Synchronized Modulation Kelvin Probe Force Microscopy for Surface Photovoltage Studies in Optoelectronic Systems

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We introduce Synchronized Modulation Kelvin Probe Force Microscopy (SM-KPFM), an advanced in-operando technique that synchronizes external stimulus modulation (e.g., illumination or bias) with the atomic force microscope (AFM) scan direction to improve surface photovoltage (SPV) measurements. This method addresses common challenges in conventional KPFM [1], such as spatial drift, thermal effects, and probe degradation. Specifically, synchronized illumination KPFM illuminates the sample during the retrace scan and keeps it dark during the trace scan, enabling real-time comparison of surface potential within a single scan cycle. We demonstrate the technique on a silicon photodiode and a molybdenum disulfide (MoS_2) bilayer on gold electrodes, showing that SM-KPFM provides accurate, drift-free SPV maps with enhanced clarity of photovoltaic effects at the MoS_2–gold interface. This approach reduces artifacts and improves the reliability of SPV measurements, making SM-KPFM a powerful tool for nanoscale studies of optoelectronic materials.

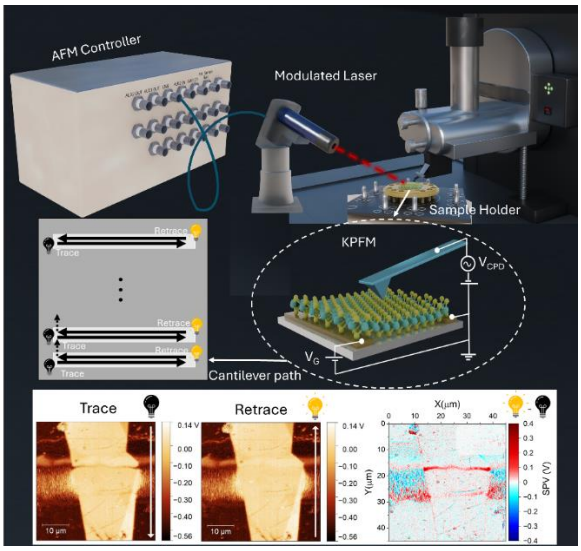

Figure 1. Schematic illustration of the SM-KPFM setup. In this method, external stimulus modulation, such as illumination and/or bias (V_G), is synchronized with the AFM scan direction. A modulated laser is connected directly to the AFM controller's Line Output, enabling real-time switching between dark (trace scan) and illuminated (retrace scan) conditions without external synchronization hardware. The cantilever path shows the laser off during the trace and on during the retrace scan, producing two images: one for the trace in the dark and one for the retrace under illumination. The inset shows a representative MoS_2 sample on gold electrodes, with contact potential difference (V_{CPD}). The bottom panels display KPFM maps along with their pixel-wise difference (retrace minus trace), which reveals the SPV of the sample.

Reference

[1] ACS Appl. Mater. Interfaces 2022, 14, 22, 26295–26302