabrication process focus on mechanism to improve SDE, but effective absorption of material depends on the incidence and structure of the cavity largely. Most of the SNSPDs are made on Si substrates, but backside illumination cannot meet the application requirement of wavelengths less than 1000nm because of great loss of Si. Therefore, frontal illumination cavity structure is an ideal choice for all wavelengths.
- Aiming to design an optical cavity, NIST fabricated WSi-SNSPD by Au mirror and 93% SDE is obtained at 1550nm, and SIMIT prepared NbN-SNSPD with SDE approximately 80% for wavelength from visible to near infrared using Distributed Brag Reflector. Both of Au mirror and DBR are characterized high reflection performance, and they agreed to adopt frontal illumination to improve absorption efficiency.
- Here we introduced fabrication of NbN-SNSPD containing Au mirror and measured the SDE in far-field way from frontside illumination.

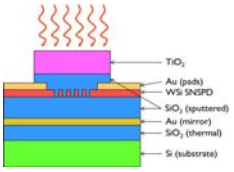

Fig.1. Diagram showing tungsten silicide layer in red @NIST

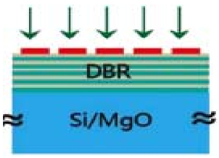

Fig.2. DBR optical structure for SNSPD@SIMIT

1. Device design and simulation

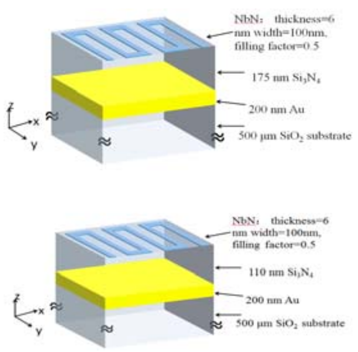

Fig.3. Schematic of SNSPD with an optical cavity on Au mirror

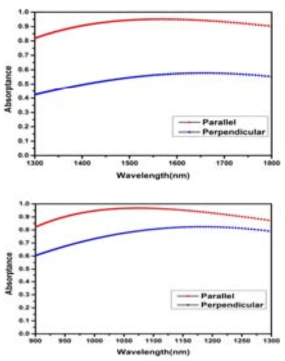

Fig.4. Calculated optical absorptance at 1064nm for parallel and perpendicular polarizations

2. Structure and characterization

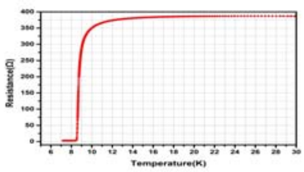

Fig.5. Superconducting transition temperature of NbN film

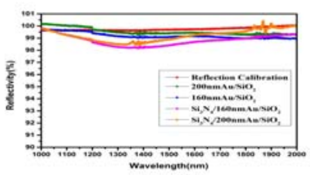

Fig.6. Reflection spectrum of Au mirror and cavity on Au mirror

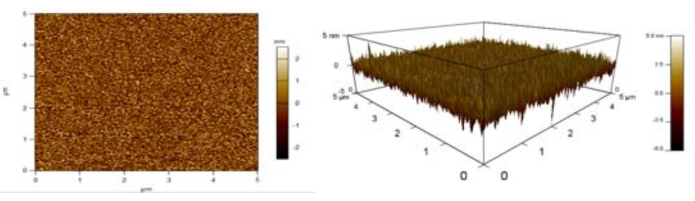

Fig.7. Atomic force microscopy image of Au mirror and root mean square roughness of Au mirror

3. Fabrication and measurement

Fabrication:

UV lithography+Sputtering(Au)
↓
PECVD(SiO_2+SI_3N_4)
↓
DC film deposition (Sputtering)
↓
UV lithography+Sputtering Au (electrode)
↓
EBL(nanowire)+RIE

Fig.8. Details of Fabrication Process

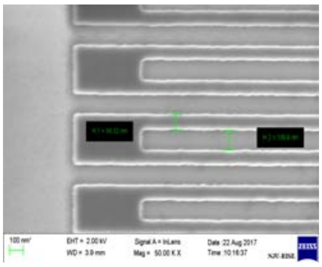

Fig.9. Scanning electron microscopy image of nanowire with 100nm width

4. Results

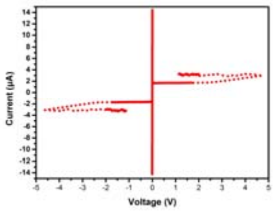

Fig.10. I-V characteristics of SSPD@2.2K

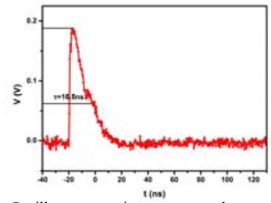

Fig.11. Oscilloscope persistence map and a recovery time constant of approximately 16.8 ns

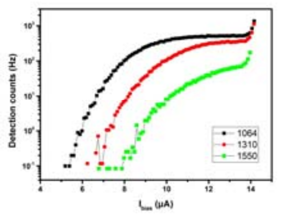

Fig.12. Detection response counts@2.2K

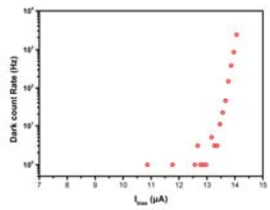

Fig.13. Dark Count Rate of SNSPD@2.2K

Conclusions

1. We designed NbN-SNSPD with optical cavity by Si_3N_4 on Au mirror and fabricated device at wavelength of 1064nm.

2. We measured the reflectance of Au mirror, Si_3N_4 on Au mirror. Measurement results show that their reflectance spectra cover the near-infrared band and a high reflectivity is obtained.

3. The chart of AFM show the root mean square (RMS) roughness of Au mirror is 0.67nm and Si_3N_4 on Au is 0.8nm.

4. We observed oscilloscope persistence map of the response at a bias current of 13 μA and a recovery time constant of approximately 16.8ns.

5. We measured the photon response counts of the device at Gifford–McMahon cryocooler in far field way from front-side illumination. The device presents a saturation detection trend in the target wavelength.

References

[1] F. Marsili et al. "Detecting single infrared photons with 93% system efficiency", Nature Photonics, 7(2013), pp.210-214.

[2] Lixing You et al. "Superconducting nanowire single-photon detector on dielectric optical films for visible and near infrared wavelengths", Superconductor Science and Technology, 30(2017), pp.1-7.

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