Spin dependent single electron tunneling in self-assembled magnetic nanoparticles

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Tunnel magnetoresistance (TMR) has attracted much attention in recent years because of potential applications for magnetic heads and magnetic random access memories (MRAMs). A lot of studies have been devoted to magnetic tunnel junctions (MTJs) with layered structure consisting of ferromagnetic metal/insulator/ferromagnetic metal. If the size of MTJ is so small that the electrical charging energy overcomes thermal fluctuation, single electron tunneling (SET) phenomena represented by Coulomb blockade and Coulomb staircase are expected to appear. In previous papers[1,2], we reported the enhancement and oscillation of TMR due to *spin dependent* SET, using device structures consisting of a microfabricated Co-Al-O granular film between two nonmagnetic or ferromagnetic electrodes. However, there were the following important problems: The first one was the microfabrication process in which focused ion beam technique was used, and therefore ion irradiation damage was introduced in device structures, leading to the difficulty in obtaining reproducible results and systematic investigation. The second one was the size distribution of magnetic particles in granular films prepared by sputtering, leading to the difficulty in high temperature measurement of SET because the current paths were determined by large particles with small charging energy. In this paper, we review the recent developments of our study on spin dependent SET including the attempts to solve these problems.

In order to prepare a device structure free of ion irradiation damage, electron beam lighography technique has been used for microfabrication. A 0.5x0.5 μm^2 pillar structure consisting of Al electrode/Al-O, 2 nm/Co-Al-O, 15 nm/Co electrode was prepared on a thermally oxidized Si substrate, and TMR was measured for current-perpendicular-to-plane (CPP) geometry as a function of bias voltage. A clear reproducible result has been obtained: TMR oscillates associated with Coulomb staircase, and inverse TMR appears periodically around the steps of the Coulomb staircase. The result has been compared precisely to the orthodox theory calculation, and consequently, it has been found that spin accumulation in magnetic particles plays a significant role for the TMR behavior.

In order to improve the size distribution of magnetic particles, we are trying to fabricate two-dimensional array of magnetic particles self-assembled on a thin insulating layer (tunnel barrier) by molecular beam epitaxy. Isolated Fe or Co particles with a diameter in the range 1-4 nm were grown epitaxially on MgO, 2 nm/Co electrode, using a MgO(001) substrate. Clear TMR oscillation has also been observed in a CPP geometry sample with the Fe particles grown on MgO, although the measurement temperature is still low (4.2 K).

References

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