

A Recommendation Inspection to Control Sub-Surface Damage in Sapphire

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We will recommend an inspection practice for single-crystal optics, we do this with a hope: that it is a good start on developing a generally useful sub surface damage inspection standard serviceable for all single crystal based optics. The approach, which is now well demonstrated as effective for sapphire, requires test pieces successfully progress through four separate inspection steps. Passage from one step to the next is conditional on passing the current one. Failure at any step requires rejection and return for reworking. These steps range from using shop floor practices - a careful visual inspection - onto use of x-ray topography, an advanced diagnostic. The possibility to rework inspected parts is the key argument for just inspecting, over using proof testing. Preferably, both are and would be used as complementary methods.

This approach to inspection distills our experiences with the Sapphire Statistical Characterization And Risk Reduction (SSCARR) Program. SSCARR tried to establish a fracture-strength database for sapphire windows and domes, and to develop means to detect and control subsurface damage. SSCARR specifically raised the questions: what allowances in both the fabrication of parts and performance expectations for parts must be made for subsurface damage? NIST's role was to identify and evaluate ways to non-destructively inspect sapphire for sub surface damage, SSD, and to then recommend a "practical" detection practice. Eleven different forensic methods were considered. A second task was to correlate pre-inspection results/observations with actual fracture performance which will also be briefly reported here.

Optical components frequently use brittle materials, and fabrication involves damaging the surface material to shape parts. A residue of SSD is expected from the processing. In sapphire, this damage can be surface stresses, large scratches, twins, cracks, edge chips, and digs - craters in the surface. Subsequent fabrication steps always try to remove the SSD from a preceding step or all of the preceding steps. Just how much material to remove and in what way affects the cost and time to make parts. Effective SSD control is your best reason for inspecting optical components.

The practice has four inspection steps. First, parts are visually examined for significant flaws. Second, a Polariscopes is used to reveal sub-structure and "large" bulk strains. Third, light microscopy is used to detail significant flaws. Fourth, the component is examined using x-ray topography at the NIST, Materials Science Beamline at the National Synchrotron Light Source of the Brookhaven National Laboratory.

To illustrate the technical points and to establish credibility for the approach, we will draw solely on our SSCARR experiences, where ASTM Type B modulus of rupture bars to measure fracture strength in four point bending. The bars were supplied by the prime vendors for each missile system and were to exactly "represent" flight components. Our inspection was to address surface

quality. The bars were made in groups of 25 or more pieces, of one gauge surface condition and crystallo-graphic orientation. Each groups represented different vendor, and specific window or dome areas. Since THAAD and ARROW use octagonal planar windows, there are three geometrical regions to consider. Each area had a specific and different surface finish. The Block IVA missile uses a hemispherical dome; and nominally one surface condition. But this shape uses all crystallographic orientations, which predictably leads to different local surface conditions. The specific test pieces for our task were selected for two reasons. One was to represent key SSCARR factors, the other to define the Diagnostics performance envelopes.

Using just finish proved to be a serious obstacle to effective inspection. The MOR bar finishes ranged from ground through to super-polished. In between were the edge, bevel and side finishes. We force fit "finish" into three grades: ground, intermediate and polished. Surface finish numbers obtained from non-contacting profilometry proved useful numerical descriptors of the surface relief, but not the mechanical performance. Finish values ranged from 0.7 nm Ra, THAAD optical faces; down to 1.4 m, ARROW side finish. The range of finish was the key obstacle to using just one inspection method. For this inspection recommendation, we are simplifying the problem to inspecting parts with a less than 10 nm Ra surface finish.

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