Magnetoresistance Properties of Planar-Type Ferromagnetic Tunnel Junctions with Vacuum Barriers Fabricated by Field-Emission-Induced Electromigration

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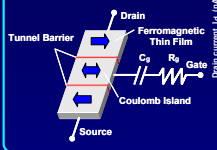
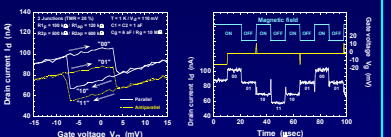
① Introduction

RC-FMSET[3]

Schematic Diagram





Clear Hysteresis of TMR | Multivalued Functions

Spin-Polarized Tunneling in Ferromagnetic Tunnel Junctions (MTJs)

- Magnetoresistive Nanoscale Memory/Storage Devices
- Ferromagnetic Single-Electron Transistors: FMSETs[1, 2]
  - ➔ FMSET Coupled with a Resistance-Capacitance Circuit (RC-FMSET)[3]
    - ➢ Clear Hysteresis of Tunneling Magnetoresistance (TMR)
    - ➢ Multivalued Functions (Interplay of Spin and Charge)
    - ➢ Enhancement of TMR

[1] J. Shirakashi and Y. Takemura, J. Appl. Phys. 89, 7365 (2001).
[2] J. Shirakashi and Y. Takemura, J. Appl. Phys. 91, 7442 (2002).
[3] J. Shirakashi and Y. Takemura, J. Appl. Phys. 93, 6873 (2003).

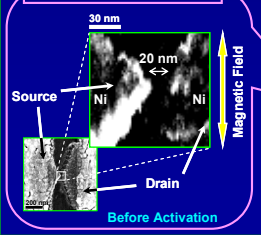
TMR Effects in FMSETs Produce Promising Physical Phenomena

② Fabrication of Ni Nanogap Using Activation Method

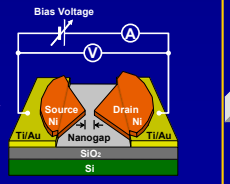
① Conventional Electron-Beam Lithography and Lift-Off Process
② Electromigration Approach: Field-Emission-Induced EM (Activation)[4-10]
➔ Control of Tunnel Resistance by Only Adjusting the Magnitude of Preset Current I_s

[4] S. Kayashima, et al., Jpn. J. Appl. Phys. 46, L907 (2007).
[5] S. Kayashima, et al., J. Phys. Conf. Ser. 100, 052022 (2008).
[6] Y. Tomoda, et al., J. Vac. Sci. Technol. B 27, 813 (2009).
[7] Y. Tomoda, et al., IEEE Tran. Mag. (2009) in print.
[8] Y. Tomoda, et al., J. Phys. Conf. Ser. (2009) in print.
[9] W. Kume, et al., J. Nanosci. Nanotechnol. (2009), in print.
[10] T. Watanabe, et al., J. Nanosci. Nanotechnol. (2009), in print.
[11] J. G. Simmons, J. Appl. Phys. 34, 2581 (1963).

Representative Planar-Type Nanogap (25 nm-Thick Ni)

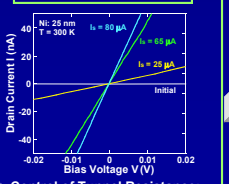


Setup for Activation Process



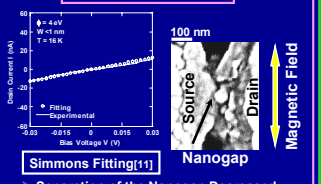
➢ Initial Gap Separation of the Nanogap: 45 nm

Change of I-V Properties (I_s = 25 → 80 μA)



➢ Control of Tunnel Resistance: Over 100 TΩ → 169 kΩ
After Activation (I_s = 25~80 μA)

After the Activation with Preset Current I_s = 80 μA



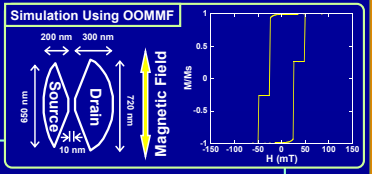
Simmons Fitting[11]

➢ Separation of the Nanogap Decreased from 45 nm to less than 1 nm
After Activation (I_s = 80 μA)

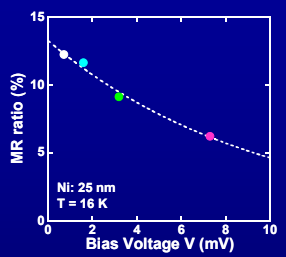
③ Magnetoresistance Properties of Ni Nanogap

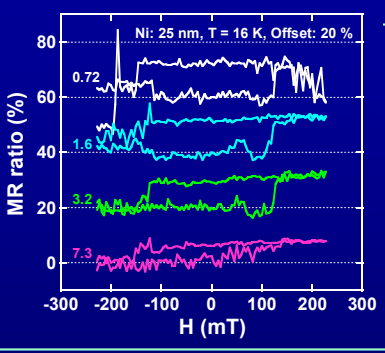
- Asymmetrical Butterfly Pattern: Induction of Magnetic Shape Anisotropy
  - ➔ Hysteresis Loop Simulation Using Object Oriented Micromagnetic Framework (OOMMF) for Asymmetrical Butterfly Shape Nanomagnet of Ni with a Thickness of 25 nm

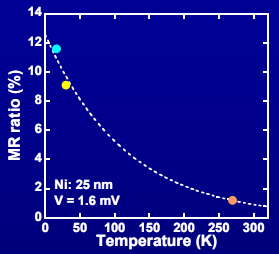
Simulation Using OOMMF



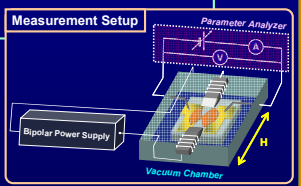
Magnetoresistance Data







Measurement Setup



- Magnetoresistance (MR) Curves of the Nanogap After Performing the Activation with Is = 80 μA
  - ➔ Typical Shape of Minor Loop Characteristics
  - ➔ Increase of the Coercive Field as Compared with the Calculated Result by OOMMF
  - ➔ The MR Ratio Corresponds to That Estimated by Julliere Formulation (MR = 11.2 %, P_{Ni} = 0.23)
    - ➢ The Ni Nanogap Acts as a Planar-Type Ni/Vacuum/Ni Ferromagnetic Tunnel Junction
- Strong Dependencies of MR Ratio on Bias Voltage and Measurement Temperature

④ Conclusions

- Field-Emission-Induced-Electromigration (Activation)
  - ➔ Control of Tunnel Resistance by Only Adjusting the Magnitude of Preset Current I_s: Over 100 TΩ → 169 kΩ (I_s = 25 → 80 μA)
- Planar-Type Ni/Vacuum/Ni Ferromagnetic Tunnel Junctions Fabricated by Activation Approach
  - ➔ MR Properties Exhibited Typical Shape of Minor Loop Characteristics
    - ➢ The MR Ratio Corresponds to That Estimated by Julliere Formulation → The Ni Nanogap Simply Acts as a Ni/Vacuum/Ni Junction
    - ➢ Strong Dependencies of MR Ratio on Bias Voltage and Measurement Temperature
- Activation Technique is Suitable For the Fabrication of Various Nanoscale Devices with Vacuum Tunnel Barriers