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Fabrication and Evaluation of Magnetic Tunnel Junction with MgO Tunneling Barrier

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1. Introduction

Demand to a high density and high performance nonvolatile memory has rapidly grown as the market for mobile information devices has expanded. Flash memory is the nonvolatile memory most widely used in current mobile information devices. However, there is a big concern in Flash memory that the programming and erasing speed is very low. Meanwhile, MRAM (Magnetoresistive Random Access Memory) has recently attracted considerable attention due to its non-volatility and high programming speed [1]. There is a great deal of interest in using MTJs (magnetic tunnel junctions), which offer high TMR (Tunnel MagnetoResistance) ratio, for MRAM. However, the TMR ratio of a traditional MRAM with amorphous aluminum oxide as the tunnel insulator is limited to less than only several tens of percents. This is because electrons are easily scattered by the random atomic arrangement of the amorphous aluminum oxide layer when electrons pass through this layer. Meanwhile, the TMR ratio decreases as the applied voltage increases. Therefore, it is very effective to employ a more appropriate tunnel insulator for the high TMR ratio. Especially, the MgO film is a candidate of a new tunnel insulator with high TMR ratio because it easily becomes the single crystalline [2]. Meanwhile, it is necessary that MTJ film is formed on a word line in order to switch the magnetic field in the MTJ by the current flowing though the word line. Therefore, the surface roughness of word line significantly influences the crystallographic properties of tunnel insulator.

In this study, we have fabricated and evaluated the MTJ with the MgO tunnel insulator formed on the word line.

2. Device Fabrication

Figure 1 shows a cross section of a fabricated MTJ structure. The MTJ is formed on the word line for switching the magnetic field by the current though the word line. We fabricated this structure according the following process. First of all, the silicon oxide layer with the thickness of 1.2 μm was deposited. After that, the trench was formed in the region where the word line is to be formed and Ta/NiFe/Ta/Cu multi-layer was deposited by sputtering. The NiFe layer, Ta layer and Cu layer act as the yoke layer, the barrier layer and the seed layer for Cu electroplating, respectively. After the deposition of Ta/NiFe/Ta/Cu multi-layer, the word line is formed by filling Cu into the trench by electroplating which is followed by CMP (Chemical Mechanical Polishing). Figure 2 shows the SEM cross-sectional image of the structure after the word line was fabricated. After the formation of word line, the oxide with the thickness of 100nm was deposited as the interlayer dielectric between the word line and the bottom electrode layer. The bottom electrode layer and the MTJ film were deposited on this interlayer dielectric by sputtering after via formation. Figure 3 shows the multi-layered structure of MTJ where Ta is used as a bottom electrode layer, NiFe as a buffer layer, IrMn as a anti-ferromagnetic pinned layer, and CoFe/Ru/CoFeB stacked layer as the SAF (Synthetic Anti Ferromagnetic) pinned layer. After the formation of SAF pinned layer, MgO tunnel insulator with the thickness of 2 nm was deposited and followed by the deposition of CoFeB film which acts as the free layer. Then, the multi-layer of MTJ with the free layer, the tunnel insulator layer, the pinned layer and the bottom electrode layer was etched using Ar milling method After the formation of the interlayer dielectric between the MTJ film and the bit line, the via was formed in the interlayer dielectric and then Al was deposited as the bit line. Figure 4 shows the SEM cross-sectional image of the MTJ with the word line fabricated according to the process described above.

3. Results and Discussions

Figure 5 shows the magnetic switching characteristics of the MTJ fabricated on the Cu word line. As is obvious in the figure, the very high TMR ratio of 138.5% was obtained. The RA was 1.5 kΩ・μm^2 for the parallel polarization and 3.6 kΩ・μm^2 for the anti-parallel polarization.

The magnetic switching characteristics of two kinds of MTJs with word line and without word line are compared in Fig.6. It is clear in the figure that the magnetic switching characteristic of MTJ with the word line has more gentle slope than that without the word line in the magnetic field range over 500 Oe. Therefore, it can be considered that the area where the switching of magnetic field is very hard exists in the pinned layer of MTJ with the word line. Figure 7 shows AFM (Atomic force microscopy) images for the surface of Cu word line after the CMP process and the surface of Ta bottom electrode. The average roughness of Ta layer was 0.5nm. Meanwhile, the average roughness of Cu word line was 1.3nm that is two times higher than that of the Ta layer. The area where the switching of magnetic field is very hard might be formed due to this smaller surface roughness of the word line. On the other hand, the magnetic field to switch the polarity of magnetization in the free layer should be less than 250 Oe. It is obvious from Figs, 5 and 6 that the switching magnetic field for the free layer in the fabricated MTJ is less than 250 Oe.

4. Conclusions

We have fabricated and evaluated the MTJ with the MgO tunnel insulator formed on the Cu word line. The very high TMR ratio of 138.5% was obtained in this MTJ. The RA was 1.5 kΩ･μm^2 for the parallel polarization and 3.6 kΩ･μm^2 for the anti-parallel polarization. Thus, it was confirmed that the MgO tunnel insulator is indispensable in order to realize the MTJ with high TMR.

Acknowledgement

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References

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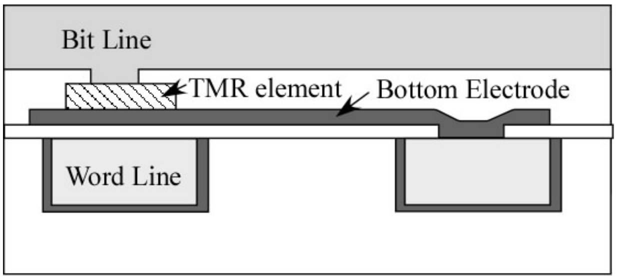

Fig.1. Cross sectional structure of fabricated MTJ.

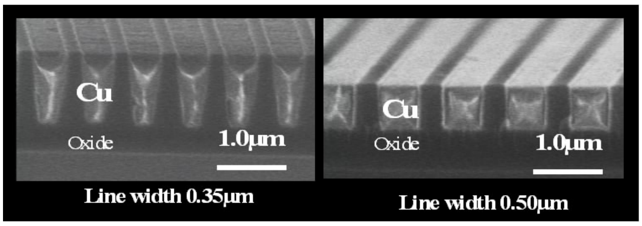

Fig. 2. SEM cross-sectional image of the word line after CMP process.

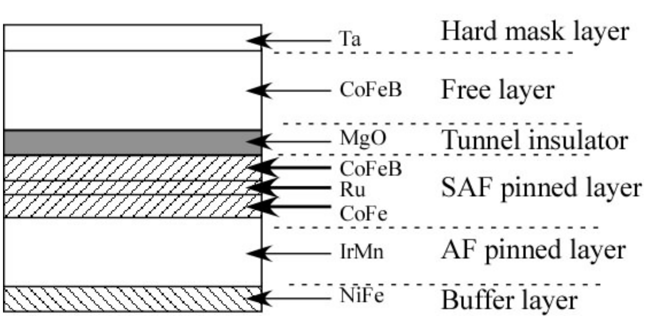

Fig.3. Cross-sectional structure of MTJ

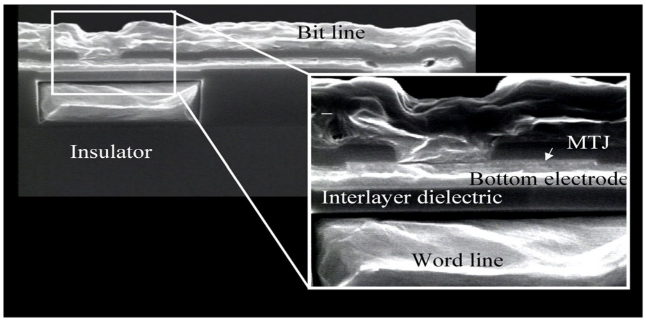

Fig.4. SEM cross-sectional image of MTJ with word line

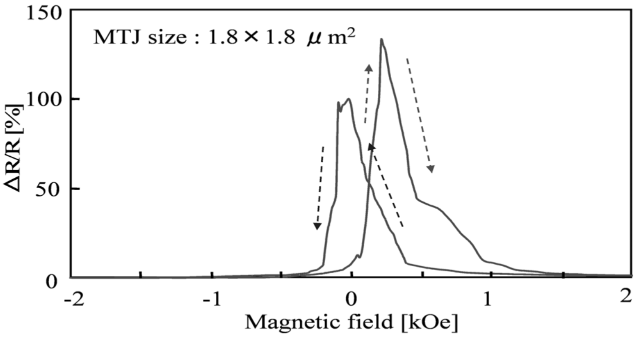

Fig.5. Magnetic switching characteristics of the MTJ fabricated on the Cu word line.

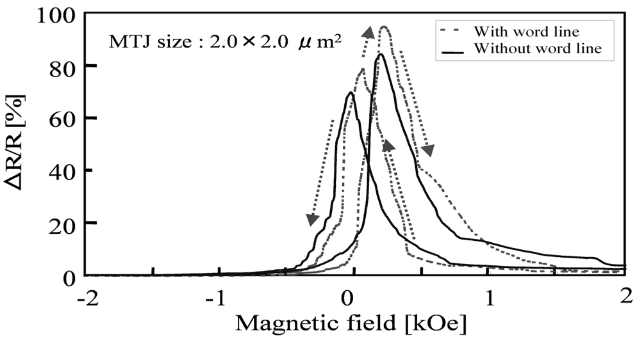

Fig.6. Comparison of magnetic switching characteristics between two kinds of MTJs with word line and without word line.

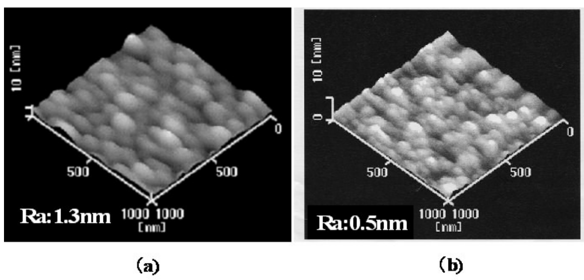

Fig.7. AFM images for (a) the surface of Cu word line after the CMP process and (b) the surface of Ta bottom electrode.