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Improvement of Critical Temperature of Superconducting NbN and NbTiN Thin Films Using an AlN Buffer Layer

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ABSTRACT

Superconducting hot electron bolometer (HEB) mixers have matured as the most sensitive heterodyne detectors for astronomy and atmospheric science in the THz region. The HEB mixer fabrication is based on an ultra thin superconducting film such as Nb, NbN, and NbTiN. In general, the critical temperature (T_c) of such thin films is much lower than those of the corresponding bulk materials. In order to improve T_c of the thin films, we have employed an AlN film as a buffer layer between a substrate and NbN/NbTiN films. The AlN film is deposited on the quartz or glass substrate in a mixture of Ar and N_2 gas by DC reactive magnetron sputtering. We optimize the Ar and N_2 flow rates to ensure that the X-ray diffraction from the 002 surface of Wurtzite type AlN is dominant. We measure the T_c values of the NbN and NbTiN films with the AlN buffer layer (20 nm) deposited on quartz and glass substrates respectively. For the 8 nm NbTiN film on the grass substrate, T_c is increased from 8.4 K to 11.0 K by insertion of the AlN buffer layer. For the 10 nm and 6 nm NbN films on the quartz substrate, the T_c is increased from 6.9 K to 11.4 K and 6.1 K to 9.8 K respectively. The improvement in Tc would originate from better epitaxial growth of the NbN and NbTiN films on the AlN buffer layer than on the bare substrate. The HEB mixer fabrication using the NbN and NbTiN films with the AlN buffer layer is ongoing.

Ⅰ. INTRODUCTION

We are developing superconducting hot electron bolometer (HEB) mixers, aiming at ground-based astronomical observations in the THz band. In the case of the phonon-cooled HEB mixers, we have to use a superconductive film with thickness as thin as a few nm for rapid and efficient cooling of the mixer. As superconductive materials, NbN and NbTiN are usually used. Although these materials have high critical temperature (T_c) of about 16 K for the bulk case, T_c of the thin film tends to be much lower than that. Since T_c should be as high as possible for good performance of the HEB mixers, it is an essential task for us to realize the thin superconductive films with high T_c.

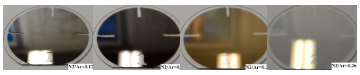
This time we introduced an AlN buffer layers between a superconducting film and a substrate to improves matching between them. In fact, the AlN buffer layer is reported to be effective for the NbTiN film [1], but its application to NbN has not been reported, as far as we know. So far MgO and SiC have been used as the buffer layer for NbN[2, 3]. In the present study, we have carefully examined this technique not only for NbTiN, but also for NbN.

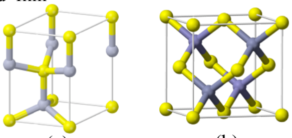
Ⅱ. PREPERATION OF AlN FILM

◇ AlN and other films were fabricated by using the sputtering chamber designed for the HEB mixer fabrication.

◇ The AlN film was fabricated by the reactive DC magnetron cathode. The distance between the target and the substrate is 70 cm.

◇ Increasing the N_2 flow from zero, the deposited film gradually becomes transparent.





(a) (b)

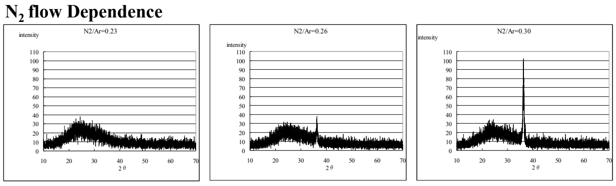
◇ It is known that there are two types of crystal structure for AlN:

(a) Wurtzite -hexagonal lattice

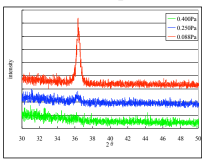
(b) Sphalerite -cubic lattice

According to an X-ray diffraction (XRD) method, the 002 surface of Wurtzite-type AlN is dominant. Then we optimized the process conditions for AlN so as that the highest XRD intensity of the 002 surface is obtained.

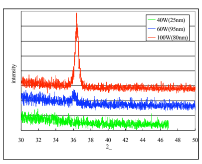
N_2 flow Dependence



Pressure Dependence



Power Dependence



Process Conditions For AlN

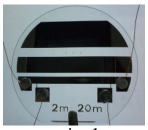
N_2/Ar	0.33
Total Pressure	0.088 Pa
Sputtering Power	100 W
Sputtering Voltage	~ 400 V
Deposition Rate	~ 16.2 nm/min

Ⅲ. NbTiN

◇ The NbTiN film was fabricated by the RF assisted DC magnetron cathode. The distance between the target and the substrate is 150 mm.

◇ The sputtering condition of NbTiN is shown below.

N_2/Ar	0.089
Total Pressure	0.416 Pa
Sputtering Power	220 W
Sputtering Voltage	~ 310 V
Deposition Rate	~ 5.0 nm/min



Four-terminal pattern

◇ The fabricated films (NbTiN, NbTiN with an AlN buffer layer) were cooled by the 4 K GM refrigerator for the T_c measurement. T_c was measured by the four-terminal method.

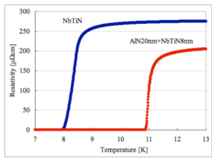
◇ Using an AlN buffer layer, T_c was improved by almost 3 K.

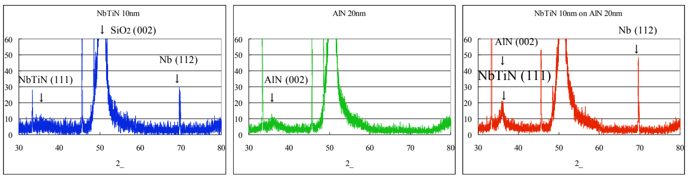
◇ The XRD pattern of these films shows that 111 surface of NbTiN grows in the favor of AlN.

・The films were deposited on a quartz substrate.

・AlN (002) diffracts at 2θ=36.04°

・NbTiN (111) diffracts at 2θ=36.06°





Ⅳ. NbN

◇ The NbN film was fabricated by the RF assisted DC magnetron cathode. The distance between the target and the substrate is 150 mm.

◇ The sputtering condition of NbN is shown in the right table.

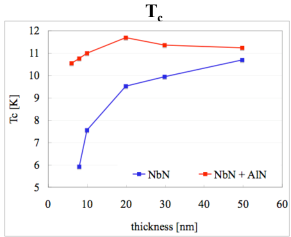
◇ The measurement method was same as NbTiN.

◇ T_c and the reisistivity were improved significantly.

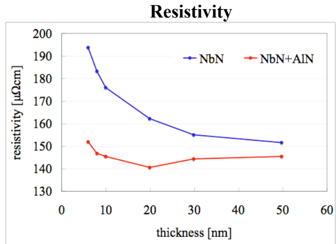
Process Conditions For NbN

N_2/Ar	0.115
Total Pressure	0.250 Pa
Sputtering Power	250 W
Sputtering Voltage	~ 360 V
Deposition Rate	~ 9.9 nm/min

T_c

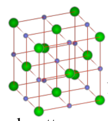


Resistivity



◇ NbN and NbTiN have the same crystal structure; NaCl type, with similar lattice constants.

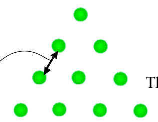
Materials	Lattice type	Lattice constant [nm]
NbTiN	NaCl	a = 0.438[4]
NbN	NaCl	a = 0.439[5]
AlN	Wurtzite	a = 0.311, c = 0.498[6]



NaCl type lattice

The 111 surfaces of NbN and NbTiN crystals look like hexagonal pattern and this “lattice constant” coincides with that of AlN. This may contribute to the improvement of T_c and the resistivity.

$$\frac{\sqrt{2}}{2}a_{NbN}=\frac{\sqrt{2}}{2}\times 0.439=0.31\cong a_{AlN}$$



The 111 suffance of NbN

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