Investigation of graphene on SiC under neutron irradiation by Raman Spectroscopy

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Introduction

Impact of neutron radiation on QFS graphene

- We have fabricated hydrogen-intercalated QFS **graphene** on semiinsulating high-purity **4H-SiC**(0001)
- Passivated it with an $\mathbf{Al_2O_3}$ layer

- Exposed it to a **fast-neutron** fluence of ≈6.6×10^{17} cm^{-2}

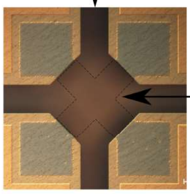

Figure 1. Nomarski interference contrast optical image of the test structure in the form of a Hall effect sensor featuring a cross-shaped 100 µm × 300 µm epitaxial CVD QFS-graphene mesa on 4H-SiC(0001)

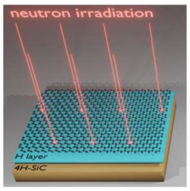

Figure 2. Schematic of the sample neutron irradaition process

Micro-Raman characterization

- **Backscattering geometry** of the Renishaw inVia confocal microscope.
- **532-nm** (2.33 eV) line of a continuous-wave Nd:YAG laser and the Andor Newton CCD detector.
- Three types of rectangular **3721-point 30 µm × 30 µm** maps were recorded.
- For high imaging resolution the lateral steps in both X and Y directions were set at **0.5 µm**.

The first one was kept at the **graphene level** (1310 cm^{-1} to 2825 cm^{-1}).

The second one, spectrally identical, was collected 4 µm **below the SiC**(0001) **surface.**

The third one was collected slightly **below graphene level** (-450 cm^{-1} and 1410cm^{-1}).

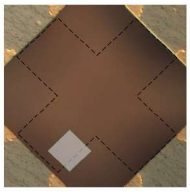

Figure 3. Close-ups of the graphene mesa. Marked in white is the region intended for high-resolution Raman mapping.

Results and Discussion

The **3721-point 30 µm × 30 µm** post-NR Raman map of the **2D band width** (Full Width at Half Maximum) is presented in Fig. 4. It features a 5 µm × 30 µm horizontal reference stripe collected outside of the graphene mesa.

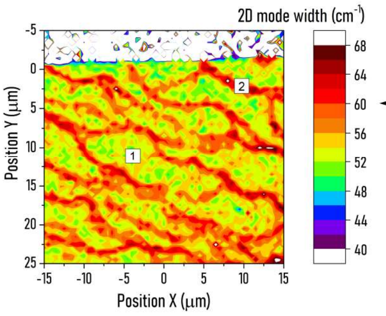

Figure 4. High-resolution post-neutron-irradiation Raman map (2D band width).

Within the **terraces,** the **2D mode** is typically **46–58 cm^{-1}** wide and its width increases to **58–68 cm^{-1}** at the **step edges**, as this area is traditionally associated with additional graphene inclusions located beneath the continuous sheets.

Then, datapoints from Fig. 5 classified as either terrace-related (green) or step-edge-related (red) were assigned their 2D band width and illustrated in the form of histograms in Fig. 6. Within the **terraces,** the average **2D** mode is **54 cm^{-1}**, and it rises to **60 cm^{-1}** on average at the **step edges**.

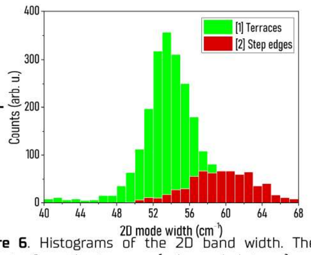

Figure 6. Histograms of the 2D band width. The data originate from the terraces (color-coded green) and step edges (color-coded red) and correspond to Fig. 5.

Combined the data presented in Fig. 5 and Fig 6. , the histograms suggest that the **terraces** are decorated with a **graphene bilayer** and the **step edges** with a **trilayer**.

First, in order to interpret **the number of graphene layers**, we focused on the substrate-related longitudinal optical (**LO**) A_1 **mode** at **964 cm^{-1}**. Three areas from Fig. 4 were chosen to have their **relative intensity** of the **LO mode** presented in the form of histograms:

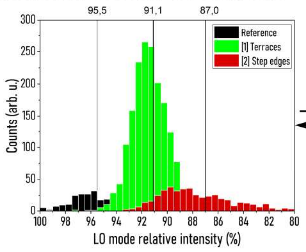

Figure 5. Histograms of the 4H-SiC longitudinal optical (LO) A1 mode relative intensity at 964 cm^{-1} within the terrace (color-coded green) and step edge (color-coded red) regions.

The histograms were plotted against theoretical lines expected for **single**, **two**, and **three** layers of graphene.

However, in both cases, the defect density was seven orders of magnitude lower than the fluence, which indicates that graphene has a small cross-section for neutrons.

Within the **terraces**, the **intensity ratio** of the **D** and **G modes** is typically **0.15**, which translates into the average distance between defects **Ld** equal **31 nm** and a **defect concentration** of **3.3× 10^{10} cm^{-2}**.

Interestingly, at the **step edges** the **intensity ratio** of the **D** and **G modes** is on average **0.19**, as if the **steps** were **more affected** by the **neutron irradiation**. This value suggests an average inter-defect distance of **28 nm** and a **defect concentration** of **4.2 × 10^{10} cm^{-2}**.

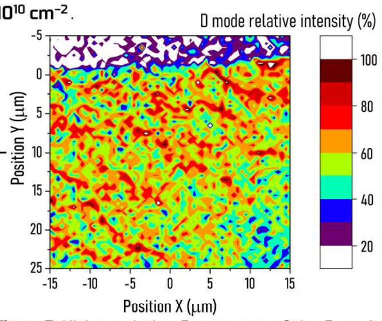

Figure 7. High-resolution Raman map of the D mode relative intensity. The map corresponds to Fig. 4.

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Conclusions

- The **terraces** are decorated with a **graphene bilayer** and the **step edges** with a **trilayer**.
- It is evident that the neutron flux penetrated through the 100-nm-thick atomic-layer-deposited Al2O3 passivation layer to reach the sensor's active region and possibly deeper.
- The **QFS graphene** appears to be only **moderately affected** by the **irradiation dose,** which is the first direct experimental support for the structural resistance of graphene to NR and consequently of the entire Al2O3 /GR/SiC system.
- The effect was more pronounced within the SiC **step edges** than the terraces.

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Acknowledgements

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