Crystal Surface Preparation

Technical Information Note
Document #526

All polished crystals look pretty because they reflect and refract light. We are accustomed to seeing gemstones this way. Scintillation crystals, whether in a cylindrical, prismatic or parallelepiped geometry are also more pleasing to look at when they are all polished rather than crystals with sanded or roughened surfaces. It may seem obvious that polishing all of the surfaces of a scintillation crystal is the best way to prepare it – perhaps because that is the way they are imagined or visualized mentally. But...

For a scintillation crystal, the important factor is how efficiently the light is channeled to the photomultiplier tube (PMT). In a material with an index of refraction higher than the air around it, there is a critical angle beyond which light will not leave the material, but be reflected internally. A common example is that of a fish underwater. The fish can look up and out and see all the way to the shore, but the view is compressed into a narrow cone. This is like the fish eye lens provided in hotel doors or used on cameras. Beyond this cone angle, only reflections (like a mirror) from below the water are seen.

Similarly, inside a scintillating crystal, the light is internally reflected beyond a certain angle. And if the adjacent surface is polished and at a shallow angle, it can internally reflect again, and again at the next surface and so on at the next surface. This kind of reflection is termed specular reflection and the mirror like surface is called a specular surface.

For materials with a high index of refraction like NaI, CsI and BGO, the cone angle of light that passes in and out is even narrower than it is for water and so more light is reflected inside. If a high index material like NaI, CsI or BGO is all polished, then it is possible to trap some fraction of the scintillation light reflecting around inside. This results in a reduction of the light collected by the PMT and worse energy resolution. (For a mathematical treatment, see *Trapping of Fluorescent Light in Cylindrical Scintillators* by C. Carrier and R. Lecomte NIM A278(1989)622-624.)

In making a detector, it is important to avoid such internal trapping. We do this by roughening the surfaces so that light is scattered at a random angle thus preventing this internal trapping. Such a surface is called a diffuse surface and it causes diffuse reflections.

Geometry is also important. For detectors with aspect ratios near 1, all surfaces are roughened (sanded or diffused) except where the PMT is placed. (Aspect ratio is the ratio of length to diameter.) This helps to get the light to the PMT without trapping any inside the crystal. The light is randomly scattered until it is absorbed by the PMT.

For a detector with a large aspect ratio like a 1.75" diameter x 12", much of the lateral surfaces are polished to make it act like a light pipe to help channel the light from the far end of the crystal up to the PMT. There is a trade-off between trapping light and piping it down to the PMT. Some light is sacrificed in this approach as compared to all sanding but an improvement in uniformity is achieved which helps to get better pulse height resolution.

For very large and long detectors, most commonly a combination of the two techniques (polishing or roughening the surfaces) is used to optimize light collection for the different shapes that are encountered. These effects are studied in different geometries in BGO. See *Effect of Surface Roughness and Crystal Shape on Performance of Bismuth Germanate Scintillators* by Hiroyuki Ishibashi, Seikichi Akyama and Mitsuru Ishi, JAP, No. 9, September 1986,pp.1435-1438.

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