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Re-entrant superconductivity in the V/Fe superconductor/ferromagnet layered system

L.R. Tagirov^{a,b,*}, I.A. Garifullin^c, N.N. Garif'yanov^c, S.Ya. Khlebnikov^c,
D.A. Tikhonov^c, K. Westerholt^d, H. Zabel^d

^aTheoretical Physics Department, Kazan State University, Kremlevskaya Str. 18 Kazan 420008, Russia

^bGebze Institute of Technology, Gebze/Kocaeli 41400, Turkey

^cKazan Physicotechnical Institute of RAS, Kazan 420029, Russia

^dInstitut für Experimentalphysik/Festkörperphysik, Ruhr-Universität Bochum Bochum D-44780, Germany

Abstract

We present an experimental investigation of the proximity effect in Fe/V/Fe trilayers prepared by RF-sputtering. At a V-thickness of 290 Å we observe a re-entrant behavior of the superconductivity when increasing the thickness of the Fe-layer. © 2002 Elsevier Science B.V. All rights reserved.

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The most spectacular experimental result in recent years, concerning the proximity effect in superconductor/ferromagnet (S/F) layered systems, was the observation of oscillations of the superconducting (SC) transition temperature T_c as a function of the ferromagnetic (FM) metal layer thickness d_F [1,2]. An increase of T_c with increasing d_F contradicts the physical intuition, since it is expected that the strong exchange field in the ferromagnet should destroy superconductivity. Wong et al. [3] were the first to observe a non-monotonic T_c -dependence on the Fe-layer thickness with fixed V-thickness in V/Fe multilayers. Peculiar $T_c(d_{Fe})$ -dependences have also been observed in Nb/Gd [4] and Nb/Fe [5]. In V/Fe [6], contrary to the previous results [3], T_c oscillations as a function of the iron thickness were not observed.

Thin films were prepared by RF-sputtering on Al_2O_3 (11 $\bar{2}$ 0) substrates. Series 1 and 2 were prepared at a substrate temperature of 300°C, whereas for series 3 and 4 we used a slightly lower temperature of 260°C. Pure Ar

(99.999%) at pressures of 5×10^{-3} mbar was used as sputter gas. Pure V (99.99%) and Fe (99.99%) targets were used for the deposition. The deposition rates of 0.3 Å/s for Fe and of 0.5 Å/s for V were found to be optimal for the structural properties of the films.

In order to study the dependence of T_c on the thickness d_{Fe} (or d_V) carefully in our experimental setup we prepared series of 10 or 16 Fe/V/Fe trilayers with different d_{Fe} (d_V) at constant d_V (d_{Fe}) within one run. During the deposition of the V-layer in the set with constant d_V the substrate holder was rotated 4 times by 90° to ensure an identical V-thickness within each set. In a final step, all samples were covered by a protective Al_2O_3 cap layer of about 50 Å thickness.

Small angle X-ray reflectivity measurements of the samples series 1, 2 gave an average interface roughness of 10 Å (rms). For series 3, 4 the interface was definitely sharper, as revealed by a roughness of 6 Å. Using the Parratt formalism [7], we checked the d_V values within one series when changing the Fe-layer thickness; the scatter of d_V did not exceed 1%.

The residual resistivity ratio RRR of our samples varied between 4 and 5. Taking the BCS coherence length of V $\xi_0 = 440$ Å and the mean free path $l = 50$ Å we estimate a coherence length $\xi_S = 80$ Å.

*Corresponding author: Theoretical Physics Department, Kazan State University, Kremlevskaya str. 18, Kazan 420008, Russia.

E-mail address: lenar.tagirov@ksu.ru (L.R. Tagirov).