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Anomalies of low-temperature properties in plasma-oxidized magnetic tunnel junctions

KIST K. I. Lee*, J. H. Lee and K.-H. Shin

Korea university K. Rhie

Inha university B. C. Lee

Sizable room temperature tunneling magnetoresistance (TMR) in magnetic tunnel junctions (MTJ), composed of two ferromagnetic electrodes separated by a thin insulating barrier, have ignite the intensive research both from scientific and technological points of view. A simple model proposed by Juliere has explained the observed TMR surprisingly well, where the TMR is expressed in terms of the spin polarization P of the ferromagnetic electrodes. After that report, theoretical and experimental studies of the temperature dependence of TMR ratio have been conducted to investigate the transport mechanism of spin dependent tunneling in MTJ. In this work, the effects of annealing, as well as the effects of oxidation time on the temperature dependence of TMR are investigated experimentally.

Bottom exchange biased magnetic tunnel junctions with the layer stacks of Ta(5 nm)/NiFe(6 nm)/FeMn(8 nm) /CoFe(4 nm)/Al_2O_3(1.6 nm)/CoFe(2 nm)/NiFe(10 nm)/Ta(5 nm) (from bottom to top) were fabricated *in-situ* on a thermally oxidized Si(100) wafer by a 6 target DC magnetron sputter system with a base pressure better than 5×10^{-8} Torr. Tunnel barrier (Al_2O_3) was formed by plasma oxidation of 1.6 nm thick Al in a separated load-lock chamber, by applying relatively high DC bias (-150W) to Al target in pure oxygen of 20 mTorr. A cross geometry junctions were fabricated by a photolithography and ion beam etching process. Four point probe method was used for characterization in the temperature range of 2~300 K and magnetic field up to 1 Tesla in Quantum Design PPMS (Physical property measurement system). A series of samples were heat treated by the rapid thermal annealing (RTA) method for 10 sec at the each annealing temperatures(T_A) of 250, 300, and 400℃. Another series of samples were fabricated with different oxidation time, and were annealed at 300℃.

Figure 1 shows the temperature dependence of TMR for samples annealed at different temperatures. The solid circles represent the TMR of as-grown junction, and the triangles, the open circles, and the squares are for junctions annealed at 250, 300, and 400℃, respectively. The TMR improved significantly by annealing at 250 and 300℃, but deteriorated severely when annealed at 400℃. The optimal temperature for the RTA method is about 300℃. At this annealing temperature, TMR value reaches to 48 % measured at room temperature and 59 % at 80 K. It is known that the TMR usually decreases monotonically with increasing temperature due to the decrease of the polarization. However, our samples show a novel temperature dependence of TMR. It is notable that the TMR increases as a function of temperature in a certain range. This is in contrast to the temperature dependence of TMR observed by others.[2] As grown, the TMR increases with increasing temperatures from 80 K to 160 K and decreases thereafter. For the junction annealed at 250℃, the highest TMR is observed at 140 K. When annealed at 300℃, the temperature dependence is similar to those observed by others, but still the TMR measured at 100 K is slightly larger than that measured at 80 K.

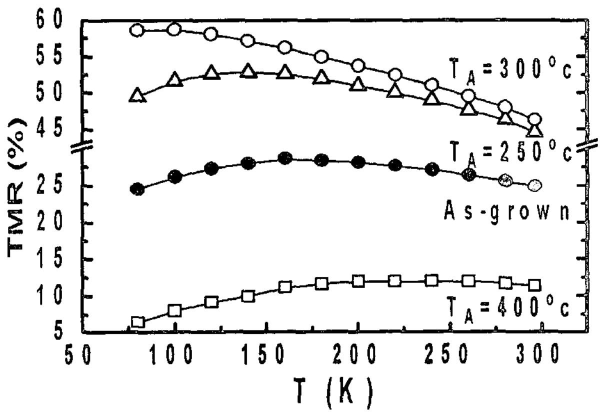

Fig. 1. Temperature dependence of TMR for junction annealed at different temperatures.

We investigated the effects of annealing and of oxidation time on the temperature dependence of TMR. Abnormal temperature dependences of TMR were observed, as well as these properties were varied with annealing and oxidation processes. These results are attributed to the oxidation of the bottom ferromagnetic layer. The increase of TMR as a function of temperature in a certain range is explained phenomenologically with spin-dependent transfer rates related with impurity states in the barrier.

REFERENCES

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