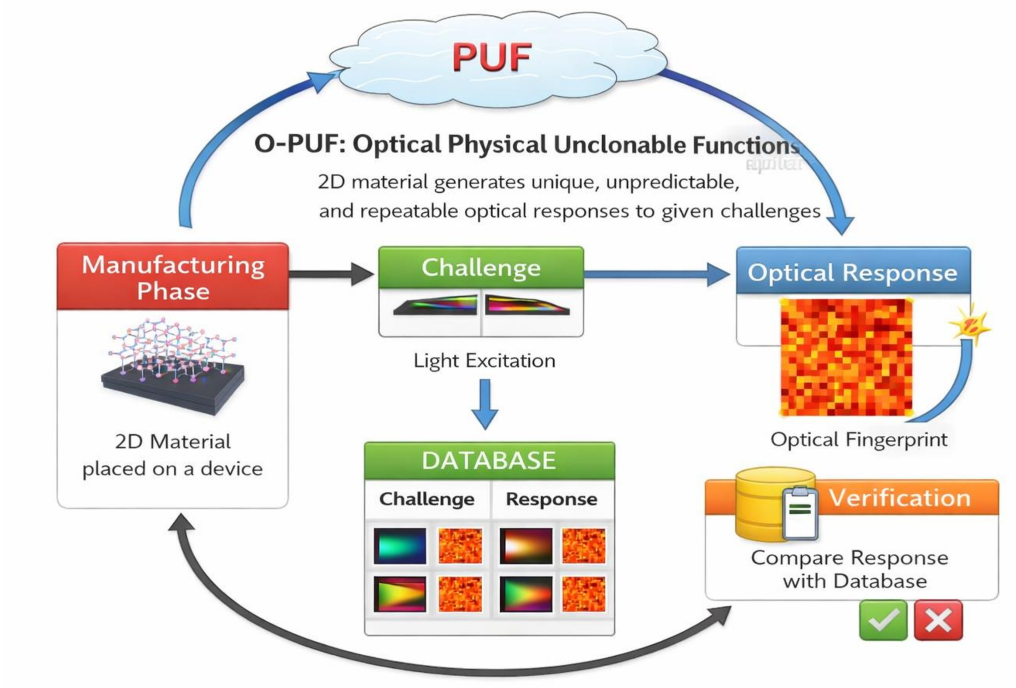
Graphene-MoS_2 van der Waals Heterostructure applied for optical physical unclonable functions

Fangling Wu

Physics | Lancaster University

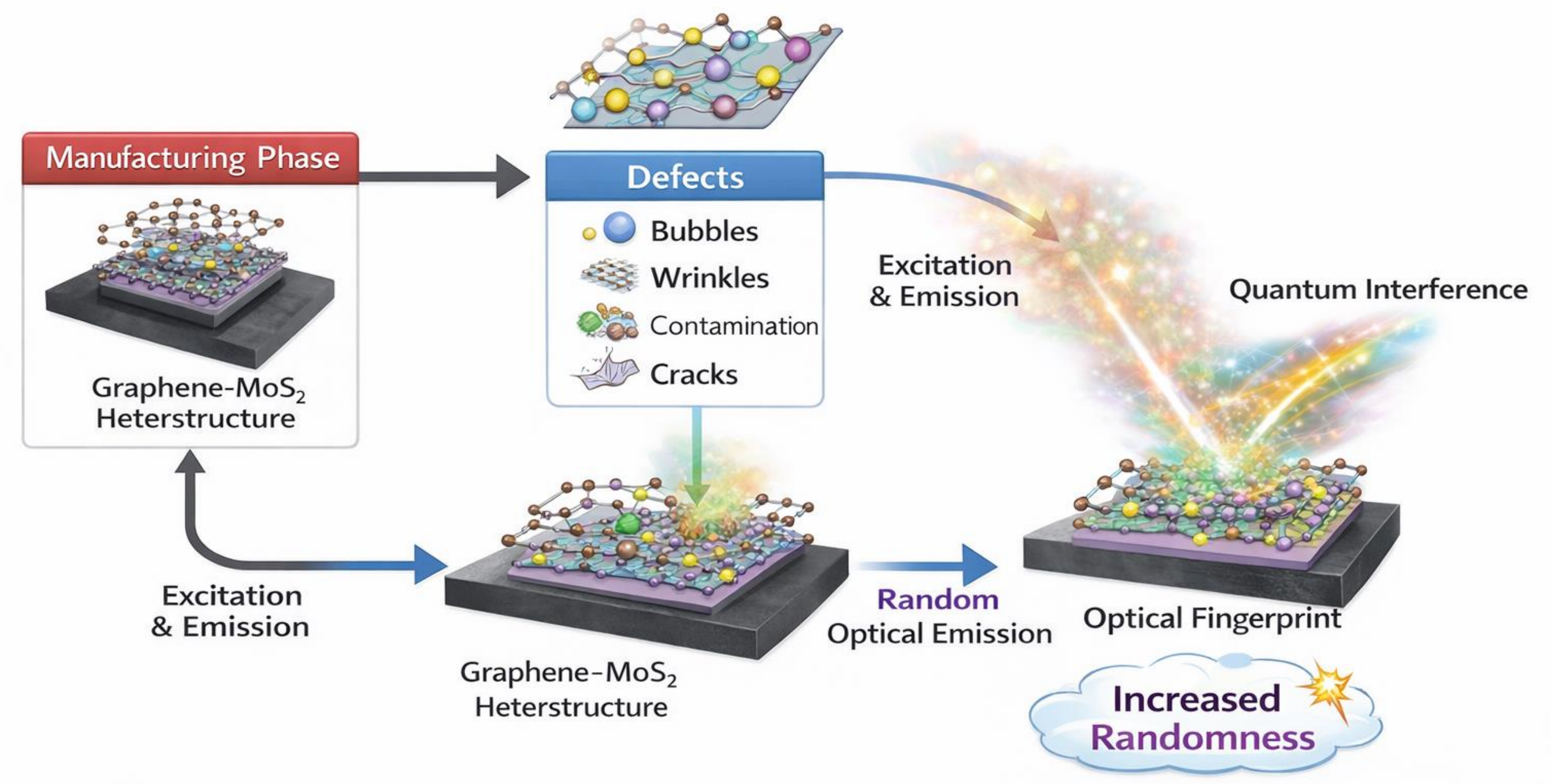
Introduction

Physical unclonable function



- Imperfections such as dangling edges, vacancies, and substitutions present in 2D materials could be used as an optically active unique identity. For example, measuring wavelength and intensity shifts across a monolayer, could enable the extraction of a unique fingerprint with unrivalled security.

How Graphene-MoS2 applied as optical PUF



Defects in Gr-MoS_2 alter interlayer coupling, causing light scattering and quantum interference

Fabrication

Dry stacking process of Graphene-MoS_2

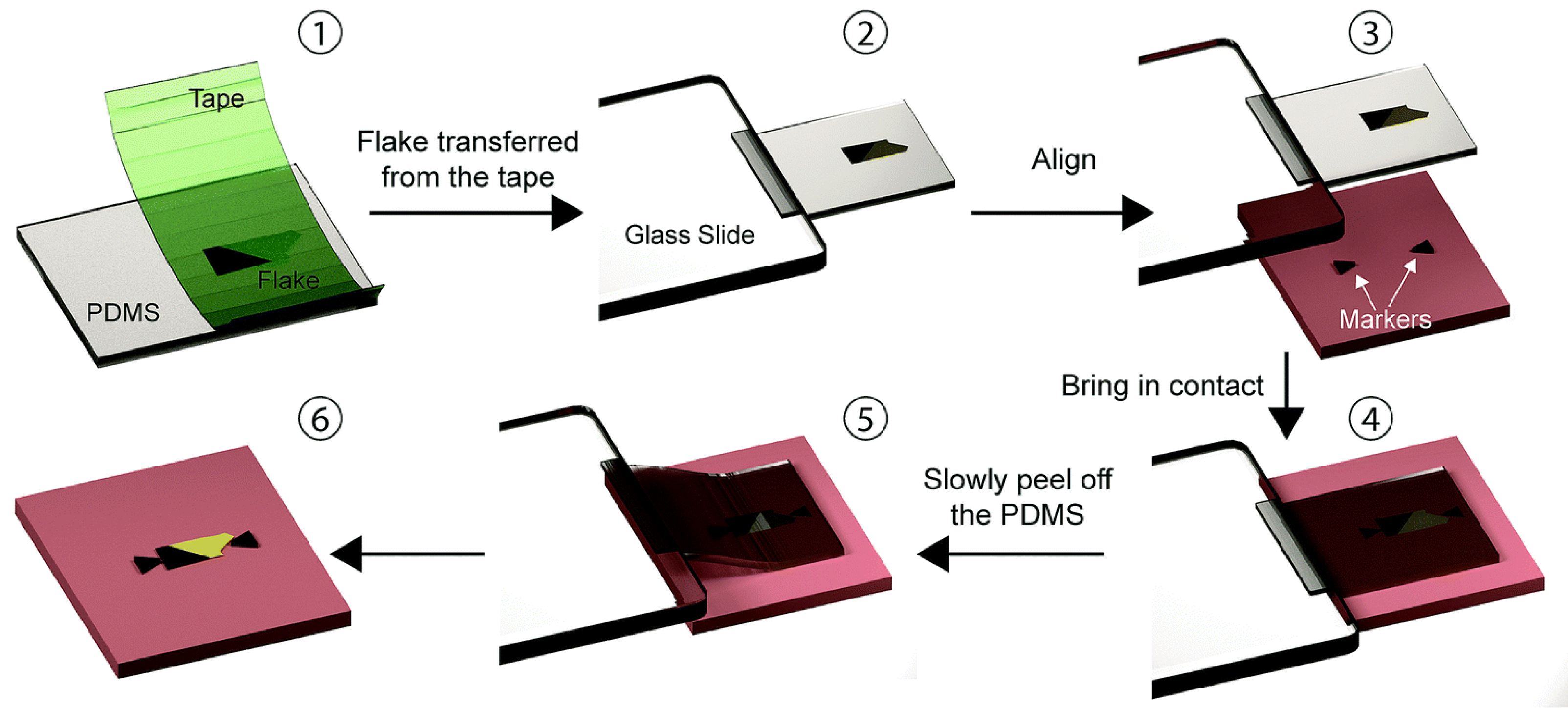


Fig 3. Dry transfer process of Graphene-MoS_2 van der Waals Heterostructure.(Reproduced with permission from the Royal Society of Chemistry from Frisenda et al., Chemical Society Reviews 47, 53–68 (2018))

Optical microscope images of the Graphene-MoS_2 on SiO_2

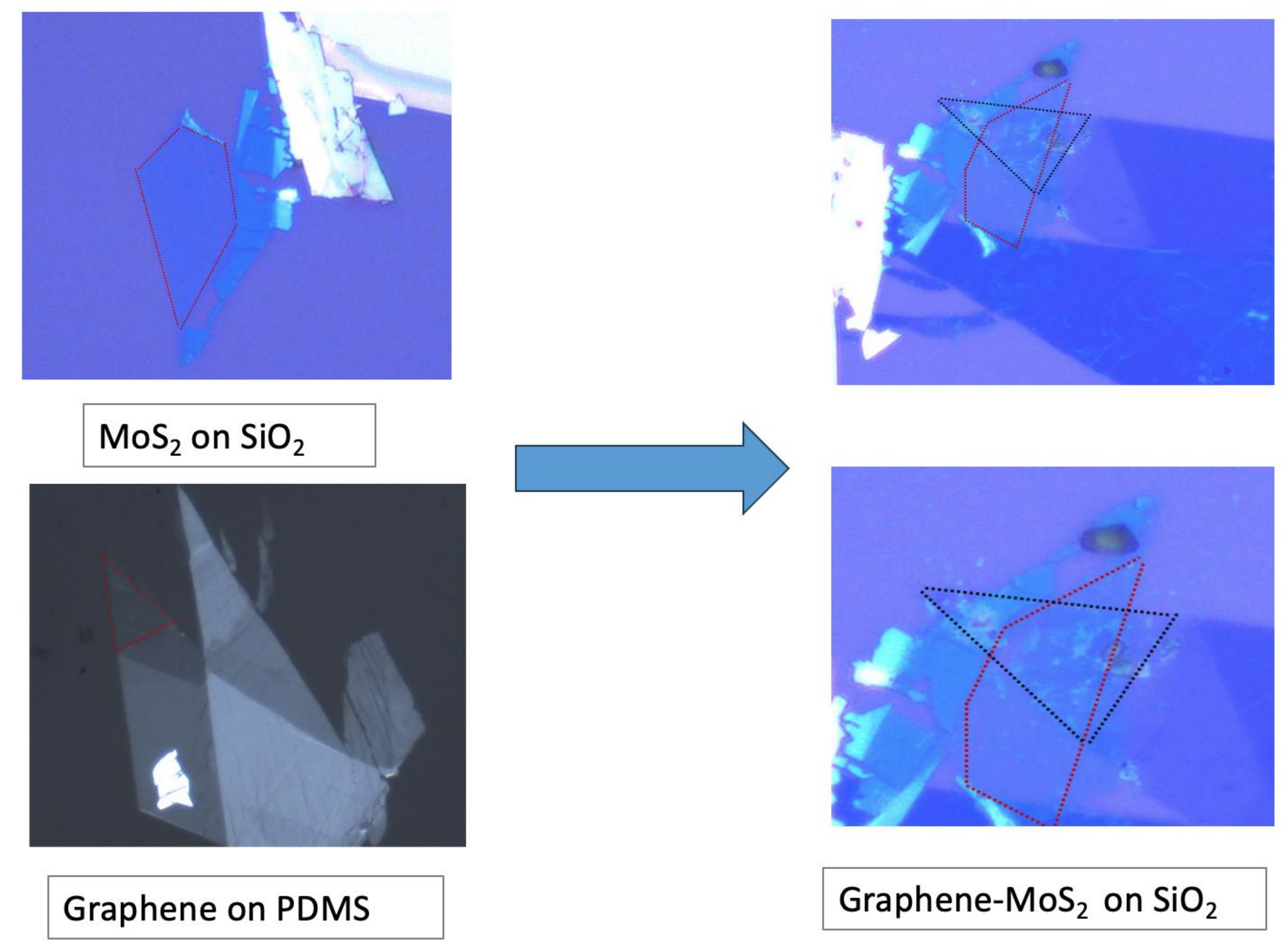


Fig 4. Optical microscope images of MoS_2 on SiO_2; Graphene on PDMS ; Graphene-MoS_2 on SiO_2

Characterization

Photoluminescence at room(300k) and low temperature(12k)

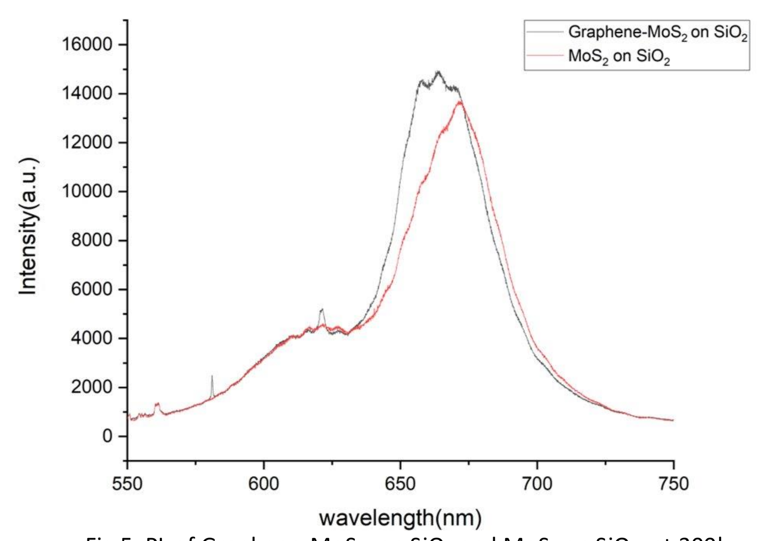


Fig 5. PL of Graphene-MoS_2 on SiO_2 and MoS_2 on SiO_2 at 300k

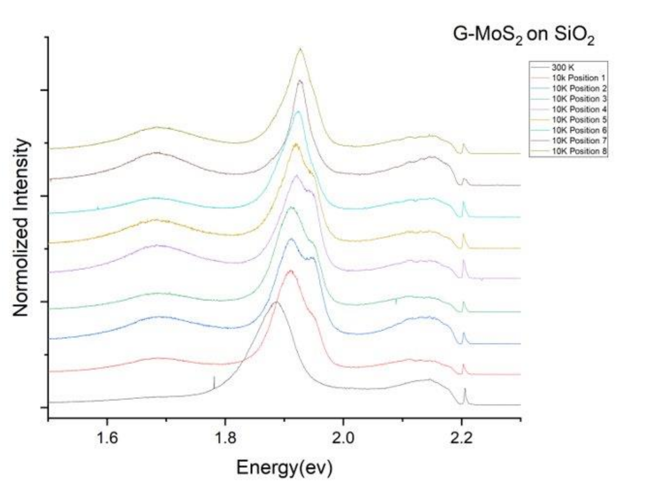


Fig 6. PL of Graphene-MoS_2 on SiO_2 at 300k and 10k (at different position)

- **Peak Position & Shift**: G-MoS_2 is blue-shifted relative to MoS_2, suggesting changes in MoS_2's electronic structure due to graphene. This could be due to strain, charge transfer, or dielectric modifications.
- **Multiple Peaks**: G-MoS_2 has multiple peaks around 650nm, unlike the singular peak in MoS_2. This points to additional excitonic transitions, potentially from trions or interlayer states.
- **Broadening of Peaks**: G-MoS_2 peaks are broader than MoS_2's. This broadness might be due to varied local environments at the graphene interface or increased electron-phonon interactions.
- **Positional Variation**: Across different positions, there's a notable difference in the peak shapes and intensities. This suggests spatial inhomogeneities in the G-MoS_2 layer, possibly arising from local variations in layer thickness, strain, or defects.

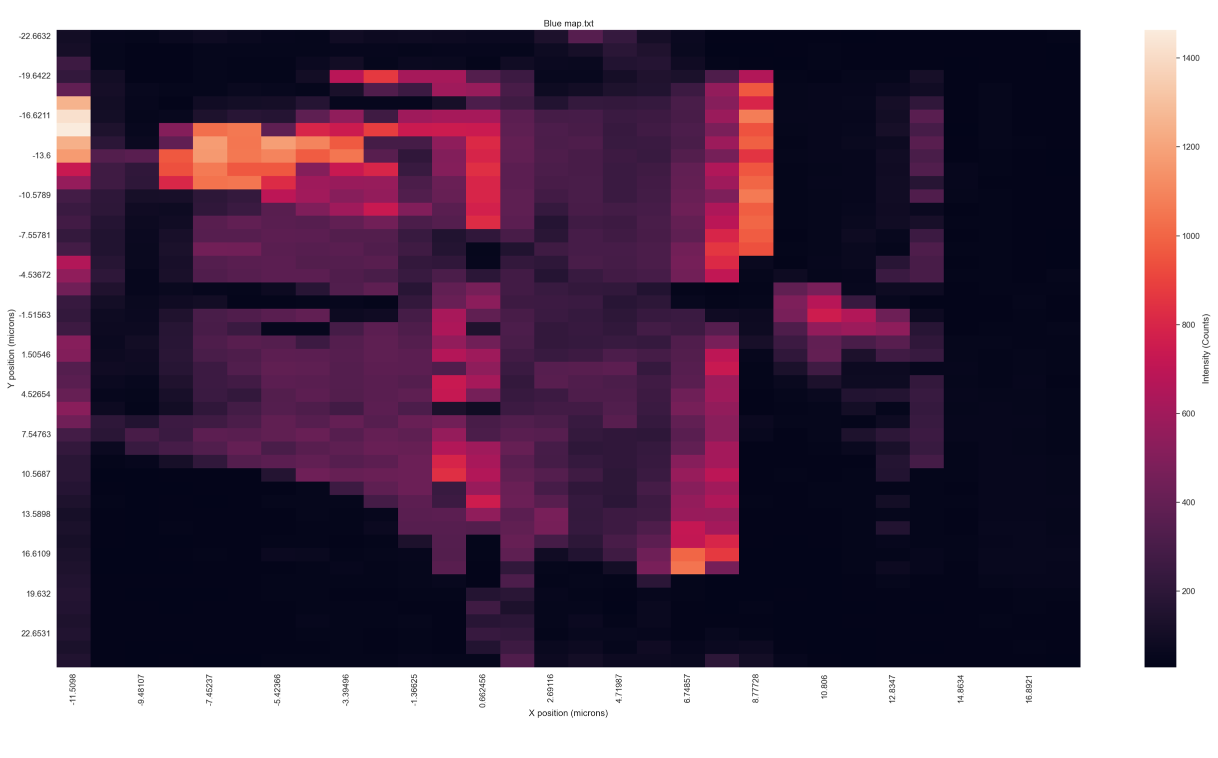


Fig 7. PL map of Graphene-MoS_2 on SiO_2

- The PL map clearly illustrates spatial variations in intensity, emphasizing the non-uniform optoelectronic characteristics of the sample across different positions. Such spatially-dependent intensity fluctuations can serve as a Physical Unclonable Function (PUF).

Conclusion

- The presented study underscores the significant potential of Graphene-MoS_2 van der Waals heterostructures in optical physical unclonable functions.
- A distinctive aspect of the Graphene-MoS_2 heterostructure that bolsters its security application is the variability in its interlayer coupling.
- This variability arises due to factors like stacking order, stacking angle, as well as the presence of bubbles and wrinkles.
- These inherent variations not only contribute to the uniqueness of each heterostructure but also amplify its security attributes.
- The observed intensity variations across the PL map further emphasize its capability in generating a spatially-dependent, unique response, making it an ideal candidate for PUF applications.

Future Work

- **Image Processing:** A prime focus in the next stages will be on converting the PL maps into binary representations. Such a transformation is expected to streamline the validation of the PUF characteristics and their consistency.
- **Scaling Up:** Endeavours will be directed towards magnifying the size of the heterostructures, thus ensuring the adaptability of this methodology for wider-ranging applications.
- **Entropy Enhancement:** To augment the security features of the PUF even further, we will explore approaches to deliberately introduce defects. Such enhancements are projected to increase the system's entropy, making it more unpredictable and resistant to tampering.

References

- *Lee, C. D., et al. (2020) 'Charge Transfer Dynamics in Graphene-MoS_2 van der Waals Heterostructures', Physical Review B, 85(15), pp. 155415.*
- *Nguyen, L. M., et al. (2019) 'Spatial Inhomogeneities in van der Waals Heterostructures: Causes and Consequences', 2D Materials, 6(1), p. 015009.*

Email: f.wu5@lancaster.ac.uk fangling.wu334@outlook.com