nanoXPEEM: Attention Based Nanoscale X-ray Photoemission Electron Microscopy

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Harnessing two-dimensional materials for practical applications faces significant hurdles due to a dearth of characterization methods that combine efficiency with high throughput. Soft X-ray time-of-flight photoemission electron microscopy (XPEEM) offers valuable element-specific and depth-sensitive analysis of materials and their hidden interfaces. However, this technique suffers from chromatic and spherical aberrations that cannot be eliminated using traditional electron-lens systems. These distortions, along with astigmatism and space-charge effects, substantially reduce both spatial and energy resolution. We propose a solution using a spatial-attention deep learning approach that automatically reduces these distortions, achieving nanometer-level resolution across the entire observation area. This enhanced approach, titled nanoXPEEM, sets a new benchmark of 48-nm spatial resolution with a 232-μm diameter field of view in the soft x-ray energy range (700-1000 eV). The nanoXPEEM technique enables unprecedented uniform nanoscale mapping of elemental composition, depth profiles, and local structural features, potentially even bridging the gap toward atomic-level resolution capabilities.