Bull. Inst. Chem. Res., Kyoto Univ., Vol. 65, No. 4, 1987

Superconducting Transition of Thin V Films Sandwiched in between Amorphous Si Layers

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Received June 27, 1987

We have measured the superconducting transition of thin V films sandwiched in between amorphous Si layers. The transition is sharp for all samples, indicating that homogeneous V films are successfully prepared. It is demonstrated that the Si layers do not give the crucial influence on the transition temperature. However, the reproducibility of the transition temperature becomes worse for the covering Si layer of less than 100Å.

KEY WORDS: Superconducting transition temperature/ Thin film/ Vanadium/ Amorphous silicon/

I. INTRODUCTION

The characteristic length of superconductivity is the longest among all kinds of the long range orders. This nature enables us to realize a two-dimensional (2–d) superconducting system, where the system size in one direction is smaller than the characteristic length. Thus the superconductivity in thin films has been widely investigated both theoretically and experimentally, and several interesting properties have been uncovered.

First, the superconducting fluctuation is largely enhanced in 2–d systems.[1] Second, the Kosterlitz-Thouless transition, which was predicted in the 2–d neutral superfluid, can occur in thin-film superconductors with a high sheet resistance.[2] Third, the disorder involved in the system, such as defects and grain boundaries, strongly suppresses the superconductivity in the 2–d system, resulting from the electron localization and/or interaction effects.[3–5]

We believe that the above-mentioned dimensional character of superconductivity should be explored more systematically. In this respect, multilayers composed of superconducting and insulating layers are useful systems, where the dimensionality can be controlled between 2–d and 3–d by varying the insulating layer thickness. The goal of our research is to reveal the dimensional characteristics of superconductivity by means of V–Si multilayered systems. Prior to this study, however, we have to make clear the following aspects. (a) Under our preparation condition (vacuum evaporation at room temperature), the structure of the deposited Si was found to be amorphous. Is it possible to form a thin homogeneous V film on such an amorphous layer? (b) In order to study the dimensional characteristics of T_c of the V–Si

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system, we expect that the Si layers play a role only as the tunneling barrier between the V layers. Therefore, it is needed to know whether the Si layers in itselves influence T_c of the system. (c) What about the reproducibility of T_c of thin films?

To address these problems, we prepared a series of ultrathin V films sandwiched in between Si layers. Measurements were made on T_c, on the resistivity ρ (or the sheet resistance $R_{\square}$), and on the residual resistance ratio RRR. In this paper, we report these results and give some discussion in the context of the above-mentioned problems.

II. EXPERIMENTAL

The V–Si systems were prepared by ultrahigh-vacuum electron-beam evaporation. The chamber was evacuated down to 10^{-10} Torr range by a cryopump. A mylar sheet was used as the substrate, which was kept at room temperature. As the basic material, a single film of 100-Å Si layer was deposited on the mylar. Then, a thin V layer was deposited. Finally a Si layer covers the V film.

We first measured the superconducting transition of V films with various thickness (25–50 Å), where the covering Si layer is fixed at 100 Å. Next, by fixing the V-layer thickness at 50 Å, we changed the thickness of covering Si layers d_{si}, where d_{si} ranges from 30 Å to 350 Å.

The samples were cut into a strip (1×10 mm^2). The resistive measurements were made with the ac and dc four-probe methods, where both measurements fell into the same results. Silver paint was used for the electric contact.

III. RESULTS AND DISCUSSION

All of the samples exhibit the superconducting transition. In Fig. 1, we show typical transition curves for various thicknesses of V layers. The transition width is 50 mK or less for most of the samples. Such a sharp transition supports a successful formation of a continous, thin film of V, and therefore this system can serve as a model of 2–d superconductor. A large superconducting fluctuation expected in 2–d systems was observed above T_c. The analysis is the subject of a further publication.

Figure 2 shows T_c as a function of d_{si}. For $d_{\mathrm{si}} > 100$ Å, T_c is insensitive to d_{si} although there is a small deviation. T_c's are within 3.2 ± 0.1 K. For the samples with d_{si} less than 100 Å, T_c's rather disperse, irrespectively of d_{si}.From the figure, it is unlikely that T_c depends crucially on d_{si}. It seems that the Si layers are irresponsible for T_c of the system, that is our expectation. One problem is the dispersion of T_c results, especially in the small d_{si} region. Oxidization may occur even in the V layers and worsen the reproducibility of T_c for samples with thin Si layers.

To get more insight into this problem, we plotted T_c's as a function of resistivity (or sheet resistance) (see Fig. 3) and of residual resistance ratio (see Fig. 4). As seen in the figures, there exist distributions in ρ and RRR in spite of the same nominal-thickness of the V films. Besides, T_c varies systematically with ρ and RRR; T_c increases with the decrease of ρ and with the increase of RRR. Such a correlation has been observed in several bulk materials and is understood to be due to the density-of-states broadening induced by disorder.[6,7] Our results therefore imply that there is a variation in the normal state properties, such as the mean free path, of the prepared V films, and that this distribution brings about the variation of T_c.

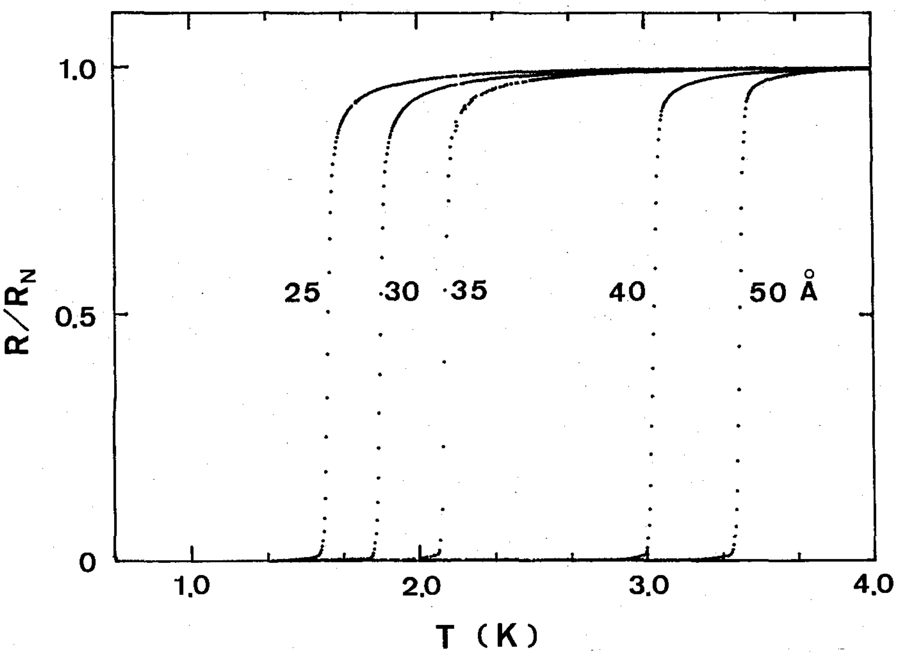

Fig. 1. Resistive-transition curves of thin V films sandwiched in between 100–Å Si layers. Note that, for thinner V films, T_c becomes lower and the super-conducting fluctuation above T_c is enhanced.

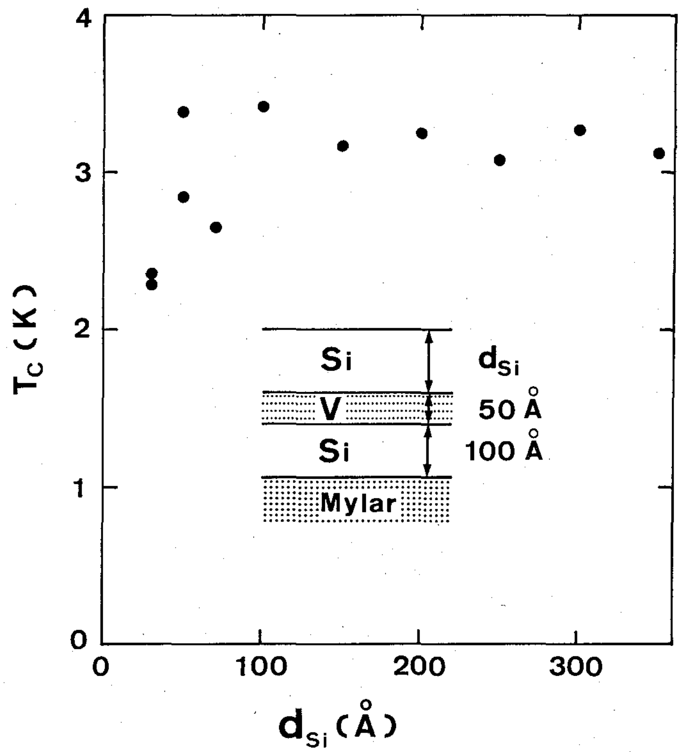

Fig. 2. T_c versus the thickness of covering Si layer d_{Si}. Inset shows the sample structure.

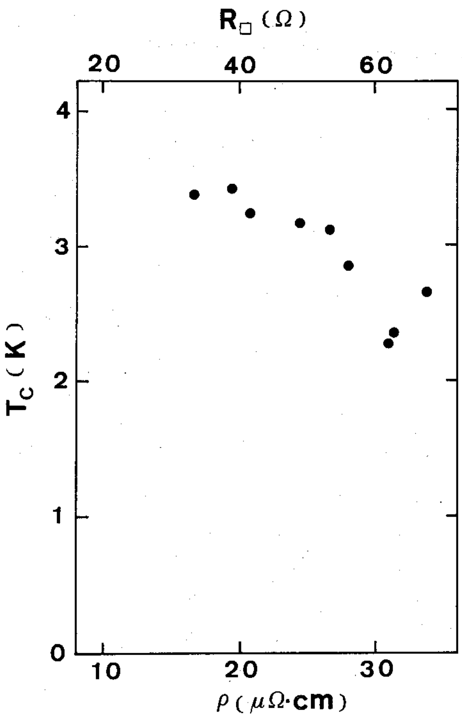

Fig. 3. T_c versus the resistivity ρ or the sheet resistance $R_\square$.

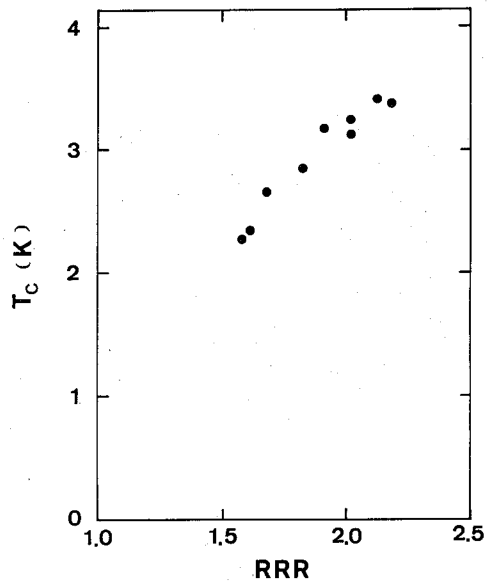

Fig. 4. T_c versus the residual resistance ratio RRR.

There may be some room for improvement of the reproducibility of the film quality.

In any event, reliable results of T_c have been achieved for the samples with thicker d_{si}. Based on these experimental evidences, the study of V–Si multilayered systems are in progress.

ACKNOWLEDGMENTS

This work was supported in part by a grant-in-aid for scientific research from the Ministry of Education, Science, and Culture of Japan.

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