Effect of Oxygen Supplied to Ferromagnetic Layers of Magnetic Tunnel Junction

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Recently, there are reports the observation of the Kondo effect in MgO based MTJs[1-2]. These MTJs have the zero-bias anomaly (ZBA) or the logarithmic temperature-dependence peak. In this study, this behavior can explain the reduced TMR ratio of MgO-based MTJs compared with the theoretical expectation at low temperature.

We were studied that tunneling magnetoresistance was found to be suppressed with decreasing temperature for mangetic tunnel junctions (MTJs) oxidized under high plasma power[3]. We assume that ferromagnetic layer under AlOx tunnel barrier change to the $Co_{84}Fe_{16}O\delta$ layer during the deposition process of the tunneling barrier. In order to prove the assumption, a series of MTJs were fabricated to investigate the effects of oxygen in ferromagnetic layers on TMR. The samples were deposited by dc magnetron sputtering and the layer structure is SiO_2/Ta(5)/NiFe(6)/IrMn(8)/$Co_{84}Fe_{16}$(3)/$Co_{84}Fe_{16}O\delta$(2)/AlOx/$Co_{84}Fe_{16}$(2)/NiFe(6)/Ta(10) (thickness in nm). The Al2O3 barrier was formed by oxidizing 1.6nm Al layer with oxygen plasma. The samples were deposited in oxygen contaminated chamber and it is expected a small amount of oxygen is included already in the CoFe layers. In order to add more oxygen, we grew the $Co_{84}Fe_{16}O\delta$ layer by mixing oxygen (1% and 2%) intentionally to Ar during the deposition process. Three types of MTJs were investigated; oxygen contaminated sample (no mixture of oxygen inAr), 1% mixture of oxygen in Ar, and 2% mixture of oxygen in Ar. These samples were not heat treated. The MTJs were patterned by photolithography with the junction size $50\times50\mu m^2$. For comparison, a conventional control junction was fabricated in the same condition except that it was grown in oxygen free chamber with pure Ar and treated by a continuous annealing method.

In order to investigate the origin of TMR reduction at low temperature, we examined the temperature dependence of the junction resistance. The resistance of MTJs with different O2 concentration in CoFe layer is plotted as a function of temperature in Fig. 1. Here R_P and R_{AP} are the junction resistance when the magnetizations of both electrodes are parallel (P) and antiparallel (AP), respectively. At 300 K, R_P for all of our MTJs is almost the same (less than 10 $k\Omega$). As temperature decreases, R_P increases dramatically and reaches several hundred $k\Omega$ around zero temperature. The more the oxygen is included in the $Co_{84}Fe_{16}O\delta$layer, the faster the resistance increases with lowering temperature. For the control junction (see the Fig.1), the temperature dependence of R_P (the open square) displays a typical behavior: it increases slightly as temperature decreases and shows about 30% increase of resistance around 2 K. For ideal tunnel barriers, the junction resistance is expected to decrease with increasing temperature due to thermal excitations of tunneling electrons. In the inset, the resistance difference($\triangle R = R_{AP} - R_P$) between antiparallel (AP) and parallel (P) magnetizations is plotted as a function of temperature. In contrast to the rapid increase of junction resistance, $\triangle R$ slightly increases with lowering temperatures. The temperature dependence of $\triangle R$ for the MTJs with $Co_{84}Fe_{16}O\delta$ layers is basically same as that for the control junction. For usual MTJs, the resistance difference $\triangle R$ increases slowly with decreasing temperature, which is related to the temperature dependence of magnetization of the FM layer. In the MTJs with $Co_{84}Fe_{16}O\delta$ layers, the increase of $\triangle R$ at low temperature means that the spin polarization (SP) of tunneling current is not destroyed in spite of dramatic increase of R_P. In other words, even though a strong scattering mechanism is introduced with lowering temperature, SP is well maintained.

In summary, we fabricated MTJs with a slight amount of oxygen included in the magnetic layers. As temperature decreases, the TMR decreases and the junction resistance increases dramatically. The temperature dependence of the junction resistance was analyzed with Kondo model and scaling behavior was observed. The results are similar to those for previous MTJs with over-oxidized AlOx tunnel barriers[3] while the Kondo parameters are different.

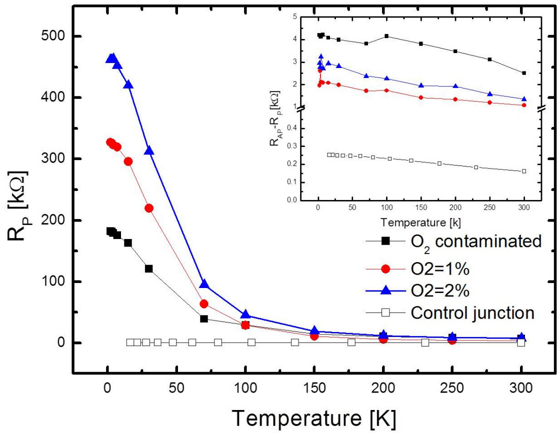

FIG. 1: Temperature dependence of junction resistance R_P (parallel alignment) with oxygen contaminated sample (no mixture of oxygen in Ar : solid square), 1% mixture of oxygen in Ar (solid circle), and 2% mixture of oxygen in Ar (solid triangle). The resistance difference R_{AP}—R_P is displayed in the inset.

Reference

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