Prediction of Deuterium–Tritium Ice-Layer Uniformity in Direct-Drive Inertial Confinement Fusion Target Capsules

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High-yield inertial confinement fusion targets require that the uniformity of the DT ice layer be less than 1-μm rms (Ref. 1). The uniformity of the ice layer (i.e., the solid/gas phase boundary) is affected by the surrounding helium environment and the structure that supports the target. To aid the designer of target support structures, the sensitivity of ice-layer uniformity to support structure thermal conductivity and a 3-mW heat source in the surrounding helium are studied using computational fluid dynamic simulations.

Figure 1 shows the detailed geometry used for the multiphase conjugate heat-transfer numerical model. The environment around the target and target support consists of low-pressure (2-Torr) helium gas that carries the heat produced by tritium beta decay to a surrounding copper shroud, which is connected to the cryocooler.

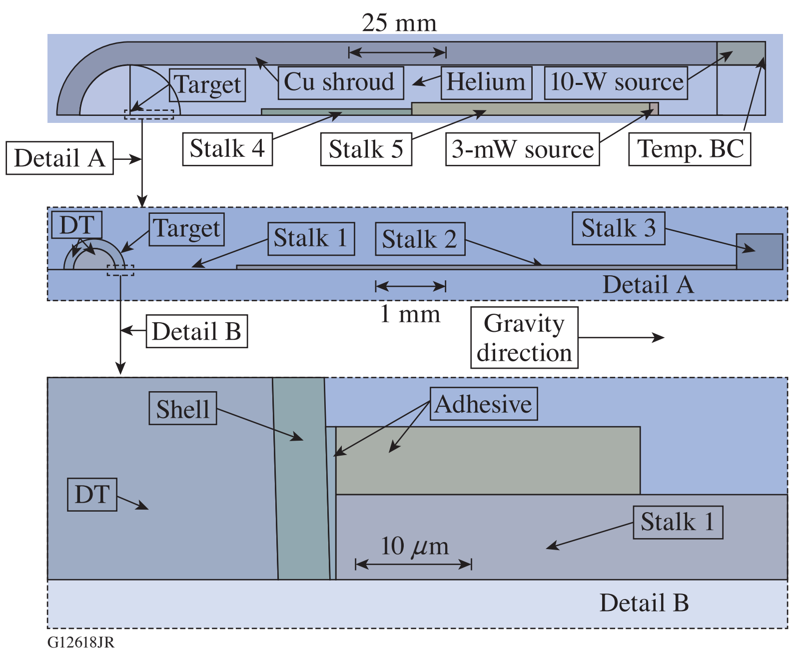

Figure 1
Model geometry detail. Temp. BC: temperature boundary condition.

Figure 2 shows one of the meshes used. The outer portion of DT closest to the target capsule uses an element size of ~5 × 5 μm to resolve the gas/ice phase boundary. Elements representing the 17-μm SiC support, target capsule shell, and adhesive are also ~5 × 5 μm in size. Other areas of the model use a coarser mesh for a more-efficient solution. Based on a mesh refinement study, the results presented are mesh independent. Sensitivities to various parameters were studied with this model.

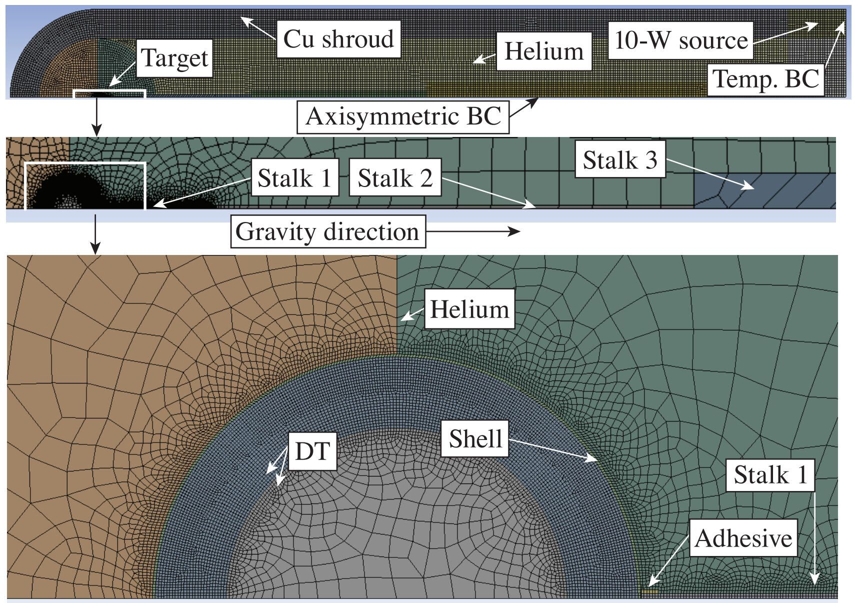

Figure 2
Model of mesh detail.

Experimental data of DT ice-layer uniformity were used to validate several of the multiphase conjugate heat-transfer numerical simulations. Based on experiment results and/or numerical simulations, the following conclusions were made:

- When heat sources are present in the helium environment, it is advantageous for the lower portion of the support structure to have a thermal conductivity of less than ~2 W/m/K.
- For the temperature variations and helium pressures studied, multiphase conjugate heat-transfer ice-layer models yield the same results as multiphase conduction-only models.
- The thermal conductivity of the fiber directly touching the target capsule must be a close match to helium thermal conductivity (0.026 W/m/K) to produce uniform ice layers.
- High target-shell thermal conductivity (~27 W/m/K) mitigates locally thick ice near a highly conductive (~1.5-W/m/K) support stalk.

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