Radiation Damage and Light Transmission Studies on Air Core Light Guides

U. Akgun, P. Bruecken, A. S. Ayan, F. Duru, J. Olson, E. A. Albayrak, E. Gülmez, A. Mestvirishvili, Y. Onel, and I. Schmidt

***Abstract*—This report summarizes the radiation damage and the light transmission efficiency studies done on air core light guides with three different types of reflective material: two types of aluminized Mylar and a highly reflective plastic film from 3M called Radiant Mirror Film. The variations in light transmission efficiencies of these reflective materials have been studied with respect to the wavelengths of the incident light. The light transmission with one type of aluminized Mylar, which shows better reflectivity in UV range, deteriorated 14% after 10 Mrad of γ-ray irradiation from a 9.5 kCurie ^{137}Cs source. Light guides with the other type of aluminized Mylar and Radiant Mirror Film do not seem to be affected from radiation, and they show superior light transmission efficiency in the visible region.**

***Index Terms*—Air core light guide, aluminized mylar, HEM, light guide, light transmission, radiation hardness, reflective film.**

I. Introduction

AIR core light guides are routinely used in a wide range of high energy physics experiments to carry the photons to the photomultiplier tubes (PMT). There is a loss of light during the transmission depending on the length, shape, and the reflecting film of the air core light guide. On the other hand, their use help smear the photocathode nonuniformities of the PMTs [1].

The reflecting films used in the air core light guides are multilayered, in which the material thicknesses are scaled in order to produce constructive interference effects on different incident light wavelengths and angles. The air core light guides and the reflective films have a wide variety of applications in new energy technologies [2], electronics, magnetic media, industrial specialty, and imaging. The previous studies done on reflective films present some structural damages [3], and degradation on reflectivity [4], [5] under irradiation. In particle physics the intense high energy beams are known to cause radiation damages on detector components [6]. Especially, in the future collider experiments which are going to run at unprecedented energy levels for years, the issue of radiation hardness as well as the light transmission efficiency of the reflective films become important.

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U. Akgun, P. Bruecken, A. S. Ayan, F. Duru, J. Olson, E. A. Albayrak, A. Mestvirishvili, Y. Onel, and I. Schmidt are with the University of Iowa, Iowa City, IA 52242 USA (e-mail: ugur-akgun@uiowa.edu).

E. Gülmez is with Bogazici University, Bebek, Istanbul 34342, Turkey.

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We report the results of the radiation damage and light transmission studies done on air core light guides with three different reflective films. Aluminum tubes of 2.5 cm in diameter and 43 cm in length are used as light guides, and the inside of the tubes are lined with a reflecting film. The films used in this study are a 25 μm thick aluminized Mylar (Type-1 AM), a new and thicker aluminized Mylar (Type-2 AM) which has extra Nb_2O_5 and SiO_2 layers, and a new highly reflecting film (3M™ Radiant Mirror Film) often referred to as High Efficiency Mirror (HEM). Thicker Type-2 aluminized Mylar was developed by the Fraunhofer Institute for Electron Beam and Plasma Technology for the purpose of maximizing the reflectivity at higher angles of incident light [7]. HEM consists of hundreds of layers of polymer with non-isotropic indices of refraction in thicknesses chosen to produce optical interference that results in an exceptionally high reflectivity [8].

II. Radiation Damage

Three air core light guides prepared with each reflecting film were irradiated by using 9.5 kCurie ^{137}Cs source at the University of Iowa Radiation Research Center. The light guides were positioned on a movable table and exposed to 10 MRad radiation in 72 hours. For uniform irradiation, the position of the light guides, and their distance to the cylindrical shape radioactive source, were changed.

These nine air core light guides were tested before and after irradiation at the University of Iowa PMT test station. The detailed description of this setup can be found elsewhere [9].

The air core light guides were attached to a computer controlled X-Y scanner which scans the light through the surface of the light guide. The X-Y scanner can move along the x and y directions with 6.35 μm step size (Fig. 1).

The transmitted light intensity was measured with a Hamamatsu R7525HA PMT [10]. The PMT and the light guide were coupled with a black tube holder. The distance between the two was 5 mm. The dynode horizontal position was defined to be the x-axis.

A 337 nm nitrogen laser (LSI, model VSL-337ND) with a block of scintillator in front was used as the light source for the radiation damage tests. The light coming out of scintillator block had a range of 390–500 nm, and a non-gaussian distribution with a peak light intensity at 420 nm, where the PMT sensitivity was at its highest. The laser stability was monitored with a PIN diode.

The light source and the air core light guide were placed in two different light tight boxes. The light was transferred by a 600 μm core diameter quartz fiber. For all of the light guides

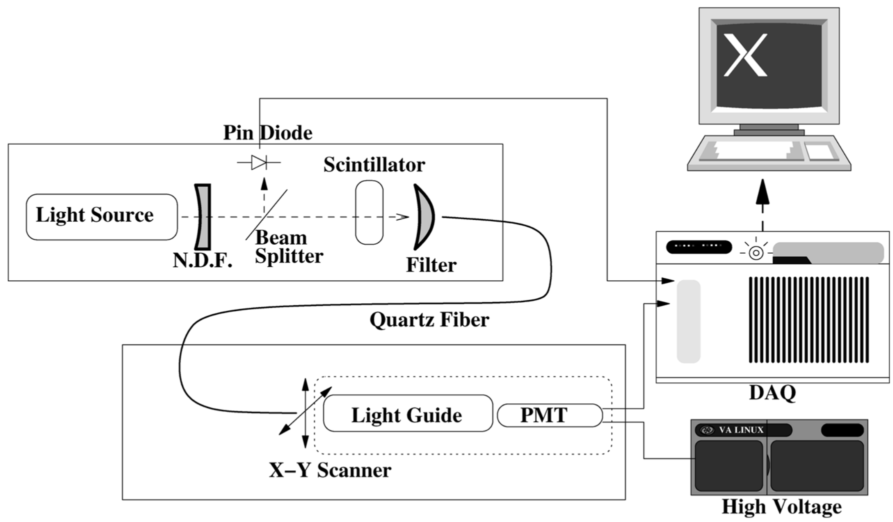

Fig. 1. Air core light guide radiation damage test setup.

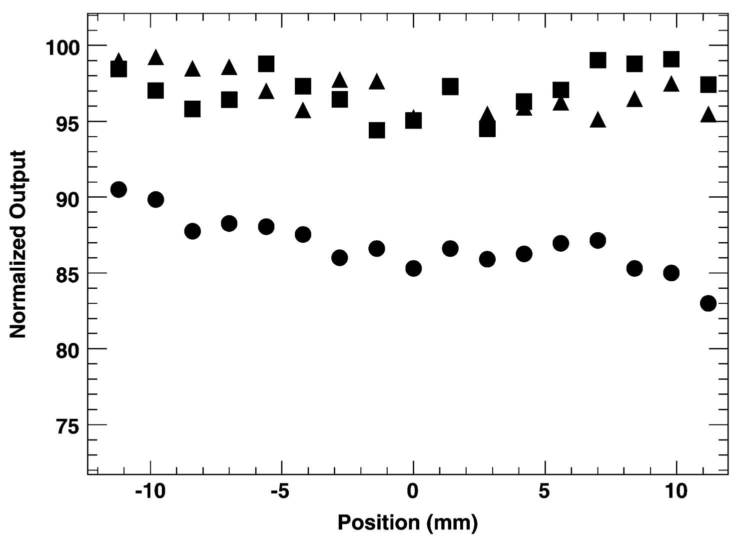

Fig. 2. Light transmission ratios as a function of position along a diameter of the light guides, with three different reflecting films, after the irradiation. The outputs are normalized with respect to the values before the irradiation. Circles, squares, and triangles denote Type1 AM, Type 2 AM, and HEM, respectively.

the light transmission was measured as a function of x and y position. With the help of the X-Y scanner, the light guide and the PMT were moved so that the end of the fiber sends light down the tube from left to right and from top to bottom with 1.4 mm step sizes. The fiber position is kept fixed throughout the tests.

To ensure consistency in the results, a control tube was run before and after each light guide. Each time the tube was attached to the X-Y scanner, the reflector seams inside the tube were always directed straight up, as was the PMT base label. By this way, the PMT dynodes were aligned relative to the seam of the reflecting material in the same way for all measurements. The light guide was clamped into the scanner so that the end of the tube just comes to the tip of the fiber, but does not touch the fiber. The PMT anode signal was integrated by an ADC (LeCroy 2249A) to determine the total charge on the PMT from the light pulse.

The results of the radiation damage tests are summarized in Fig. 2. Since we have irradiated three light guides from each reflecting films, the average of the corresponding groups are shown. The y-axis of the Fig. 2 shows the ratio of the total collected charge by the PMT before and after the irradiation. The x-axis represents the position of the fiber along the light guide diameter in arbitrary units. Since the light guides have no preferred orientation, the results for x and y positions with respect to the PMT dynode are averaged. The ratios for the signal before and after the radiation are consistent within 3% variation for the Type-2 AM and the HEM, showing that they are almost not affected by the 10 Mrad radiation. Type-1 AM shows some degradation to the extend of $14\% \pm 2\%$, after the irradiation.

III. Light Transmission Efficiency

The light transmission with the reflective films through the air-core light guides were tested with different light sources;

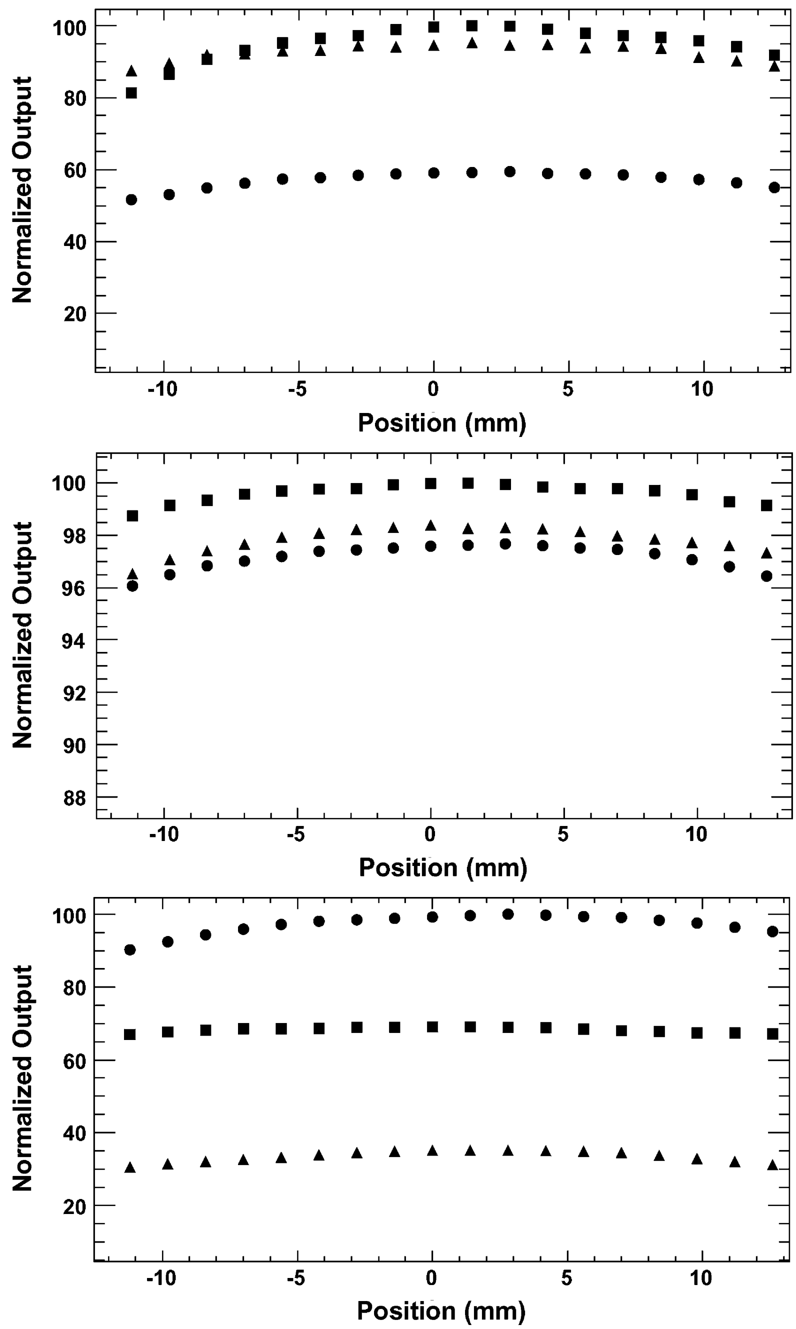

Fig. 3. Normalized light transmission ratios as a function of position along a diameter of the light guides with three different reflecting films and the light sources: 450 nm blue LED (top), mercury light bulb (middle), 380 nm UV LED (bottom). Circles, squares, and triangles denote Type1 AM, Type 2 AM, and HEM, respectively.

a 450 nm Blue LED, a 380 nm UV LED and a mercury light bulb. We tested three air core light guides, each prepared with a reflective film. The test setup was kept the same as the radiation tests, which is described above, except the light source. In case of mercury light bulb, which is a DC light source, a picoammeter (Keithley) was used to measure the PMT output instead of an ADC.

The top part of Fig. 3 shows the data taken with blue LED as the light source. When the incident light has a wavelength of 450 nm, Type-2 AM transmits light about 8% better than HEM, while Type-1 AM transmits only as much as 50% of the Type-2 AM.

The middle part of Fig. 3 shows the results with the mercury light bulb. The mercury light spectrum has photons from different wavelength regions (see Fig. 4). The photons that can be detected by the Hamamatsu R7525HA PMT are in the 300 nm and 650 nm wavelength region. The integration of different light intensities and wavelengths from mercury source gives comparable transmittance values for all three reflective films. However Type-2 AM is still slightly more efficient than the others.

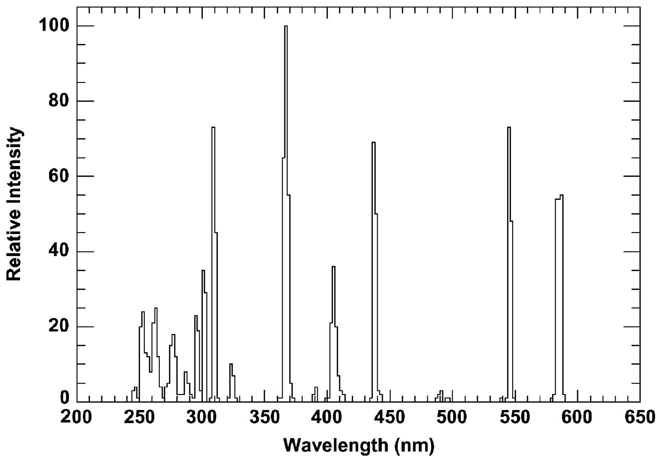

Fig. 4. The emission spectrum of the mercury light bulb.

The bottom part of Fig. 3 shows the results with the 380 nm UV LED as the light source. In contrast to above measurements, Type-1 AM performs better than the other reflective films in the UV range. Type-2 AM transmits light at 70% of the Type-1 AM. HEM loses its transmission ability drastically in the UV range and transmits light at around 30% of Type-1 AM.

IV. Conclusion

Three different types of reflecting material were tested for their radiation hardness in an air core light guide at the University of Iowa. The light guides were exposed to gamma rays using ^{137}Cs as the radiation source. The comparison of the light transmission efficiencies for three types of reflective films before and after 10 Mrad irradiation was given. The results showed that Type-1 AM reflective film lost almost 14% of light transmission capability after 10 Mrad of radiation, while HEM and Type-2 AM lost only about 3%.

One would expect the reflectivity of aluminum on Mylar to be highly resistant to radiation. However, since the aluminum layer on Type-1 AM sample was quite thin (60 nm), the Mylar layer was responsible for part of the reflection and Mylar degradation under the radiation caused the light loss. This can be avoided with a thicker aluminum layer which will reflect all the photons.

In the case of Type-2 AM, there are 2 extra layers of 53 nm Nb_2O_5 and 66 nm SiO_2 on 10 nm Cr adhesion and 70 nm aluminum reflective surfaces. A 75 μm thick polyester film was used for mechanical and thermal stability of the reflective film [7]. The extra layers make the photons reflect directly from aluminum which makes the film radiation hard.

On the other hand, even though the HEM material shows almost no degradation, it is known to luminesce after irradiation [11].

The light transmission efficiencies of the three reflective films were compared with three different light sources; blue LED (450 nm), UV LED (380 nm), and a mercury light bulb. The results showed that Type-1 AM was better than the other two in the UV range. Even though the Type-2 AM reflective film has poorer light transmission in UV, it is superior in visible region. On the other hand HEM is a good reflective film in visible range but transmits light at 30% of that of Type-1 AM in the UV region.

Depending on the application one might prefer to use one of the reflective materials tested. The tests, which are explained in this report, shows that under high radiation environment the Type-2 AM would be a better reflective material choice for an air core light guide, provided that the incoming signal is in the range of 400 nm to 600 nm.

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