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Preparation of Large Area NbN/AlN/NbN Josephson Junctions

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AℓN has been used as a barrier material in large josephson junctions. The chemical and structural compatibility of AℓN with NbN make it possible to fabricate NbN/AℓN/NbN junctions by sequential reactive sputtering in a common Ar and N_2 atmosphere. In a junction with an area of about 1.0 × 1.0 mm^2, having a transition temperature of 14.5K, the measured I-V and first derivative curves yield a sum gap value of about 3.0 meV.

1. INTRODUCTION

Recently there has been a growing interest in studying the propagation and generation of electromagnetic waves via the Josephson effect in SIS superlattices[1,2]. It is predicted that an increased output of Josephson radiation may be achieved from such structures, arising partly from the increased number of junctions but also through an increase in the velocity of the modes which occurs when the thickness of the superconducting layers becomes much less than the corresponding London penetration depth, λ_L. A large, multilayer Josephson junction will facilitate the observation of the above mentioned effects and one has to choose carefully both the electrode and insulating barrier materials to achieve the desired structure. In this regard, a NbN/AℓN/NbN junction seems to be very attractive. Aluminum nitride, a compound with the wurtzite crystal structure, has a wide band gap (5.9 eV) and a high resistivity (10^9-10^{11} Ω cm)[3,4]. It is refractory and stable. The chemical and structural compatibility of AℓN with NbN makes it possible to fabricate successive NbN/AℓN/NbN junctions by sequential reactive sputtering in a common Ar and N_2 atmosphere[5].

In this paper, we report, as the first step toward large area multi-layer Josephson junctions, some preliminary results on preparing sandwich NbN/AℓN/NbN Josephson junctions.

II. Sample Preparation

NbN/AℓN/NbN junctions were produced by DC magnetron sputtering in a turbopumped system with four Research S-guns. Two guns contained (99.9% purity) niobium targets and one gun contained an aluminum (purity 99.999%) target. Usually the base pressure before sputtering was about 5×10^{-7} Torr. The deposition was carried out in a reactive mixture of high-purity (99.999%) argon and nitrogen. The flow rates of Ar and N_2 were independently controlled by needle valves. The pressures were measured by an ion gauge or by a thermocouple gauge. A chromel-alumel thermocouple was used to monitor the substrate temperature.

Before sputtering the substrates were heated to above 300°C for several hours to promote a clean surface. The discharge voltage and current were typically 280-300V, 1.5-1.8A for NbN, and 220-240V, 0.6-1.0A for AℓN. The thicknesses of the deposited films were monitored by crystal sensors via a film deposition controller. An independent determination was achieved by recording the deposition times, and subsequently measuring the accumulated film thickness with a profiler. The junction area of 1.0×1.2 mm^2 was defined by a set of stainless steel masks; the resulting junctions had a crossed strip geometry. The total pressure in the sputtering chamber was 5-10 m Torr and the N_2 partial pressure was adjusted to achieve the optimal conditions. The substrate temperatures were 200°C - 300°C. The substrates were clean polished [0001] single crystal sapphire.

III. EXPERIMENTAL RESULTS AND DISCUSSION

X-ray diffraction scans show that the deposited NbN films have the B1 structure with a (111) preferred growth orientation. As is well known, NbN is a granular superconductor. The grain size can be deduced from Scherrer's formula[6]

$$D = \frac{0.9\lambda}{2w\cos\theta} \quad ,$$

where w is the full width at half maximum and λ is the X-ray wave length. After correcting for the instrument broadening, we estimate that the grain size is about 100A.

The midpoint transition temperatures of the NbN electrodes were measured using the standard four-probe method. T_c's depend critically on the N_2 partial pressure, as shown in Fig. 1. The highest transition temperature of our films is 14.5K.

At the optimized N_2 partial pressure all as-deposited AℓN films are transparent. Several thicker AℓN films were prepared separately and, with the aid of the film profiler yielded the sputtering rate. The barrier thickness can be estimated from the observed sputtering rate and to confirm this estimate, a junction with a relatively thick AℓN barrier was prepared. The I-V curve is shown in Fig. 2. Assuming that tunneling occurs through a trapezoidal WKB barrier of a given width, height, and asymmetry, Simmons derived an expression for the tunneling current at low bias voltage[7].

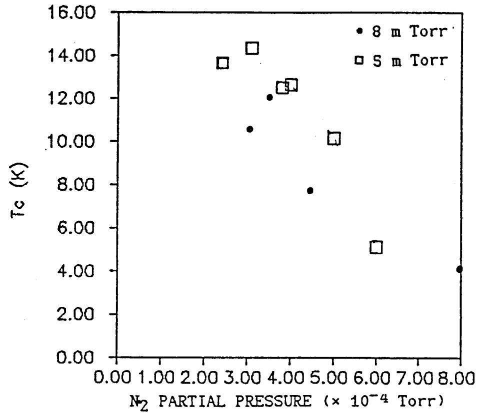

Fig. 1. The transition temperatures of the NbN electrodes vs N_2 partial pressure.

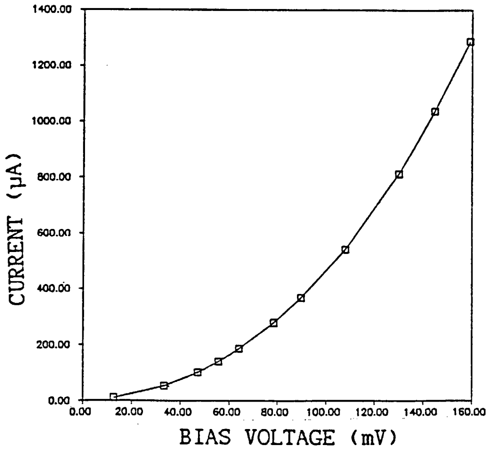

Fig. 2. I-V curve of a NbN/AℓN/NbN junction measured at 2.65K. The data yield an effective barrier height of 0.225 eV and barrier width of 52A, respectively.

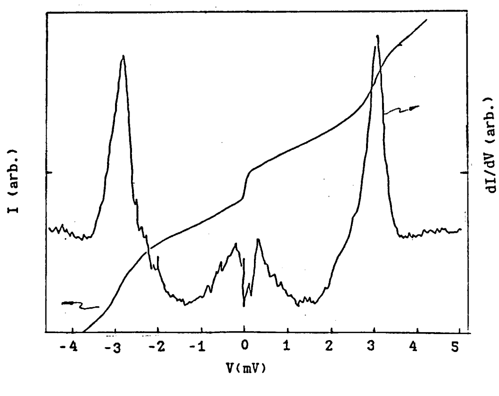

Fig. 3. I-V and first derivative curves of the NbN/AℓN/NbN junction. The AℓN barrier width is 16A.

Using the data in Fig. 2, for the sample examined, we obtain an effective barrier thickness t = 52A, and an effective barrier height $\bar{\phi}$ = 0.225 eV. The thickness is in good agreement with the calibrated sputtering rate, and the effective barrier height is consistent with the reported general relation between barrier thickness and height[8].

Shown in Fig. 3. are the I-V and the first derivative dI/dV vs V curves for a NbN/AℓN/NbN junction. The transition temperatures of the NbN electrodes are about 14.5K and the AℓN barrier width is about 16 A. The curves were traced in an SHE VTS-50 instrument equiped with a specially designed transport probe. Upon cryocycling the performance of the junction is reproducible, from which we conclude that AℓN is a stable barrier material. No particular attention was paid to shield out the earth magnetic field. The relatively sharp peaks in the dI/dV vs V curve are used to determine a sum gap value of about 3meV. The observed energy gap is smaller than what would be expected on the basis of the bulk transition temperature. The zero bias anomaly observed in Fig. 3 could arise from junction inhomogeneity or defects. A more interesting possibility arises from the fact that the junction has a large area so fluxon dynamics can have a dramatic effect on the I-V characteristics[9], resulted in the appearance of zero field steps (ZFS), Fisk steps, or a displaced linear slope in I-V curves. Further calculations, based on the modified sine-Gordon equation, are required to clarify the role of the fluxon dynamics in the observed I-V characteristics.

In conclusion, the experiments indicate that AℓN may be a promising barrier material in an all-NbN Josephson junction technology.

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