Controlled oxidization process for ultra-thin aluminium films in high-performance magnetic tunnel junctions by using the microwave-excited plasma with radial line slot antenna

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In order to realize magnetic tunnel junctions (MTJs) with large TMR ratio and low resistance-area product (RA), the formation process of very thin insulating layer should be precisely controlled. While the plasma oxidization of metal Al films generally provides large TMR ratio in MTJs, high-energy ion irradiation from plasma discharging space is liable to damage the structure of ultra-thin oxide layers, and high-reactivity of oxygen plasma makes it difficult to oxidize Al layer precisely down to the interface to the lower ferromagnetic electrode. The authors thus developed the microwave-excited-plasma oxidization technique with radial line slot antenna to reduce the space potential of plasma [1] and studied the influence of inert gases mixed in the oxidizing plasma on MTJ properties [2]; and succeeded to obtain 60% TMR ratio at room temperature in resultant Co-Fe/Al-O/Co-Fe MTJs. In the present study, Langmuir probe diagnosis and optical emission spectroscopy were performed for $Ar+O_2$, $Kr+O_2$, and $He+O_2$ plasma, in order to clarify the physical factors to affect the formation process of tunnel barrier. As results, we found that Kr reduces the electron temperature of plasma at the substrate position down to ~1 eV, which is effective to minimize the ion irradiation damages for Al-O barrier, and that the oxidizing species excited in plasma, such as radicals and ions, are drastically change with changing the kind of inert gases. Within the observed optical emissions from oxygen radicals in the respective plasma, only λ = 558 nm emission ($O(2p)^1S \rightarrow O(2p)^1D$) showed the corresponding variation in its integral intensity with the variation of resistance-area product of MTJs, when the oxygen concentration was changed. The intensity of 558 nm emission in $Kr+O_2$ plasma was 2~3 order in magnitude stronger than that in $Ar+O_2$ plasma. Taking into account a long life time (100 ~ 200 s) of $O(2p)^1D$ state, we concluded that $O(2p)^1D$ radical, effectively produced in $Kr+O_2$ plasma, plays a leading role on the oxidization process of Al films. Using the same plasma source for nitridation of metal Al films, 49% TMR ratio, the champion value for MTJs with nitride barrier, was obtained in Co-Fe/Al-N/Co-Fe MTJs. The oxidization/nitridation process of Al films by using the microwave-excited plasma is totally discussed.

References

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