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Barium Fluoride Surface Preparation, Analysis and UV Reflective Coatings at Lawrence Livermore National Laboratory

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BARIUM FLUORIDE SURFACE PREPARATION, ANALYSIS AND UV REFLECTIVE COATINGS AT LAWRENCE LIVERMORE NATIONAL LABORATORY

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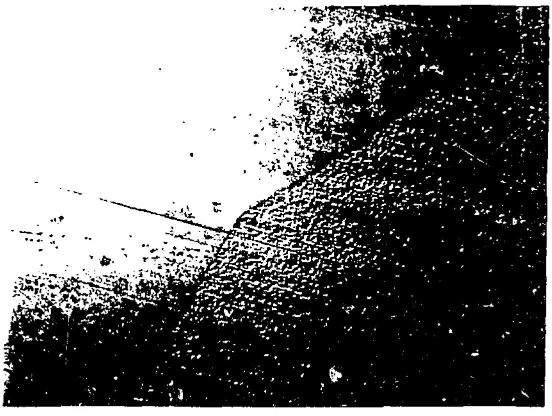
Lawrence Livermore National Laboratory (LLNL) has begun a program of study on barium fluoride scintillating crystals for the Barium Fluoride Electromagnetic Calorimeter Collaboration. This program has resulted in a number of significant improvements in the mechanical processing, polishing and coating of barium fluoride crystals. Techniques have been developed using diamond-loaded pitch lapping that can produce 15 angstrom RMS surface finishes over large areas. These lapped surfaces have been shown to be crystalline using Rutherford Back-scattering (RBS). Also, special polishing fixtures have been designed based on mounting technology developed for the 1.1 m diameter optics used in LLNL's Nova Laser. These fixtures allow as many as five 25-50 cm long barium fluoride crystals to be polished and lapped at a time with the necessary tolerances for the 16,000 crystal Barium Fluoride Calorimeter. In addition, results will be presented on coating barium fluoride with UV reflective layers of magnesium fluoride and aluminum.



1. Barium Fluoride Surface Preparation and Analysis

Surface preparation is critical to the performance of barium fluoride crystals for a number of reasons. First, an improperly prepared (machined, ground, polished, lapped) crystal suffers from induced stresses and deformations in the first few hundred microns of the surface. These stresses can manifest themselves in the formation of cracks (crazing) over time, or more quickly when subjected to extremes of heat, radiation, humidity, etc.. Surface stresses can be minimized using well-known polishing and lapping techniques that *gently* bring the surface to a final finish. These techniques have been developed at LLNL for barium fluoride. Also, improper surface preparation can introduce contaminants into the surface of the crystal. Under certain conditions these contaminants can migrate into the bulk of the crystal and cause extended areas of radiation susceptibility.

Improperly prepared surfaces are easily identified under optical microscopy, and other analysis techniques such as Rutherford Backscattering (RBS). In the case of RBS, helium ions bombard the surface and can channel into the crystal preferentially along the crystal planes. If the surface of the crystal is amorphous, no preferential backscattering is observed. If the crystal surface is crystalline, the crystal lattice is readily identified as peaks in the backscattering number. Figure 1 shows results for crystals prepared at LLNL using improper and proper polishing methods.

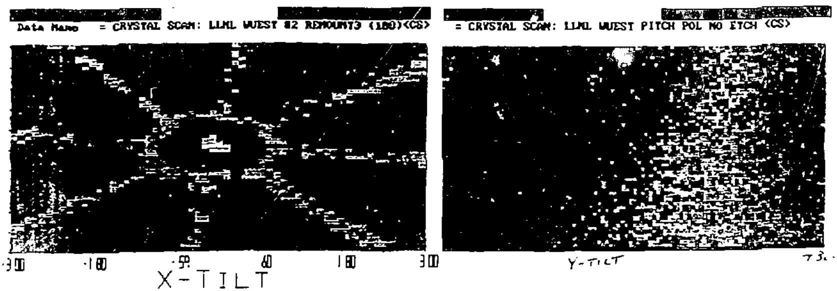


Figure 1. RBS images of polished barium fluoride surfaces showing examples of good and bad crystalline surfaces

A number of surface preparation techniques were explored at LLNL, including ion beam milling, diamond turning, and various polishing/lapping techniques. In terms of surface finish, diamond-turned surfaces are the best with 6 Å RMS demonstrated. However, RBS analysis of diamond-turned surfaces reveal that they are amorphous. The photograph on the title page shows an example of diamond-turned barium fluoride with a noticeable crystal grain boundary. Ion beam milling provides the best crystalline surface, however the uniformity of the surface and the finish is not very good.

A polishing technique – pitch lapping with diamond abrasives – provides the best combination of surface finish (10-20 Å RMS) and surface crystallinity. The technique is applied after more standard polishing techniques and is a simple wheel (lap) prepared with a low melting temperature synthetic pitch. Grooves are formed in the pitch in a pattern to allow cutting fluids, abrasives and ground material to be washed away during the lapping process. The key to the process is a final polish with an abrasive of very uniformly sized diamond, typically 1/2 μm or 1/4 μm diameter, imbedded in the pitch. In addition, a non-aqueous cutting fluid such as low viscosity silicon oil, or ethylene glycol is used to uniformly disperse the diamond and to carry away waste material. Water is not a good fluid for diamond because of the tendency of diamond to agglomerate in water. Water is also not desirable because of the slight solubility of barium fluoride in water.

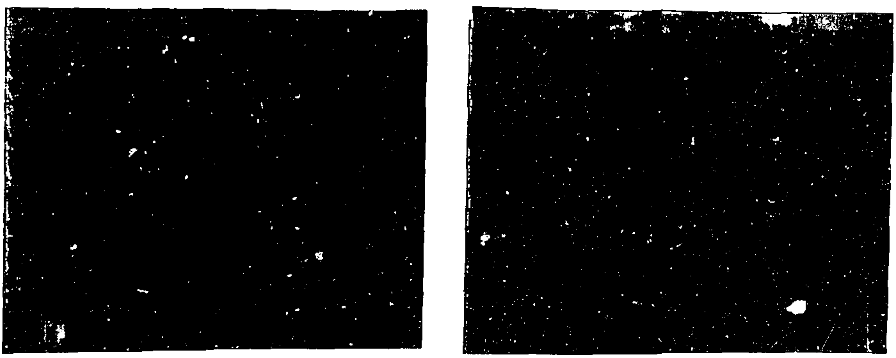


Figure 2. Photographs of polished barium fluoride surfaces comparing a Chinese polish to the improved LLNL polish (magnification x179).

Figure 2 compares two polished surfaces, the first being a photograph of a polished surface provided by the Zhongnan Optical Instrument Factory in China and the second polished by LLNL methods. We have verified these surfaces using Atomic Force Microscopy (AFM). This analysis supports optical measurements and also provides insights into the mechanics of the polishing technique.

The polishing techniques developed at LLNL are simple to implement and are essentially extensions of standard polishing techniques already in practice in the US and in China. We feel that these techniques are easily transferred to the Chinese for large scale production and incur little added cost to the overall production of finished crystals. LLNL engineers and physicists have visited China to work with the Chinese to develop this capability.

LLNL has also designed fabricated a set of special polishing fixtures that allow up to 5 crystal halves or pairs (50 cm length) to be polished at the same time. These fixtures will be used to demonstrate the technique of multiple polishing. It is expected that flatness can be maintained across the full 25 cm x 25 cm area of grouped crystal halves at the level of a fraction of a wavelength of visible light. Also surface finish can be maintained to about 20 Å. These fixtures are again easily adapted to existing techniques and machines in the US and China. It is anticipated that these techniques would be provided to the Chinese for mass production of crystal pairs.

2. UV Reflective Surface Coatings R&D

High quality surface preparation is also important for insuring the proper application of a reflective coating that exhibits good reflectivity in the UV, as well as long term stability. LLNL has experimented with the application of magnesium fluoride and aluminum coatings on barium fluoride. Measurements of front surface reflectance of 500 Å aluminum coatings on barium fluoride have been made along with measurements of reflectance through a thin (2 mm) sample of barium fluoride (back reflectance). Measurements indicate that reflectivity at 220 nm is about 90%.

Diffuse scattering measurements of the aluminum coating have also been made for front surface scattering. It is assumed that this is representative of the diffuse scattering on the back surface into the barium fluoride crystal. Measu ements have also been made on magnesium fluoride coatings on barium fluoride to determine the critical angle for total internal reflection.

Additional work is planned to study the long term integrity of coatings. For example, if microscopic pits or pin-holes occur, moisture can come into contact with the crystal surface, eventually leading to a degradation of the coating in that region due to chemical reactions that may occur.

LLNL is also helping to provide this data to physicists at Oak Ridge National Laboratory to help model the response of a barium fluoride crystal using a specially written Monte Carlo program. In addition, studies of the response of 50 cm long crystals to cobalt-60 and iron-55 gamma rays and x-rays are being carried out at LLNL. These studies are being made for different coating materials and combinations of coatings in an effort to provide uniform collection of scintillation light along the length of the crystal.

3. Conclusions

The polishing and coating techniques described in this paper have been shown to provide surfaces with high quality finishes as well as very good macroscopic tolerances. These techniques are extensions and refinements of basic polishing technology and are easily transferred to industry, or, as we have demonstrated, to our Chinese collaborators. As other crystals become important for scintillation detectors, we feel that our experiences described here can be applied for precision mechanical processing and coatings. We have begun a similar program to study cerium fluoride and we have successfully diamond-turned cerium fluoride to surface finishes of the same quality as barium fluoride. Also, our coating techniques are directly applicable to the somewhat longer wavelength emission of scintillation light in cerium fluoride. Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract W-7405-ENG-48.