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# Fabrication of MgO-based Magnetic Tunnel Junctions for Magnetic Field Sensor

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## 1. Introduction

The discovery of the tunnel magnetoresistance (TMR) effect at room temperature (RT) in magnetic tunnel junctions (MTJs) spurred intensive investigation of MTJ applications for spin-electronics devices, such as magnetic random access memory and various magnetic field sensors (read heads of magnetic storage, micro-compasses). The low power consumption and small device size of MTJs makes them useful for magnetic field sensor applications. However, the detectable magnetic field has been limited, because MTJs with amorphous Al-oxide barriers exhibited relatively small TMR ratios below 100%. The discovery of large TMR ratios over 200% at RT in MgO barrier-based MTJs [1],[2] enables the design and fabrication of highly sensitive magnetic field sensors.

To use MTJs as magnetic field sensors, linear field response, and hysteresis-free switching of the free layer in the MTJs are required. For those requisitions, we fabricated MTJs with rectangular free layer.

In addition, to achieve high sensitivity, both a high TMR ratio and a low magnetic anisotropy field ($H_k$) of the free layer are necessary. For a low $H_k$, we invented CoFeB/ Ru/ $Ni_{80}Fe_{20}$/ free layer. This structure is called synthetic ferri film, CoFeB layer and $Ni_{80}Fe_{20}$ layer have ferri-magnetic coupling by middle thin Ru layer.

In this work, we fabricated MTJs with a CoFeB/Ru/NiFe synthetic ferrimagnetic free layer and investigated systematically the effect of the shape of free layer.

## 2. Experiment

The MTJs were deposited onto thermally oxidized Si(001) wafers using an ultrahigh vacuum ($P_{base}$ < 2 x $10^{-6}$ Pa) magnetron sputtering system. The stacking structure of the films was as follows, Sub.(Si/$SiO_2$)/ Ta(5)/ Ru(10)/ $Ir_{22}Mn_{78}$(10)/ $Co_{75}Fe_{25}$(2)/ Ru(0.9)/ $Co_{40}Fe_{40}B_{20}$(3)/ MgO(2)/ $Co_{40}Fe_{40}B_{20}$(3)/ Ru(0.9)/ $Ni_{80}Fe_{20}$(*t*)/ Ta(5) (in nm). The thickness of the $Ni_{80}Fe_{20}$ layer was 10, 20, 30, and 70 nm. The top $Co_{40}Fe_{40}B_{20}$(3)/ Ru(0.9)/ $Ni_{80}Fe_{20}$(*t*)/ Ta(5) free layer of the MTJs were rectangles with aspect ratios form 1:1: to 1:60 patterned by conventional photo-lithography processes. After microfabrication, the MTJs were annealed at 275-375$^{o}$C for 1 hour in a high vacuum furnace by applying a magnetic field of 10 kOe. The direction of the magnetic field was vertical to the long side of the rectangular free layer to set the magnetization direction of the free layer and the $Ir_{22}Mn_{78}$(10)/ $Co_{75}Fe_{25}$(2)/ Ru(0.9)/ $Co_{40}Fe_{40}B_{20}$(3) pinned layer orthogonal to each other.

## 3. Result and Discussion

Figure 1 shows typical magnetoresistive minor loops for the MTJs with 30-nm-thick $Ni_{80}Fe_{20}$ and various aspect ratios of the free layer. In this figure, MTJs were annealed at 300-325$^{o}$C. The loop for 2.5-aspect-ratio showed hysteresis. In contrast, the loops for 5 and 15 aspect ratios showed linear resistance response against magnetic fields. From gradients at zero-field, TMR/2$H_k$ values which are an index of sensitivity were evaluated.

Figure 2 shows the aspect ratio dependence of TMR/2$H_k$ values. The MTJs in figure 3 were annealed at various temperatures. In this figure, the data that shows linear resistance responses against magnetic field are indicated by closed marks, and the data that show magnetoresistive loops with hysteresis are indicated by open marks. For the MTJs with 10-nm-thick $Ni_{80}Fe_{20}$, linear resistance responses were only observed in the MTJs with an aspect ratio of 60. At $Ni_{80}Fe_{20}$ thicknesses of 20 or 30 nm, linear resistance responses were observed in the MTJs with aspect ratios over 12 or 5. For the MTJs with 70-nm thick $Ni_{80}Fe_{20}$, the MTJs showed linear resistance responses for all aspect ratios. The linear resistance responses in MTJs with thick $Ni_{80}Fe_{20}$, even low aspect ratios, can be explained by magnetostatic energies in the free layers. For the MTJs with thick $Ni_{80}Fe_{20}$, if the magnetization of the free layer turns to the short side of the rectangle, a large amount of magnetic poles arises at the side of the pillar and increases the magnetostatic energy. Therefore, the magnetic easy-axis, which is parallel to the long side of rectangles, is more stable in MTJs with thick $Ni_{80}Fe_{20}$. We observed a large TMR/2$H_k$ value of 4.8 %/Oe in the MTJ with a $Ni_{80}Fe_{20}$ layer of 70 nm and an aspect ratio of 1.0. This value is larger than those for the reported MTJs with an amorphous Al-oxide barrier [3].

Magnetic field sensors are used in wide range applications, which make control of the detecting field ranges ($H_{range}$) necessary. Figure 3 shows the aspect ratio dependence of $H_{range}$ for the only MTJs that shows a linear resistance response. As seen in figure 3, various $H_{range}$ values were obtained by control of the aspect ratio and the $Ni_{80}Fe_{20}$ thickness.

**Summary**

We fabricated MTJs with CoFeB/ Ru/ $Ni_{80}Fe_{20}$ synthetic ferrimagnetic free layers and systematically investigated the effect of the shape and thickness of the free layer on the magnetic sensor performance. We obtained a large TMR/2$H_k$ value of 4.8 %/Oe in the MTJ with a $Ni_{80}Fe_{20}$ layer of 70 nm and an aspect ratio of 1.0. This value is much larger than that for MTJs that have an Al-oxide barrier. In addition, we controlled the detection field range by changing the aspect ratio and the $Ni_{80}Fe_{20}$ thicknesses.

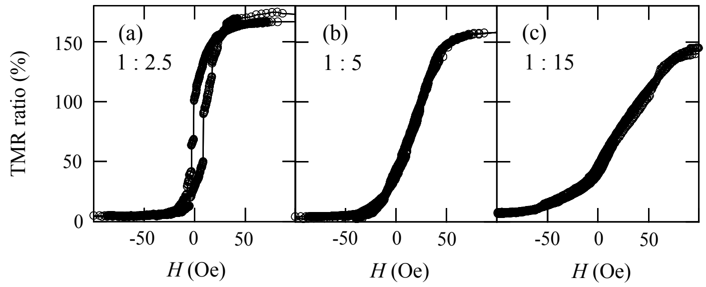


Fig.1 Typical magnetoresistance minor loops of MTJs with 30-nm-thick-$Ni_{80}Fe_{20}$. Free layers of the MTJs were rectangles with aspect ratio 1:2.5 (a), 1:5 (b), and 1:15 (c).

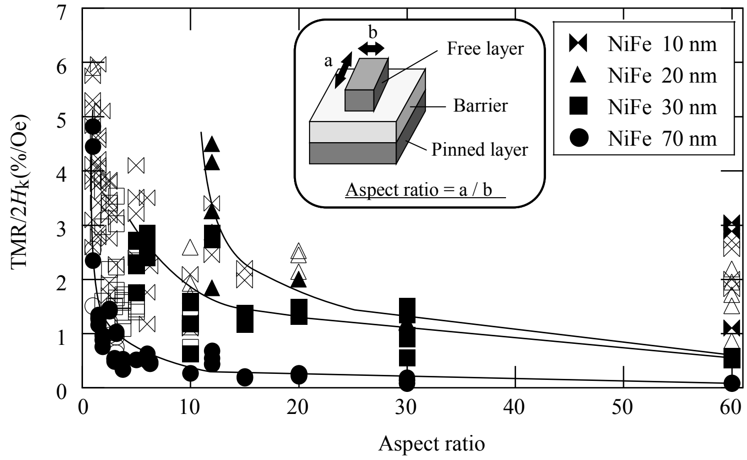


Fig.2 Aspect ratio dependence of TMR/2$H_k$ for MTJs with various $Ni_{80}Fe_{20}$ thicknesses. Closed marks indicate MTJs that show linear resistance responses against the magnetic field, and open marks indicate MTJs that show hysteresis loops.

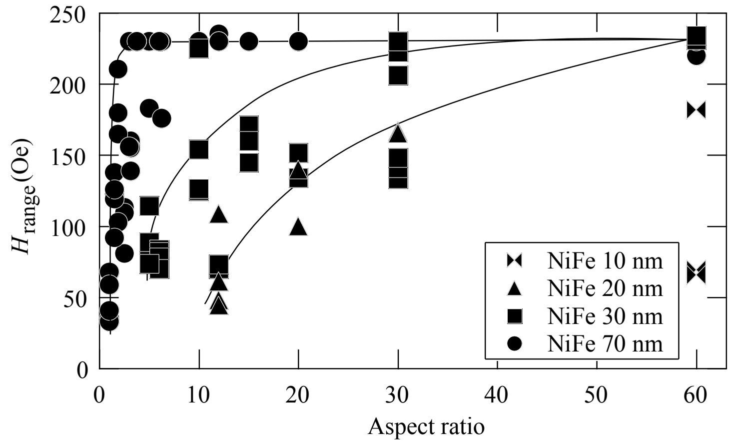


Fig. 3 Aspect ratio dependence of the linearity range ($H_{range}$) values for various $Ni_{80}Fe_{20}$ layer thicknesses.

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