Fabrication of 3 THz superconducting hot electron bolometer mixers

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Abstract— **We developed a fabrication method of niobium nitride (NbN) ultrathin films deposited on a silicon (Si) substrate for terahertz applications. First, a magnesium oxide buffer layer was deposited on a Si substrate at approximately 525 °C. After deposition of the layer, NbN ultrathin films were deposited at ambient temperature. Using the buffer layer, we found the transition temperature of the 3.5-nm-thick NbN thin films to be approximately 10 K. The same method was applied to fabricate hot electron bolometer mixers (HEBMs) on a Si substrate. The receiver noise temperature was found to be approximately 1930 K (DSB) at 3.1 THz.**

I. Introduction

HEBMs are expected to be used as low-noise heterodyne mixers in the terahertz frequency region [1-3]. Using single-crystal magnesium oxide (MgO) substrates, we fabricated epitaxial NbN ultra-thin films with good superconductivity and realized NbN-HEBMs with good performance [4]. However, the transmittance of the MgO substrate is depleted above several terahertz. On the other hand, a Si substrate shows good transmittance in the terahertz frequency region. Therefore, we developed a method to fabricate NbN thin films with good superconductivity. Using this method, we designed and fabricated HEBMs on a Si substrate. The receiver noise temperature at 3.1 THz was also evaluated.

II. Fabrication and Evaluation of NbN-HEBMs

To fabricate NbN ultra-thin films with good superconductivity on a Si substrate, we thought that a MgO thin film can be used as an intermediate layer. To form the MgO buffer layer, we used a sputtering system capable of film formation at high temperature. First, we heated the Si substrate up to 525 °C. The vacuum chamber used was pumped by a cryopump and the typical background pressure was 3×10^{-5} Pa. The MgO thin films were deposited by reactive dc-magnetron sputtering. The target was 99.9% of pure Mg, with a diameter of 3 inch. Argon (Ar) and oxygen (O_2) were used for MgO sputtering. Table I lists the sputtering conditions for the dc-MgO film. During the MgO deposition, the substrate temperature was also kept at 525 °C. As a buffer layer, the MgO thin-film thickness was set at 50 nm. The MgO (200) peak of the X-ray diffraction pattern was clearly observed.

After deposition of the MgO buffer layer, NbN ultrathin films were deposited by reactive dc-magnetron sputtering.

Table 1 Sputtering conditions of the DC-MgO films.

Target	Mg 99.9%, 3-inch
Gas/ Pressure	Ar:O_2=10:1 / 0.27 Pa
Power	200 W dc
Substrate temp.	525 °C
Deposition rate	3.3 nm/min

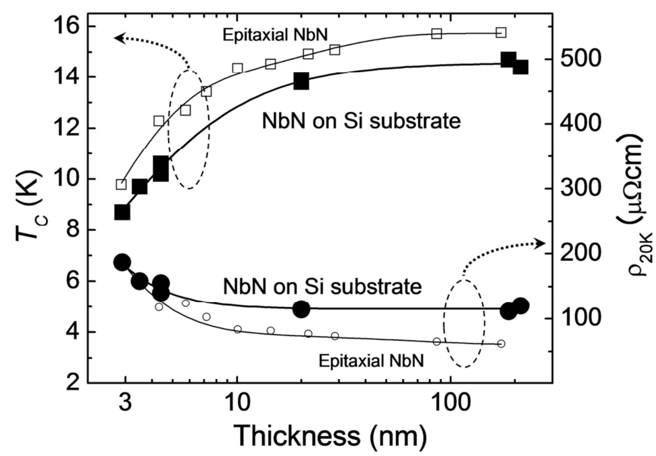

Fig. 1. T_C and 20 K-resistivity ρ_{20K} of NbN thin films deposited on a Si substrate as functions of the film thickness. For comparison, T_C and ρ_{20K} of the epitaxial NbN films are also indicated.

NbN deposition was carried out at ambient temperature to ensure the good reproducibility. The fabrication process of NbN deposition was basically the same as the one described by Kawakami *et al.* [5, 6]. The T_C and 20 K resistivity ρ_{20K}, plotted as functions of the NbN thickness, are shown in Fig. 1, where the T_C and ρ_{20K} of the epitaxial NbN films using the MgO single-crystal substrate are included for data comparison. In the region with a thickness of several nanometers, the NbN thin films on Si showed properties comparable to those of the epitaxial NbN thin film.

Fig. 2 shows the dc resistance versus temperature of the NbN-HEBM fabricated on a Si substrate. The inset shows the *I*–*V* characteristics. The normal resistance of the mixer was approximately 70 Ω, and the T_C of the NbN strip was about 9.4 K. Fig. 3(a) shows the receiver setup for evaluation of the 3.1-THz HEBMs. Here, a terahertz quantum cascade laser (QCL) was used as the local oscillator (LO). The receiver

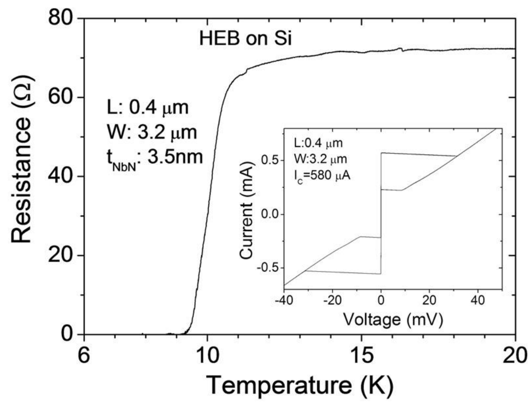

Fig. 2 The dc resistance versus temperature of the HEBM fabricated on a Si substrate. The inset shows the I–V characteristics of the HEBM at 4.2 K.

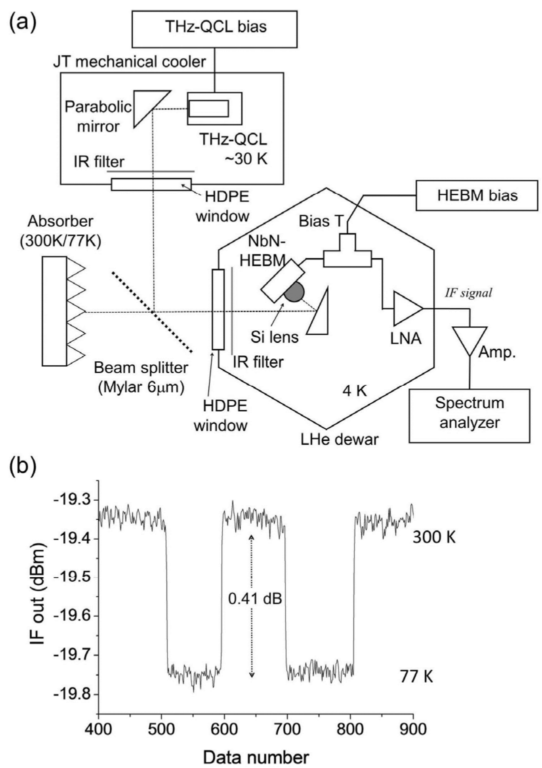

Fig. 3 (a) Schematic layout of the measurement setup. (b) The IF response for hot (300 K) and cold (77 K) loads.

noise temperature was evaluated using the standard Y-factor method at room temperature (300 K) and liquid-nitrogen-cooled (77 K) loads. The incoming radiation entered the dewar through a 1-mm-thick high density polyethylene (HDPE) window and Zitex infrared filters. The IF output response to the hot and cold loads is also shown in Fig. 3(b). Distinct IF responses to the hot and cold loads were observed, and the maximum Y-factor was estimated to be approximately 0.41 dB. No corrections were made for losses at the front of the receiver, and the double sideband (DSB) receiver noise temperature was estimated to be approximately 1930 K at 3.1 THz.

III. Conclusions

We developed a fabrication method of NbN ultrathin films deposited on the Si substrate. By using a magnesium oxide buffer layer of 50 nm thick, NbN films with good superconductivity were deposited on a Si substrate at ambient temperature. In the region with a thickness of several nanometers, the NbN thin films on Si showed properties comparable to those of the epitaxial NbN thin film. HEBMs on a Si substrate were fabricated and they showed low receiver noise temperature of 1930 K (DSB) at 3.1 THz.

Acknowledgment

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