Effect of temperature gradient on junction magnetoresistance of magnetic tunnel junction devices

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ABSTRACT

Combining the quantum transport theory with new field of Spin Caloritronics, we investigate on the influence of thermal gradient on the magneto tunnel junction structure under various circumstances. The results indicate enhancement in performance of spintronic device is possible using thermal energy.

INTRODUCTION

Due to its predictive powers quantum transport theory has been considered as the most powerful tool to model the device which is being scaled down to nanometer level. Its versatile applicability remained not only in the field of semiconductor electronics but also into the relatively new field of Spintronics, which spin properties of electrons as well as charge properties are utilized for a functionality of device [1-2].

Meanwhile, attempts to integrate thermal effects into Spintronics have brought upon the new field of Spin Caloritronics. The beliefs that lots of potential is to be found using these newly discovered physical effects, has initiated a vigorous amount of research related to interaction between heat, spin and the charge. Especially, independent electron effect, which could be understood as thermoelectric generalization of collinear magneto-electronics [3], has drawn an attention as it could be directly applied on a commonly used spintronic devices such as giant magnetoresistive (GMR) spin valves or magneto tunnel junctions (MTJ).

In this paper we adopt the quantum transport theory to explain the effect of thermal gradient on ferromagnet-insulator-ferromagnet MTJ structure and investigate on the possibility of enhanced device performance as thermal gradient is applied along with electrical bias.

SIMULATION APPROACH

The schematics of MTJ structure used in this paper can be illustrated as in Fig.1. Non-equilibrium Green's Function method (NEGF) was used to calculate the spintronic properties assuming that electron transport coherently throughout the device. Each leads of the device was assumed as simple Stoner-Wohlfarth ferromagnets with the Fermi Energy and the exchange field given as $E_F = 2.2eV$ and $\Delta = 1.45eV$, respectively [4]. In particular, we adopted single band tight-binding approximation with an effective electron mass ($m^*=m_0$) in the ferromagnetic region and the tunneling region [4].

To test the effect of thermal gradient between two leads in various devices, the simulations were done for different barrier oxide thicknesses (0.3-0.7-1.1-1.5 nm) and barrier heights (3.5-4.0-5.0 eV).

Furthermore, we tried to figure out physical parameters related to junction magnetoresistance (JMR) which is crucial for operation of electronic devices conserving good reliability.

DISCUSSION

To see the correlation between junction magnetoresistance and the thermal gradient, we have varied temperature of left lead (FM1) from 270K to 330K while maintaining temperature of right lead (FM2) as 300K. JMR calculated for electron channel in different levels of energy is shown in Fig.2(a) for small electric bias. Above the exchange field energy ratio between spin-up current and spin-down current reaches unity showing rapid decrease in the JMR ratio. To calculate the total overall JMR value of the device, it should be multiplied by normalized weight factor ω (E_z), which is normalized value of current flowing for each energy level in parallel configuration.

Our investigation shows that JMR decreases when negative thermal gradient is applied while opposite effect is shown for opposite thermal gradient. The reason can be explained by shift of the ω (E_z) toward the lower energy level as temperature difference between FM2 and FM1 becomes larger. This set up weight factor higher for the lower energy where JMR value is larger leading to increase in overall JMR of the device.

To further speculate such effect in more details, we have speculated a phenomenon under various device parameters. In Fig.3(a), JMR characteristics for conventional without concerning thermal gradient is shown. The JMR showed bigger value for thinner barrier thickness and higher barrier height as was well verified [1]. When thickness of the oxide barrier is varied the total percentage of the JMR change is bigger for thinner oxide barrier, while the ratio between JMR values is bigger for JMR device with thicker oxide values. (Fig.3(b)) We were able to observe similar trends when we varied barrier height as in Fig.3(c). The range of JMR variation as a function of temperature was bigger for higher barrier energy of U_{barr}=5.0eV, where overall JMR value is larger. On the other hand, the ratio of JMR between low temperature and high temperature was bigger for lowest barrier energy. This indicates that thermally induced JMR is less affected by tunnel barrier and barrier thickness compared to electrically induced JMR.

Final remarks involve ways to obtain higher thermally induced JMR value. As it can be seen from Fig.4, for higher exchange field energy, JMR tends stay high for the higher energy regime near the Fermi level. Thus, when materials with high exchange field such as CoFeB, Permalloy or Heusler alloy is used, the thermal effect on the JMR is expected to be much greater than usual ferromagnets. Also, when higher bias is applied on the tunnel junction, the change in energy dependent JMR value is also expected to increase the thermal effects.

CONCLUSION

The effect of thermal gradient in normal MTJ structure was speculated using simple modelled EDISON tool with reasonable outcomes and predictions. Results show that thermally induced magnetic signals are less affected by parameters such as thickness and height of tunnel barrier, but can be show more dominant behaviour when spin exchange field of ferromagnet is high or when enough bias is applied.

Such thermal behaviours could be useful for reliability of MTJ structure as it increases the JMR. Another application of the effect might be its usage as a thermosensor as it has JMR shows almost linear dependence to temperature difference between two leads of MTJ.

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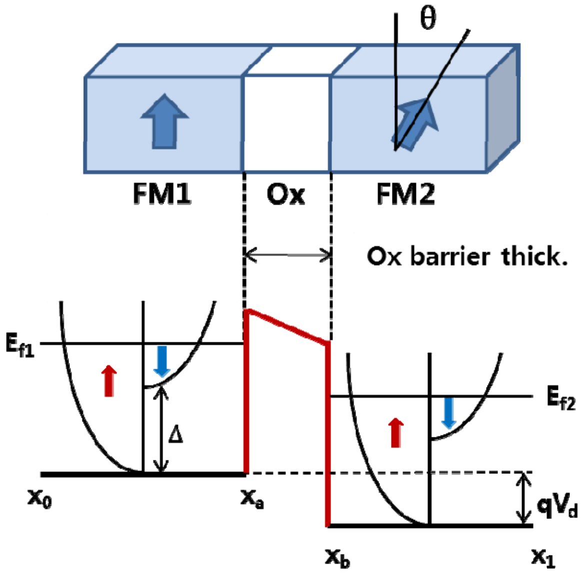


Fig.1. Schematics of magnetic tunnel junction and its energy configuration

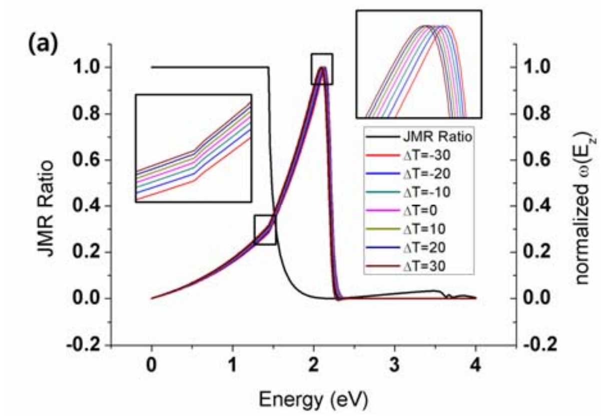


Fig.2. JMR Ratio and normalized ω (E_z) as function of energy level. Difference in temperature cause shifting of normalized ω (E_z)

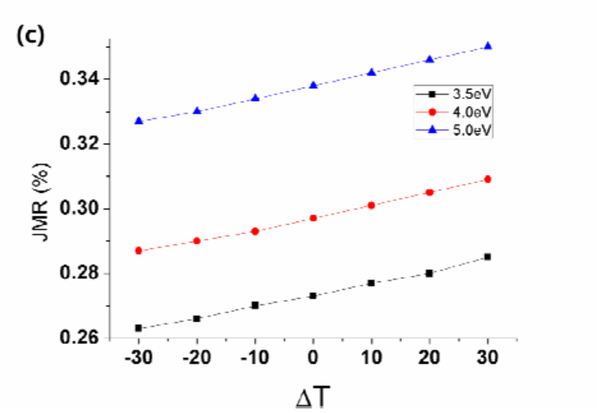
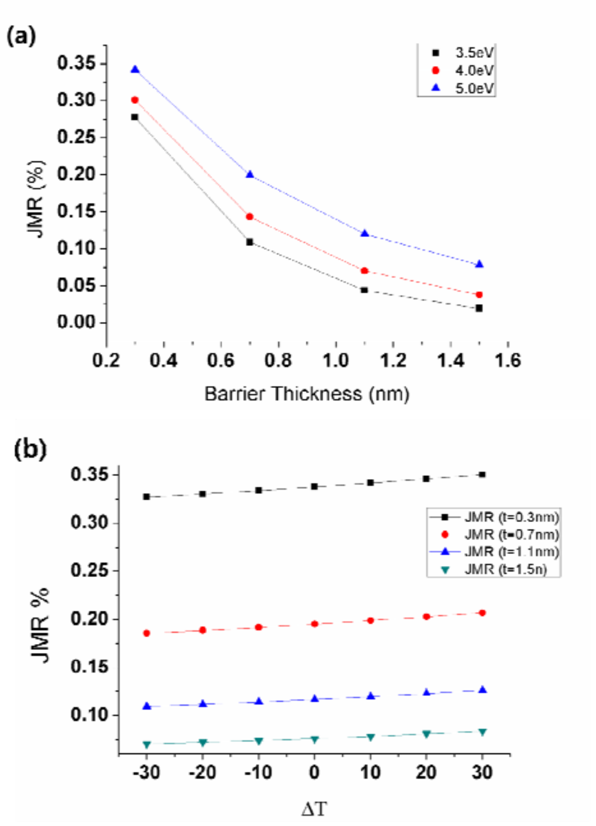


Fig.3. JMR of device as a function of (a) barrier thickness for different barrier height, (b) temperature difference for different barrier thickness and (c) temperature difference for different barrier height



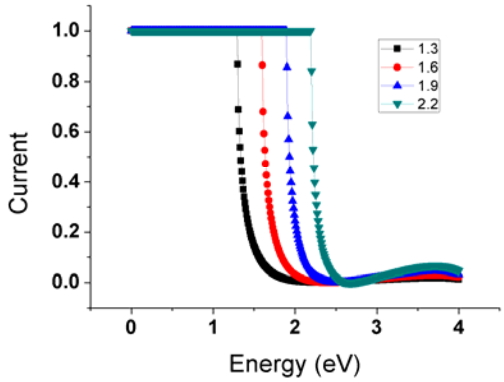


Fig.4. Change in energy dependence of JMR for different exchange field energy