# Operando band visualization of III-V infrared sensor using UHV-KPFM

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Heterostructures based on III-V semiconductors form the backbone of a wide range of high-performance optoelectronic devices. The carrier transport in these systems is governed by the band diagram formed across the heterostructure and its response to external stimuli. However, obtaining an accurate, spatially resolved picture of the band diagram under operating conditions remains challenging, as existing techniques often lack the combined capabilities of nanoscale spatial resolution, quantitative accuracy, and operando compatibility.

In this study, we address this challenge by employing ultrahigh vacuum (UHV) Kelvin probe force microscopy (KPFM) to visualize the band diagram of a III-V infrared sensor under actual operating conditions. The use of atomically flat III-V(110) cross-sections, prepared via *in situ* cleavage under UHV, effectively suppressed surface band bending and provided direct access to the bulk electrostatic potential [1,2]. As a result, band diagrams can be reconstructed from contact potential difference (CPD) profiles obtained during device operation.

Figure 1a shows a schematic of the operando KPFM setup. A sharp metallic tip (~10 nm) mounted on a qPlus sensor was used instead of conventional cantilever-type probes with larger tip radii (25-30 nm). The device consists of GaAs and InAs layers epitaxially grown on an n-GaAs(111)A substrate, forming an n-InAs/i-GaAs/GaAs(111)A structure. Figure 1b shows the CPD profiles measured across the device layers under applied bias, from which we can directly reconstruct evolution of band diagram. The reconstructed band diagrams revealed several key features: strong Fermi-level pining at the substrate surface, and shifts in band offset at the heterointerface—features that underlies the high infrared-detection sensitivity. In addition, CPD profiles obtained under infrared illumination clarified the accumulation of photoexcited holes near the substrate surface. This hole accumulation suggests the presence of a rate-limited process that reduces overall charge extraction efficiency. Our approach is broadly applicable to complex III-V heterostructures and paves the way for atomic-scale band engineering in next-generation optoelectronic and quantum devices.

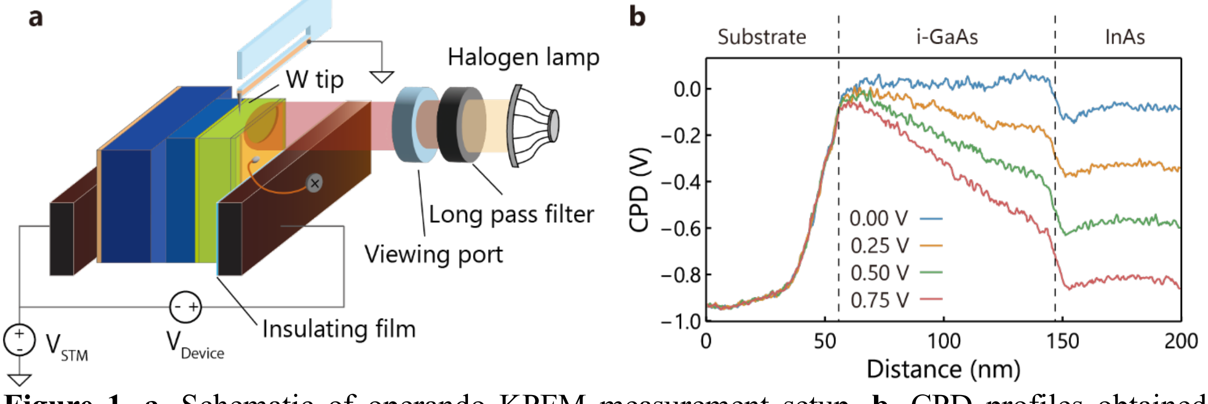


**Figure 1. a,** Schematic of operando KPFM measurement setup. **b**, CPD profiles obtained across the device layers under applied bias.

References:

[1] N. Ishida, *et al.* Nanotechnology **35**, 065708 (2024).

[2] N. Ishida, *et al.* Nanotechnology **36**, 075701 (2025).