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Meeting-report

Polarity Switching and Josephson Junction Interfaces Investigated by Multislice Ptychography

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Recently, the epitaxial growth of single phase, atomically smooth β-Nb_2N has enabled superconductivity with a critical temperature $0.35<T_c<0.6$ K [1] in thin-film geometry. This opens the opportunity for large area fabrication of Josephson junctions (JJ) with potentially lower defects densities in comparison to amorphous and polycrystalline materials. Understanding the defects or inhomogeneous phases present is key to eliminating undesired energy levels and improving quantum coherence in superconducting qubits beyond what is possible today.

A JJ consisting of a β-Nb_2N/AlN/ β-Nb_2N trilayer structure grown by molecular beam epitaxy is shown in the high-angle annular dark field (HAADF) image in Figure 1(a). The integrated differential phase contract (iDPC) image shown in Figure 1(b) captures the lighter Al and N elements not visible in the HAADF image and reveals regions of varying polarity (indicated by blue arrows) in the AlN tunnel barrier layer. However, in the region where the different polarities of AlN meet, the iDPC image fails to capture the details of these overlapping domains. We address this challenge using multislice ptychography, which enables reconstructions of the 3D electrostatic scattering potential in samples up to 30 nm thick, and achieves double the resolution of a commercial STEM, light-atom imaging, and depth sectioning [2]. The enhanced lateral resolution in the ptychography reconstruction is shown in Figure 1(c) where the individual atoms in the overlapping AlN domains can be clearly distinguished.

Figure 2(a) illustrates the depth sectioning capability by capturing different slices in depth. The movement of the Al atom is tracked in the depth profile in Figure 2 (b). In addition, the ptychography reconstruction shows the polarity reversal in the AlN layer is correlated to the AlN/Nb_2N interface structure. The key to obtaining these structures is the multislice ptychography's ability to accounts for channeling of the electron beam within crystalline samples to isolate contributions from separate domains or interface structures. Figure 2(c) shows a depth slice of the Al-polar AlN/Nb_2N interface which follows the bulk β-Nb_2N structure terminating with a Nb atom. In contrast, a depth slice of the N-polar AlN/Nb_2N interface in Figure 2(d) shows a deviation from the bulk β-Nb_2N structure terminating with an N atom in line with the pervious Nb-N atoms resembling δ-NbN, the more common and higher superconducting critical temperature structural phase of NbN_x. Compared to HAADF or iDPC which suffers from blurring along the projection axis of non-uniform atomic columns, the ptychographic reconstruction is sufficiently clear that we are able to map the atomic positions utilizing the increased lateral resolution to distinguish changes in bond lengths. Multislice ptychography has enabled the visualization of polarization domain boundaries and junction interface defects that offers insight into the electrical properties of the Nb_2N/AlN/Nb_2N JJ [3].

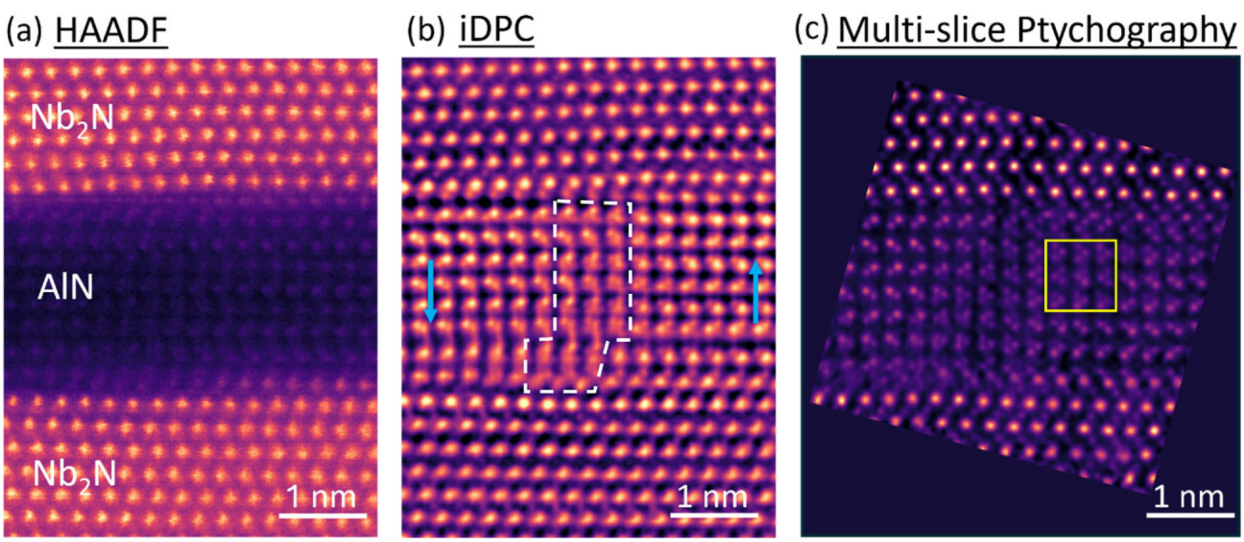

Fig. 1. Comparison of lateral resolution and N atom imaging capability: (a) HAADF image, (b) iDPC image, and (c) ptychographic reconstruction of Nb_2N/AlN/Nb_2N JJ. The iDPC image can resolve the direction of polarity in the AlN tunnel barrier indicated by blue arrows. The white dash box indicates the region of polarity domain overlap that can only be resolved by ptychography.

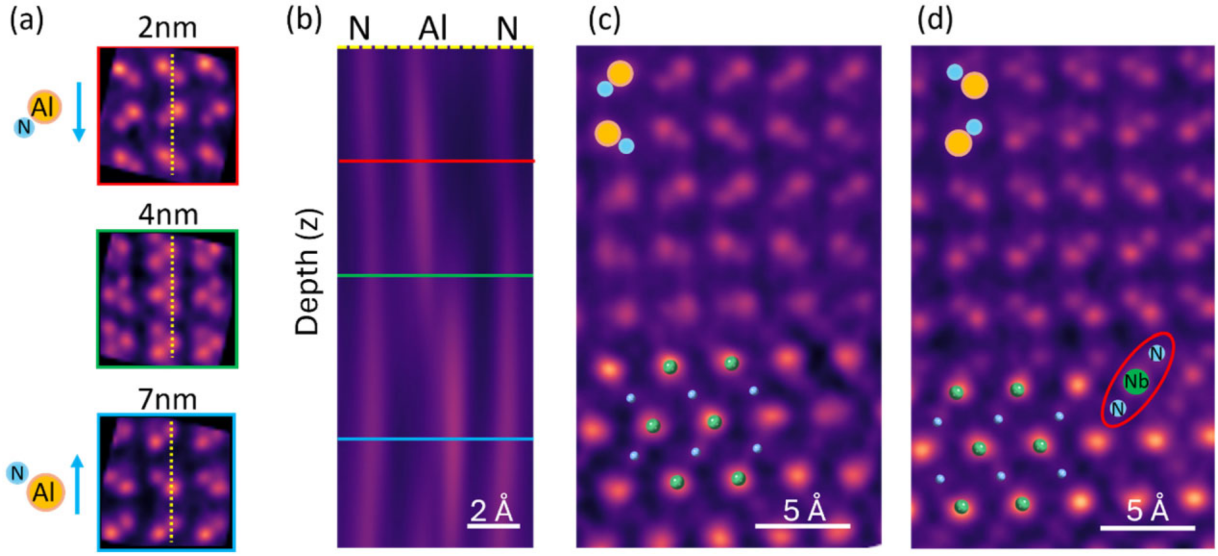

Fig. 2. Demonstration of depth sectioning in multislice ptychography. (a) Different depth slices of the AlN tunnel barrier (yellow boxed region in Fig. 1(c)). (b) Depth profile along yellow dashed line in (a) showing alternating Al site. (c) Al-polar AlN/Nb_2N interface with overlaying structure of bulk Nb_2N. (d) N-polar AlN/Nb_2N interface showing deviation from bulk Nb_2N for the terminating N atom.

References

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