Reduced low frequency noise in electron beam evaporated MgO magnetic tunnel junctions

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We compare low frequency noise in magnetic tunnel junctions with MgO barriers prepared by electron-beam evaporation with those prepared by radiofrequency sputtering, both showing a high tunneling magnetoresistance. The normalized noise parameter in the parallel state of junctions with evaporated barriers is at least one order of magnitude lower than that in junctions with sputtered barriers, and exhibits a weaker bias dependence. The lowest normalized noise is in the $10^{-11} \text{um}^2 \text{m}^2$ range. A lower density of oxygen vacancies acting as charge trap states in the evaporated MgO is responsible for the lower noise. © 2010 American Institute of Physics. [doi:10.1063/1.3431620]

Magnetic tunnel junctions (MTJs) have attracted a great deal of attention since the demonstration of the tunneling magnetoresistance (TMR) effect at room temperature. Following theoretical predictions, a large TMR ratio of up to 200% at room temperature in MTJs with CoFeB electrodes and MgO tunnel barriers was achieved. A record room temperature TMR of 604% has since been reported in a pseudo spin valve stack, which is close to the theoretical temperature $T_M$ of 60%. Major advances in MTJs have led to important applications in hard-disk read heads, sensors, and magnetic random access memory. Magnetic tunnel junctions (MTJs) are in nanometers; 1.2 nm, 1.5 nm, and 2.0 nm were grown by electron-beam evaporation in a separate ultrahigh vacuum chamber of the Shamrock sputtering tool. For the EB-MTJs, the MgO layers with $t=1.2–3.5$ nm were grown by rf sputtering from two MgO targets in a target-facing-target gun, in another chamber of the Shamrock system having a base pressure of $1 \times 10^{-7}$ Torr. After deposition of the bottom electrodes in the HV chamber (base pressure $1 \times 10^{-7}$ Torr), the wafer was then transferred back to the HV chamber to complete the stack. For rf-MTJs, MgO with $t=1.2–3.5$ nm was grown by rf sputtering from two MgO targets in a target-facing-target gun, in another chamber of the Shamrock system having a base pressure of $1 \times 10^{-8}$ Torr. All MTJ layers were deposited without breaking the vacuum during the growth process. The stack was patterned into microscale MTJs with an area ranging from 3 to 1150 $\mu m^2$, using either electron-beam or UV lithography. High vacuum postannealing of the devices was performed in the temperature range of 325–425 °C in an applied mag-

FIG. 1. (Color online) MR curves for an EB-MTJ and a rf-MTJ. Inset is a sketch of the multilayer stack investigated in this work, where thicknesses are in nanometers; $1.2<t<3.5$. 

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amplifier noise and thermal noise have been subtracted from as a function of frequency for the EB- and rf-MTJs. The high quality of our MgO barriers of both types. Figure 2 gives barrier thickness. The high magnetoresistance reflects values are 9 kΩ μm² and 26 kΩ μm², respectively. We note here that our EB-MTJs show a similar TMR ratio to the rf-MTJs but the RA is greater for the EB junctions with a given barrier thickness. The high magnetoresistance reflects the high quality of our MgO barriers of both types. Figure 2 plots the normalized noise power spectral density (ASν/V²) as a function of frequency for the EB- and rf-MTJs. The amplifier noise and thermal noise have been subtracted from the measured Sν. We only show the noise power spectral density under low current bias, to avoid the complication of bias dependence of α. A 1/f low frequency noise is observed for either the parallel or antiparallel state for both types of MTJs but the noise in the antiparallel state is always higher.

It is evident in Fig. 2 that our EB-MTJ possesses a much lower normalized noise power spectrum in the parallel state compared to the rf-MTJ, despite the fact that all the other layers in the stack are grown in exactly the same way. Low frequency noise in MTJs in the parallel state is thought to be dominated by barrier noise. Our results, therefore, indicate that the electron-beam evaporated MgO barrier is quieter than the rf sputtered one.

We note that the normalized noise in the parallel state of an MTJ decreases with thermal annealing, and reaches its minimum after annealing at 300 °C for 1 h. All magnetotransport and noise measurements were performed by a four-probe method at room temperature. Positive bias is defined as the direction of electrons tunneling from the free to the pinned CoFeB layer. Further details on the sample growth process and measurement can be found in Refs. 20–22.

Figure 1 shows MR curves for an EB-MTJ and a rf-MTJ. The TMR ratios are 212% and 203%, and their RA values are 9 kΩ μm² and 26 kΩ μm², respectively. We also observe that the electron-beam evaporated MgO barrier is quieter than the rf sputtered one. Variation in the barrier quality. We note that the normalized noise in the parallel state of MTJs first falls with decreasing RA, then reaches a roughly constant value (~10⁻¹⁰ μm²) as a function of annealing temperature.

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MTJ in its antiparallel state is related to the appearance of random telegraph noise (not shown).

It is found that the tunnel barrier and the barrier/ electrode interfaces can be improved during the annealing process, which leads to a high TMR due to crystallization of CoFeB electrodes and improved quality of the MgO barrier. In our case, the CoFeB layers in both types of MTJs are expected to be quite similar, as they were both grown by sputtering and underwent exactly the same annealing treatment. The difference of α must largely originate from the MgO barrier due to the different oxide growth methods. It has been shown that upon annealing, the rf-MgO retains a larger d-spacing, while the evaporated MgO has the same d-spacing as bulk MgO. A higher density of oxygen vacancies forms in the MgO barrier near the two interfaces for the rf-MTJs, while the density of oxygen vacancies in the MgO layer is much lower, and supports the conclusion of other authors that sputtered MTJs have an apparent noise floor due to a particular defect type which has to be eliminated by an improved fabrication process.

In conclusion, a lower 1/f noise, characterized by the Hooge parameter α, obtained in EB-MTJs compared to that found in rf-MTJs is attributed to the absence of charge trap states in the MgO tunnel barrier associated with oxygen vacancies. Electron-beam evaporation is an alternative way to produce high quality MgO tunnel barriers with noise performance comparable to that found for fully epitaxial single crystalline junctions grown by MBE. It is faster and more cost effective, and it could be easily integrated in industrial production. TMR-based magnetic field sensors with electron-beam evaporated MgO barriers offer about an order of magnitude improvement in their signal-to-noise ratio compared to those with conventional sputtered MgO tunnel barriers.

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