分割型電圧フィードバックEMによる金属ナノチャネルの抵抗制御性の向上に関する研究

Study on Progress of Resistance Control of Metal Nanochannels Using Stepwise Feedback-Controlled Electromigration

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1. Introduction

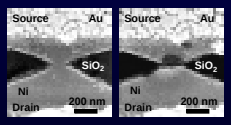
- **Fabrication Method of Nanogaps Using Electromigration**
  - ➔ It is a simple method achieved by only passing a current through a metal nanowire[1].
  - ➔ The typical procedure induces an abrupt break that yields a nanogap with a high tunneling resistance[1].
  - ➔ We propose a stepwise feedback-controlled electromigration (SFCE) approach to address this problem[2, 3].
  - ➔ Wide-range control of channel resistance of metal nanowires can be achieved using SFCE approach[3].

[1] H. Park et al., Appl. Phys. 75, 301 (1999). [2] 高橋他: 秋季第69回応用物理学会学術講演会 4a-H-4 (2008). [3] S. Itami et al., J. Nanosci. Nanotech. (2009) in print.

2. Resistance Control Using SFCE

Fabrication of Devices

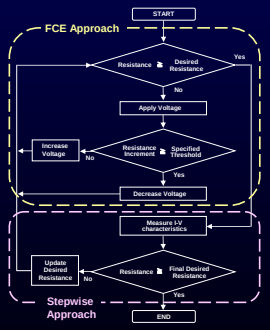
EB Lithography + Lift-off



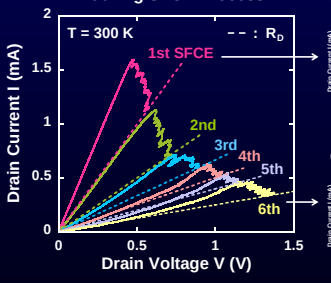
Before SFCE After SFCE

Ni Channel
- Width: 50~130 nm
- Thickness: 30 nm
- Resistance: 307 Ω

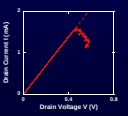
SFCE Procedure[2, 3]



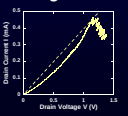
I-V Characteristics during SFCE Process



I-V Curve during 1st SFCE

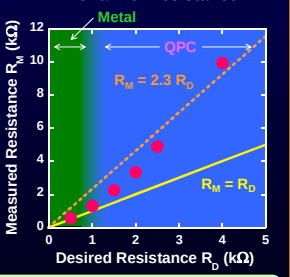


I-V Curve during 6th SFCE



Nonlinear I-V curves were observed with the evolution of the SFCE cycle.

Controllability of Channel Resistance



Quantum Point Contact (QPC) Regime

$R_M > R_D$

3. Investigation of the Controllability on Channel Resistance in QPC Regime

Estimation of Channel Resistance

Channel Resistance R_H during SFCE Process

$$R_H = \frac{V}{I}$$

Drain Current I in QPC Regime

$$I = g_0 V (1 + kV^2)$$ [4, 5]

g_0 (A/V): Low-Bias Conductance
k (1/V²): Nonlinear Coefficient

$$R_H = \frac{1}{g_0 (1 + kV^2)}$$

@ V = 0

$$R_H(V = 0) = \frac{1}{g_0} \equiv R_L$$

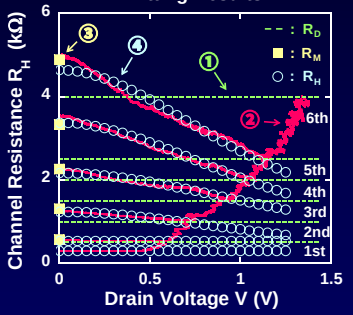
R_L: Channel Resistance in Low Voltage Regime

Fitting Procedure Using Calculated Channel Resistance

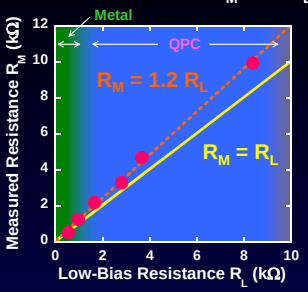
Fitting Procedure

① The desired resistance R_D is set.
② The R_H-V curve is obtained during the SFCE cycle.
③ The measured resistance R_M is obtained in low voltage regime after performing each SFCE step.
④ The R_H-V curve is fitted using $R_H = 1 / g_0(1+kV^2)$.

Fitting Results



Relation between R_M and R_L



Fitting Parameters

SFCE	R_D (kΩ)	R_H (kΩ)	R_M (kΩ)	R_L (kΩ)	g_0 (1/V)	k (1/V²)
1st	0.50	0.50	0.57	0.55	3.5	*
2nd	1.0	1.0	1.3	1.2	1.9	*
3rd	1.5	1.5	2.3	1.7	0.82	0.53
4th	2.0	2.0	3.3	2.8	0.46	0.44
5th	2.5	2.5	4.9	3.7	0.30	0.64
6th	4.0	4.0	10	8.4	0.22	0.72

R_D: Final Channel Resistance during SFCE
*: Not Applicable

The R_M agrees well with the R_L.

Improvement of SFCE Process

New SFCE Procedure

Set R_D
↓
Apply Voltage V and Monitor R_L
↓
$R_L = R_D$
↓
Stop Voltage V
↓
Measure R_M @ Low Voltage Regime
↓
Update R_D

[4] M. Yoshida, et al., Appl. Phys. Lett. 87 103104 (2005). [5] 伊丹他: 秋季第70回応用物理学会学術講演会 10a-ZH-3 (2009).

4. Conclusions

- **Study on the Controllability of Channel Resistance by Using Drain Current in QPC Regime**
  - ➢ Fitting by the Calculated Channel Resistance R_H during SFCE Process
    - ➔ The calculated R_H characteristics fit well with the R_H-V curves obtained during each SFCE step.
  - ➢ Comparison of the Measured Resistance R_M with the Channel Resistance R_H and the Low-Bias Resistance R_L
    - ➔ The R_M nearly corresponds to the R_L ⇒ $R_M = 1.2\ R_L$

Further Improvement of the Controllability of Channel Resistance for Metal Nanochannels Using R_L instead of R_H