A Newly Investigated Approach for the Control of Tunnel Resistance of Nanogaps Using Field-Emission-Induced Electromigration

Kazutoshi Takiya, Yusuke Tomoda, Watari Kume, Shunsuke Ueno
Takato Watanabe, and Jun-ichi Shirakashi
Department of Electrical and Electronic Engineering, Tokyo University of Agriculture and Technology

① Introduction

◆ Field-Emission-Induced Electromigration ("Activation")

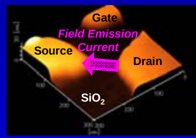
The "Activation" is based on moving atoms induced by *Fowler-Nordheim (F-N) field emission current*.

⇒ *Conventional Activation Scheme*: *Field Emission Current* Induced by *Voltage Source* (V_{source})

Advantages: ① Wide-Range Control of Tunnel Resistance of Nanogaps[1-3]

② Magnetoresistance Properties of Ni/Vacuum/Ni System[4, 5]

[1] S. Kayashima et al., Jpn. J. Appl. Phys. 46 (2007) L907.
[2] S. Kayashima et al., J. Phys. Conf. Ser. 100 (2008) 052022.
[3] Y. Tomoda et al., J. Vac Sci. & Technol. B 27 (2009) 813.
[4] Y. Tomoda et al., IEEE Trans. Mag. 45 (2009) 3480.
[5] Y. Tomoda et al., J. Phys. Conf. Ser. 200 (2010) 062035.

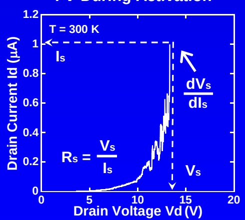


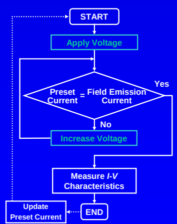
Disadvantage: *Relatively Large Power Consumption During "Activation" Procedure*

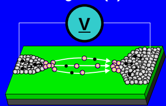
⇒ ***A Newly Investigated Activation Scheme***: *Field Emission Current* Generated by *Current Source* (I_{source})

② Activation Methods: Voltage Source Mode vs. Current Source Mode

Conventional Activation Scheme (Voltage-Source-Based Activation)





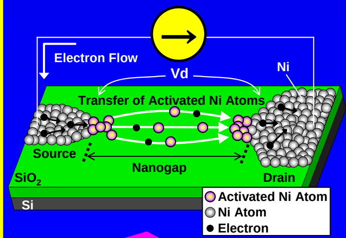


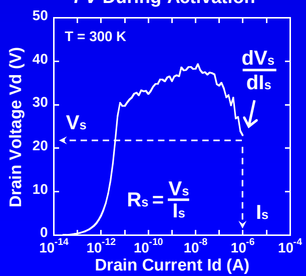
Voltage Source (*Previous Work*)

In order to reduce the power consumption during activation ･･･,

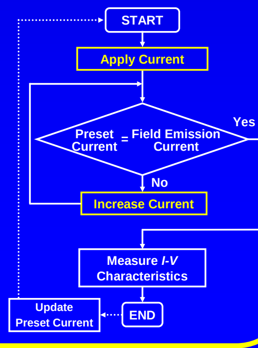
Newly Investigated Activation Scheme (Current-Source-Based Activation)

Current Source (*This Study*)

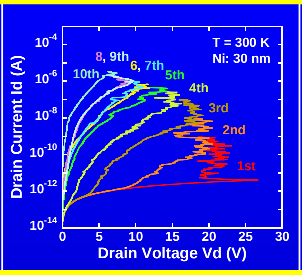
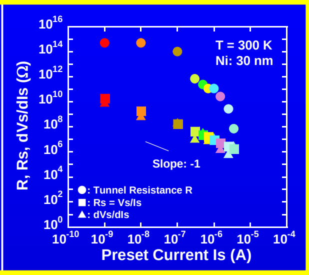
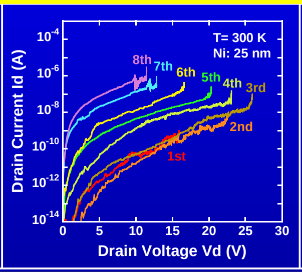
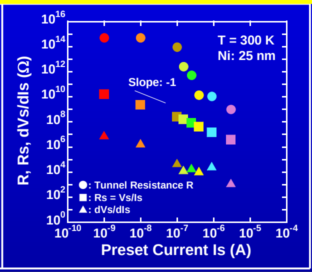




Activation Parameters
Is: Preset Current
Vs: Voltage @ Is
Rs: Vs/Is
dVs/dIs: Differential Resistance

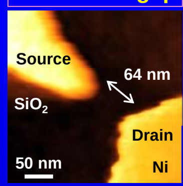


③ Resistance Control of Nanogaps Using A Newly Investigated Activation Scheme

	I-V During Activation	Control Properties of Resistances
Current Source (*This Study*)		
Voltage Source (*Previous Work*)		

Before Performing Activation with I_{source}

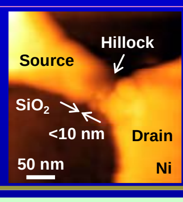
Initial Nanogap



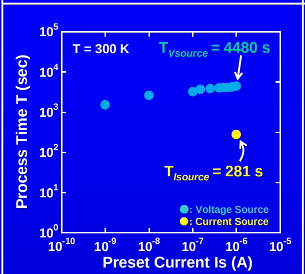
Is = 3.5 μA

After Performing Activation with I_{source}

Formation of Hillock



Process Time for Activation



$T_{Vsource}$ = 4480 sec @ Is = 1 μA
$T_{Isource}$ = 281 sec @ Is = 1 μA

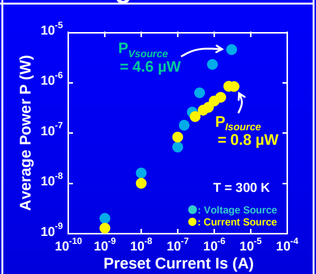
I_{source}: 16 Times Shorter

Migration of Ni Atoms

⇓

Effective

Power Consumption During Activation



$P_{Vsource}$ = 4.57 μW @ Is = 3.0 μA
$P_{Isource}$ = 0.84 μW @ Is = 3.5 μA

I_{source}: 10 Times Lower

Resistance Control of Nanogaps

⇓

Efficient

④ Conclusions

(1) Tuning of Tunnel Resistance of Nanogaps by Preset Current in *Current-Source-Based Activation*

⇒ Preset Current Is: 1 nA → 3.5 μA ⇒ Tunnel Resistance R: 100 TΩ → 70 MΩ (Insulating → Tunneling) @ 300 K

(2) Easy and Effective Migration of Ni Atoms Across The Nanogaps in *Current-Source-Based Activation*

⇒ Process time of activation procedure is 16 times shorter than that of *Voltage-Source-Based Activation*.

(3) Precise and Efficient Control of Tunnel Resistance of Nanogaps in *Current-Source-Based Activation*

⇒ Power consumption dissipated in the nanogaps is approximately 10 times lower than that of *Voltage-Source-Based Activation*.

These results indicate that *Current Source Mode* is suitable for tuning of tunnel resistance of nanogaps.