Lateral encroachment of Ni silicide into Si nanowire

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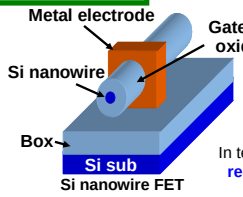
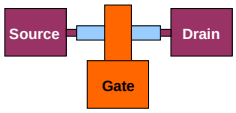
Introduction



- Quasi-one-dimensional electron transport
- Gate-all-around (GAA) structure

High I_{ON}/I_{OFF} ratio

A promising device to replace planer MOSFET

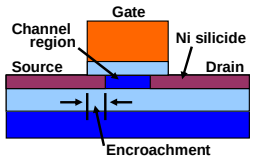


Overhead view of Si nanowire FET

In terms of increase I_{ON} in Si nanowire FET, reduction of S/D resistance is effective

Ni silicidation of sorce/drain (S/D)

Objective



Vertical section of Si nanowire FET

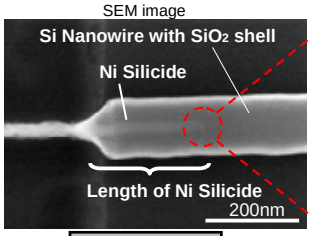
- Characterizing the mechanism of Ni silicide encroachment
- Controlling and suppressing the encroachment length of Ni silicide into Si nanowire

Applying the Ni silicidation of S/D to Si nanowire FET

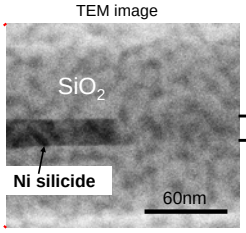
Encroachment of Ni silicide into Si nanowire

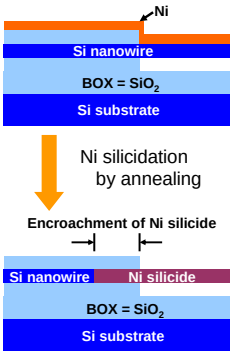
Applying to fabrication of Si nanowire FET

SEM image



TEM image



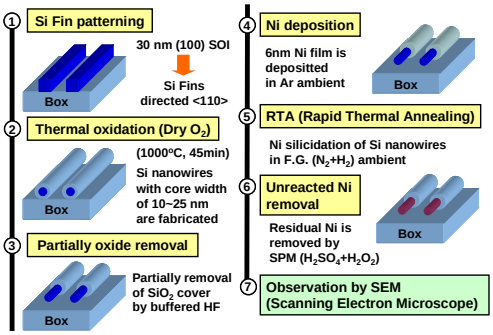


Adverse Problem

- Increase of parasitic resistance
- Short between S/D
- Uncontrollable effective gate length

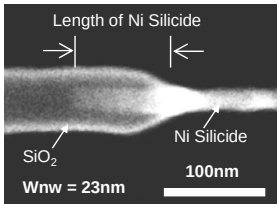
Controlling method of Ni silicide encroachment is necessary

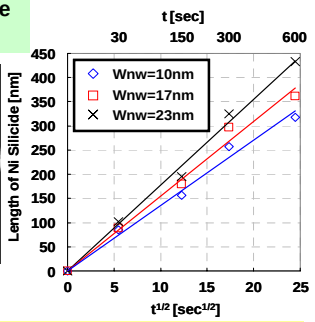
Fabrication Process



Results

Annealing Time Dependence





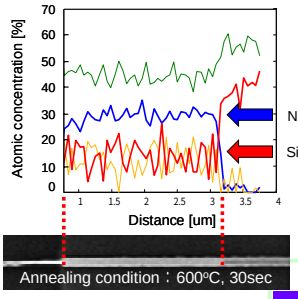
Diffusion equation

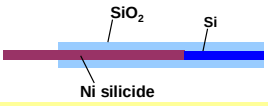
$$\lambda \propto A\sqrt{t}$$

λ : Length of Ni silicide [nm]
t : Annealing time[sec]

- Ni silicide encroachment governed by the Ni diffusion.

AES (Auger Electron Spectroscopy) Analysis

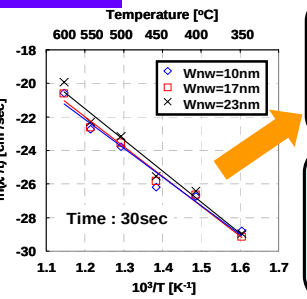




- Uniform formation of Ni_2Si was confirmed by AES analysis.
- With high temperature (600°C) annealing, Ni rich phase was formed. (in case of bulk, NiSi was formed)

Annealing Temperature Dependence

Arrhenius plot



Activation energy

W_{nw} [nm]	10	17	23
E_a [eV]	1.48	1.52	1.60

Activation energy on bulk Si

Ni silicide	NiSi	Ni_2Si
Activation energy [eV]	1.4	1.5

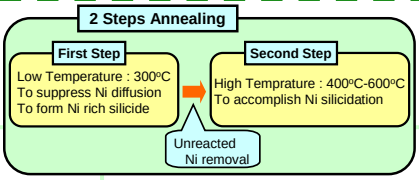
S. P. Murarka: *SILICIDES FOR VLSI APPLICATIONS* (Academic Press, New York, 1983) Chap.5

- Experimental data fits to the activation energy for Ni_2Si

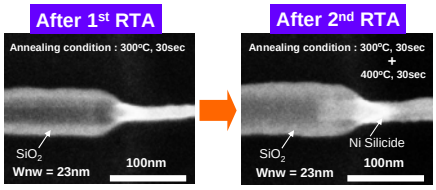
Suppression method of Ni silicide encroachment

2 Steps Annealing

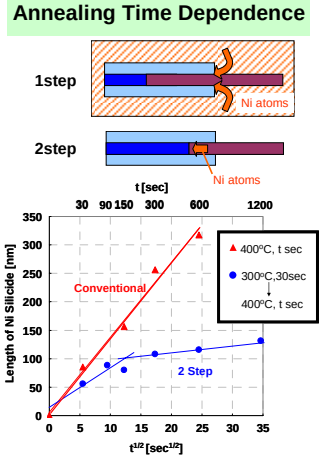
Phase control in nano-scale structure is possible



SEM Images after 1st and 2nd Annealing Step



Annealing Time Dependence

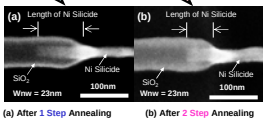


- Although the encroachment was observed during first 150 sec, further annealing hardly increased.

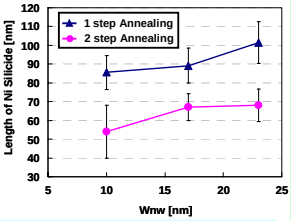
Annealing condition

400°C, 30 sec

300°C, 30 sec
400°C, 30 sec



Comparison of Annealing Conditions



- 2 step annealing method is very effective to suppress the encroachment by removing residual Ni after 1st step.

Conclusions

Mechanism of the encroachment of Ni silicide

- The encroachment governed by Ni diffusion.
- Activation energy indicates that Ni_2Si was formed by annealing for 30 sec between 350-600°C.
- AES analysis indicates that Ni_2Si was formed by annealing for 30 sec at 600 °C.

Suppression of the encroachment into Si nanowire

- 2 step annealing method dramatically suppressed the encroachment of Ni silicide into Si nanowire.
- In 2nd annealing of 2 step annealing, the encroachment occurred during 150 sec at 400 °C by phase change of ahead formed Ni rich silicide at 1st step.