Comparison of Shadowgraphy and X-Ray Phase-Contrast Methods for Characterizing a DT Ice Layer in an Inertial Confinement Fusion Target

D. R. Harding, M. D. Wittman, N. Redden, D. H. Edgell, and J. Ulreich

Laboratory for Laser Energetics, University of Rochester

Shadowgraphy and x-ray phase-contrast (XPC) imaging are two techniques that are used to characterize the deuterium–tritium (DT) ice layer in inertial confinement fusion targets. Each technique has limitations that affect how accurately they can characterize small crystalline defects and measure ice-thickness nonuniformities that may be only a few micrometers in height. The purpose of this study is to determine if shadowgraphy is overly sensitive to the size of defects at the ice surface and insufficiently sensitive to the shape of longer-wavelength roughness, and if XPC is too insensitive to defects at the ice's inner surface.

Multiple ice layers with different thicknesses (40 to 63 μm), thickness uniformities (peak-to-valley variations that range from <2 to 12 μm), and crystal defects were analyzed using shadowgraphy and XPC techniques. The inability to rotate the target so that the same region of the ice layer was imaged by each method limited how extensively the two techniques could be compared; however, the relative accuracy of each technique for measuring the size of the perturbation to the ice near the fill tube could be compared because the thermal profile (and therefore the low-mode ice thickness distribution) around the target is axisymmetric around the fill-tube axis: crystal defects that intersected the fields of view of both techniques could also be compared. Results from each technique agreed when the ice layer was uniformly thick and the crystal lacked defects. That agreement worsened as the number of defects at the surface of the ice layer increased or as the perturbation to the ice layer at the fill tube increased. Shadowgraphy is very sensitive to identifying defects in the crystal, and the size of those defects was consistently larger than the size reported by XPC and unlikely to be physically possible since β-heating is expected to smoothen them. Large defects, such as features that typically occur at each end of the *c* axis of the DT crystal, were measured using both techniques.

The dimensions of the ice layer near the fill tube that was thicker (or thinner) than elsewhere were reported by shadowgraphy to be smaller in height and area than by XPC. This is shown in the ice-thickness measurement of a 2-D slice through the target (Fig. 1). XPC analysis reported the ice layer to have a shape with the majority of the spectral power in low modes, which is expected for a thermal nonuniformity induced by the fill tube; shadowgraphic analysis of the ice layer showed the profile at the fill tube to be smaller in height and width. Two separate shadowgraphic analyses that use caustics to trace different paths through the target and, in theory, image the same ice/vapor surface, did not consistently report the ice perturbations to have the same size or shape. The XPC method, in theory and from the consistency of the experimental results, provided the best assessment of low-mode ($\ell < 7$) roughness in ice layers, and the shadowgraphy method using the brightest caustic provided the best method for detecting the presence of grooves in the ice, although not for quantifying the size of them. Caution: If multiple grooves are present, the analysis can be ambiguous and it is best to melt and reform the ice layer.

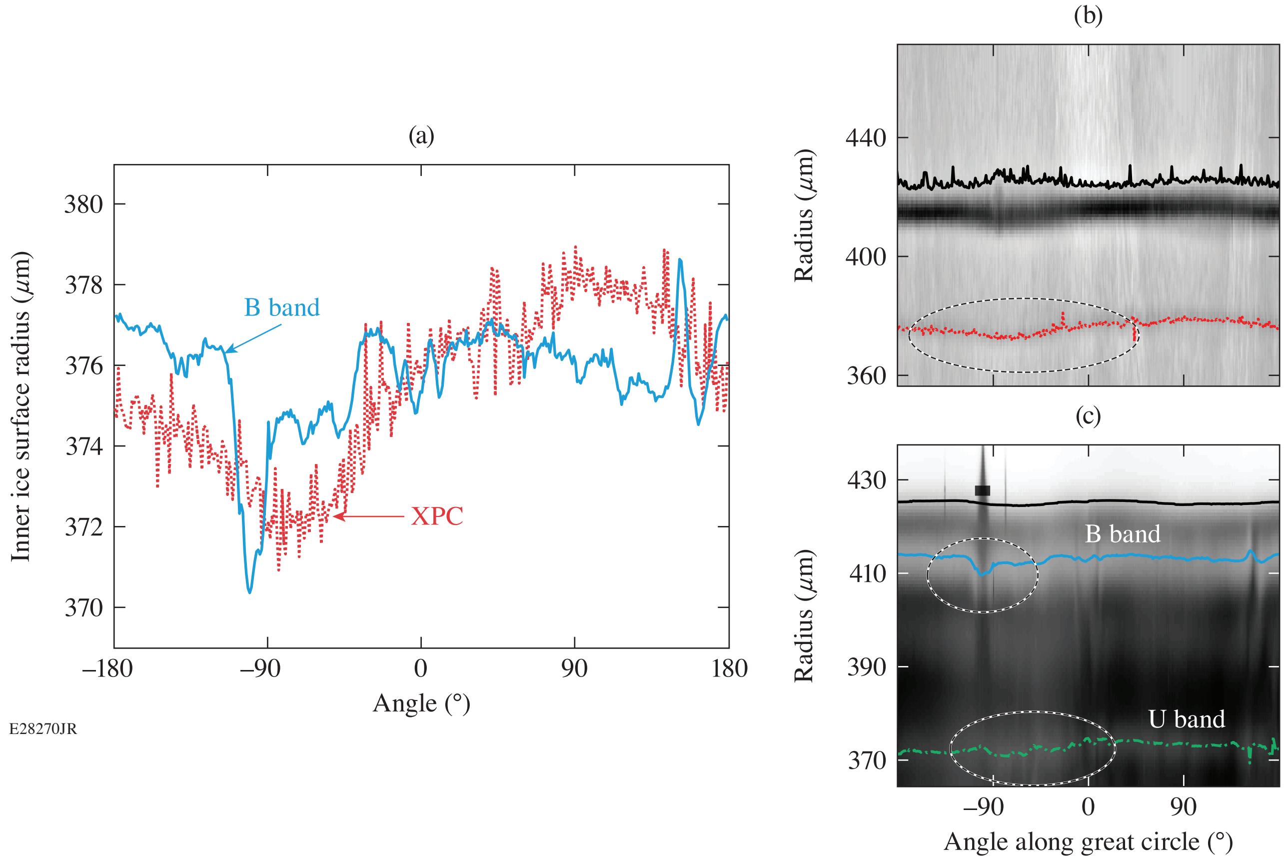

Figure 1
(a) Unwrapped ice/vapor interfaces characterized by shadowgraphy (B band) and XPC analysis are superimposed over each other to demonstrate the effect of the fill tube on the thickness uniformity of the ice layer. The 41-μm-thick ice layer is reported to have a larger and wider perturbed region (circled) in (b) the XPC image and analysis than in (c) either of the (circled) B- and U-band analyses (solid blue line and dashed green line, respectively). The fill tube is located at –90°.

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