Bull. Mater. Sci., Vol. 14, No. 4, August 1991, pp. 895–897. © Printed in India.

Double-dimensional crossover in layered superconductor

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Abstract. The critical magnetic fields H_{c2} of superconducting layered structures V/Cu were investigated. The double-dimensional crossover 3D-2D-3D was observed on the temperature ($H'_{c2}(\theta)$) dependences of critical magnetic fields. The field crossover 3D-2D is caused by strong temperature dependence of superconducting coherence length ξ_s near T_c. The second crossover 2D-3D is provided by temperature dependence of normal metal coherence length ξ_N and reflects the 3D isotropization of layered structure V/Cu at low temperature.

1. Introduction

Dimensional crossover from three-dimensional (3D) to two-dimensional (2D) behaviour in S/N layered structures has been the subject of great interest during the last few years (Beasley 1980). The superconductivity in such structures is localized in S-layers (2D) at low temperatures, but the sharp increase of superconducting coherence length at $T \to T_c$ leads to appearance of large superconducting domain, which overlaps many layers (3D). Dimensional crossover should be observable in the temperature dependence of parallel critical magnetic field $H''_{c2}(T)$ and angular dependences $H_{c2}(\theta)$ at different temperatures. $H_{c2}(T)$ changes from square-root law ($H_{c2} \sim (T_c - T)^{1/2}$) to linear law ($H_{c2} \sim (T_c - T)$) as $T \to T_c$, while angular dependence $H_{c2}(\theta)$ changes from "cusp"-like (2D) to "soft" like (3D) behaviour, when temperature rises. However the low-temperature properties ($T \ll T_c$) of such structures have not been investigated properly.

2. Experiment

The temperature and angular dependences of upper critical field were investigated for magnetron-sputtered multilayers V/Cu with different thicknesses of vanadium and copper layers: $d_V = 25$ nm, $d_{Cu} = 10$–20 nm, and the number of layers $N_V = 10$, $N_{Cu} = 11$. The sample rotation inside the superconducting magnet was operated with accuracy of 0.1°, and the temperature was measured by a calibrated Ge-thermometer.

3. Results and discussion

Figure 1 shows the angular dependences $H_{c2}(\theta)$ for V/Cu (25 nm/10 nm) at different temperatures, where $\theta = 0°$ corresponds to parallel field. The transition of behaviour from "soft"-like (figure 1A) to "cusp"-like (figure 1B) near the $\theta = 0°$ orientation corresponds to 3D → 2D-dimensional transition mentioned above. At lower temperatures the "cusp"-like form of the dependence is maintained (figure 1C).

Such dependences, as superconducting resistive transitions in parallel magnetic field $R(H)$ at different temperatures, and $H''_{c2}(T)$ seem to be more informative. Near T_c the transitions $R(H)$ are narrow enough. While temperature lowers the broadening of $R(H)$ is observed which is conditioned by 3D→2D dimensional crossover. However for much lower temperatures ($T \sim 0{\cdot}4\,T_c$) the transitions $R(H)$ narrow again. Such behaviour was found for different thicknesses of copper layers ($d_{Cu} = 10$ nm, 15 nm, 20 nm), the transition narrowing beginning at lower temperatures with d_{Cu} rising. Dependences $R(H)$ for perpendicular field orientation did not show any anomalies. Figure 2 shows temperature dependences of H''_{c2} and $H^{\perp}_{c2}$ for sample with $d_{Cu} = 15$ nm. The critical field is defined as $R(H)$ resistance mid-point at fixed temperature. $H_{c2}(T)$ is linear in the whole temperature range, while $H''_{c2}(T)$ is non-monotonous. Near T_c parallel field $H''_{c2} \sim (T_c - T)$ and turns into $H''_{c2} \sim (T_c - T)^{1/2}$ as temperature lowers (3D→2D dimensional transition). At much lower temperatures ($T \sim 0{\cdot}4\,T_c$) this

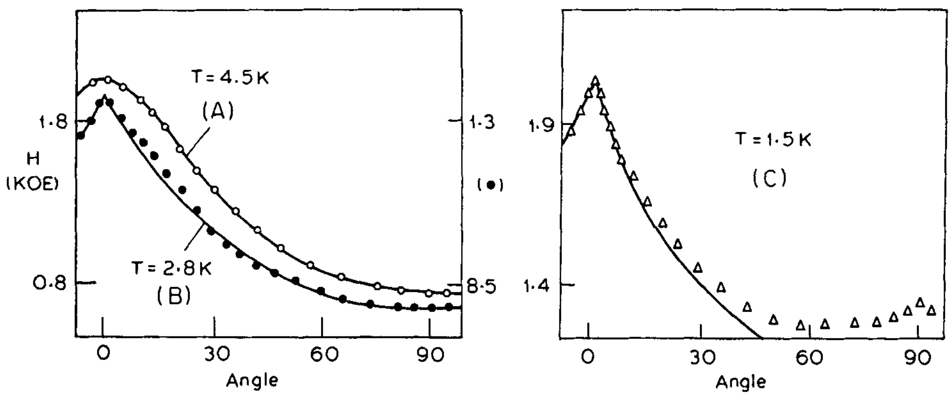

Figure 1. Angular dependences $H_{c2}(\theta)$ for V/Cu with $d_V = 25$ nm, $d_{Cu} = 10$ nm.

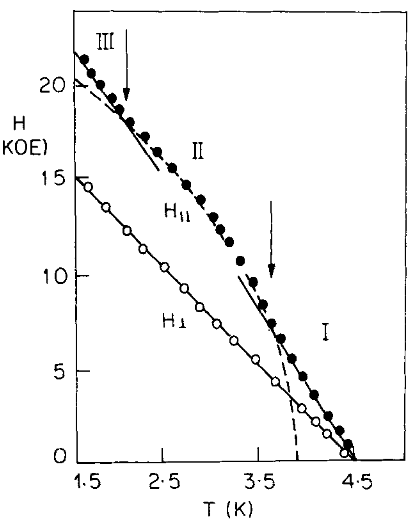

Figure 2. Temperature dependences $H''_{c2}(T)$ and $H^{\perp}_{c2}(T)$ for V/Cu with $d_V = 25$ nm, $d_{Cu} = 15$ nm.

dependence becomes linear again, linearization temperatures coinciding with $R(H)$ narrowing temperature and shifting identically with d_{Cu} variation.

The anomalous behaviour of $H''_{c2}(T)$ and $R(H, T)$ may be explained by the assumption of double 3D → 2D dimensional crossover in our systems. The first of them is caused by superconducting coherence length divergence at $T \rightarrow T_c$. We believe the second transition appears as a result of normal metal coherence length divergence at $T \rightarrow 0$ ($\xi_N \sim T^{-1/2}$). This leads to isotropization of structure and its transition in 3D state, while angular dependence $H_{c2}(\theta)$ for low temperatures (figure 1C) corresponds to surface superconductivity in such a state. Our explanation is also in agreement with 2D → 3D transition temperature decreasing when d_{Cu} increased.

Acknowledgements

We would like to thank Mr V Oboznov for help in sample preparation and Prof. A Golub for useful discussion.

Reference

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