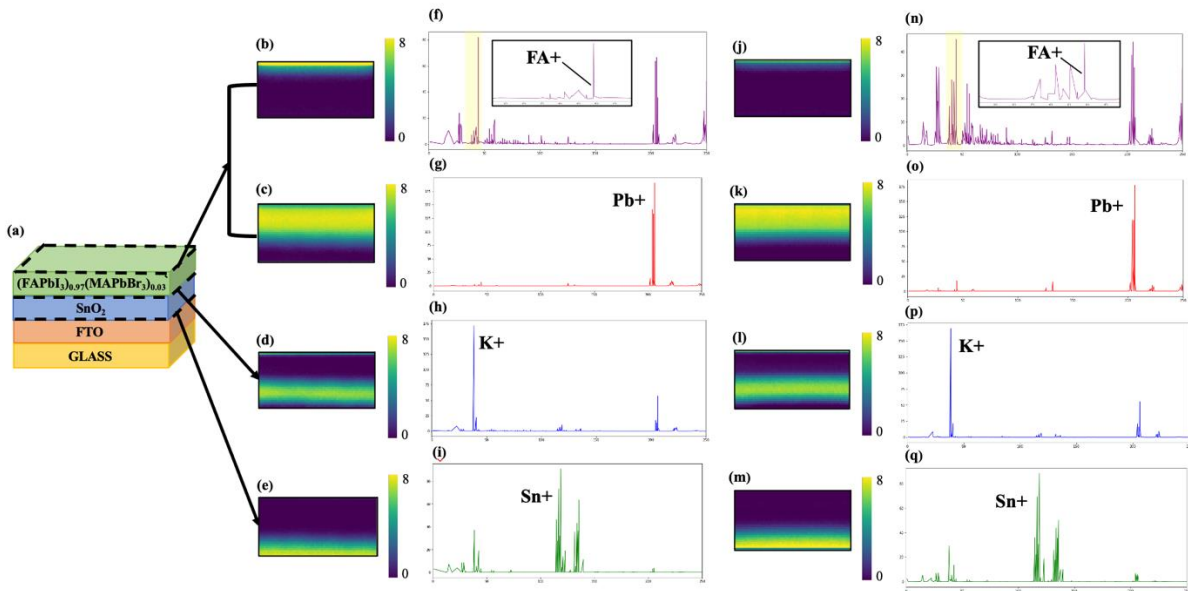


**Figure 1:** (a-d) Height and current images of c-AFM for hybrid sample #1 under light on and light off conditions. Zoom-in boxes provide visual insight into fused grain boundary areas located optically between height and current images. (e-f) Similar image analysis is conducted for hybrid sample #2 light and light-off conditions. It should be noted that fused morphology is present in both hybrid samples with combined processing, but not shown in samples prepared with exclusively CVD or nanoparticles. Scan rate was set at 0.5 Hz for a series of 256 points and lines. Scanning duration took approximately 12 minutes, switching optical light in-between scans.



**Figure 2:** (a) A schematic of the PV stack featuring dashed outlines of the interfacial components represented by the Non-negative Matrix Factorization (NMF) (b-e) Separation of each NMF spectra component for hybrid sample #1 and (f-i) corresponding spectra map highlighting the intensity of  $\text{FA}^+$ ,  $\text{Pb}^+$ ,  $\text{K}^+$ , and  $\text{Sn}^+$ . Color bars for NMF components are normalized on a scale of 8 quantify the intensity of each component (j-q) Light-soaked hybrid sample #1 is featured showing the same array of analysis showcasing a similar response to fresh hybrid sample #1. However, the surface organics are much more varied and of less intensity due to aging and acquired surface contaminants.

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