SPIN IMBALANCE ENHANCED MAGNETORESISTANCE IN CO-AL-CO DOUBLE-TUNNEL JUNCTIONS

J. H. Shyu^{1,2}, F. Y. Tang², Y. D. Yao², and J. W. Chen¹

¹Department of Physics, National Taiwan University, 106, Taipei, Taiwan, R.O.C.

²Institute of Physics, Academia Sinica, Nankang, 115, Taipei, Taiwan, R.O.C.

Spintronics is a new branch of electronics in which electron spin, in addition to charge, is manipulated to yield a desired outcome. One method, which is called spin-valve effect [1], utilizes two ferromagnetic electrodes composed of parallel or antiparallel magnetization alignments to control transports of spin-polarized current. In nanoscale devices, such as a single-electron transistors (SETs) consisted of double-tunnel junctions, majority spin-polarized current is suppressed by the spin-valve effect and the spin electron is accumulated in the central island. If the central island is made of superconductor, the resultant nonequilibrium spin density strongly suppresses the superconductivity. The magnetoresistance is strongly affected by the suppressed superconductivity. In this study, we investigate the enhancement of magnetoresistance by spin imbalance in Co-Al-Co double tunnel junctions.

The samples were fabricated by using electron-beam lithography and three-angle shadow evaporation techniques. A native Al_2O_3 covers up the superconducting island and two ferromagnetic electrodes are piled up on the both ends of it. The cross section, which is smaller than the spin relaxation length, of ferromagnetic electrodes forms a single domain to inject or detect the spin-polarized current.

The theory by Takahashi, Imamura, and Maekawa [1] predicted the spin imbalance in the tunneling currents gives rise to the nonequilibrium spin density in the superconducting island in a double-tunneling junction system. Decreases of Δ_A with increasing source-drain voltage V , with Δ_A being the superconducting gap when the two ferromagnetic leads are in antiferromagnetic alignment. In this alignment, excess spins accumulate in the superconducting island, and the chemical potential of the majority and minority spins are shifted oppositely by $\delta\mu$ from the equilibrium state. This chemical potential difference plays the role of pair breaking energy, leading to a suppression of superconducting gap from Δ_0 to Δ_A . And Δ_A strongly affects the transports.

We measured our samples by using a dilution refrigerator at 200 mK and applied parallel magnetic fields along the current direction up to 2.5 T. It's below the critical temperature of Al and the central island is in superconducting state. IV characteristics are nonlinear because of a superconducting gap. The superconductivity of the Al island is destroyed by applying magnetic fields and IV characteristics becomes linear as the Al island is in normal state. So we can estimate the voltage difference between the superconducting state and the normal state is as a function of superconductivity as published by C. D. Chen, et al [3]. In small magnetic field region, the superconductivity is almost constant. Near zero field, the drop voltage difference is not caused by magnetic field, but is induced the spin imbalance. So we understand here not only applied magnetic field but also spin imbalance suppress the superconductivity.

Now we discuss magnetoresistance as a function of bias voltage. Tunneling conductance is determined by IV characteristics: $G = dI / dV$, and tunneling magnetoresistance (TMR) is calculated by this formula: $\text{TMR} = (G_F/G_A) - 1$. G_F indicates tunneling conductance in the ferromagnetic alignment of magnetization, G_A indicates tunnel conductance in the antiferromagnetic alignment of magnetization. We found out the magnto-conductance near a critical value of bias voltage is enhanced dramatically.

Fig. 1. (Up) Differential conductance of the ferromagnetic alignment and the antiferromagnetic alignment of magnetization; (down) and magneto-conductance as a function of bias voltage.

We created the spin imbalance in the central island of a double-tunnel junction system. If the central island is superconducting, the superconductivity is suppressed by the spin imbalance thereby influences the magnetotransport. Near the superconducting gap magnetoresistance is enhanced as expected.

[1] R. Meservey and P. M. Tedrow, Physics Reports 238, 173 (1994).

[2] S. Takahashi, H. Imamura, S. Maekawa, Phys. Rev. Lett. 82, 3911 (1999).

[3] C. D. Chen, Watson Kuo, D. S. Chung, J. H. Shyu, C. S. Wu, Phys. Rev. Lett 88, 047004 (2002)