分割型電圧フィードバックEM によるマイグレーション過程の検討

Investigation of Electromigration Process of Nickel Nanochannel Using Stepwise Feedback-Controlled Electromigration

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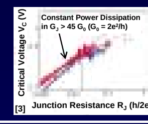
1. Introduction

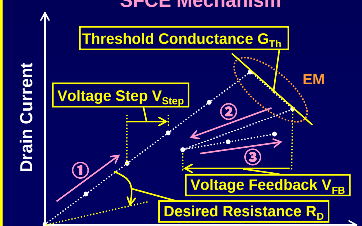
- Fabrication of Nanogaps Using Feedback-Controlled Electromigration (FCE) Scheme
  - ➔ Nanogaps were obtained by only passing a current through metal nanowires[1, 2]
  - ➔ Significant deviation from Constant Power Dissipation Model (= Joule Heating Model) was observed[3]
- Investigation of Electromigration (EM) Mechanism of Metal Nanowires
  - ➔ Power dissipated at contact during EM process was estimated by Joule Heating Model[1]
  - ➔ Surface Diffusion Potential was observed in Quantum Point Contact (QPC) regime[3]



[1] D. R. Strachan, et al., Appl. Phys. Lett. 86 (2005) 43109.
[2] K. Takahashi, et al., J. Vac. Sci. Technol. B 27 (2009) 805.
[3] A. Umeno, et al., Appl. Phys. Lett. 94 (2009) 162103.

2. Stepwise Feedback-Controlled Electromigration (SFCE)

SFCE Mechanism



SFCE Procedure
① Voltage is increased by V_{Step}
② Voltage is decreased at G_{Th} by V_{FB}
③ These process are repeated until channel resistance achieves R_D

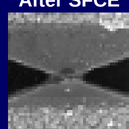
Experimental Condition

Fabrication Method:
EB Lithography and Lift-off Process
SFCE Process: in Vacuum (10^{-3} 〜 10^{-4} Pa)

Before SFCE

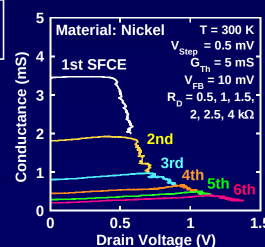
Material: Nickel
Initial Resistance: 200 〜 300 Ω
Thickness: 20 nm
Channel Width: 50 〜 130 nm

After SFCE

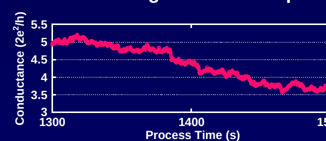


Final Resistance: 9.9 kΩ (32 R_0)
Process Time: 26 min

SFCE Process



During 6th SFCE Step

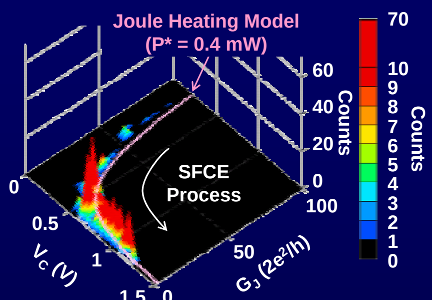


Observation of Quantum Conductance in Units of 0.5 G_0 ($G_0 = 2e^2/h$)
(No Spin Degeneracy even without External Fields)
➔ Formation of Ferromagnetic Domain Structure in Ni Nanochannel[2]

Successive Control of Resistance in QPC Regime
➔ High Controllability of Channel Resistance
➔ Observation of Smoothly Constricted Ni Nanochannel after SFCE

3. EM Mechanism in QPC Regime

Histogram of V_C along Evolution of G_J

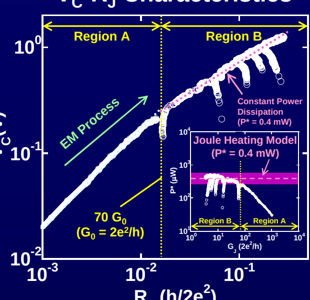


Joule-Heating Model[1]

$$R = R_0 + R_J$$
$$V_J = IR_J = \frac{I}{G_J}$$
$$\frac{1}{G_J} = \frac{V_C^2}{P^*}$$

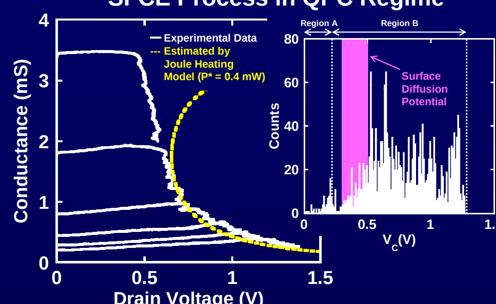
R: Channel Resistance (Ω)
R_0: Initial Resistance (Ω)
R_J: Junction Resistance (Ω)
V_J: Junction Voltage (V)
I: Current (A)
G_J: Junction Conductance (S)
P*: Critical Power (W)
V_C: Critical Voltage (V)

V_C-R_J Characteristics



Slope of Region A: 1
Slope of Region B: 1/2
➔ Constant Power Dissipation (G_J < 70 G_0) (P* = 0.4 mW)
➔ G_J = 70 G_0: Transition Point between Different EM Mechanisms

SFCE Process in QPC Regime



Experimental data correspond to Joule Heating Model (P* = 0.4 mW)
Spectra of experimental data become broader than those of Surface Diffusion Potential of Ni (V_C = 0.3 〜 0.5 V[4]) in QPC regime
➔ Smoothly Evolving EM in QPC Regime

[4] R. T. Tung, et al., Surface Sci. 97, 73-87 (1980).

Observation of Constant Power Dissipation in "QPC Regime"

4. Conclusion

- Controllability of Channel Resistance Using Stepwise Feedback-Controlled Electromigration (SFCE)
  - ➔ Quantum conductance was observed at room temperature
  - ➔ Channel resistance was successively controlled using SFCE procedure
- Investigation of SFCE Process of Ni Nanochannel in QPC Regime by Joule Heating Model
  - ➔ Mechanism of EM was changed at G_J = 70 G_0 (G_J < 70 G_0: Constant Power Dissipation)
  - ➔ SFCE process was stable even in QPC regime, suggesting Joule Heating Mechanism (P*: Constant Value)

Possibility of Universal Control of Electromigration Using SFCE Process