Ultrarapid Thermal Annealing Induced by DC Arc Discharge Plasma Jet Irradiation

S. Higashi, H. Kaku, T. Okada, T. Yorimoto, H. Murakami and S. Miyazaki,
Graduate School of Advanced Sciences of Matter Hiroshima University, Japan

Outline

1. Background and Objectives
2. Experimental
   - Generation of Thermal Plasma Jet (TPJ) and Its Application to Ultrarapid Thermal Annealing (URTA)
3. Results and Discussion
   - Noncontact Temperature Measurement Technique with Millisecond Time Resolution
4. Summary

Background & Objectives

- Ultrarapid Thermal Annealing (URTA) is one of the key process technologies
- Formation of Si nanocrystals in SiOx
- A Noncontact Temperature Measurement Technique

Objectives of This Work are...

- To Develop a New URTA Technique and a Temperature Measurement Technique with Millisecond Time Resolution
- To Demonstrate the Application of URTA to Electronic Device Fabrication

About Thermal Plasma Jet (TPJ)

- Thermal Plasma Source with Simple Structure
- Low Cost URTA Processing

Experimental

Application of TPJ to RTA

Oscillation in Transient Reflectivity

Produce Laser (CW)

Noncontact Temperature Measurement Technique

Procedure of Analysis

- 2-3 Heat Diffusion Simulation
- Optical Simulation
- Multiple reflection and Interference

Temporal Variation of Temperature
Impurity Concentrations in TPJ Crystallized Si Films

- Total Reflection X-Ray Fluorescence (TXRF)
- Secondary Ion Mass Spectroscopy (SIMS)

Application to Si Wafer

- Oscillation of Transmissibility
- Simulated Transient Reflectivity

Crystallization of a-Si Films by TPJ Irradiation

- Crystallinity & Process Window
- Surface Morphology

OES of Ar Thermal Plasma Jet

- Strong Emission Lines From Atomic Ar are Observed in NIR
- No Emission Lines From Cu was Detected

Experimental

- Application of TPJ to RTA
- Oscillation in Transient Reflectivity

Annealing Condition & Surface Temperature

<table>
<thead>
<tr>
<th>Annealing Condition &amp; Surface Temperature</th>
<th>SiO2 Glass Sub.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Reflection X-Ray Fluorescence (TXRF)</td>
<td>Impurity Concentrations in TPJ Crystallized Si Films</td>
</tr>
<tr>
<td>Secondary Ion Mass Spectroscopy (SIMS)</td>
<td>Application to Si Wafer</td>
</tr>
</tbody>
</table>

Crystallized Si Films Detected from TPJ:

- Contamination was Below Detection Limit.

Experimental set up for thermal plasma jet (TPJ) annealing. Preformed a-Si film was exposed to the plasma and step & repeat method was performed.
Transfer Characteristics
Defect density in Si Films decreases with annealing temperature.

Carrier Concentration in TPJ crystallized Si Films increases with increasing temperature.

Electrical Conductivity as functions of annealing temperature:

Electrical Conductivity of TPJ crystallized lightly-doped Si Films
Average P Concentration: $4.3 \times 10^{17} \text{ cm}^{-3}$

- Carrier Concentration in TPJ crystallized Si Films increases with increasing temperature.
- Defect density in Si Films decreases with annealing temperature.

Electrical Properties of TPJ Crystallized Si Films
Defect Reduction by Hydrogen Plasma Treatment @ 250°C, 60s
Average P Concentration: $4.3 \times 10^{17} \text{ cm}^{-3}$

- TPJ crystallized films have lower defect density compared to ELA films.
- Output characteristics and Process Flow for ELA and TPJ Si Films.

TFT Fabrication Process Flow

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>a-Si Deposition</td>
</tr>
<tr>
<td>2</td>
<td>Crystallization</td>
</tr>
<tr>
<td>3</td>
<td>Gate Electrode Formation</td>
</tr>
<tr>
<td>4</td>
<td>Gate SiO₂ Formation</td>
</tr>
<tr>
<td>5</td>
<td>Gate Oxidation in Oxygen Reactive</td>
</tr>
<tr>
<td>6</td>
<td>Defect Reduction</td>
</tr>
</tbody>
</table>

TFT Performances

Output Characteristics
- Drain Current ($I_D$): $62 \mu A$ @ $V_D = 6 \text{ V}$
- Drain Current ($I_D$): $3.4 \mu A$ @ $V_D = 4 \text{ V}$
- $g_m$ (transconductance): $>10^4 \text{ S}$
- Process Temperature: $280 \text{ °C}$
Formation of Nanocrystals in SiOx

Raman Scattering Spectra of TPJ Annealed SiOx Films
PL Spectra of TPJ Annealed SiOx Films (excitation : 325 nm)

Ramanshift (cm⁻¹)
550 700 600 500 400 650 450
as deposited
1200 mm/s, 1444K
1000 mm/s, 1566K
800 mm/s, 1673K
700 mm/s, 1673K

Wavelength (nm)
600 800 1000 1200
1200 mm/s, 1212K
1000 mm/s, 1369K
800 mm/s, 1527K
700 mm/s, 1664K
As deposited

Conclusions

1. A New RTA Technique Utilizing Thermal Plasma Jet (TPJ) and Noncontact Temperature Measurement Technique with Millisecond Time Resolution have been Developed.
2. Substrate Surface Temperature is Controlled From 960 to 1781 K with Typical Annealing Duration of 3 ms.
3. Amorphous Si (a-Si) Films are Crystallized Through Solid Phase or Melting & Resolidification Depending on the Annealing Condition.
4. TFTs Fabricated Using TPJ Crystallization Technique Show Good Electrical Performance with $\mu_E$ of 62 cm²/Vs and $V_{th}$ of 3.4 V.
5. Nano- and Micrometer Sized Si Crystalline Growth is Achieved by TPJ Annealing of SiOx Films.