III – V Semiconductor Etching
Process Quality Rather Than Quantity

Alan Webb
(formally of Plessey, GEC, Marconi, Bookham, Oclaro etc......)

Wednesday 12th October 2016

Ricoh Arena, Coventry, UK
Part of The 7th Vacuum Symposium UK
Caswell, Northamptonshire
Caswell Science and Technology Park
Optoelectronics

- Lasers
- Modulators
- Amplifiers
- Detectors
Laser Fabrication

- Purchased bare wafer
- MOVPE Growth (2 stages)
- Gratings fabrication
- MOVPE Overgrowth
- Dielectric Deposition & Etch
- Metal Deposition
- Photolithography
- Plan view of chip
- Cross section of Ridge
- 3” wafer: ~2500 die
- Bar Cleave / Facet coating
- Wafer Thinning
- Etch & Dep Tools
- Photolithography Tracks
- MOVPE Reactor
- Completed Laser Chip
- Bare Wafer
A Bonded Chip
III - V Dry Etching

GaInAsP material system grown on InP

Halogens : eg. Cl Br I

or CH₄ / H₂
Developing the Process

It is difficult to develop a process progressing through several different material structures and maintain complete control.

It is even more difficult with the restraint of the peripheral architecture on the rest of the wafer.

However, it can be done.
Cl$_2$ / N$_2$ Etch
Dry Etched Grating

Production Grating (30um wide)
700μC/cm² Dose
125°C Bake for 1min.

Mag = 150.00 K X
EHT = 5.00 kV
WD = 5 mm
Signal A = InLens
Photo No. = 3002
Date: 27 Apr 2004
Time: 12:58:19
Grating Fabrication

Low power oxygen RIE to de-scum
AFM used to assess mark space ratio prior to etch
Target mark/space is 1±0.3
TEM micrograph showing an overgrown DFB laser grating (grating period ~240nm)
Dry Etch Requirements

- Gentle
- Precise
- Controllable
- Physical + chemical
- Methane (CH$_4$) + Hydrogen (H$_2$)
Etch Mechanism

- Etching and Deposition
- Polymer formation
- Polymer removal
- Gas mixture critical
- Elimination of residuals
- Vacuum quality
$CH_4 + H_2$

- Large amount of $H_2$ to initiate breakdown
- Cracking of $CH_4$ results in polymer
- Contamination control
- Vacuum quality
- Low power plasma - dimension control
Processes to Consider

Simplified with no other interference !!!

O₂ RIE

\[ 4C + 3O_2 \Rightarrow 2CO_2 + 2CO \]

\[ CH_3 + 2C + 3O_2 \Rightarrow H_2O + OH + 2CO_2 + 2CO \]

The III – V semiconductor reaction :

\[ \text{InP} + CH_4 + H_2 \Rightarrow \text{methyl / ethyl (Gp III)} + PH_3 \]

\[ \text{InP} + 3CH_4 + H_2 \Rightarrow \text{In(CH}_3\text{)}_3 + PH_3 + H_2 \]

GaAs etc
Residual Gases

- The number of unwanted atoms and molecules within the environment can have a detrimental effect on dry processing.

- Both gas phase and surface effects can occur, which produce unwanted results.

- Poor quality etching could be the result.
Contamination Control

- Unwanted Reactions
- OH
- H₂O
- O
- O₂
- CO
- Monitor N₂ and Ar
In Situ Monitoring

Mass Spectrometer Monitoring of Methane Hydrogen Etching for Grating Fabrication
Mass Spectrometry - Raw Data
High resolution Mass Scan

High Resolution Mass Scan

residual gases - air leak

m / q

pp
## Species to Monitor?

<table>
<thead>
<tr>
<th>Species</th>
<th>Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>1</td>
</tr>
<tr>
<td>H₂</td>
<td>2</td>
</tr>
<tr>
<td>CH₄</td>
<td>16</td>
</tr>
<tr>
<td>O</td>
<td>16</td>
</tr>
<tr>
<td>O₂</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td></td>
</tr>
<tr>
<td>CH₃</td>
<td>15</td>
</tr>
<tr>
<td>COH</td>
<td>29</td>
</tr>
<tr>
<td>SiH</td>
<td></td>
</tr>
<tr>
<td>OH</td>
<td>17</td>
</tr>
<tr>
<td>H₂O</td>
<td>18</td>
</tr>
<tr>
<td>CO</td>
<td>28</td>
</tr>
<tr>
<td>CO₂</td>
<td>44</td>
</tr>
<tr>
<td>SiO</td>
<td></td>
</tr>
<tr>
<td>Ar</td>
<td>40</td>
</tr>
</tbody>
</table>
Species to Monitor?

Dominant species from etchant or reactions or important species to realise precise control?

Are they the same?
In - Situ Plasma Monitoring
A Methane (CH4) Hydrogen (H2) Etch Process

In-situ Process Monitoring

![Graph showing gas concentrations over time](image-url)
HBr Ridge Etch
Bromine has 2 stable isotopes: 79Br (50.69%) and 81Br (49.31%).
Bromine has 2 stable isotopes: 79Br (50.69%) and 81Br (49.31%).
Developing the Process for Manufacture

Developing a process is even more difficult for reproducibility and repeatability, such that it is the same for wafer to wafer, for batch to batch, hour by hour, day by day, because that is what manufacturing demands !!!
HBr Batch Processing

Etch process stablisation
Complex Features Realised
Requirements

Precise control of the vacuum, residual gas and the plasma environment are all important in being able to reliably reproduce complex features within optoelectronic devices.

These are the fundamental building blocks of many types of integrated chips.
Chip-on-tile for angled waveguide output
Questions?