Influence of Sputtering Gas on Resistivity of Thin Ni Silicide Films

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Metal source/drain FETs

Advantages of metal Schottky S/D
- Atomically abrupt junction
- Robust against short-channel effect
- Low parasitic resistance
- Low temperature process capability

Silicides for metal S/D
- Clean interface owing to reactive formation
- Thermally stable up to ~500°C
- Germanides for Ge substrate
- Ni-InGaAs alloy for InGaAs substrate

Silicide S/D has been a candidate for scaled MOSFETs


S. H. Kim, VLSI symp. (2011)
Precise control of Ni atom supply and temperature is required (commonly 2-step annealing).
Stacked sputtering process

Multi layered-deposition of Ni and Si layers

- Atomically flat interface can be achieved
- Interface position can be well-defined
- Applicable for scaled channel

No diffusion of Ni atoms into Si channels

Stacked sputtering process is promising for Schottky S/D for future Fin or nanowire FETs
Silicide film stability on temperature

XPS measurement of silicide film

Sheet resistance and surface roughness

Hy=7938.57eV
Ni2p_{3/2}
RTA: 1min in N_2

Phase of the silicide is mainly NiSi_2

NiSi_2 films with stacked silicidation process are resistant up to 900 °C annealing

Wide process temperature window (350~900°C)
A strong correlation between Ar gas diffusion and silicide phase
Control of the amount of residual Ar might be the key to further reduce the resistivity
Use of Kr gas as working gas for sputtering

- Incorporation of working gas in the film is dependent on the atomic radius of the gas.
- Less incorporation of Kr atoms is reported for sputtering.

By use of Kr gas as working gas, it has the potential to decrease the resistivity of film.

Purpose of this study

• Kr gas has been used for sputtering gas
• Achievement of NiSi$_2$ film with low resistivity as low as bulk value
Experimental Procedures

- **n-Si (100) substrate**
- SPM cleaning and 1% HF treatment
- Deposition of silicide materials by using RF magnetron sputtering in Ar or Kr gas
- Silicidation by rapid thermal annealing for 1min. in N₂ ambient from 200 °C to 900 °C at 25 °C intervals
- Measurement of sheet resistance by means of four probe method

(8 sets of Si/Ni (total thickness of 10nm))

- NiSi₂
- 8 sets
- Annealing for 1min.
- A set of Si/Ni bilayer stacked for 8 sets
Resistivity of NiSi$_2$ by means of Kr sputtering

The resistivity of stacked NiSi$_2$ by means of Kr gas sputtering was equivalent to that of bulk one.

Specific resistivity of bulk NiSi$_2$: 34~50 $\mu\Omega\cdot$cm
A model of release of included gas from the deposited film

The film fabricated by use of Kr gas become low resistivity at low temperature because of the difference in the amount of incorporated gas at grain boundary and in the film (the crystal structure).
Conclusions

- Change the sputtering gas from Ar to Kr

  The resistivity of NiSi$_2$ films could be equivalent to that of bulk NiSi$_2$ (that is 34~50 $\mu\Omega$-cm) even when low temperature annealing.

  The resistance was very thermally stable between temperature ranges of 400 to 900 $^\circ$C.

Use of Kr gas when sputtering process is expected to decrease to resistivity of film and use of NiSi$_2$ films as S/D material is also expected.
Thank you for your attention

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~ Back Up ~
Intensity of Kr gas in the film

Kr 3d\textsubscript{3/2} & Kr 3d\textsubscript{5/2}  

RTA 1min. in N\textsubscript{2}

Pressure 2Pa  
Thickness 10nm

Intensity (a.u.)

Binding energy (eV)

as depo

500°C

800°C
Comparison of sheet resistance

Sheet resistance (Ω/sq.) vs. Annealing temperature (°C)

- Ni:3.0nm on n-Si(100)
- Ni:5.5nm on n-Si(100)
- RTA 1min. in N₂

NiSi₂ Target

Si/Ni stack by Ar

Si/Ni stack by Kr

n-Si(100)
### Reported Ni Silicides

<table>
<thead>
<tr>
<th>Phase</th>
<th>Resistivity ($\mu\Omega \cdot \text{cm}$)</th>
<th>Crystal structure</th>
<th>Density (g/cm$^3$)</th>
<th>$T_{\text{silicide}} / T_{\text{Ni}}$</th>
<th>Si consumption / $T_{\text{Ni}}$</th>
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<tbody>
<tr>
<td>Ni</td>
<td>7-10</td>
<td>Cubic</td>
<td>8.91</td>
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<tr>
<td>Si</td>
<td>Dopant dependent</td>
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<td>2.33</td>
<td>—</td>
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