Ex-situ Ohmic Contacts to n-InGaAs Prepared by Atomic Hydrogen Cleaning

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Issue:
• InP HBTs need contact resistivity ($\rho_c$) < 2x10⁻⁸ Ω·cm² for $f_t$ and $f_{max}$ > 1 THz
• ~10⁻⁸ Ω·cm² $\rho_c$ with in-situ contacts, but process flows often demand ex-situ contacts
• Unpredictable native oxides; High temperature processing

Fundamental Scaling Laws:
To double device bandwidth:
• Cut transit time 2x:
  – Reduce thickness 2:1 😊
  – Capacitance increases 2:1 😞
• Cut RC delay 2x
  – Scale all resistivities by 4:1

Our Approach:
• Surface preparation by atomic hydrogen cleaning
• Increased doping

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**Experimental Details:**
- Highly doped n-In\textsubscript{0.53}Ga\textsubscript{0.47}As by solid source MBE
- Surface exposed to air
- Atomic hydrogen cleaning in MBE
- Surface observed under RHEED before metal deposition
- Transmission Line Model (TLM) for contact resistance measurement

**Experimental Results with Mo Contact Metal**

<table>
<thead>
<tr>
<th>Process</th>
<th>Surface Preparation</th>
<th>$\rho_c$ ($\Omega \cdot \mu m^2$)</th>
<th>$\rho_h$ ($\Omega \cdot \mu m$)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>In-situ</em></td>
<td>As grown</td>
<td>1.0 ± 0.6</td>
<td>4.3 ± 2.6</td>
</tr>
<tr>
<td><em>Ex-situ</em> (air exposure)</td>
<td>H clean (MBE)</td>
<td>1.3 ± 0.5</td>
<td>5.2 ± 3.0</td>
</tr>
<tr>
<td></td>
<td>Dil. HCl</td>
<td>2.3 ± 1.0</td>
<td>9.0 ± 3.4</td>
</tr>
</tbody>
</table>

- Electron concentration, $n = 5 \times 10^{19}$ cm$^{-3}$
- Mobility, $\mu = 770$ cm$^2$/Vs
- Sheet Resistance, $R_{sh} = 15$ ohm/□ (100 nm thick film)

**H cleaned (MBE) contacts are comparable to in-situ contacts**
Thermal Stability:
• Contacts annealed under N₂ flow at 300 and 400 °C for 1 minute duration
• Low resistivity maintained after anneal: \(1.3 \pm 0.5\) \times 10^{-8} \Omega\text{-cm}^2

Conclusions:
• Atomic hydrogen effectively cleans air-exposed semiconductor surfaces
• \(\rho_c \sim (1.3 \pm 0.5) \Omega\text{-}\mu\text{m}^2\) for atomic hydrogen cleaned Mo-nInGaAs contacts
• Contact resistivity comparable to in-situ Mo-nInGaAs contacts
• Mo contacts are thermally stable on InGaAs up to 400 °C

✓ Contacts suitable for THz transistors

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