Control of Tunnel Resistance of Si Nanogaps Using Field-Emission-Induced Electromigration

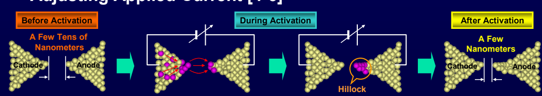
S. Nishimura, Y. Eto, Y. Kuwabara, and J. Shirakashi
Department of Electrical and Electric Engineering, Tokyo University of Agriculture and Technology

1. Introduction

- Electromigration
  - → Failure of Metal Lines and Nanowires in Microelectronic Devices
  - → Directed Migration of Atoms Caused by Large Current Density
    - ⇒ Au: 10^8 A/cm² (@ RT) [1]
    - Ni_2Si: 10^4 A/cm² (@ 275 ℃) [2]
    - Co_2Si: 10^8 A/cm² (@ RT) [3]

[1] C. Durkan, et al., J. Appl. Phys. 86,1280 (1999).
[2] J. S. Huang, et al., Phys. Rev. Lett. 76, 2346 (1996).
[3] C. Kothandaraman, et al., IEEE Electron Device Lett. 23, 523 (2002).
[4] S. Kayashima, et al., Jpn. J. Appl. Phys. 46, 907 (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).

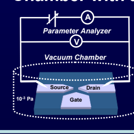
- Activation Method
  - → Control of Tunnel Resistance of Nanogap Electrode by Only Adjusting Applied Current [4-6]

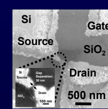


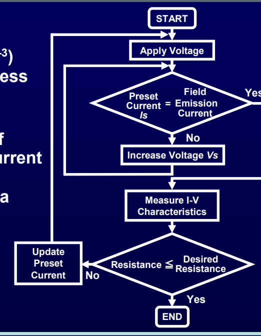
In This Study: Control of Tunnel Resistance of Planar Si Nanogaps Using Activation

2. Experimental Method

- Fabrication of Si Nanogaps with Initial Gap Separation of 30 nm
  - → SOI Substrate (Top Layer: 10^{15} cm^{-3})
  - → EB Lithography, Wet Etching Process
- Electromigration Method: Activation
  - → Flowchart of Activation Procedure
    - ⇒ Control of Tunnel Resistance of Si Nanogaps by Only Preset Current
  - → Performing Activation in Vacuum Chamber with a Pressure of 10^{-3} Pa

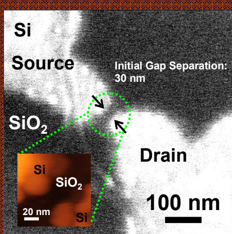




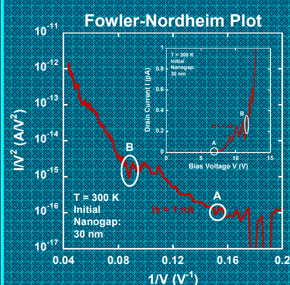


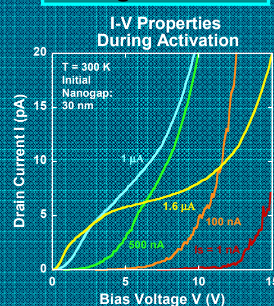
3. Control of Tunnel Resistance of Si Nanogaps

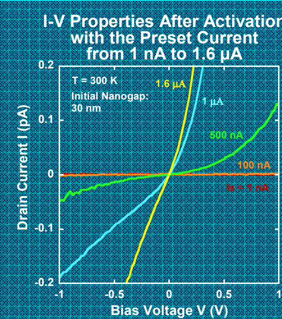
Before Activation



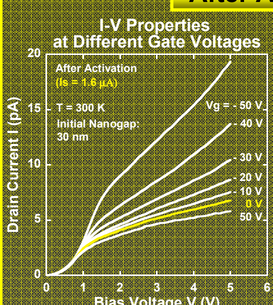
During Activation

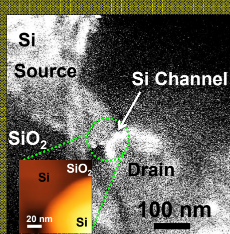






After Activation

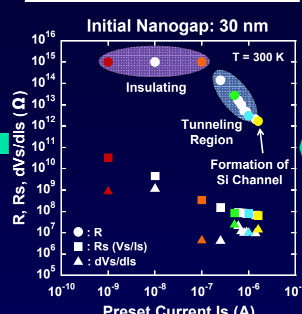




- Electrical Properties after Activation with the Preset Current of 1.6 μA
  - → Conductance Change Induced by Gate Voltages
- Estimation of the Number of Moving Si Atoms from Source to Drain Electrode
  - → Theoretical [6]: 10^8 atoms
  - Experimental: 10^7 atoms

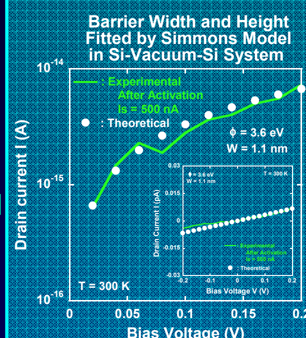
[6] Y. Tomoda, et al., J. Vac. Sci. & Technol. B 27, 813 (2009).

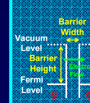
Resistances vs Preset Current



- Tunnel Resistance R
  - → 10^{15} Ω ~ 10^{12} Ω (Is = 1 nA ~ 1.6 μA)

Barrier Width and Height Fitted by Simmons Model in Si-Vacuum-Si System





- Barrier Height: 3.6 eV (Electron Affinity: 4.05 eV)
- Barrier Width: 1.1 nm

4. Conclusions

- Control of Tunnel Resistance of Si Nanogaps Using Activation Process
  - → Decrease of Tunnel Resistance R from 10^{15} Ω to 10^{12} Ω with Increase of Preset Current Is from 1 nA to 1.6 μA
    - ⇒ Reduction of Gap Separation by Only Adjusting Preset Current Is during Activation
  - → Barrier Height and Width Fitted by Simmons Model in Si-Vacuum-Si System
    - ⇒ Barrier Height: 3.6 eV (Barrier Height Lowering Due to Mirror Image Effect), Barrier Width: 1.1 nm
  - → Conductance Change Induced by Gate Voltages ⇒ FET Action Due to Formation of Si Channel