Design and Implementation of a Digital Optical Microscope for Measurement of Submicron Defects on Cryogenic DT Targets

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Submicron particles on the exterior surface of cryogenic deuterium–tritium (DT) target shells may contribute to hydrodynamic instability during target implosions that reduce predicted performance. Particles that originate from pre-existing shell defects or foreign material present within the target Fill/Transfer Station and are observed to exist on the surface after filling with a DT gas. Currently available imaging tools are limited to resolution of the order of 3 μm (Ref. 1). A digital optical microscope system has been developed that provides *in-situ* capability to image 0.5- to 1.0-μm features that are within a critical size range identified by physics considerations. The system design is described and initial results are presented.[2] Initial results indicate that the fill cycle process results in a statistically minor increase in defect count (+10%) and affected area (+4%), and that the pre-to-post fill particle distribution is unchanged.

The Fill/Transfer Station (FTS) is an existing system that houses a target during its fill cycle. Current target evaluation is done at a separate characterization station that is incompatible with cryogenic temperatures. Close examination of a target requires removal of the thermal shroud, which requires that the imaging system exist in a cryogenic environment. The target is held at a temperature of 40 to 50 K during observation.

A commercially available 40×, 0.60 N.A. long-working-distance microscope objective meets the 0.5-μm resolution goal. The projected 20-μm feature size implies that a camera sensor with pixel size less than 10 μm is required to avoid aliasing. A room-temperature test bed was designed and built to verify proof-of-concept using identical optics and illumination to enable comparison of pre- and post-fill images. A quasi-collimated illuminator was designed to reduce the formation hot spots in the target region that originate from LED source points and provide uniform irradiance in the target plane.

The prototype system is shown in Fig. 1. The mechanical design is comprised of three sections: an illuminator, the microscope holder and motion stage, and the charge-coupled–device camera. The microscope and illuminator assemblies are compatible with cryogenic temperatures while the camera is housed within a vacuum bubble to provide isolation from the cold environment. Heat sinks were included to provide for dissipation of thermal sources (LED and camera power supply). With the microscope located outside of the thermal shroud, the microscope translation stage is motorized with a range sufficient to move the objective to the target. Limit switches connected to the controls interface prevent inadvertent collisions between components. A prototype system was installed on the FTS.

The control system provides the ability to remotely power and adjust the LED illumination level, regulate the camera vacuum bubble temperature, and deliver motion control to the microscope and camera stages. To reduce the impact of target vibration and thermal load, the illumination is pulsed and synchronized with the camera's electronic shutter setting. The acquisition pulse width is adjusted to provide optimal integration time on the sensor. Interlocks prevent interference between the microscope, the FTS shroud puller, and the moving cryostat. A software interface is included for image acquisition, display, analysis, and storage. All major component controls are deliverable over an Ethernet connection.

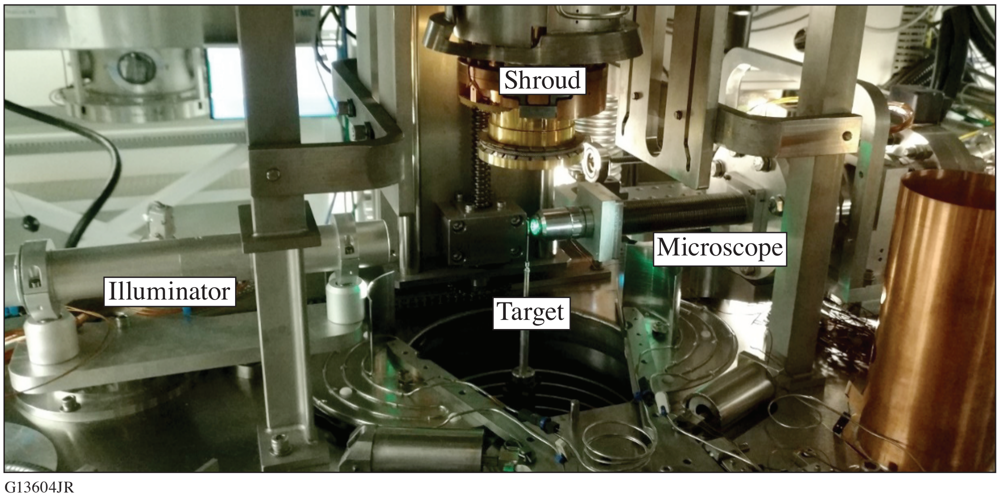

Figure 1
Installed FTS system showing key components.

A set of 12, 178 × 210-μm locations using pre-existing fiducial markers were established about the equator of the target shell, each of which was characterized under pre- and post-fill conditions. The warm temperature pre-fill and cryogenic post-fill optical systems used the same design with similar performance but separate systems. Each area was analyzed using all-in-focus (AIF)[3,4] and maximally stable extremal region (MSER)[5] image-processing techniques to detect and characterize micron-scale shell features. Images were pre-processed to normalize the bright-field background and optimize contrast. The AIF images were generated from a stack of eight to ten through-focus positions, which were then subject to an MSER algorithm for defect detection and statistical computation. A single target was used with a shell made from a glow-discharge polymer (GDP) process. Approximately 1% of the total shell area was analyzed and the results extrapolated. Figure 2 shows a side-by-side image comparison of one location for pre- and post-fill conditions.

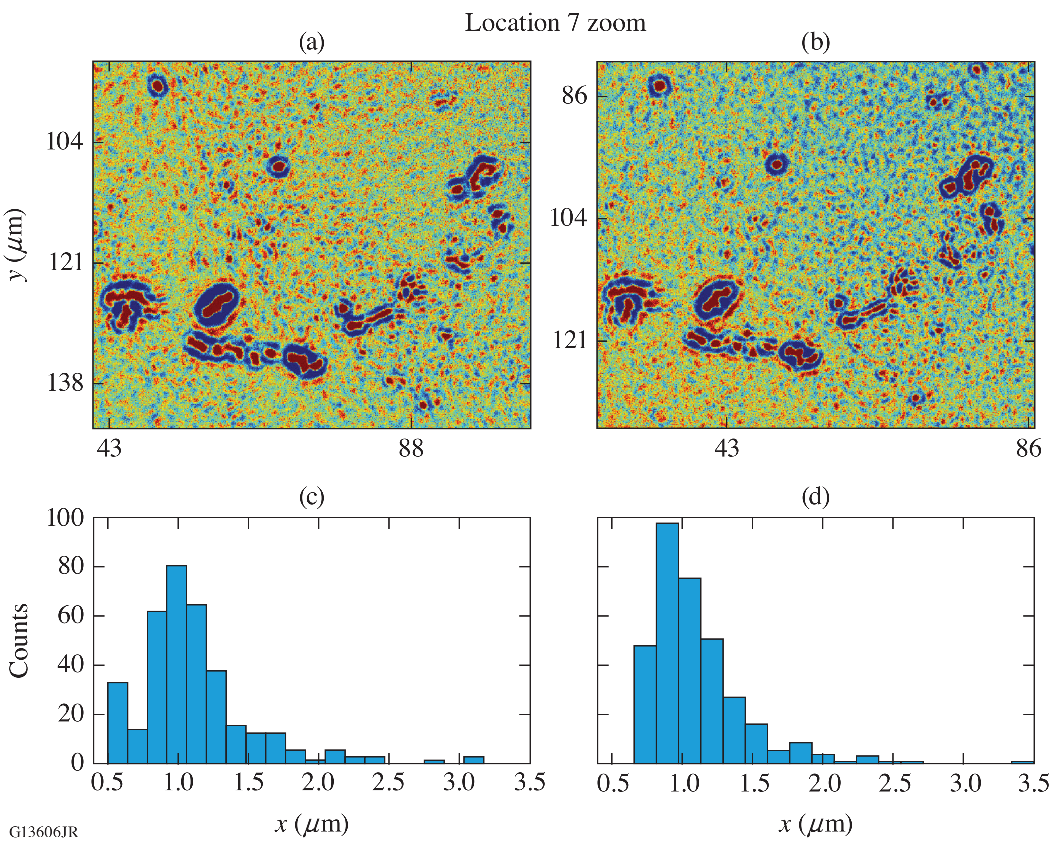

Figure 2
Image comparison for one of the 12 analyzed target areas.

The AIF/MSER techniques used found a 10% increase in feature counts and a 4% increase in feature area upon completion of the fill process (Fig. 3). While the plots suggest good agreement between the pre-fill and post-fill analysis, at present there is no assignment of error or degree of confidence assigned to the measurements.

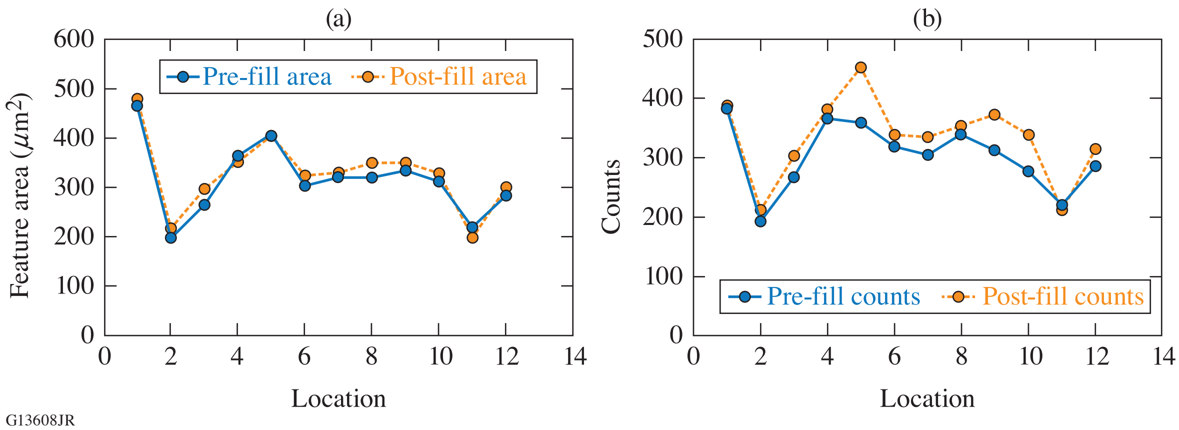

Figure 3
AIF/MSER analysis summary.

No new defects were identified between pre- and post-fill observations with the prototype system. Equivalent diameter size distribution for observed particles was between 0.5 to 2 μm (identified most significant for seeding hydrodynamic instabilities). Initial results indicate that the fill process does not significantly add to defect contribution, and that pre- and post-observation defect distributions are unchanged.

Future work is anticipated to include the testing of target shells made from materials other than GDP (e.g., polystyrene) containing fewer pre-existing defects and the collection of larger data sets to strengthen the statistical significance of results that are obtained. Periodic recharacterization of the platform using a surrogate target is also planned to monitor possible long time-scale system drift.

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