The Investigation of $\text{In}_{0.22}\text{GaAs/GaAs}$ Multi-quantum Wells Solar Cells

Yan-Kuin Su, Tzung-Han Wu, Shyh-Jer Huang, Hsin-Chieh Yu, Chiao-Yang Cheng, Hsi-Jung Wu
Outline

• Introduction
• Experiment
• Results and discussion
• Conclusion
Introduction

The gap between GaAs and Ge is too large.
✓ Energy loss → Heat
Introduction

- Advantages of quantum well solar cells
  - Easy adjustment of absorption range
  - Apply to MJSC
  - Better temperature coefficient
    → Beneficial to concentrator system

- When e-h pairs generated
  - Radiative recombination
  - Nonradiative recombination
  - Escape from the well states
    - Thermionic emission
    - Field-assisted tunneling
Experiment

- MOVPE (AIXTRON 200) horizontal reactor
- Substrate: (100) n$^+$-GaAs
- Precursors
  - TMGa, TMIn, AsH$_3$, DMHy, DEZn, Si$_2$H$_6$
- Characterization Techniques
  - HRXRD, PL, AFM, etc.

**QWs Structure**

![QWs Structure Diagram]

- GaAs barrier
- InGaAs well
- GaAs Sub.

\[ \times 3 \]
**Results and Discussion**

### Growth in low V/III ratio

<table>
<thead>
<tr>
<th>Sample</th>
<th>QW1</th>
<th>QW2</th>
<th>QW3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Growth Temperature</td>
<td>650°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TMIn/III</td>
<td>0.1842</td>
<td>0.2927</td>
<td>0.4294</td>
</tr>
<tr>
<td>V/III</td>
<td>6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- 0.44 nm
- 1.36 nm
- 2.12 nm
Results and Discussion

Comparison of growth in low and high V/III ratio

<table>
<thead>
<tr>
<th>Sample</th>
<th>QW2</th>
<th>QW4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Growth Temperature</td>
<td>650°C</td>
<td></td>
</tr>
<tr>
<td>TMIn/III</td>
<td>0.2927</td>
<td></td>
</tr>
<tr>
<td>V/III</td>
<td>6</td>
<td>100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PL measurement</th>
<th>QW2</th>
<th>QW4</th>
</tr>
</thead>
<tbody>
<tr>
<td>PL Intensity (a.u.)</td>
<td>$6.1 \times 10^7$</td>
<td>$2.5 \times 10^8$</td>
</tr>
<tr>
<td>PL FWHM (meV)</td>
<td>56</td>
<td>14</td>
</tr>
</tbody>
</table>

Comparison of growth in low and high V/III ratio

- Sample QW2: 1.36 nm
- Sample QW4: 0.45 nm

Graphs showing intensity versus Omega-2Theta for QW2 and QW4.
Results and Discussion

**Growth in high V/III ratio**

<table>
<thead>
<tr>
<th>Sample</th>
<th>QW4</th>
<th>QW5</th>
<th>QW6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Growth Temperature</td>
<td>650°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TMIn/III</td>
<td>0.2927</td>
<td>0.3901</td>
<td>0.4945</td>
</tr>
<tr>
<td>V/III</td>
<td>100</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Growth in high V/III ratio

- TMIn/III: 0.2927 for QW4, 0.3901 for QW5, 0.4945 for QW6
- V/III: 100

Intensity vs. wavelength graph

- QW4: 0.45 nm
- QW5: 1.38 nm
- QW6: 7.19 nm
Results and Discussion

**Optimization of optical quality**

<table>
<thead>
<tr>
<th>Sample</th>
<th>QW7</th>
<th>QW8</th>
<th>QW9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Growth</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td></td>
<td></td>
<td>650°C</td>
</tr>
<tr>
<td>TMIn/III</td>
<td></td>
<td>0.3901</td>
<td></td>
</tr>
<tr>
<td>V/III</td>
<td>50</td>
<td>200</td>
<td>242</td>
</tr>
</tbody>
</table>

**PL Intensity (a.u.)**

- **Wavelength (nm)**: RT
- **Intensity (a.u.)**
- **Omega-2Theta (sec)**
- **Wavelength (nm)**
- **Intensity (a.u.)**

- **QW7**: 2.39 nm
- **QW8**: 1.34 nm
- **QW9**: 1.26 nm

**QW9 ➔ Indium content = 22%**
Results and Discussion

In$_{0.22}$GaAs/GaAs quantum well solar cells

<table>
<thead>
<tr>
<th>Sample</th>
<th>SC1</th>
<th>SC2</th>
<th>SC3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pairs</td>
<td>10</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>InGaAs well</td>
<td>16nm</td>
<td>8nm</td>
<td>4nm</td>
</tr>
<tr>
<td>GaAs barrier</td>
<td>40nm</td>
<td>20nm</td>
<td>10nm</td>
</tr>
<tr>
<td>Total InGaAs</td>
<td>160nm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Results and Discussion

- **illuminated J-V**
- **EQE**
- **Dark I-V**

Sample | $V_{oc}$ (V) | $J_{sc}$ (mA cm$^{-2}$) | FF (%) | Efficiency (%) |
--- | --- | --- | --- | --- |
SC1 (10 QW) | 0.34 | 9.52 | 46.31 | 1.499 |
SC2 (20 QW) | 0.43 | 13.63 | 52.33 | 3.066 |
SC3 (40 QW) | 0.58 | 15.9 | 71.07 | 6.552 |

Extend to 1100 nm
Conclusion

- The growth condition of In$_{0.22}$GaAs/GaAs QWs
  - TMIn/III ↑ → In content ↑ & strain ↑
  - Roughness ↑
  - Optical and crystalline quality ↓
  - High V/III ratio can improve the above problems.

- In$_{0.22}$GaAs/GaAs quantum well solar cells
  - The pairs of QWs ↑ → Conversion efficiency ↑ (1.499% → 6.552%)
  - The absorption edge can be extended to about 1100 nm.
Thanks for Your Attention!!