Low-frequency noise in MgO magnetic tunnel junctions

著者	安藤　康夫
journal or publication title	Journal of applied physics
volume	99
page range	08T306-1-08T306-3
year	2006
URL	http://hdl.handle.net/10097/34668

Low-frequency noise in MgO magnetic tunnel junctions

Anis Faridah Md Nor,[a)] Takeharu Kato, Sung Jin Ahn, Tadaomi Daibou, Kazunaga Ono, Mikihiko Oogane, Yasuo Ando, and Terunobu Miyazaki
Department of Applied Physics, Graduate School of Engineering, University of Tohoku, Aobayama 6-6-05, Sendai 980-8579, Japan

(Presented on 3 November 2005; published online 18 April 2006)

Noise measurements have been performed in MgO-based tunnel junctions with normalized resistance in the range of 10^5-10^7 Ω μm^2 and various magnetoresistance ratios were investigated. Noise measurements in the frequency range of 1–1000 Hz shows magnetically dependent pure $1/f$ power spectra at low frequency. The $1/f$ noise scales with bias voltage, indicating that the $1/f$ noise can be attributed to magnetic tunnel junction resistance fluctuations. Bias voltage dependence of random telegraph noise (RTN) was observed, indicating electronic origin due to the charge-trapping mechanism. In the presence of the easy-axis bias field, our data exhibit a magnetic-field dependence of RTN that originates from magnetization fluctuations. A phenomenological noise parameter, defined for the comparison of noise levels in different junctions, was shown to be independent of the junction resistance-area product in the range investigated. This observation suggests that the decrease in tunnel resistance does not play an important role in reducing $1/f$ noise. © *2006 American Institute of Physics*. [DOI: 10.1063/1.2165142]

I. INTRODUCTION

Magnetic tunnel junctions (MTJs) are under extensive investigations recently since they are good candidates for use as magnetoresistance (MR) read head sensors and magnetic random access memory devices in future high-density information storage applications. For sensing applications, the ultimate detection sensitivity is limited by the device's intrinsic noise. In the low-frequency region, MTJ noise is dominated by $1/f$ noise.[1] This has been generally attributed to either electrical sources (field-independent charge trapping near or in the oxide barrier) or magnetic sources (field-dependent magnetization fluctuations).[2,3] It has been reported recently that MgO-based MTJ devices exhibit large MR ratio, more than 200% at room temperature.[4,5] Such large MR ratio is very desirable and it indicates a great possibility of MgO-based MTJ being realized in information storage applications in the future. Most of the work on noise in MTJ have been reported for Al–O-based tunnel junctions.[1,2,6,7] In this paper, we report on low-frequency noise measurements on MgO-based MTJ devices. Our results indicate that the $1/f$ noise is due to resistance fluctuations and that the random telegraph noise (RTN) originates from two sources. One is of electronic origin, which is due to charge trapping, and the other one is of magnetic origin, associated with magnetization fluctuation. The investigated MTJ devices show a normalized noise level that is not dependent on MR ratio values.

II. EXPERIMENT

The MTJs studied in this work were deposited on thermally oxidized Si wafers using a multitarget high-vacuum magnetron sputtering system. The MTJ layer structure is Ta(10)/NiFe(20)/IrMn(15)/$(Co_{75}Fe_{25})$(2)/Ru (0.85) / $(Co_{50}Fe_{50})_{80}B_{20}$(5) / MgO(2.5) / $(Co_{50}Fe_{50})_{80}B_{20}$(5) / Ta(10)/Ru(7)/NiFe(20)/Ta(5). The thickness values indicated in parentheses are in nanometers. The samples were patterned using standard optical lithography, followed by ion-beam etching to make micron-sized junctions and contact pads for both voltage and current leads. An easy-axis direction in the samples has been defined during sputtering and enhanced by the process of postannealing. Noise measurements were performed in a shielded room on samples with various normalized resistances in the range of 10^5-10^7 Ω μm^2 and various MR ratios ranging from 0% up to about 133% were investigated. The sample with 0% MR labeled as S1 was made by varying the sputtering conditions to provide an amorphous structure in MgO tunnel junction for comparison purposes. Two static magnetic field along the easy-axis, H_e, and hard-axis, H_h, directions were provided by two Helmholtz coils perpendicular to each other. A battery and a variable resistor provide a dc-sense current to the device. The voltage V across the junction is fed into a homemade battery-powered low-noise preamplifier built using the INA103 instrumentation amplifier with a gain of 1000. The amplified MTJ noise is then digitized and processed using an Agilent vector signal analyzer (89410A) to obtain the noise power spectral density. During the measurements, the easy-axis field is swept from parallel to antiparallel direction with about 1 Oe increment in the proximity of the hysteresis region. At each applied field, the junction was allowed to equilibrate for 1 min before the noise measurement was performed. The noise spectral density was observed to have a $1/f$ dependence at frequencies below about a few kilohertz. Noise measurements reported here were done in the frequency range of up to 1 kHz. In this paper, the noise at different bias voltages and the noise in the presence of an easy-axis bias field were measured at room temperature. The normalized $1/f$ noise in the parallel state from different MgO tunnel junctions of various MR ratios were investigated and compared with the noise obtained from Al–O barrier MTJ.

[a)]Electronic mail: anis@mlab.apph.tohoku.ac.jp

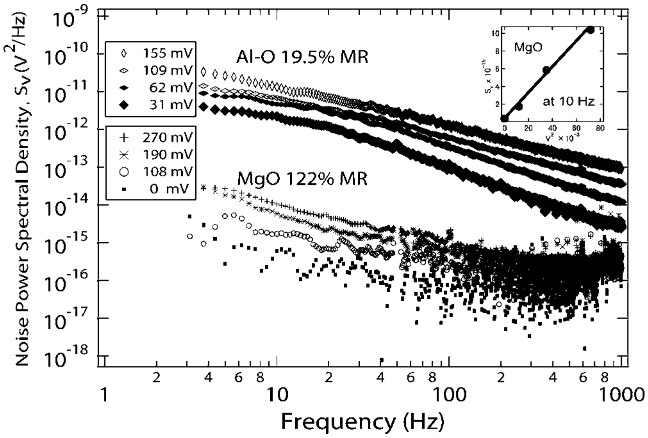

FIG. 1. Noise power spectral density S_v as a function of frequency of Al–O and MgO junctions at different bias voltages in parallel magnetization state. The sample resistance was 155 Ω and the MR was 19.5%. The MgO sample resistance was 269 Ω with 122% MR. Inset is S_v measured at 10 Hz frequency as a function of bias field for 122% MgO sample.

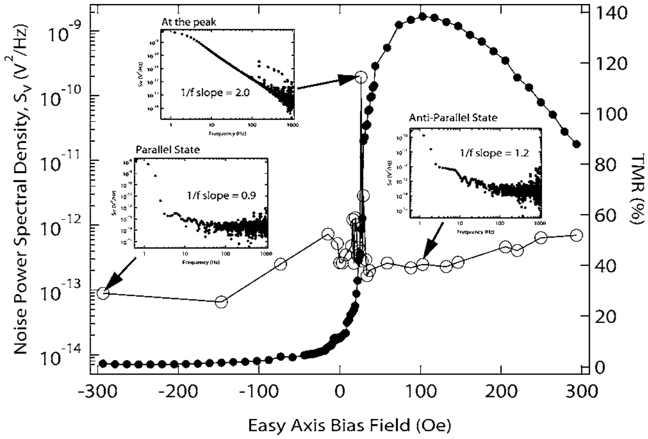

FIG. 2. Noise power spectral density S_v (left axis) at 10 Hz and MR (%) (right axis) as a function of varying easy-axis bias field (Oe) for MgO tunnel junction with 136% MR, showing magnetically dependent RTN at the transition region. Inset are noise power spectral densities S_v's as a function of frequency measured at noise peak and highly parallel and antiparallel states. The $1/f$ slope for each curve was indicated.

III. RESULTS AND DISCUSSION

The typical noise power spectral density measurements for MgO- and Al–O-based junction at various bias voltages for 122% and 19.5% MR are shown in Fig. 1. In MgO tunnel junction the $1/f$ noise dominates the low-frequency region and its magnitude increases with the applied bias voltage as V^2 (refer to inset in Fig. 1), indicating that the $1/f$ noise can be attributed to resistance fluctuations[2,3] as characterized by Hooge's formula.[8] The $1/f$ slope is near 1, indicating that the noise is due to the charge-trapping processes in the barrier.[9] In Al–O tunnel junction, however, even at the lowest applied bias voltage of about 31 mV, the Lorentzian effect associated with RTN is observed, indicating the presence of low energy barrier charge traps. The RTN could be attributed to two-level fluctuators and charge trapping in the barrier and/or barrier/metal interfaces,[10] indicating that the current flow across the junction is inhomogeneous.[11] The RTN was also observed in MgO tunnel junction at higher applied bias voltages of about 420 mV (graph is not shown). The dependence of RTN on applied voltage bias support a charge-trapping mechanism.[3] The appearance of fluctuators at certain bias voltage values corresponds to the bias overcoming the charging energy of the trap, i.e., the electrons has a non-negligible probability of either tunneling through the trap or getting there by thermal activation as a result of decreased energy barrier, which increased the electron transmission.[12]

Noise measurements performed in the presence of varying easy-axis bias fields for the MgO-based junction exhibiting a MR ratio of 136% is shown in Fig. 2. The MR measurements were performed *in situ* to show noise correlation with magnetization states. Near the transition region from parallel to antiparallel state, the noise activity is quite high and a sharp peak was observed. The position of this peak coincides with the steepest gradient of the MR-H curve suggesting that the noise is magnetic in origin and originated from the free layer.[2] The noise spectra at the peak region have strong Lorenztian character, suggesting that the noise comes mostly from a single, effective two-level fluctuator (see inset in Fig. 2). Similar observations were also reported, and the RTN observed was presumed from small domains switching back and forth between 0 and 180°.[12] Our results support this assumption since the noise at strongly antiparallel and parallel states show pure $1/f$ noise without any hint of RTN characteristics (see inset graphs). At large applied magnetic fields, the RTN levels off since all the domains have completely switched and are prevented from changing state by the strong external field. In the presence of an external magnetic field, the RTN observed earlier is of electronic origin and can be observed at large voltage biases.

In order to compare the $1/f$ noise levels of different junctions at room temperature, we consider the normalized noise parameter, $\alpha_H = fS_vA/V^2$, where A is the junction area and V is the dc voltage applied across the sample. We calculated the α_H from the noise spectra obtained at 1 mA applied current and at the frequency of 10 Hz where the $1/f$ noise is clearly seen. The α_H and the TMR (%) as functions of the resistance-area product is shown in Fig. 3. The α_H of the MgO-based junctions were shown to be around 10^{-9}–10^{-8} μm^2 in the resistance-area product range investigated, except for sample S1 with 0% MR which show α_H with three orders of magnitude higher than other samples. The large

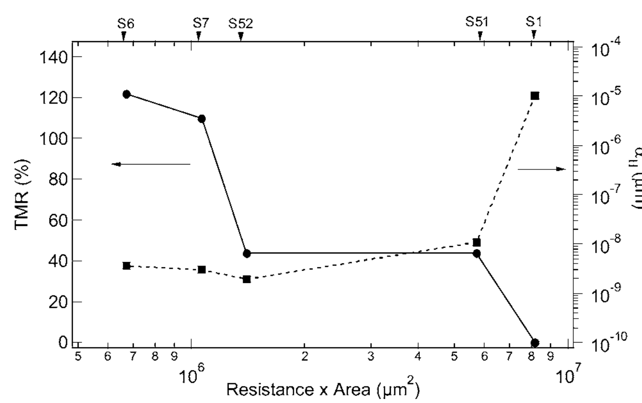

FIG. 3. Variation of MR (left axis) and normalized noise parameter (right axis) at 10 Hz and 1 mA current on resistance × area values for various MgO tunnel junctions. The lines are guides for the eyes.

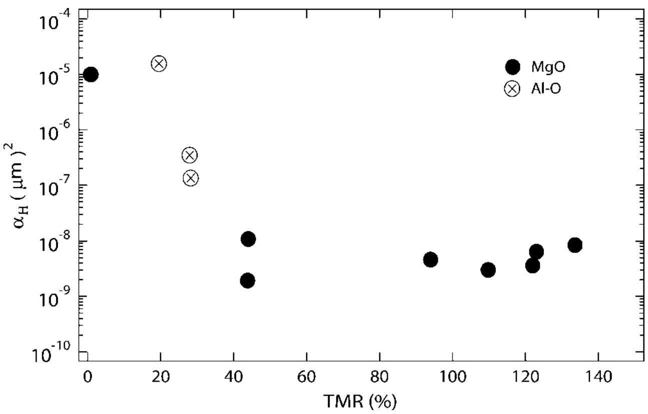

FIG. 4. Normalized noise parameter α_H $(\mu m)^2$ as a function of TMR (%) for Al–O and MgO tunnel junctions showing that noise decreases as the TMR (%) increases.

value of α_H in sample S1 may be due to the amorphous structure of the Al–O tunnel barrier. In Fig. 3, α_H is roughly independent of the resistance-area product—this suggests that the decrease in tunnel resistance does not play an important role in reducing $1/f$ noise. This is in contrast to Al–O tunnel junctions where the noise level was shown to scale with the junction resistance-area product.[10]

The normalized noise parameters for several MgO- and Al–O-based tunnel junctions as functions of TMR % are shown in Fig. 4. In general, noise decreases and reaches saturation level as the MR % of the samples increases. In Al–O junctions the noise level decreases as the MR % varies from about 19% to 28%. However, noise from MgO tunnel junction does not show much change even though the MR % variation was larger, ranging from about 45% to 133%. This difference in behavior is probably due to the differences in the structure of the two barriers, with Al–O being amorphous whereas MgO is in the crystalline form. It is expected that the crystalline MgO surface is much smoother than the amorphous Al–O surface, and it has been suggested that the MR ratio of a MTJ is dependent on the smoothness of the barrier-electrode interface.[13] Thus low-frequency noise in a magnetic tunnel junction can probably be reduced by improving the smoothness of the tunnel barrier-electrode interface.

IV. CONCLUSIONS

The $1/f$ noise observed from MTJs can be attributed to resistance fluctuations due to charge trapping in the barrier. Bias voltage dependence of RTN was observed in both MgO and Al–O MTJs. This was attributed to charge traps present in the tunnel barrier. Magnetic-field-dependent noise was observed to show RTN and this may be due to domain switching or domain-wall jumps in the free magnetic layer. This noise is absent at high applied field due to the strong pinning effect of the external field. Comparison between Al–O and MgO MTJ noise suggests that the smoothness of the tunnel barrier surface is important in reducing the level of $1/f$ noise in MTJs.

ACKNOWLEDGMENTS

One of the authors (A.F.M.N.) would like to thank the Japanese Society for Promotional of Science for sponsoring her research scholarship in Tohoku University, Japan, and Dr. Burhanuddin Kamaluddin of the University of Malaya for technical support.

[1]X. Liu and G. Xiao, J. Appl. Phys. **94**, 6218 (2003).
[2]E. R. Nowak, M. B. Weissman, and S. S. P. Parkin, Appl. Phys. Lett. **74**, 600 (1999).
[3]S. Ingvarsson, G. Xiao, S. S. P. Parkin, W. J. Gallagher, G. Grinstein, and R. H. Koch, Phys. Rev. Lett. **85**, 3289 (2000).
[4]S. S. P. Parkin, C. Kaiser, A. Panchula, P. M. Rice, B. Hughes, M. Samant, and S. H. Yang, Nat. Mater. **3**, 862 (2004).
[5]D. D. Djayaprawira *et al.*, Appl. Phys. Lett. **86**, 092502 (2005).
[6]C. Ren, X. Liu, B. D. Schrag, and G. Xiao, Phys. Rev. B **69**, 104405 (2004).
[7]K. B. Klaassen, X. Xing, and J. C. L. V. Peppen, IEEE Trans. Magn. **40**, 195 (2004).
[8]P. Dutta and P. M. Horn, Rev. Mod. Phys. **53**, 497 (1981); M. B. Weissman, *ibid.* **60**, 537 (1988).
[9]P. Dutta, P. Dimon, and P. M. Horn, Phys. Rev. Lett. **43**, 646 (1979).
[10]W. K. Park, J. S. Moodera, J. Taylor, M. Tondra, J. M. Daughton, A. Thomas, and H. Brückl, J. Appl. Phys. **93**, 7020 (2003).
[11]E. R. Nowak, R. D. Merithew, M. B. Weissmann, I. Bloom, and S. S. P. Parkin, J. Appl. Phys. **84**, 6195 (1998).
[12]S. Ingvarsson *et al.*, J. Appl. Phys. **85**, 5270 (1999).
[13]D. Song, J. Nowak, and M. Covington, J. Appl. Phys. **87**, 5197 (2000).