Atomic-Scale Analysis of Metal-Semiconductor and Quantum Well Interfaces: Developing Metrics for Quantum Device Engineering

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Abstract

Understanding and engineering metal-semiconductor and semiconductor quantum well interfaces are crucial for optimizing the performance of quantum devices. Atomic-scale disorder and strain at these interfaces can significantly impact electronic properties, including carrier mobility [1] and superconducting behaviour [2]. High-resolution scanning transmission electron microscopy (HRSTEM) has become an indispensable tool for characterizing these interfacial phenomena due to its ability to provide Z-contrast imaging, which is sensitive to atomic number variations, while operating at low electron doses and short dwell times to minimize material damage. This capability is particularly beneficial for analysing heterogeneous interfaces where compositional and structural complexities are prevalent.
In this study, we utilize HRSTEM, geometric phase analysis (GPA), and advanced image processing using Python libraries to investigate structural properties in two key systems:
(1) Metal-Semiconductor interfaces, where atomic-scale structural variations and strain distributions at the interfaces of Al-based superconductors with III-V semiconductor layers were analysed. The textured nature of Al thin films induces distortions at the metal-semiconductor interface, leading to localized strain fields. We will discuss how these strain variations could influence electronic properties, underscoring the necessity for precise control over interface morphology during fabrication.
(2) Semiconductor quantum well interfaces were studied to assess interface roughness and compositional variations. By leveraging HRSTEM image processing and advance image processing using Python libraries (Figure 1), we establish metrics for interface quality that could be correlated to electron mobility of 2DEG system.
These insights emphasize the critical role of interface quality in the development of efficient quantum devices.

References

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[2] Y. Liu, Q. Meng, P. Mahmoudi, Z. Wang, J. Zhang, J. Yang, W. Li, D. Wang, Z. Li, C. C. Sorrell, S. Li, Adv. Mater. 36 (2024) 2405009.

Figures

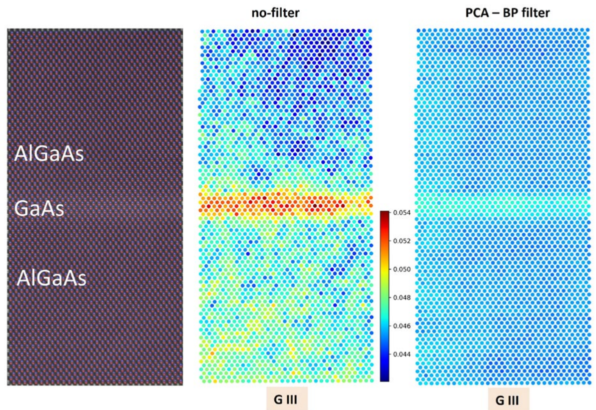

Figure 1: Cross-sectional HRSTEM image of a GaAs/AlGaAs quantum well (left). Digital image processing showing group III intensity variations across the 1.5nm GaAs QW before filters (centre)and after digital filters (right) were applied to subtract noise due to scattering