Phase slips and Superconductor-Insulator Transition in Nitride nanowire

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Introduction

One-dimensional (1D) superconducting nanowires (SNWs) are being considered to develop superconducting devices[1]. In order to realize novel devices using nanowires, it is necessary to clarify the superconducting transport characteristics that depend on the disorder, wire length *L*, width *w*, and many other parameters. In such low-dimensional superconductors, quantum effects slightly influence the superconducting characteristics. For instance, on when the film thickness d of the two-dimensional (2D) specimens decreases, the superconducting transition temperature T_C is gradually depressed and then the superconductivity disappears for films thinner than the critical thickness dc, where the 2D superconductor-Insulator transitions (SIT) occurs[2,3].

The SIT originates from the fluctuations of an amplitude and/or a phase of superconducting order parameter. Especially, SNWs can be strongly affected by thermally activated phase slip (TAPS)[4] and/or quantum phase slips(QPS)[5] which play an important role in the properties of SNWs. The effect of TAPS to resistance R(Ω) sharply decays as a result of the temperature drop below Tc. On the other hand, the QPS represents the residual resistance required to suppress the superconductivity at T = 0 K. Numerous studies have been conducted on the various materials that can be used for SNWs. However, there still are fundamental problems in determining the effect of TAPS and QPS on the temperature dependency of resistance R(T) because SNW specimens with the same material can present different R(T) characteristics. Further, some investigations show no evidence of QPS behavior on nitride nanowire at very low temperatures.

Methods

NbN and NbTiN films were firstly prepared by deposition at ambient temperatures on (100)-MgO substrates by DC reactive magnetron sputtering. The background pressure of the chamber was maintained below 2.0×10^{-5} Pa. The relative amounts of argon and nitrogen were controlled by mass flow controller during sputtering. The total pressure was maintained at 2 mtorr and the substrate was not heated intentionally during deposition. Details of preparation procedures of NbTiN thin films are previously reported[6]. TiN films were also deposited on (100) MgO single crystal substrates by reactive dc-magnetron sputtering of a Ti target under a 1 mTorr of mixture of argon and nitrogen. The base pressure of the deposition chamber was maintained below 1×10^{-7} Pa because Ti has a high gettering effects. The substrates were first bombarded with argon ions for about 1 min. The dc power was provided by current regulated power supplies set at 1.7 A. We prepared two kinds of samples with different substrate temperatures: ambient and 1073 K. The temperature was monitored by W-Re thermocouples, mounted to the backside of the substrate holder.

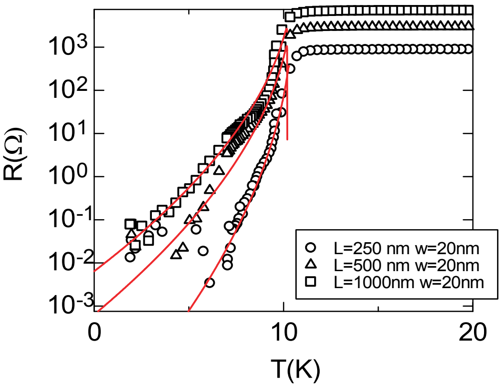

Fig. 1. *R*(T) for the NbTiN SNW with *d* = 5 nm, w = 20 nm and L = 250,500, 1000 nm. Solid lines are calculated using QPS theory.

The The superconducting transition temperature, the temperature dependence of resistivity, and the Hall coefficients of films were measured by a standard method. The nitride nano wires were fabricated from

2D films with by a conventional e-beam lithography method and a reactive ion etching method with CF_4 plasma. The ranges of L and w of nanowires are $250 \leqslant L \leqslant 1000$ nm and $10 \leqslant w \leqslant 30$ nm, respectively. To eliminate the influence of the contact resistance, measurements of transport properties were performed by four-probe method.

Results

Figure 1 shows the superconducting transport properties for the NbTiN SNW with $d = 5$ nm, $w = 20$ nm, $L = 250, 500, 1000$ nm. Superconducting SNWs that have $dR/dT > 0$ under low temperatures and low $R(\Omega)$ characteristics, experience the initial drop of $R(\Omega)$ almost at the same temperature owing to the superconducting transition. An increase in R^N causes T_c and the residual resistance to monotonically decrease and increase, respectively. Prior to the detailed discussions on the SIT of 1D specimen from a viewpoint of quantum phase transition, we will present some transport properties of the present SNWs from the characteristics of low dimensional superconductors. The solid line is calculated using QPS theory. The calculation using the QPS model agrees accurately with the resistive tail in the range of 5 magnitude orders.

Conclusion

The analysis based on the model for the SNW which is being dual element up to Josephson junction, suggests that the separation of the superconducting and insulator phases may be controlled by the ratio of QPS amplitude energy E_S and inductive energy of SNW E_{Li}, E_S/E_{Li}. For the present NbTiN series, we observed that SIT may occur at $0.2 < . E_S/E_{Li} < 0.5$ For the detail of analysis, we will present these results at a workshop.

References

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Kazumasa Makise received his Ph.D. in 2007 from Kyushu University. After completing a doctoral program and serving as researcher of National Institute of Material Science (NIMS), he joined National Institute of Information and Communications Technology (NICT) in 2009. He has been engaged in research on low dimensional superconducting thin film and nanowire properties and superconducting electronics. Ph D. (Science)