MAGNETIC FIELD-INDUCED NON-SUPERCONDUCTING STATES IN TANTALUM FILMS

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Introduction

In a naïve picture that interaction effect and superconducting pairing mechanism are removed by destroying superconductivity with increasing disorder (usually tuned by film thickness) or magnetic field (B), the disorder- or B-induced non-superconducting state would correspond to a non-interacting 2D Fermi liquid which is expected to be an insulator according to the traditional scaling theory of localization [1]. Recent experimental results, however, have shown that the electronic transport properties in B-induced non-superconducting states cannot be described within the traditional paradigms. An unexpected metallic phase in the limit of zero temperature has been reported in homogeneously disordered MoGe films [2], and a strongly non-monotonic magnetoresistance in the high B-induced insulating phase is observed in InO films [3]. Although many recently proposed theories point out the possibility of fermionic quasiparticles or bosonic interactions in the B-induced nonsuperconducting phase, a consensus on the origin and mechanisms behind the phenomena are yet to be reached. In order to provide a new insight to the problem, we investigate transport properties of homogeneously disordered superconducting tantalum films in the high B-induced non-superconducting regime.

Experimental

The samples are dc sputter deposited, homogeneously disordered tantalum films, with thickness in the range from ~ 3 nm to ~ 6 nm, on Si substrates. The films are patterned into a bridge for the standard four leads transport measurements with a shadow mask. A portion of the experiments studying transport characteristics of a 5 nm thick tantalum film are carried out at NHMFL, in a top loading dilution refrigerator with a 18/20 T magnet. The magnetic field is applied in the direction perpendicular to the sample plane.

Results and Discussion

With increasing B from zero, the tantalum films are found to exhibit a “superconductor-metal-insulator” transition in the limit of zero temperature. The three phases are found to exhibit qualitatively different voltage-current (VI) characteristics. In the superconducting phase, the VI’s are hysteretic. In the metallic phase, the VI’s are reversible and the differential resistance shows a valley structure centered at zero current. The differential resistance in the insulating phase exhibits a peak structure. The width of the metallic regime, both in magnetic fields and temperature, appears to widen with decreasing disorder in the film. Magnetoresistances up to 18 T at ~ 20 mK are measured to be always positive. Absence of any peak structure in the high B insulating phase is in contrast to some recent theories expecting a peak in magnetoresistance due to breaking of localized Cooper pairs in the insulating regime [4]. However, the strength of the insulating phase measured by the height of the differential peak is found to have a nonmonotonic dependence on the magnetic fields.

Conclusions

Homogeneously disordered superconducting tantalum films are found to exhibit a B-induced “superconductor-metal-insulator” transition in the limit of zero temperature. Transport characteristics in the metallic and insulating phase have been studied up to 18 T.

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References

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