High Quality Graphene Formation on Improved 3C-SiC Epilayer

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With its excellent electronic, mechanical, photonic properties and 2D nature, graphene is believed to be able to push the semiconductor industry into the beyond-CMOS era. Among all the synthesis methods, the Graphene-On-Silicon (GOS) technology is attractive thanks to its low production cost, high scalability, and easiness for NEMS elaboration. More specifically, this graphene is formed by thermally decomposing thin 3C-SiC epilayer grown on Si substrate. However, the graphene formed from the GOS suffers from mediocre quality. Aiming at the betterment of this process, we investigate the influence of the SiC layer quality on graphene. In this study, we compare graphene growth on SiC epilayers grown by different epitaxial growth techniques (MBE&CVD). The properties of the SiC films are characterized before graphitization using XRD, AFM, SEM and LEED to reveal the difference in the film quality. Then we apply the same graphitization process to both layers and confirm the formation of graphene using LEED. The graphene quality is measured by the intensity ratio between D band and G band ($I_D/I_G$) of the Raman spectrum. As a result, we have found out that the morphology of the SiC surface plays a crucial role in the graphene formation. And we have obtained a much higher graphene quality using CMP treated SiC epilayer. Additionally, the cooling speed after graphitization is also studied and proven to influence the graphene quality.
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I. Introduction

I.1 What is Graphene?
- Atomically thick layer of sp² bonded carbon atoms arranged in a honeycomb lattice
- Excellent electronic, mechanical, and photonic properties
- Possible applications include beyond-CMOS technology, ultra fast FET, NEMS sensors, etc.

I.2 Methods

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
<th>Schematic</th>
</tr>
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<tbody>
<tr>
<td>Exfoliation</td>
<td>• High Quality</td>
<td>• Random production</td>
</tr>
<tr>
<td>Chemical Vapor Deposition</td>
<td>• Fairly high quality</td>
<td>• Complex process</td>
</tr>
<tr>
<td></td>
<td>• Very large scale</td>
<td>• Contamination</td>
</tr>
<tr>
<td>Epitaxial Growth (4H/6H-SiC)</td>
<td>• Fair Quality</td>
<td>• Cost of SiC</td>
</tr>
<tr>
<td></td>
<td>• Water scale production</td>
<td>• Poor availability of large scale production</td>
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</table>

Graphene-On-Si (GOS)

GOS possible because of the similarity between 3C & 6H

Advantages
- Cheap, scalable
- Less step-bunching than bulk

Challenges
- Poor quality (low I_d/I_g ratio in Raman Spectrum)

Why this difference?
1) Surface roughness
2) Low structural quality
3) Excessive Si out-diffusion

I.3 Goal
Form high quality graphene using SiC epilayer improved according to the aspects listed above

II. Experiments

Part 1: Comparison between classic sample with improved sample
- AFM – Surface morphology (atomic structure)
- SEM – Electronic image of surface morphology
- XRD – Crystalinity (orientation) structural quality

Part 2: Graphitization
- Annealing: 1250°C, 60 minutes, 10⁻¹⁰ mbar, immediate cooling

Part 3: Comparison between EG formed on classic sample and EG formed on new improved sample
- LEED – Confirms graphene formation

Solution
Controlled Cooling

Why?
Abrupt Cooling

Assumptions
- L_d/L_g = 0.5

III. Results and Discussion

III.1 Pre-Graphitization

Classic
- RMS: 5.9nm
- Thickness ~100nm

Improved
- RMS: 0.8nm
- Thickness ~1000nm

III.2 Post-Graphitization Characterization

Classic
- Graphene Formation!

Improved
- LEED
- XPS
- GOS

Why?
- Abrupt Cooling

Solution
- Controlled Cooling
- L_d/L_g = 0.5

Why? (vs.

Jiao, Naoki, Hirokazu, Mika, and Maki.

IV. Conclusion

1) Thick SiC
- Helps seal Si out diffusion
- Low surface roughness
- Good structural quality

2) Strain relaxation (cracks) is most crucial to EG quality, and is directly related to the cooling parameters

3) Upgraded GOS quality is achieved with improved SiC epilayer and the specified cooling process, leading to a 50% reduction in the L_d/L_g ratio!

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