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Craig R. Wuest
Baruch A. Fuchs
Fred R. Holdener
Joaquim L. Heck, Jr.

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PRECISION MACHINING AND POLISHING OF SCINTILLATING CRYSTALS FOR LARGE CALORIMETERS AND HODOSCOPES

Craig R. Wuest*, Baruch A. Fuchs*, Fred R. Holdener* and Joaquim (Jack) L. Heck, Jr.**
*Lawrence Livermore National Laboratory, Livermore, CA 94551
**Oak Ridge National Laboratory, Oak Ridge, TN 37831

ABSTRACT

New machining and polishing techniques have been developed for large scintillating crystal arrays such as the Barium Fluoride Electromagnetic Calorimeter for the GEM Detector at SSCL, the Crystal Clear Collaboration's cerium fluoride or lead tungstenate calorimeter at the proposed LHC at CERN, the PHENIX Detector at RHIC (barium fluoride), and the cesium iodide Calorimeter for the BaBar Detector at PEP-II B Factory at SLAC. The machining and polishing methods to be presented in this paper provide crystalline surfaces without sub-surface damage or deformation as verified by Rutherford Back-scattering (RBS) analysis. Surface roughness of about 10-20 angstroms and sub-micron mechanical tolerances have been demonstrated on large barium fluoride crystal samples. Mass production techniques have also been developed for machining the proper angled surfaces and polishing up to five 50 cm long crystals at one time. These techniques utilize kinematic mount technology developed at LLNL to allow precision machining and polishing of complex surfaces. We will present this technology along with detailed surface studies of barium fluoride and cerium fluoride crystals polished with this technique.

INTRODUCTION

New machining and polishing techniques have been developed for large barium fluoride scintillating crystals that provide crystalline surfaces without sub-surface damage or deformation as verified by Atomic Force Microscopy (AFM) and Rutherford Back-scattering (RBS) analyses. Surface roughness of about 10–20 angstroms and sub-micron mechanical tolerances have been demonstrated on large crystal samples. Mass production techniques have also been developed for machining and polishing up to five 50 cm long crystals at one time. We present this technology along with surface studies of barium fluoride and cerium fluoride crystals polished with this technique. This technology is applicable for a number of new crystal detectors proposed at Colliders[1] including the Barium Fluoride Electromagnetic Calorimeter at SSC[2], the Crystal Clear Collaboration's[3] cerium fluoride or lead tungstenate calorimeter at LHC, the cesium iodide Calorimeter for the BaBar Detector at SLAC[4] and the PHENIX scintillating hodoscope at RHIC[5].

Lawrence Livermore National Laboratory (LLNL) has an active program of study on barium fluoride scintillating crystals for the Barium Fluoride Electromagnetic Calorimeter Collaboration, cerium fluoride and lead fluoride for the Crystal Clear Collaboration, and cesium iodide for the SLAC B Factory. This program has resulted in a number of significant improvements in the mechanical processing, polishing and coating of fluoride and iodide crystals. Techniques have been developed using diamond turning and diamond-loaded pitch lapping that can produce 15 angstrom RMS surface finishes over large areas. 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 crystals to be polished and lapped at the same time with tolerances satisfying the stringent requirements of crystal calorimeters. We also discuss results on coating barium fluoride with UV reflective layers of magnesium fluoride and aluminum.

BARIUM FLUORIDE SURFACE PREPARATION AND ANALYSIS

Surface preparation is critical to the performance of barium fluoride and other fluoride and iodide 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 long times, 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 and also applied to cerium fluoride and lead fluoride. Improper surface preparation can also 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. Because these scintillator materials emit their light typically in the UV, surface finish is especially important for good light transport properties.

A number of surface preparation techniques were explored at LLNL, including ion beam milling, diamond turning, and various polishing/lapping techniques. Ion beam milling provides the best crystalline surface, however, the uniformity of the surface, as well as the surface finish is not very good. In terms of surface finish, diamond-turned surfaces are the best with 6 Å RMS demonstrated on barium fluoride. However, RBS analysis of diamond-turned surfaces reveal that they are amorphous. Figure 1 shows an example of diamond-turned barium fluoride with a noticeable crystal grain boundary that exhibits different surface finishes. Also shown in Fig. 1 is an example of an improperly polished crystal at similar magnification.

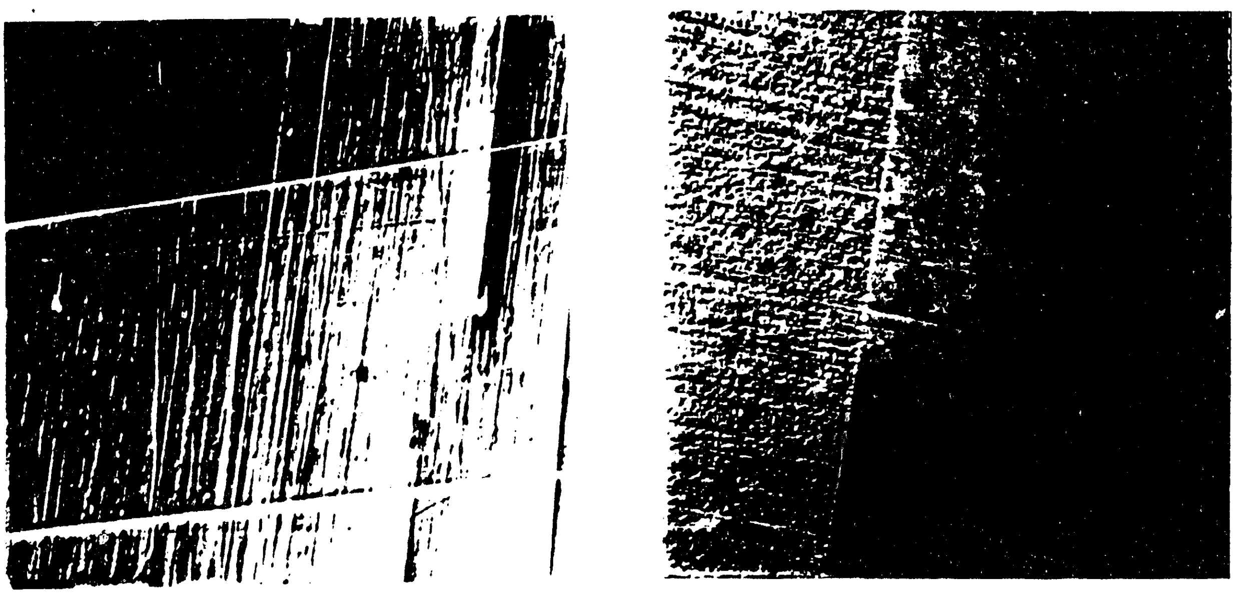

Figure 1. Photographs (179x) of polished barium fluoride surfaces comparing inferior polishing techniques (200 Å RMS in regions between the large grooves) to diamond turning (6/80 Å RMS).

A polishing technique – pitch lapping with diamond abrasives – provides the best combination of surface finish (10-20 Å RMS) and surface crystallinity for fluoride crystals. 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 polishing because of the tendency of diamond to agglomerate in water. Water is also not desirable because of the slight (large) solubility of fluoride (iodide) crystals in water. We have verified the high quality of diamond-lapped surfaces using AFM and RBS. This analysis supports our optical measurements and also provides insights into the mechanics of the polishing technique.

Improperly prepared surfaces are easily identified under optical microscopy, and by using other analysis techniques such as 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 2 shows results for crystals prepared at LLNL using improper and proper polishing methods.

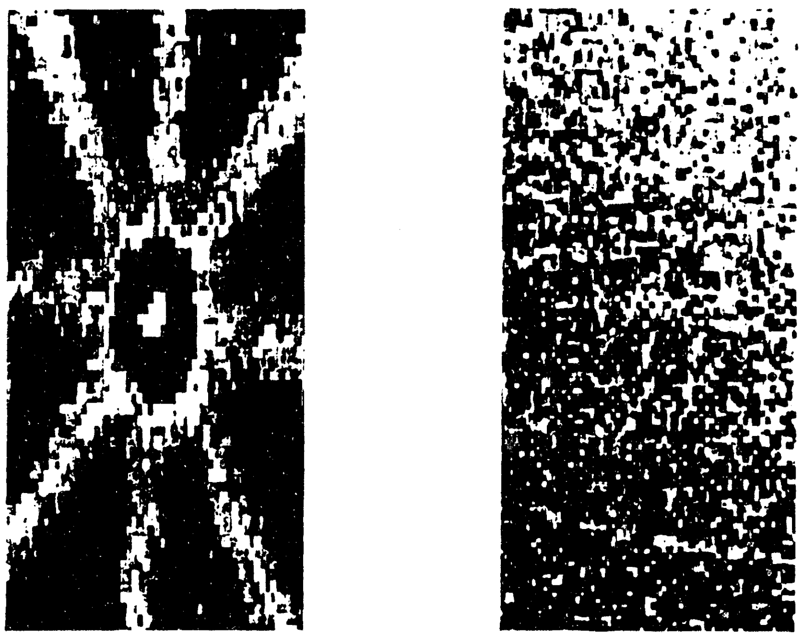

Figure 2. RBS images of standard polished barium fluoride and diamond-loaded pitch lapped barium fluoride surfaces showing bad (right) and good (left) crystalline surfaces. The images show the backscatter as a function of x and y tilt angles over a range of ±3°.

LLNL has designed and 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. Crystals are set to their proper angles for polishing by means of a 3-point kinematic mounting block with precision shims to adjust each crystal surface. The crystals are mounted to precision blocks that are held in place by magnetic couplings. These fixtures have been used to demonstrate the technique of multiple polishing and flatness can be maintained across the full 25 cm x 25 cm area of grouped crystal

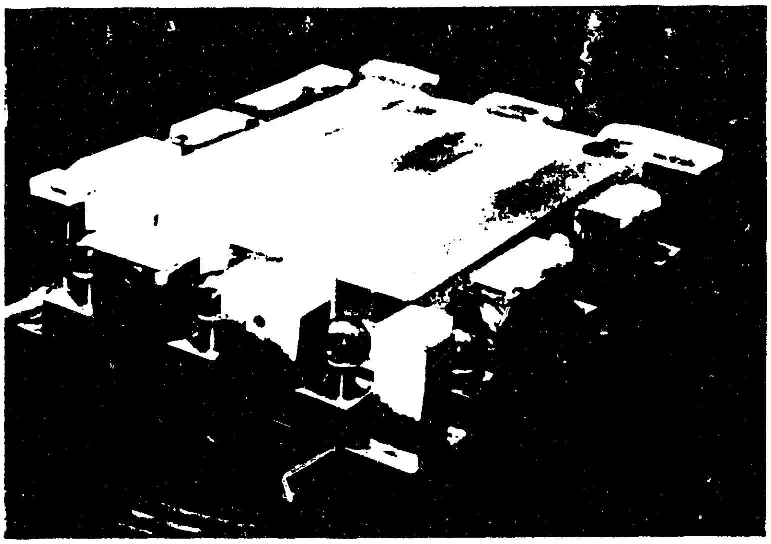

Figure 3. Polishing fixtures developed at LLNL for polishing multiple crystals with trapezoidal shapes. The fixtures allow polishing with a high degree of flatness and excellent surface finish.

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 easily adapted to existing techniques and machines in use throughout the world. It is anticipated that these techniques would be very desirable for mass production of complex, tapered crystal segments for calorimeters and hodoscopes. Figure 3 is a photograph of the various polishing fixtures. Figure 4 shows a set of five 25 cm barium fluoride crystals mounted for polishing.

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 elsewhere. We feel that these techniques are easily transferred to industry both in the US and overseas. We expect that our techniques can be utilized in production facilities for large scale production of crystal

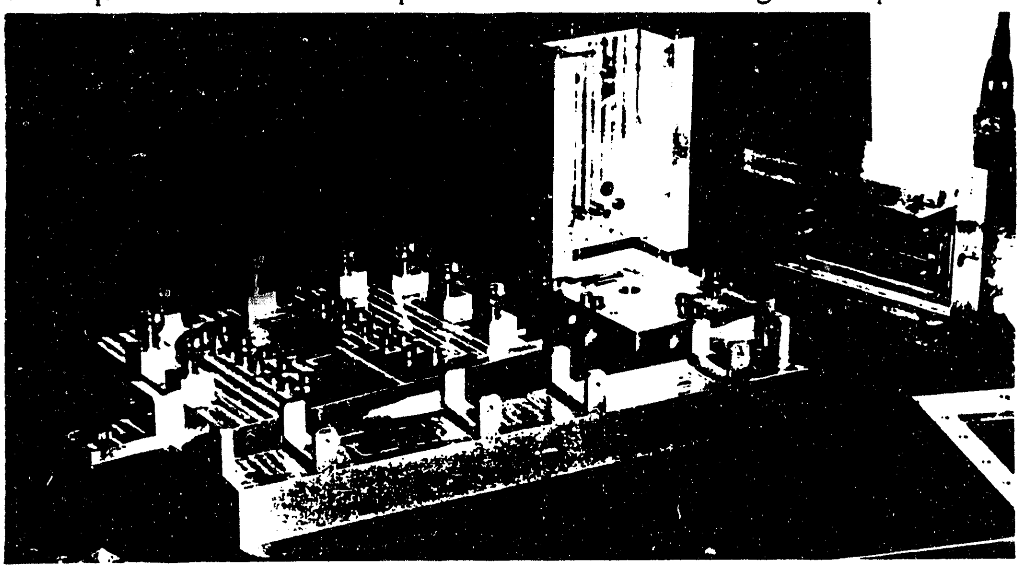

Figure 4. Five 25 cm long barium fluoride crystals mounted in the polishing tool.

scintillators with little added cost to the overall production of finished crystals. LLNL engineers and physicists have recently visited China to work with the researchers at the Shanghai Institute of Ceramics[6] and the Beijing Glass Research Institute to develop this capability.

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 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. Measurements 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 pinholes 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, and cosmic ray studies are being made at UC San Diego. 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.

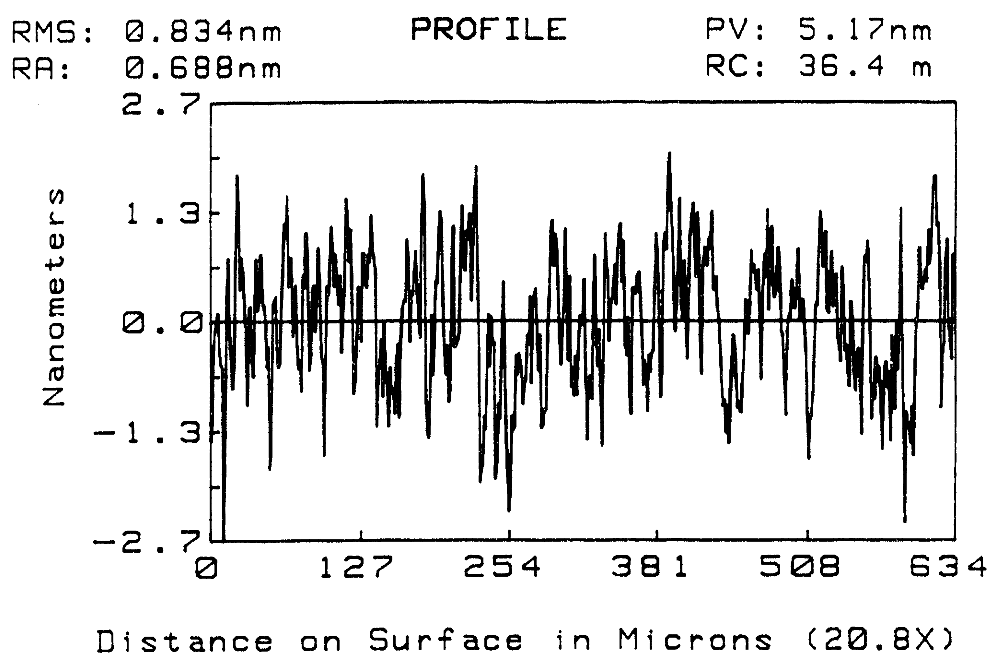

Figure 5. Surface scan of a diamond turned cerium fluoride sample. The surface finish is measured to be 8 Å RMS.

CONCLUSIONS

The polishing techniques described here have been shown to produce 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. Other crystals, such as cerium fluoride and lead tungstenate are becoming increasingly available for scintillation detectors, and we feel that our experiences described here can be applied for precision mechanical processing and coatings of these materials. We have begun a similar program to study cerium fluoride, lead fluoride and lead tungstenate and we have successfully diamond-turned cerium fluoride to surface finishes of the same quality as for barium fluoride. A surface scan of a cerium fluoride sample is shown in Figure 5. Also, our coating techniques are directly applicable to the somewhat longer wavelength emission of scintillation light in cerium fluoride, and cesium iodide.

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