Field-Emission-Induced Electromigration for Integration and Control of Nanogaps

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① Introduction: Field-Emission-Induced Electromigration (Activation)

Activation: Simple and Easy Fabrication Technique of Tunnel Devices

Ⅰ Wide-Range Control of Tunnel Resistance of Nanogaps

S. Kayashima, K. Takahashi, M. Motoyama, and J. Shirakashi, Jpn. J. Appl. Phys. 46 (2007) L907.
S. Kayashima, K. Takahashi, M. Motoyama, and J. Shirakashi, J. Phys. Conf. Ser. 100 (2008) 052022.
Y. Tomoda, K. Takahashi, M. Hanada, W. Kume, and J. Shirakashi, J. Vac Sci. & Technol. B 27 (2009) 813.

Ⅱ Ni/Vacuum/Ni Based Ferromagnetic Tunnel Junctions (MTJs)

Y. Tomoda, M. Hanada, W. Kume, S. Itami, T. Watanabe, and J. Shirakashi, J. Phys. Conf. Ser. 200 (2010) 062035.
Y. Tomoda, K. Takahashi, M. Hanada, W. Kume, S. Itami, T. Watanabe, and J. Shirakashi, IEEE Trans. Mag. 45 (2009) 3480.

Ⅲ Fabrication of Single-Electron Transistors (SETs)

W. Kume, Y. Tomoda, M. Hanada, and J. Shirakashi, J. Nanosci. Nanotechnol. 10 (2010) 7239.

Ⅳ Integration of Two SETs

S. Ueno, Y. Tomoda, W. Kume, M. Hanada, K. Takiya, and J. Shirakashi, J. Nanosci. Nanotechnol. (2011), in print.
S. Ueno, Y. Tomoda, W. Kume, M. Hanada, K. Takiya, and J. Shirakashi, Appl. Surf. Sci. (2011), in print.

→ Preset Current: Dominant Parameter for Controlling Electrical Properties of Nanogaps

② Schematic of Integration Process during Activation

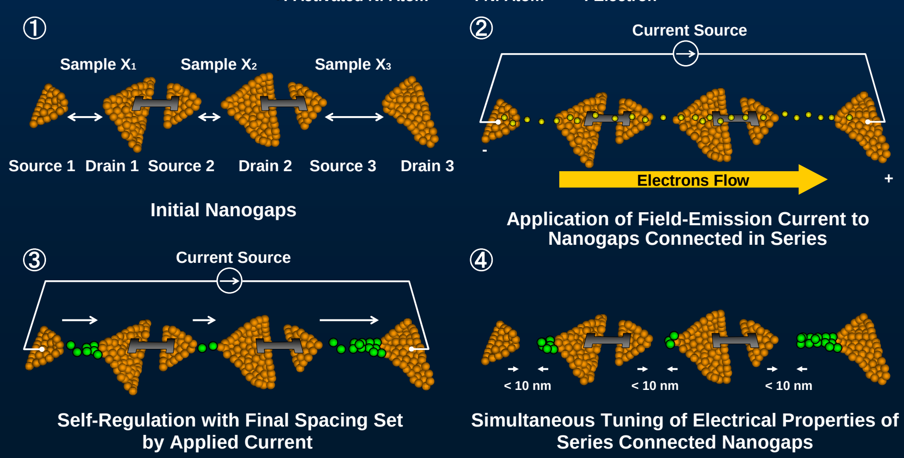
Control Parameters

Temperature: 300 K
Environment: Vacuum
Preset Current I_S:
1 nA ~ 30 μA

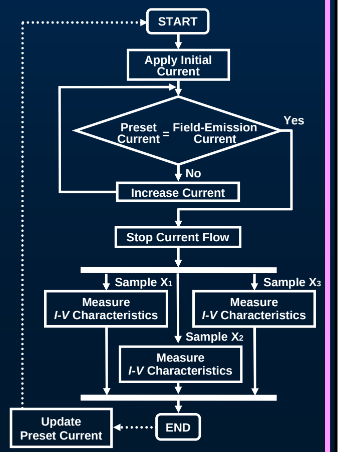
Samples

Material: Ni
Thickness: 20 ~ 30 nm
Initial Gap Separation
Sample 1: W_1 = 114 nm
Sample 2: W_2 = 80 nm
Sample 3: W_3 = 108 nm

Activation Procedure with Current Source

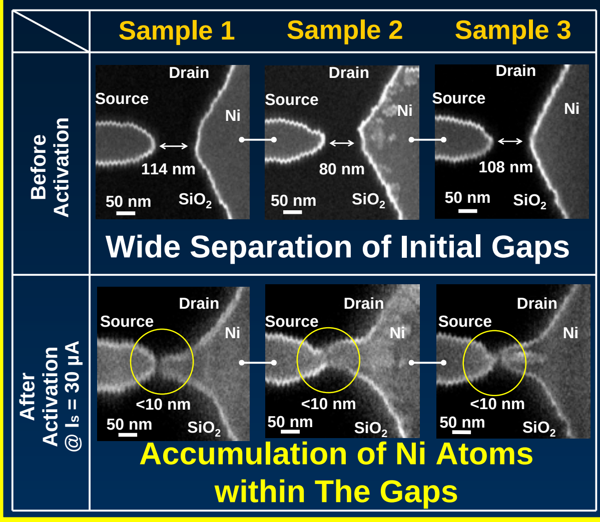


Flowchart of Experimental Procedure

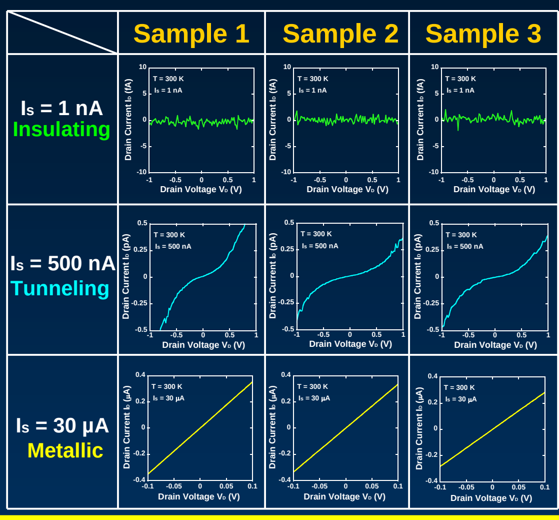


③ Simultaneous Tuning of Tunnel Resistance of Nanogaps by Activation

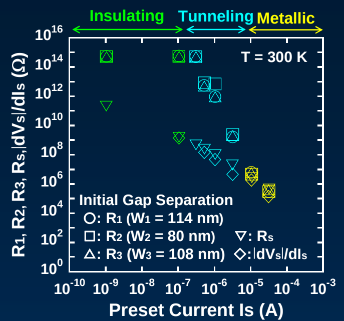
SEM Images of Series-Connected Nanogaps



I-V Properties of Samples After Performing Activation



Dependence of Resistances of Nanogaps on Preset Current I_S



Electrical Properties Are Simultaneously Tuned by Activation

④ Conclusions

➢ **SEM Images of Series-Connected Nanogaps After Performing Activation**

・Separation of gaps was simultaneously reduced to less than 10 nm after activation @ I_S = 30 μA.
⇒ Nanogaps with Precisely Controlled Gap Separations

➢ **Current-Voltage Properties of Simultaneously Activated Nanogaps Connected in Series**

・Current-voltage characteristics of samples were simultaneously varied from insulating to metallic through tunneling properties.
⇒ Simultaneous Tuning of Electrical Properties of Integrated Nanogaps

➢ **Tunnel Resistance of Nanogaps vs. Preset Current during Activation**

・Tunnel resistances of series-connected nanogaps decreased ranging from the order of 100 TΩ to 100 kΩ.
⇒ Self-Regulation with Final Spacing Set by Applied Current