AF-2-3 (Invited)

Spin accumulation and tunnel magnetoresistance in nonmagnetic nanoparticles

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Nonequilibrium spin accumulation by injecting spin polarized current gives rise to a variety of phenomena useful for spin electronics. Recently, we have found a remarkable phenomenon caused by spin dependent single electron tunneling with spin accumulation in a magnetic nanoparticle: Tunnel magnetoresistance (TMR) oscillates with a periodic sign change as a function of bias-voltage in Co/Al-O/Co-nanoparticles/Al-O/Al microfabricated pillar-structures [1]. Furthermore, the theoretical analysis reveals that the spin relaxation time in Co nanoparticles is much enhanced, suggesting that nanoparticles are suitable to efficiently realize spin accumulation.

In this study, we have successfully observed TMR associated with spin accumulation in nonmagnetic nanoparticles between ferromagnetic electrodes, which is theoretically predicted [2] and is beyond the well-known Julliere's model. The tunnel resistance (R) is found to decrease steeply with increasing bias-voltage at 4.2 K for a FeCo/Al-O/Au-nanoparticles/Al-O/FeCo junction. This indicates that with increasing bias-voltage the Coulomb blockade in Au nanoparticles disappears and then the current through Au nanoparticles increases. In the low bias-voltage region below ~100 mV, TMR simply decreases with increasing bias-voltage in proportion to the resistance. The proportional relationship between the resistance and TMR is explained by the fact that the direct tunnel current with TMR effect between two FeCo electrodes is shunted by the tunnel current without TMR effect through Au nanoparticles. With further increasing bias-voltage over 150 mV, on the other hand, TMR clearly increases and deviates from the proportional relationship. The increase in current density leads to remarkable spin accumulation in Au nanoparticles, and the observed enhancement of TMR is interpreted as the TMR effect induced by spin accumulation in Au nanoparticles.

1. K. Yakushiji et al., Nat. Mater. **4**, 57 (2005).
2. A. Brataas et al., Phys. Rev. B **59**, 93 (1999).