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Chemically Specific Buried Interface Imaging with a Coherent EUV Nanoscope

Christina Porter[1], Elisabeth Shanblatt[1], Dennis Gardner[1], Giulia Mancini[1], Robert Karl Jr. [1], Michael Tanksalvala[1], Charles Bevis[1], Henry Kapteyn[1], Margaret Murnane[1], Daniel Adams[1]

[1.] JILA, University of Colorado, 440 UCB, Boulder, Colorado, USA

Spectronanoscopy of buried structures and interfaces is an important challenge for many applications, including nanofabrication of multilayers and devices for data storage and nanoelectronics. Here, we use ptychographic coherent diffractive imaging (CDI) in a reflection geometry with a tabletop, high harmonic generation (HHG) source to perform quantitative, chemical-specific imaging of buried nanostructures and interfaces. The two damascene-style samples (SEMATECH Inc.) we imaged are comprised of Cu structures inlaid in SiO_2 and polished flat, with one sample then buried beneath a 100nm Al overlayer deposited by electron beam evaporation (Fig. 1d).

Extreme ultraviolet (EUV) HHG sources are ideally suited for nanoscale metrology and reflection mode imaging. There are many elemental absorption edges falling in this wavelength range that provide chemical-specific contrast, while most elements are also reflective enough to facilitate reflection mode imaging of thick samples. Coherent diffraction imaging is an optimal way to harness EUV light because it eliminates lossy, image forming optics while providing diffraction limited resolution [1]. Furthermore, it yields amplitude and phase contrast that provides both sample reflectivity and surface topography. Ptychography CDI is an advanced technique that uses multiple diffraction patterns collected with overlapping fields of view to robustly reconstruct both the the sample and the illumination [2-4].

Our experiment is performed using coherent 29.1nm light produced by focusing 23fs, 1.5mJ pulses centered at 785nm into a 5cm-long, hollow-core glass waveguide filled with Argon at 49Torr. We filter out the fundamental light with two Si substrates set at Brewster's angle for 785nm as well as two 200nm Al filters, then select the 27^{th} harmonic with two narrow-band multilayer mirrors. The harmonic beam is focused onto the sample with an ellipsoidal mirror to a 16um spot that is area-by-area scanned to create scatter patterns at the detector with overlapping fields of view in the sample plane, collected by a CCD (Fig. 1c). A total of 270 diffraction patterns were collected for each sample, scanning a total area of $4270\mu m^2$ on each, with an exposure time of 6min for the uncoated and 24min for the Al coated sample.

We reconstruct our images with a combination of ptychography CDI algorithms. We modify the ePIE algorithm [3] such that our absolute value squared amplitude images yield the absolute reflectivity of the sample at every pixel. This is done by normalizing the illumination at each iteration to the total amount of photons incident on the sample (in units of detector counts), measured by reflecting the beam off of a gold mirror before ptychography scans. A multicolor ptychography algorithm is then used to filter out light due to small amounts of nearby harmonics leaking through the system to produce higher fidelity images [5].

From the reflectivity images (Fig. 1a-b), we can detect interfacial reaction and diffusion on the coated sample, on both the features and the substrate. We observe a relative contrast flip between the features and substrate on the coated sample as compared to the uncoated one, which led us to hypothesize the existence of an interstitial diffusion region between the Al and the Cu features. This diffusive region was confirmed by Auger electron spectroscopy (AES). From the AES elemental depth profile, we generated a

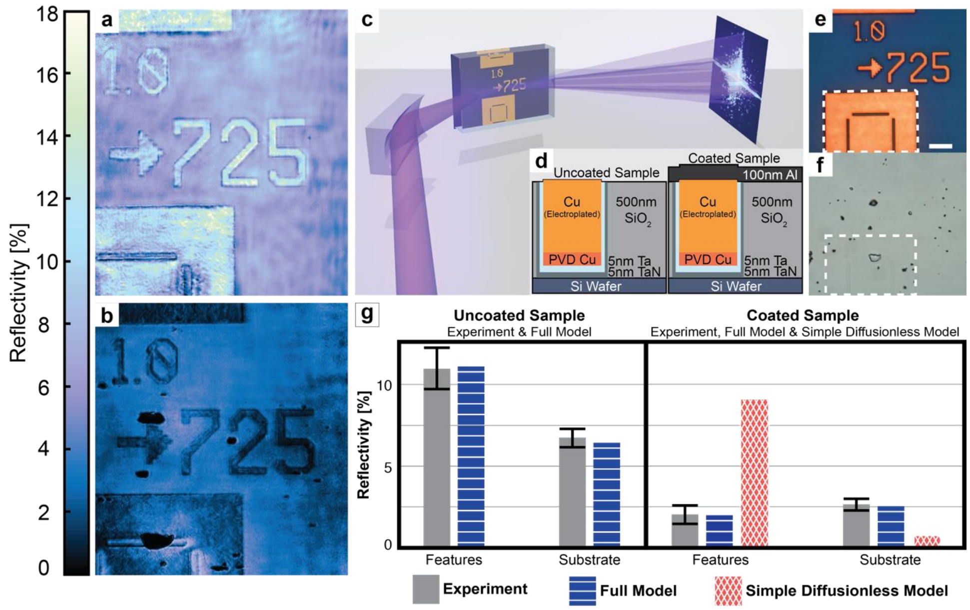

Figure 1. Ptychography CDI reconstructions of the uncoated (a) and coated (b) samples. (c) Experiment schematic. (d) Sample schematics. Optical microscope images of the uncoated (e) and coated (f) samples with a 10μm scale bar. (g) Comparison of experimental reflectivities with models.

diffusive composition profile for the coated sample that yielded a theoretical reflectivity value in good agreement with our experiment (Fig. 1g). We also used the AES to generate a composition profile for the coated substrate, which agrees with our experimental reflectivity when a diffusive Al_2O_3 layer is included, created by reduction of SiO_2 at the Al-SiO_2 interface. Without diffusion, the modeled values disagree with the experimental values (Fig. 1g), showing that our method is sensitive to interfacial diffusion.

Finally, we generate height maps from the phase images by subtracting off the phase of the complex reflectivity produced by our multilayer stack models, leaving only geometric phase due to height variation of the sample surface. These height maps agree with AFM measurements, shown in Fig. 2. Thus, this is a promising technique capable of both buried interface spectromicroscopy and surface topography imaging.

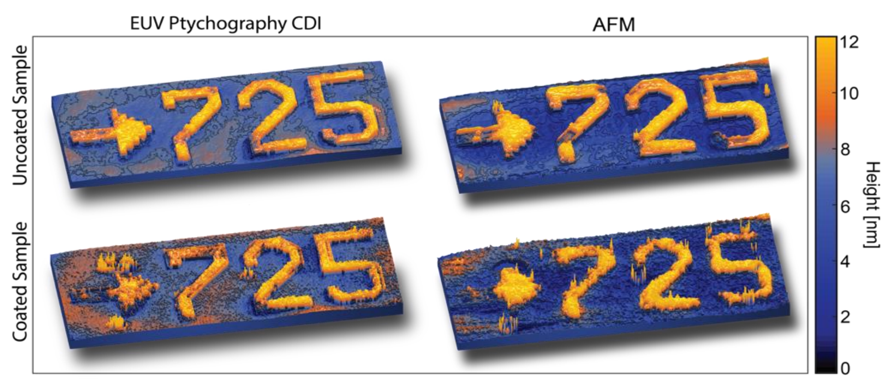

Figure 2. Height maps generated from ptychography phase images compared to AFM images of the samples. Substrates have been flattened to highlight feature heights, and the axial direction has been stretched by a factor of 200 so that feature heights are visible.

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