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Electrical conductivity and transition temperature of NbN thin films

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Abstract. Niobium nitride thin films are grown using reactive RF sputtering technique for four different partial nitrogen pressures in argon atmosphere. The superconducting transition temperature of the films has been measured. The films exhibit a negative temperature coefficient of resistivity. The electrical characterization of the films has been carried out and the conductivity measured between room temperature and liquid nitrogen temperature. This is fitted using T^p law.

Keywords. Niobium nitride; thin film; sputtering; super-conducting transition temperature.

1. Introduction

Aschermann *et al* (1941) discovered that niobium nitride (NbN) has a cubic structure and has a relatively high superconducting transition temperature. We have employed the RF reactive sputtering method (Wolf *et al* 1980) for the deposition of NbN films. In this method, while sputtering is done in an atmosphere of nitrogen and argon, the ionized nitrogen combines with niobium atom and NbN is deposited onto the substrate. The deposition parameters like substrate temperature, deposition rate and partial pressures of reactive gases influence the stoichiometry of NbN films (Bacon *et al* 1983).

NbN is a technologically promising material in the fabrication of Josephson junction devices (Classen 1984) and submillimeter wave detectors (Carr *et al* 1984). The critical current and field characteristics studies of NbN were mainly done by Ashkin *et al* (1984).

In the present work we have made use of the reactive RF sputtering technique to produce NbN films at different partial nitrogen pressures. It is observed that the values of superconducting transition temperature T_c, sheet resistivity R and resistance ratio $\beta (= R_{300}/R_{77})$ depend considerably on the partial nitrogen pressures. The electrical conductivity of the films was measured in the temperature range 77 K and 305 K and fitted using a T^p law.

2. Experimental details

The sputtering apparatus consists of a stainless steel chamber evacuated by a rotary pump and a 10 cm diffusion pump. A niobium disc (99·9% pure) was placed over the stainless steel cathode and an RF potential was applied to the cathode.

Quartz substrates of 25×5 mm were washed with detergent, water and distilled water. Subsequently they were agitated in an acetone bath in an ultrasonic cleaning device and dried in an oven. They were then placed above the cathode at a distance of 4 cm. In all cases the substrate temperature was kept at 475°C.

When the residual gas pressure in the chamber was 1×10^{-6} torr, dry nitrogen was introduced into it and the desired pressure was maintained. Pure argon gas was then introduced and the total pressure was kept at 8×10^{-3} torr in all cases. Pre-sputtering for 30 min was effected with a closed shutter which was opened for 30 min and the films deposited. When the sputtering was complete the needle valve in the argon gas line was closed and the nitrogen pressure was again checked.

The voltage and current leads were connected to the sample using indium soft bonding. The sample was placed in a copper chamber containing liquid helium. The temperature was measured by a calibrated germanium resistance thermometer. The transition temperature was measured by simultaneously plotting the potential across the voltage leads and the potential across the germanium sensor on a chart recorder. The transition temperature T_c was measured as that temperature at which the resistance of the sample was half the normal value. The transition width ΔT_c was the temperature difference between 90% and 10% values of the normalized resistance of the sample.

For measuring the voltage-current characteristics between room temperature and liquid nitrogen temperature, the samples were cooled by keeping them in a liquid nitrogen cryostat.

For different current through the samples, the potential across the voltage leads was measured by a digital multimeter (model HIL 2645) at different temperatures. The temperature of the films was measured using a copper-constantan thermocouple.

3. Results and discussion

Figure 1 shows a representative voltage-current characteristic of the sputtered NbN films for partial nitrogen pressure of 2×10^{-3} torr at different temperatures. It is seen

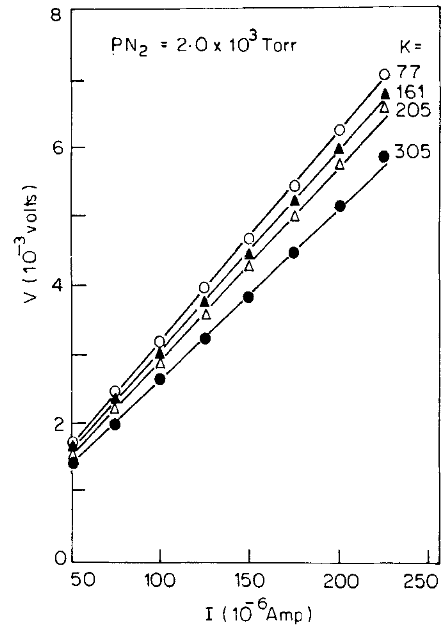

Figure 1. Voltage current characteristics at various temperatures for $P_{N_2} = 2 \times 10^{-3}$ torr.

that the resistivity increases with increasing partial nitrogen pressures while the same decreases with increasing temperature. The conductivity σ of the films was found out from the characteristic curves for various temperatures. A plot between $\log_e \sigma$ vs $\log_e T$ as shown in figure 2 is a straight line. These experimental points are fitted using a T^P law. This agrees with the observations of Ayer and Rose (1973). The P values obtained from the slopes of the temperature-conductivity graphs showed an increase from 0·07 to 0·26 as the partial nitrogen pressure increased from 2×10^{-3} to 6×10^{-3} torr. Since all P values were positive, all the NbN films showed a negative temperature coefficient of resistivity (TCR). The TCR is more negative for films prepared with higher nitrogen pressures. The calculated resistance ratio β for these samples is less than unity indicating that these films are possibly granular or of the columnar void structure (Cukauskas *et al* 1985). Keskar *et al* (1971) obtained a nearly constant unity value for β in this range of pressures. Table 1 shows the T_c and ΔT_c for different samples. Figure 3 shows a representative T_c graph of the NbN film grown at partial nitrogen pressure of 2×10^{-3} torr.

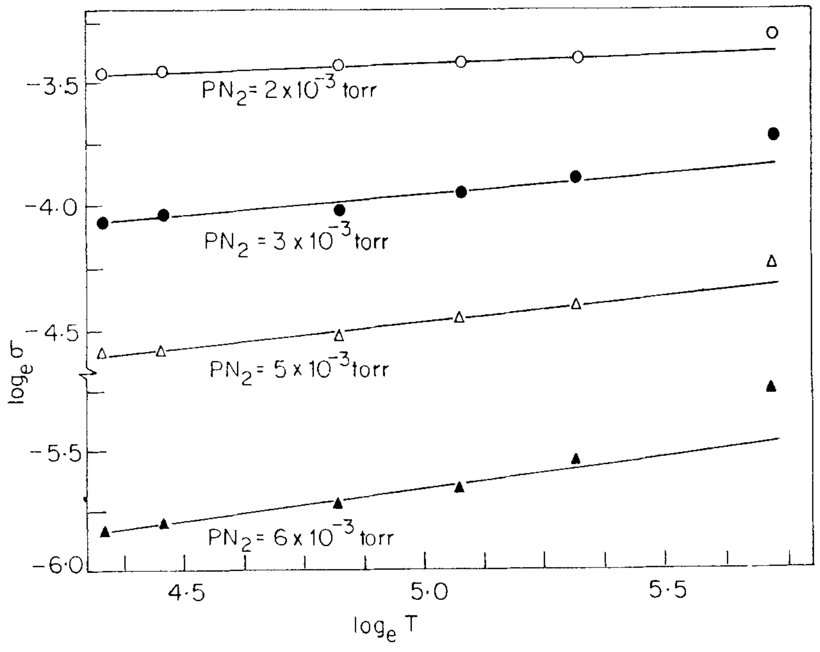

Figure 2. $\log_e \sigma$ vs $\log_e T$ for various partial nitrogen pressures.

Table 1. Superconducting transition temperature T_c and ΔT_c of NbN films at different partial nitrogen pressures PN_2.

$PN_2 \times 10^{-3}$ torr	T_c (K)	ΔT_c (K)
2	11·4	0·5
3	9·0	0·5
5	6·4	0·6
6	4·8	1·0

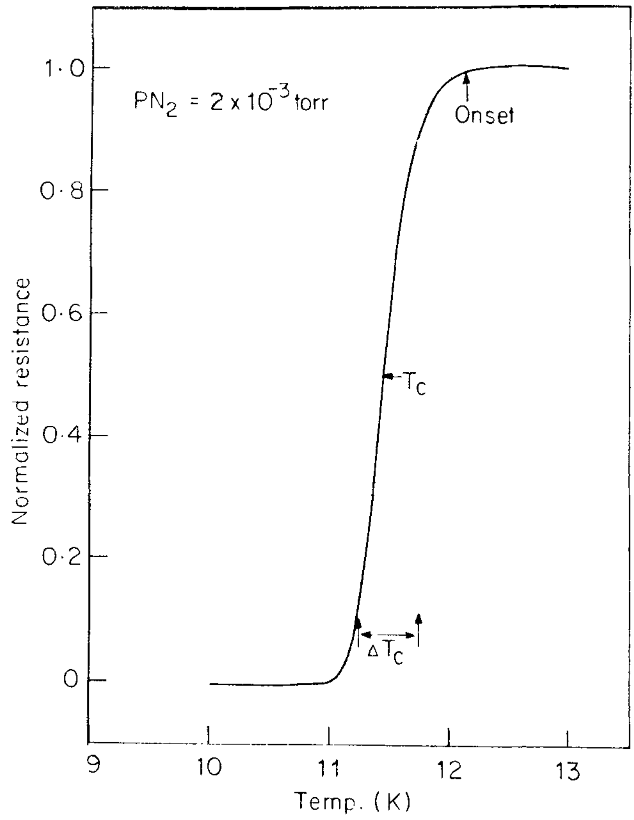

Figure 3. Superconducting transition temperature T_c graph of NbN film at partial nitrogen pressure $P_{N_2} = 2 \times 10^{-3}$ torr.

4. Conclusion

NbN films have been prepared by reactive RF sputtering technique at different partial nitrogen pressures. The films exhibit a wide range of electrical and superconducting properties which depend mainly on the partial nitrogen pressure in argon atmosphere. The films prepared on a partial nitrogen pressure of 2×10^{-3} torr have a better T_c of 11·4 K. The transition width is broad for films prepared at 6×10^{-3} torr pressure.

The conductivity of the films between room temperature and 77 K is found to obey the relation $\sigma \propto T^p$. The resistance ratio β for the films is less than unity.

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