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Fabrication of Superconducting NbN Gate MOSFET for Hybrid Circuit Applications

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Application of superconducting Nb and NbN to gate electrodes of self-aligned MOSFETs has been studied. Nb film was degraded its superconductivity by annealing at 650 °C for 5 min. On the otherhand, NbN film annealed at 800 °C for 30min showed usual transition temperature T_c about 15K. NbN gate self-aligned MOSFETs were fabricated and showed good electrical characteristics at 4.2K.

1 Introduction

Hybrid circuits consisting of semiconductor and superconductor devices have recently been proposed to utilize the advantages of each technology[1]. One of these devices, a new type of memories, is to use charge storage on MOS devices as the memory and access the memory elements by high-speed Josephson junction(JJ)devices. It will be necessary to fabricate JJs and MOSFETs on the same substrate for this purpose. However, there have been very few trials of contact between JJs and MOSFETs because of differences in operation theory and temperature.

We studied possibility of using superconducting Nb and NbN as gate electrodes of self-aligned MOSFETs. Nb and NbN having high melting points have been used as materials of JJs. If they can keep their superconductivity after thermal annealing, power dissipation and delay in circuits will be dramatically improved. Nb group superconductors are known to be active and thermal annealing degrades superconductivity[2]. First, we described the effects of thermal annealing on superconductivity of Nb and NbN. Then we described the fabrication of self-aligned superconducting gate MOSFETs.

2 Experiment

SiO_2(about1000 Å) film was grown on B doped p-type (100)oriented Si (ρ=3~5Ω cm) by thermal oxidation for 45min at 1000°C. Nb was deposited on this substrate by dc sputterring. As for NbN, we used rf magnetron planer diode sputterring. NbN film was deposited with Nb target using Ar gas mixed with N_2 and CH_4[3]. These samples were annealed in dry N_2 at 650°C and 850°C for 5~ 30min. Nb and NbN films were analized by secondry-ion mass spectroscopy(SIMS). Transition temperature(T_c)and residual resistance ratio (Rrr)were also measured before and after annealing.

After making NbN/SiO_2 gate structure by RIE process, phosphorus ions were implanted with a dose of $5\times10^{15}cm^{-2}$ at 50 KeV to form the sourse and drain regions. Samples were annealed at 800°C for 20~ 30 min to remove the implantation damage. SiO_2 was then sputtered and contact holes were opened. After sputtering NbN or Nb films, contact electrodes were patterned.

3 Results and Discussion

Unannealed Nb film showed usual Tc of about 9.2K. On the otherhand, Nb films annealed at 650°C for 5min did not show Tc above 4.2K, indicating the degradation of superconductivity. The value of Rrr are shown in Fig.1. After annealing, the values decreased to about 1. This means that metallic property of Nb film was degraded by annealing. SIMS analysis revealed that diffusion of oxygen from Nb surface was observed. This diffusion of oxygen may cause the degradation of superconductivity of Nb film[4]. Thus Nb can not be used for gate electrode.

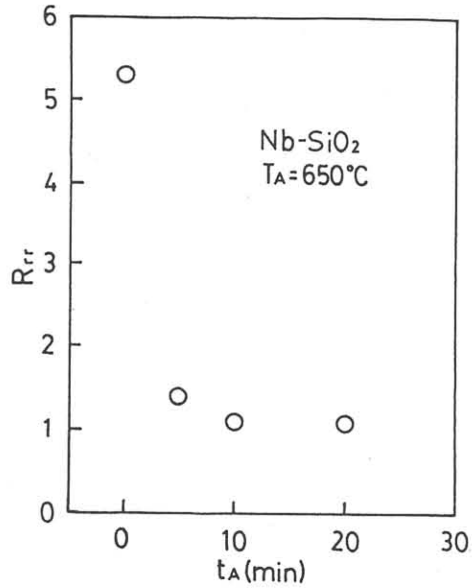

Fig. 1: Rrr of Nb films as a function of annealing time.

Figure 2 showed T_c of NbN films annealed at 650°C and 800°C as a function of annealing time. Differing from the results of Nb films, showed T_c about 15K. The values of R_{rr} are shown in Fig.3. They are almost constant for films annealed at 650°C so that property of NbN film may not be degrated by annealing at this temperature. For NbN films, no diffusion of oxygen from the surface could be obeserved from SIMS analysis. We thus conclude that NbN film fabricated in this experiment has good quality and is stable to thermal annealing and to diffusion of oxygen. This NbN film can be used as gate electrode of self-aligned MOSFETs.

Figure 4 shows the subthreshold characteristics of NbN gate NOSFETs at 300, 77 and 4.2 K.

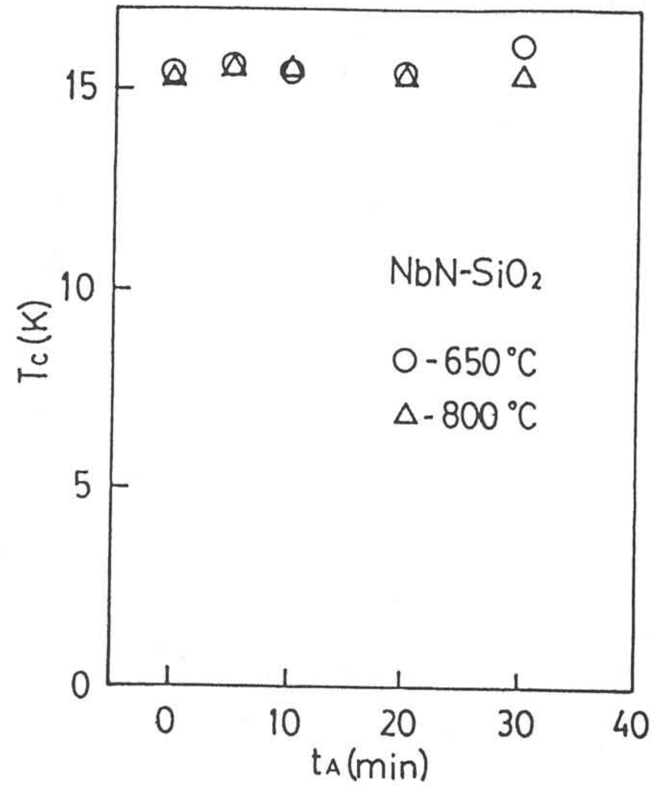

Fig. 2: Tc of NbN films as a function of annealing time.

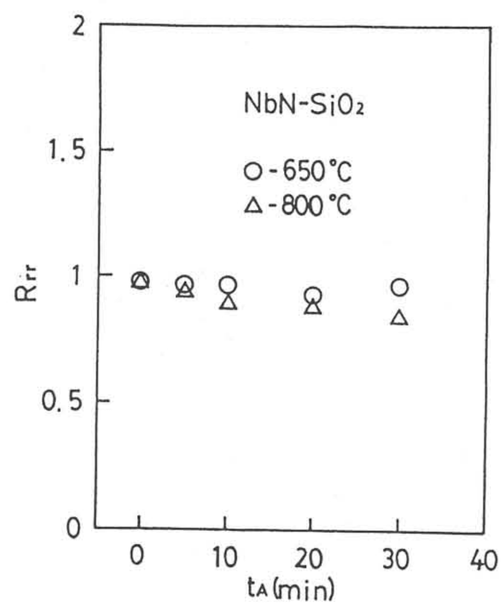

Fig. 3: Rrr of NbN films as a function of annealing time.

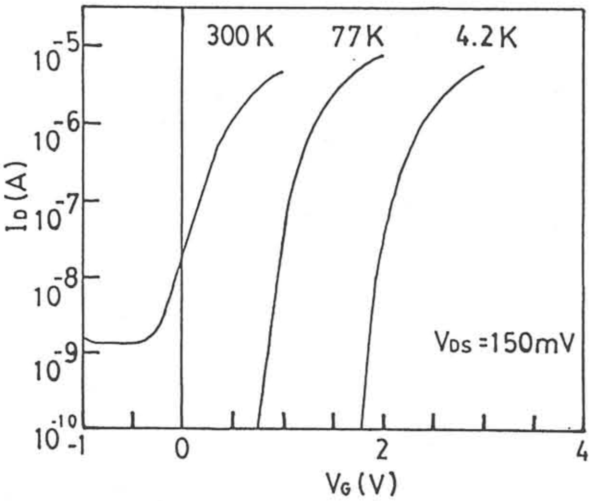

Fig. 4: Subthreshold characteristics of NbN gate MOSFET at 300, 77 and 4.2K.

The channel length is 5 μm and the channel width is 50 μm. While the values of Subthreshold swing S are somewhat larger than the expected values, subthreshold characteristics were improved with the decrease of operating temperature. Threshold voltage increases with the decrease of temperature, reflecting the temperature dependance of Fermi potential.

Drain characteristics of MOSFETs at 4.2 K was shown in Fig.5. Although a kink is observed as is the case of normal MOSFET at 4.2K, good electrical characteristics is obtained. Field effect mobility as mesured from transconductance increased with the decrease of temperature. However, the mobility increase was smaller than the theorecal prediction. This may be due to the process contamiration at the SiO_2/Si interface.

4 Conclusion

The effects of thermal annealing on superconductivity of Nb and NbN films sputtered on SiO_2 were investigated to study the applicability to gate electrodes of self-aligned MOSFETs. Superconductivity of Nb films was degraded by annealing at 650°C. NbN film showed usual Tc about 15K after annealing at both 650°C and 800°C, and was stable to annealing. We succeeded in fabricating self- aligned superconducting NbN gate MOSFETs and showed the possibility of the implementation of both superconductor and semiconductor devices on the same substrate.

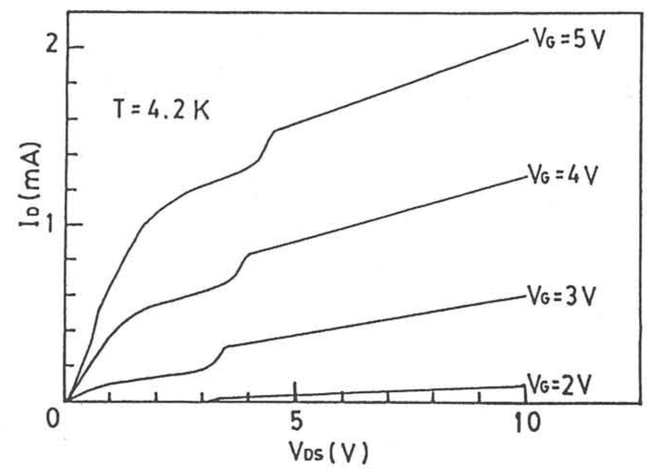

Fig. 5: Drain characteristics of NbN gate MOSFET at 4.2K.

Acknowledgements

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References

[1] T.Van.Duzer and S.Kumer, Cryogenics. 30(1990) 1014.

[2] M.Hatano, T.Nishio, and U.Kawabe, J. Vac. Sci. Technol. A6 (1988) 2381.

[3] M.Aoyagi, H.Nakagawa, I.Kurosawa, and S.Takada, Jpn. J. Appl. Phys. 31 (1992) 1778.

[4] T.Shiota, T.Imamura, and S.Hasuo, J. Appl. Phys. 70(1991) 6958.