Correlation between SiN$_x$ laser ablation and nickel silicide formation by Excimer Laser Annealing for two steps Ni-Cu metallization

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   • Performance potential

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Motivation for NiCu metallization

- Market dominating Ag pastes [SP] closer to its limits:
  - Cost reduction has a limit
  - Limitation to highest efficiencies

- Cu expected to replace Ag from 2015:
  - ideal conductor: 92% of $\sigma$(Ag)
  - cheap: 6€/kg vs 700€/kg
  - enabler for higher efficiency

p-type PERC cells > 20% achieved in 2012

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Challenges for NiCu metallization

1. ARC opening
   - Induced defects
   - Surface roughness

2. Ni deposition
   - Thickness uniformity
   - Deposition selectivity

3. Ni$_x$Si$_y$ formation
   - Crucial for adhesion
   - Ni diffusion: emitter shunts
   - Ni$_1$Si$_1$ preferred (lowest $R_{\text{contact}}$)

4. Ni/Cu/Sn plating
   - Reliability

- Focus on NiSi formation in the laser ablated areas

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**Process Flow**

- **Emitter formation**
- **Dielectric deposition**
- **Laser opening**
- **Chemical treatment**
- **Ni plating**
- **NiSi formation**

- **industrial shallow emitter**: 350nm deep
- **No drive-in steps with high-thermal oxidation**
- **no selective emitters**

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Process Flow

Emitter formation

Dielectric deposition

Laser opening

Chemical treatment

Ni plating

NiSi formation

SiNx

cSi

Standard ARC a:SiN\textsubscript{x}(H) layer

- Thickness 70nm
- PECVD RF 40 kHz
- Deposition temperature: 450°C
- Refractive index: 2.1
Process Flow

Emitter formation
Dielectric deposition
ARC opening
Chemical treatment
Ni plating
NiSi formation

<table>
<thead>
<tr>
<th>Reference</th>
<th>Talisker UV</th>
<th>Talisker Green</th>
</tr>
</thead>
<tbody>
<tr>
<td>No nitride, no ablation</td>
<td>355nm, 10ps, 200kHz</td>
<td>532nm, 10ps, 40kHz</td>
</tr>
<tr>
<td>$1/e^2 = 1.3 \pm 0.3\text{mm}$</td>
<td>$1/e^2 = 1.4 \pm 0.3\text{mm}$</td>
<td></td>
</tr>
</tbody>
</table>

Post-ablation characterization:
- Surface morphology: polished and textured cSi
- Emitter sheet resistance
- Lifetime
Laser ablated areas: morphology

- Source: UV, ps: SiNx on polished cSi

For UV, ps laser source:
- $\Phi_\text{th} \text{ ablation} \approx 0.10W$
- Suspected cSi damages $\Phi_\text{th} > 0.14W$

1/e2 beam diameter

$\Phi_1 =$ cSi damages

$\Phi_2 =$ SiNx ablation

$\Phi_3 =$ Heat-Affected Zone (HAZ)

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Laser ablated areas: morphology

- **Source**: UV, ps: SiNx on polished cSi

For UV, ps laser source:
- \( \Phi_{th} \) ablation \( \approx 0.10 \text{W} \)
- Suspected cSi damages \( \Phi_{th} > 0.14 \text{W} \)

\[ \text{Damage-free process window?} \]
Laser ablated areas: Rsheet

UV, ps

- Higher Rsheet with increasing power and decreasing speed
- Higher Rsheet after (UV, ps) vs (Green, ps) ablation
- Lower doping surface concentration
**Process Flow**

- Emitter formation
- Dielectric deposition
- Laser opening
- Chemical treatment
- Ni plating
- NiSi formation

Various cleaning solutions & bath duration:
- Clean_1 & Clean_2: Surface defects cleaning
- Clean_3: cSi light cSi etching
Laser ablated areas: Lifetime

- Improved lifetime for specific etching solution & laser ablation (highest power)
- Complete ablation mandatory for damage etch
- Deeper defects with green laser

<table>
<thead>
<tr>
<th></th>
<th>Clean_1</th>
<th>Clean_2</th>
<th>Clean_3</th>
</tr>
</thead>
<tbody>
<tr>
<td>UV, ps</td>
<td>X</td>
<td>X</td>
<td>ok</td>
</tr>
<tr>
<td>Green, ps</td>
<td>X</td>
<td>X</td>
<td>light</td>
</tr>
</tbody>
</table>
Laser ablated areas: Lifetime

Deep defects: Lifetime vs etching depth

- Source: UV, ps laser
- Clean + new SiN deposition

- Improved lifetime with etching depth
- Defects deeper than emitter for $P > 0.22$W (300-600nm)
  - Lower laser power to be further studied ($P \approx 0.12$W)

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Process Flow

- Emitter formation
- Dielectric deposition
- Laser opening
- Chemical treatment
- Ni plating
- NiSi formation

- Uniform deposition required
  - PVD, 50nm
**Process Flow**

- **Emitter formation**
- **Dielectric deposition**
- **Laser opening**
- **Chemical treatment**
- **Ni plating**
- **NiSi formation**

Excimer Laser annealing: 308nm, 150ns
- Large area beam >cm², with top-hat beam profile
- NiₓSiᵧ formation w/o emitter shunting [1]
- No passivation damages [2]

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Reflectivity at λ=308nm [%]

![Graph](image-url)
1) NiSi formation on bare cSi (No SiN\textsubscript{x} ablation)

- Smooth and continuous Ni\textsubscript{x}Si\textsubscript{y} layer from top to valleys of the pyramids
- With increasing ELA Energy Density:  
  - Thicker Ni\textsubscript{x}Si\textsubscript{y} layer
  - Wider dispersion
Nickel silicidation

2) NiSi formation in ARC openings

• Typical Rsheet decrease with increasing ELA energy density
• Formation of various Ni$_x$Si$_y$ silicide
• Nitride = barrier layer to NiSi formation
• After green, ps laser ablation:
  • Similar trend as reference
  • Lower Rsheet for lower laser power

Effect of the surface doping concentration?
2) **NiSi formation in ARC openings**

- Effective NiSi formation all over the surface
- Similar NiSi thickness dispersion
- Conditions of 1) ablation, 2) cleaning/etching and 3) silicidation interdependent

- Laser ablation:
  - No complete ablation w/o induced defects into cSi

- Cleaning/etching
  - Etching step required for damage removal
  - Deeper emitter required?
  - Partial ablation combined with etching could lead to no defects, esp. UV laser

- NiSi formation by ELA:
  - Effective NiSi formation on textured silicon and laser ablated areas
  - Thin NiSi layers (<200nm)

- Outlooks:
  - LIP-Ni thickening + ECD-Cu: $R_{\text{contact}}$ & adhesion measurements
  - Lower laser ablation power with UV, ps and adequate cleaning solution
  - New laser source enabling ablation + doping (Selective emitter approach)
  - Integration at cell level
Thank you for your attention

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