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RADIATION DAMAGE OF QUARTZ FIBERS

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Abstract

Quartz fibers are used in high energy physics experiments as the active medium in high radiation area calorimetry. Quartz fibers are also used in the transmission of optical signals. Even though quartz does not damage by moderate amounts of irradiation, the clad of the fibers and the protective coating (buffer) do damage reducing light transmission. Various types of quartz fibers have been irradiated and measured for light transmission. The most radiation hard quartz fibers are those with quartz clad and aluminum buffer.

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RADIATION DAMAGE OF QUARTZ FIBERS

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Quartz fibers are used in high energy physics experiments as the active medium in high radiation area calorimetry. Quartz fibers are also used in the transmission of optical signals. Even though quartz does not damage by moderate amounts of irradiation, the clad of the fibers and the protective coating (buffer) do damage reducing light transmission. Various types of quartz fibers have been irradiated and measured for light transmission. The most radiation hard quartz fibers are those with quartz clad and aluminum buffer.

1. INTRODUCTION

Quartz is known to be radiation hard as compared to plastic. For some time we were puzzled by the fact that some quartz fibers are much more radiation soft than others [1]. After irradiating various types of quartz fibers, finally a clear picture is emerging of what makes a quartz fiber damage by radiation.

High energy particle accelerators produce large numbers of secondary particles which damage the materials on which these particles impinge. The higher the energy, the more the production of secondary particles and the more severe is the radiation damages. Many detectors use fibers to produce optical signals (such as scintillators) as well as transmit these signals. Scintillating or clear plastic fibers damage in the several Mrad (10 kGy) of irradiation. Quartz fibers on the other hand, are much more radiation hard and can be used in more hostile environments. The quartz fiber as an active measurement medium such as in calorimetry, uses Cerenkov radiation in the quartz. The Cerenkov light production wavelength depends on the type of particle and energy. In a quartz fiber calorimeter, the quartz fiber produces Cerenkov light with the peak in the ultra violet spectrum. On the other hand many photo detectors have glass surfaces that do not transmit UV light and so the effective peak is in the blue. The radiation damage is wavelength dependent and our damage measurements cannot be applied directly to compute light reduction.

Quartz fibers used in calorimeters produce very fast signals (less than one nanosecond). Since the Cerenkov radiation is mainly due to electrons and positrons, the quartz fibers are insensitive to radioactivity of the surrounding detector material. A typical quartz fiber has a quartz core, between 0.1 to 1.0 mm in diameter and a cladding of lower index of

refraction. This cladding can be acrylic or some other material. In some quartz fibers the cladding is fluorinated quartz which is more radiation hard. Since quartz is very fragile, most manufacturers cover it with a buffer material. The buffer is often made of some kind of plastic or even a metal such as aluminum. Radiation damage depends on the cladding as well as on the buffer.

2. IRRADIATION OF QUARTZ FIBERS.

Various quartz fibers were irradiated by the Florida State University 3 MeV electron accelerator. The amount of irradiation can be controlled to within 20%. The exact amount of irradiation is measured by radiachromatic dye film[2] with an accuracy of about 7%. The method of excitation of the fiber is by a Strontium 90 beta source, where the light produced is Cerenkov radiation. A typical measurement uses a fiber of about 80 cm length, where the fiber is measured before and after irradiation. The signal was measured as a DC current in a 12 stage bi-alkali photo multiplier tube, Hamamatsu R329, which has a glass surface that does not transmit UV light. We do not observe any long term recovery from radiation damage of quartz fiber. The fibers are irradiated at a rate of about 1 Mrad per hour. The fibers were a mix of various claddings and buffers. One sample of quartz fiber did not have the buffer material.

Figures 1 through 3 are typical measurements of various quartz fibers, before and after irradiation. In figure 2 both fibers have the same diameter. The lower light yield of aluminum buffer fiber is due to the absorption of electrons from the Strontium 90 source. When the current in the photomultiplier tube gets low we observe more fluctuations, which is the reason why the low current portions of the curves are not as smooth. The aluminum buffer fibers show more fluctuations in the photomultiplier current as

the buffer thickness is not very uniform. One curious observation: when the fibers with Polyimide buffer were irradiated and then broken, a drop of water was observed to come from between the clad and the buffer. It is unclear where this drop of water came from.

Figure 1. Light yield of a quartz fiber from Belarus, before and after 7 Mrad. Quartz core with quartz clad, no buffer.

Figure 2. Light yield of two Polymicro [3] quartz fibers, before and after 3 Mrad. Top set (FVP) is quartz core, quartz clad and Polyimide buffer. Lower set (FIL) is quartz core, quartz clad and aluminum buffer.

Figure 3. Light yield of a quartz fiber from Russia, before and after 3 Mrad. Quartz core with plastic clad and aluminum buffer.

Table 1

Fibers 1 through 10 are made by Polymicro [3]. The fibers were excited by electrons from a Strontium 90 source and signal measured by a 12 stage photomultiplier tube with bi-alkali photocathode, Hamamatsu R329. The damage is the light yield reduction at the center of 80 cm fiber.

Quartz fiber	Diameter (micron)		Clad	Buffer	Damage (3 Mrad)	Damage (12 Mrad)
	core	outer				
1. FVL400440520	390	520	Doped silica	Aluminum	0	0
2. FIA200240500	202	500	Doped silica	Acrylate	0	10%
3. SHA300320345	297	343	Proprietary	Acrylate	20%	50%
4. FIP200220240	200	239	Doped silica	Polyimide	20%	40%
5. FIL300330370	300	428	Doped silica	Aluminum	0	0
6. FVP300315345	301	348	Doped silica	Polyimide	35%	55%
7. FIS200220500	203	504	Doped silica	Silicone	Breaks too easily	
8. FVP300330370	300	370	Doped silica	Polyimide	30%	50%
9. FVP300330370	300	370	Doped silica	Polyimide	33%	
Second batch	Sept.	1998				
10. FVP200220240	200	240	Doped silica	Polyimide	35%	
Second batch	Sept.	1998				
11. Russian	600		Unknown	Aluminum	40%	
12. Belarus	350	360	Doped silica	None	0% at 7 Mrad	

from and whether it is associated with the observed damage of Polyimide buffer quartz fibers. A complete survey of all the fibers with various amounts of irradiation was not possible as we did not have a wide selection of quartz fibers kinds, nor many samples of each type of fiber. The only quartz fibers with only quartz clad and no buffer did not show any damage. The fiber with quartz clad and aluminum buffer also did not show any damage. All other fibers showed irradiation damage. Table 1 shows a summary of the quartz fibers measured for irradiation damage. The loss of signal strength listed in the table is for the middle of the fibers. A note of caution: these measurements should be taken as relative radiation hardness of quartz fibers, rather than as a measurement of the absolute damage for any application, as the production of Cerenkov light and its transmission in the fibers are different in various applications.

3. CONCLUSION

Quartz fibers with either a plastic clad or plastic buffer show irradiation damage. Quartz core with quartz clad and no buffer, or aluminum buffer do not show any damage up to 10 Mrad (100kGy). All other quartz fibers show damage. Acrylate buffer shows less damage than

Polyimide buffer. We could not measure the fibers with a sticky silicone buffer as they broke too easily.

For high radiation environment, quartz fibers with quartz clad, either with no buffer or aluminum buffer, are the most resistant to radiation damage.

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