NbN/NiCu ナノワイヤ構造を用いた超伝導単一光子検出器の高速光応答
High Speed Response of NbN/NiCu Nanowire Single Photon Detector

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1 Introduction

Superconducting single photon detectors (SSPDs) have been investigated for fiber-based quantum communication systems and expected to have counting rate exceed to 10 GHz[1]. Combination of the SFQ systems and the fiber-based SSPD would be high-throughput input interface between room and cryogenic temperature[2]. However, it has been reported that speed of optical response was limited by kinetic-inductance of NbN nanowires[3]. In some reports, to solve this problem, novel structure called parallel structure has been proposed. It also has been reported that signal amplitude would increase proportional to number of nanowire connected parallel, N, and kinetic-inductance would decrease to $1/N^2$ respect to SSPDs with meander structure[4]. It has been also reported that proximized ferromagnet/superconductor nanobilayers showed fast quasiparticle decay[5].

In this study, we fabricated NbN/NiCu parallel nanowires as photo switches and examined high frequency performance of NbN/NiCu parallel nanowire photo switches.

2 NbN/NiCu thin film

Epitaxially grown NbN thin films were prepared on MgO(100) substrates by reactive dc magnetron sputtering of a 4-inch-diam Nb target in a mixture of Ar and N_2. Typical sputtering conditions were reported elsewhere[2]. The $Ni_{1-x}Cu_x$ overlayers were deposited without breaking vacuum by dc magnetron sputtering of a 4-inch diam $Ni_{0.48}Cu_{0.52}$ target. After film deposition, we examined the orientation of the films using an X-ray diffraction (XRD) method. From the Vegard's law using the obtained lattice constant of NiCu thin films by XRD, we confirmed that $Ni_{0.68}Cu_{0.32}$ thin films were obtained. Maximum critical temperature T_C of 13.6 K was obtained at N_2 flow ratio of 3 %. Critical temperatures T_Cs were decreased with decreasing NbN film thickness below film thickness of 8 nm and were constant at NbN film thickness thicker than 8 nm. Epitaxially grown NbN film with a thickness of 4 nm still has a critical temperature of about 10 K. In this study, we used 8 nm-thick and 10 nm-thick NbN thin films for fabricating NbN/NiCu parallel nanowires. NbN(10nm)/NiCu(10nm) thin films showed T_C of 6 K and smaller critical current densities at 4.2 K than NbN thin films.

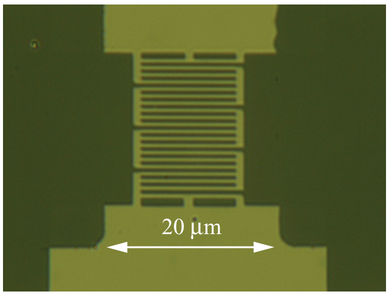
3 NbN/NiCu parallel nanowires

Measured devices including NbN/NiCu parallel nanowires were fabricated by electron beam (EB) lithography, conventional photolithography, ion etching (IE) method, reactive ion etching (RIE) method and lift-off method. For the EB lithography, we used a positive-type EB resist with about 400 nm thickness. Electron beam with 30 kV, 20∼50 pA was used for EB lithography. Typical dose density was 40∼60 $\mu C/cm^2$. Through the EB resist mask, NiCu films were patterned by IE using 1 Pa Ar gas with rf power of 200 W assisted with an inductive coupled plasma. Then, NbN nanowires were patterned by RIE using 40 Pa CF_4 gas with rf power of 200 W through the patterned NiCu films. Finally whole device structures were patterned by the photolithography and the RIE method. Figure 1 shows a micrograph of 400-nm-wide 3 parallel nanowire with co-planar transmission line.

I-V curves for NbN/NiCu nanobilayers with a different NiCu thickness were measured at 4.2 K. Critical temperatures of NbN/NiCu nanobilayers were decreased by NiCu overlayers. As well seen, critical currents Ics were decreased with increasing thickness of NiCu overlayers. Also hysteresis appeared on I-V curves disappeared with increasing the thickness of NiCu overlayers.

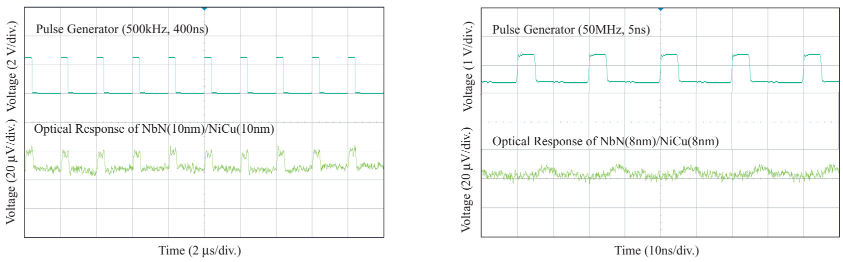
4 Photo response of NbN nanowires

Using a 850-nm VCSEL and a multi-mode optical fiber with core diameter of 50 μm, we examined optical response of NbN/NiCu nanowires. Maximum output power was 1 mW and laser power could be modulated by a pulse-pattern generator. Using an XY stage, optical fiber was fixed on the nanowires. Typical distance between the nanowires and the optical fiber was less than 500 μm.



(a)

Figure 1: Micrograph of 400-nm-wide 3 parallel nanowire with co-planar transmission line.



(a) (b)

Figure 2: High-speed optical response of (a) NbN(10nm)/NiCu(10nm) for 500 kHz, 400 ns-wide laser pulses and (b) NbN(8nm)/NiCu(8nm) for 50 MHz, 5 ns-wide laser pulses.

Figure 2 shows high-speed optical responses of (a) a 400-nm-wide NbN(10nm)/NiCu(10nm) nanowire for 400-ns-wide VCSEL pulsed laser irradiation with repetition frequency of 500 kHz and (b) a 400-nm-wide NbN(8nm)/NiCu(8nm) nanowire for 5-ns-wide VCSEL pulsed laser irradiation with repetition frequency of 50 MHz. About 20 μV voltage peaks were observed. Moreover, photo response for 1$\sim$2-ns-wide pulsed laser irradiation with repetition frequency of 100 MHz could be observed. Response speed of NbN/NiCu nanowires was almost same as that of NbN nanowires.

5 Conclusions

NbN(10nm)/NiCu(10nm) thin films showed T_{C} of 6 K and smaller critical current densities than NbN thin films. For obtaining fast photo response, we fabricated NbN/NiCu parallel nanowires in coplanar line structures. We irradiated nanowires by 850-nm laser pulses via 50-μm multi-mode optical fibers. Using 500-nm-wide NbN/NiCu nanowires, high speed responses were observed for laser pulses with repetition frequency of 100 MHz and pulse width of 2 ns.

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