WAFER-SCALED SYNTHESIS OF 2D-MoS$_2$ BY COLD-WALL CVD

Dr. Zhen-Yu Juang, CTO
SulfurScience Technology Co. Ltd.
<table>
<thead>
<tr>
<th>Material</th>
<th>Process</th>
<th>Temp. (°C)</th>
<th>No. of layers</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>MoS₂</td>
<td>MoO₃ and S powder with seeding</td>
<td>650</td>
<td>Monolayer</td>
<td>Lee et al. (2012); Ling et al. (2014)</td>
</tr>
<tr>
<td>MoS₂</td>
<td>MoO₃ and S powder</td>
<td>700</td>
<td>Monolayer</td>
<td>van der Zande et al. (2013)</td>
</tr>
<tr>
<td>MoS₂</td>
<td>MoO₃ nanoribbons and S powder</td>
<td>850</td>
<td>Monolayer</td>
<td>Najmaei et al. (2013)</td>
</tr>
<tr>
<td>MoS₂</td>
<td>MoO₃ and S powder</td>
<td>850</td>
<td>Monolayer</td>
<td>Ji et al. (2014)</td>
</tr>
<tr>
<td>MoS₂</td>
<td>MoO₃ and S powder</td>
<td>700</td>
<td>Monolayer</td>
<td>Dumcenco et al. (2015)</td>
</tr>
<tr>
<td>MoS₂</td>
<td>MoO₃ and H₂S gas</td>
<td>600</td>
<td>Monolayer</td>
<td>Kim et al. (2016)</td>
</tr>
<tr>
<td>MoS₂</td>
<td>MoO₃ and S powder</td>
<td>850</td>
<td>Mono-, bi-, and trilayer</td>
<td>Jeon et al. (2015)</td>
</tr>
<tr>
<td>MoS₂, WS₂</td>
<td>Mo(CO)₆, W(CO)₆, and diethyl sulfide</td>
<td>550</td>
<td>Monolayer</td>
<td>Kang et al. (2015)</td>
</tr>
</tbody>
</table>
High temperature zone for the precursor with high melting temperature

Low temperature zone for the precursor with low melting temperature

High temperature zone for MoS$_2$ synthesis
Low temperature zone for the precursor with low melting temperature

High temperature zone for both high- MP precursor MoS$_2$ synthesis
<table>
<thead>
<tr>
<th>Material</th>
<th>Process</th>
<th>Temp. (℃)</th>
<th>No. of layers</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>MoS₂</td>
<td>MoO₃ and S powder with seeding</td>
<td>650</td>
<td>Monolayer</td>
<td>Lee et al. (2012); Ling et al. (2014)</td>
</tr>
<tr>
<td>MoS₂−WS₂, MoSe₂−WSe₂</td>
<td>Mo(CO)₆, W(CO)₆, and diethyl sulfide</td>
<td>550</td>
<td>Monolayer</td>
<td>Kang et al. (2015)</td>
</tr>
<tr>
<td>MoS₂−WS₂, MoSe₂−WSe₂</td>
<td>WO₃, MoO₃ and S powder</td>
<td>650 - 750</td>
<td>Monolayer</td>
<td>Zhang et al. (2015)</td>
</tr>
</tbody>
</table>

- The temperatures for precursors and MoS₂ synthesis are commonly different.
- The m.p. of metal oxide precursors are normally higher than that of MoS₂ synthesis.

• Individually control the temperature of different heating zones are necessary.
PROCESS SCALE-UP

Hot-wall CVD

Wafer size for HW-CVD is limited!

http://funny-hamster.blogspot.tw/2016/01/can-hamster-eat-carrots.html
PROCESS COMPATIBILITY

Hot-wall CVD → Load-lock chamber → Back-end process

Graphene 2017
7th edition of the largest European Conference on Innovation in Graphene and 2D Materials
Cold-wall CVD
High temperature zone for the precursor with high melting temperature

Low temperature zone for the precursor with low melting temperature

High temperature zone for MoS₂ synthesis
SUMMARY

Disadvantages of HW-CVD
• Difficulty of temperature control
• Difficulty of scaled-up
• Less of compatibility

Hot-wall CVD

Cold-wall CVD

CW-CVD allows
• Precisely control the temperatures of separated heating zones
• Large wafer available
• Flexibility and compatibility to industry specifications
ACKNOWLEDGEMENT

Prof. Lain-Jong Li

Prof. Wen-Hao Chang

Dr. Ming-Yang Li

Dr. Yung-Huang Chang

Dr. Chia-Chin Cheng

Li-Syuan Lu

Chun-Yi Kuo

Thanks for your attentions