SDC-93-426

SDC
SOLENOIDAL DETECTOR NOTES

LIGHT OUTPUT FROM A SCINTILLATING FIBER HAVING A REFLECTIVE SURFACE AT ITS FAR END

December 23, 1992

M. Chung and S. Margulies
University of Illinois at Chicago

UIC-12/92-2
FTG Note
23 December 1992

LIGHT OUTPUT FROM A SCINTILLATING FIBER HAVING A REFLECTIVE SURFACE AT ITS FAR END*

M. Chung and S. Margulies

Department of Physics
University of Illinois at Chicago

Abstract

Particle tracking systems employing scintillating fibers are being considered by the Solenoidal Detector Collaboration at the Superconducting Super Collider, and by the Fermilab DØ collaboration for the 1995 detector upgrade. Although recent work has shown that the use of polystyrene-core fibers doped with p-terphenyl and 3-hydroxyflavone with Visible-Light Photon Counters results in adequate light yield for both trackers, we have nevertheless studied the light enhancement produced by placing a reflective surface at the far fiber ends.

Measurements made on a Bicron type BI-14 fiber subject to excitation by ultraviolet light confirm expectations of a simple reflection model which is presented. A reflection coefficient of 77% was obtained by coupling a front-surface mirror with optical grease to the fiber's far end; coefficients of about 45% and 60% were obtained using aluminum foil and aluminized Mylar, respectively. According to the literature, coefficients between 55% and almost 100% can be obtained using reflecting coatings. Thus, light enhancements of at least 60% from the far fiber ends should be easily achievable.

*Work done in conjunction with the Fiber Tracking Group, and sponsored, in part, by the U.S. Department of Energy, the National Science Foundation, and the Texas National Research Laboratory Commission.

1. Introduction

Particle tracking systems using scintillating fibers are being considered by the Solenoidal Detector Collaboration at the Superconducting Super Collider,[1] and by the Fermilab DØ collaboration for the 1995 detector upgrade.[2] This note presents calculations and measurements on the enhanced light output from a scintillating fiber when a reflective surface is placed at its far end.

When an ionizing particle interacts with a scintillating fiber, a fraction of the light produced is captured by total internal reflection and propagates away from the interaction point, in opposite directions, towards the two ends of the fiber. In principle, maximum use is made of this light by instrumenting each end of the fiber with a photodetector. In this way all the available light is used, and timing information is also available to locate the interaction point. In practice, however, because of the large number of fibers involved, cost considerations usually allow only one end of the fibers in a tracking system to be instrumented.

Provided that enough light is produced -- that is, provided that the photodetector can detect light produced near the far end of the fiber with reasonably high efficiency -- use of a single detector imposes no restrictions since the position of the interaction point along the fiber may be measured by using stereo fiber layers which, additionally, provide other advantages. Furthermore, if the light yield is low, detection efficiency can be increased by placing a reflective surface at the uninstrumented ends of the fibers. The price of the resulting light enhancement, however, is the presence of two time-displaced pulses for each interaction, which might complicate use of the system to provide a fast trigger. Reflective fiber ends are indeed employed in the UA2 scintillating-fiber tracker at CERN.[3]

As recently demonstrated,[4] use of Visible-Light Photon Counters (VLPCs) capable of detecting single photons and polystyrene-core fibers doped with p-terphenyl (pT) and 3-hydroxyflavone (3HF) results in adequate light yield for the trackers proposed for both SDC and DØ. Nevertheless, as a matter of interest, we have studied the effects of placing a reflective surface at one end of a scintillating fiber, and our results are presented below. In what follows, we first briefly discuss the theory, and then make comparisons with measurements. Similar work has been done by the UA2 collaboration[3] and, in the context of the SDC plate/fiber calorimeter, by E. Hernandez *et al.*[5]

2. Theory

Consider a scintillating fiber of length L, having a photodetector at one end and a mirrored surface of reflectivity r at the other end, which is excited at a distance x from the photodetector as shown in Fig. 1. If the light intensity captured and propagating away from the excitation point in each direction

is I_o, and if the light propagation in the fiber core is characterized by a single core attenuation length λ, then the light intensity at the photodetector is

$$I(x;r) = I_o e^{-x/\lambda} + r I_o e^{-(L-x)/\lambda} e^{-L/\lambda} ,$$

$$= I_o \{ e^{-x/\lambda} + r e^{-2L/\lambda} e^{x/\lambda} \} . \qquad (1)$$

The variation of $I(x;r)/I_o$ with reflectivity r for a 4-m-long typical fiber having $\lambda = 3$ m (i.e., a polystyrene-core fiber doped with pT plus 3HF, such as Bicron type BI-4 or BI-6) is shown in Fig. 2. As expected, maximum enhancement occurs for light produced at the far end of the fiber, and the enhancement decreases as the light production point approaches the detector. The variation of the light enhancement, $I(x;r)/I(x;0)$, with r is shown in Fig. 3. Significant improvement is achieved for reflectivities greater than 0.2.

3. Measurements

Measurements were made with the UIC fiber testing facility. Excitation was produced at 10 cm intervals using ultraviolet light from an Oriel Model 6035 Hg(Ar) pencil lamp.[6] The fiber light output was detected with a Graseby Optronics Model 221 silicon photodiode[7] connected to a Keithley Model 485 picoammeter having an IEEE-488 interface.[8] The entire system operates under microcomputer control. The fiber used was a Bicron type BI-14 (polystyrene-core, doped with pT plus 3HF) whose properties were being studied at that time. The sample was 4.15 m long and had a measured attenuation length of $\lambda = 2.58$ m. Each end of the fiber was epoxied into a one-inch-long lucite ferrule whose face was then machined with a tungsten-carbide fly cutter to obtain a smooth surface orthogonal to the fiber axis. One ferrule surface was coupled with optical grease to the photodiode. The machined surface of the other ferrule served to couple the far end of the fiber to various reflecting materials, with approximate orthogonality determined by eye.

Results are shown in Fig. 4. The open circles indicate photodiode current as a function of uv excitation position (for $x > 100$ cm) with the far fiber end left "open". The curve is a fit of Eq. (1) to the data, yielding a reflection coefficient of $r = (2.7 \pm 2.4)\%$. This small amount of reflection may be reduced by painting the far fiber end black (data not shown); the corresponding value of r is $(0.06 \pm 2.6)\%$.

The photodiode current obtained with a front-surface mirror coupled with optical grease to the far end of the fiber is indicated by the solid circles. The excellent agreement of the fit, shown by the

dashed curve, indicates that the simple reflection model used provides a good representation of the data. The corresponding reflection coefficient is $r = (77 \pm 2)\%$; this value decreased only slightly when no grease was used. In contrast, however, the reflection coefficient dropped to just a few percent when the rear (glass) surface of the mirror was coupled with grease to the fiber end. Aluminum foil and aluminized Mylar, both coupled with optical grease, produced reflection coefficients of about 45% and 60%, respectively.

4. Conclusions

The effects of reflection at the end of a scintillating fiber have been studied by measuring light output as a function of uv excitation position for a Bicron BI-14 fiber whose far end was coupled to a variety of surfaces. The results confirm expectations of a simple reflection model, and should be applicable to any fiber. A reflection coefficient of 77% was obtained using a front-surface mirror coupled with optical grease. Values of about 45% and 60% were obtained with aluminum foil and aluminized Mylar, respectively.

Coating the far ends of the fibers in a tracker with a reflective material thus affords a relatively simple way to increase the light yield. Based on our measurements, reflection coefficients of 60% or more should be easily obtainable. Indeed, UA2 reports 55%,[3] while a recent SDC study has obtained 96% to 100% reflection.[5] Since the light enhancement from the far end of a fiber is $1 + r$, even achievement of a modest value of $r = 60\%$ produces a very significant increase in light output.

References

1. Solenoidal Detector Collaboration Technical Design Report, SDC-92-201, 1 April 1992.

2. "E823 (DØ Upgrade): Step 1 and Beyond", DØ report, 20 May 1992.

3. J. Alitti *et al.*, Nucl. Instr. and Meth. **A273**, 135 (1988).

4. M. Atać *et al.*, Nucl. Instr. and Meth. **A320**, 155 (1992).

5. E. Hernandez *et al.*, "Fiber Sputtering and Painting", SDC-92-291, 17 July, 1992.

6. Oriel Corporation, 250 Long Beach Blvd., P.O. Box 872, Stratfort, CT 06497.

7. Graseby Optronics, 12151 Research Parkway, Orlando, FL 32826.

8. Keithley Instruments, Inc., 28775 Aurora Rd., Cleveland, OH 44139.

9. Bicron Corp., 12345 Kinsman Rd., Newbury, OH 44065.

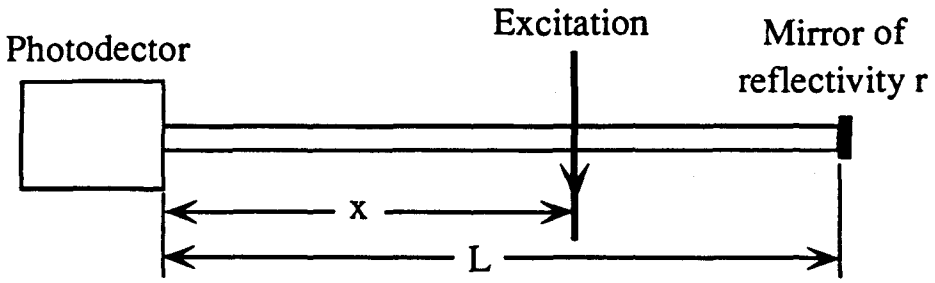

Figure 1. A scintillating fiber of length L excited at a distance x from the photodetector. The far end of the fiber is coupled to a mirrored surface of reflectivity r.

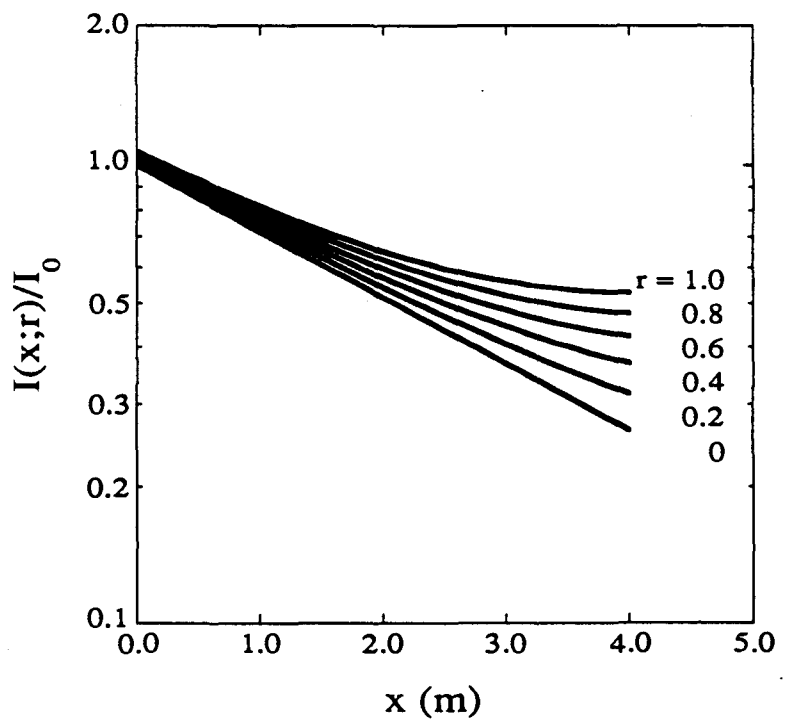

Figure 2. Variation of relative detected light intensity, $I(x;r)/I_o$, as a function of excitation position for various reflection coefficients, r, for a 4-m-long fiber with an attenuation length of 3 m.

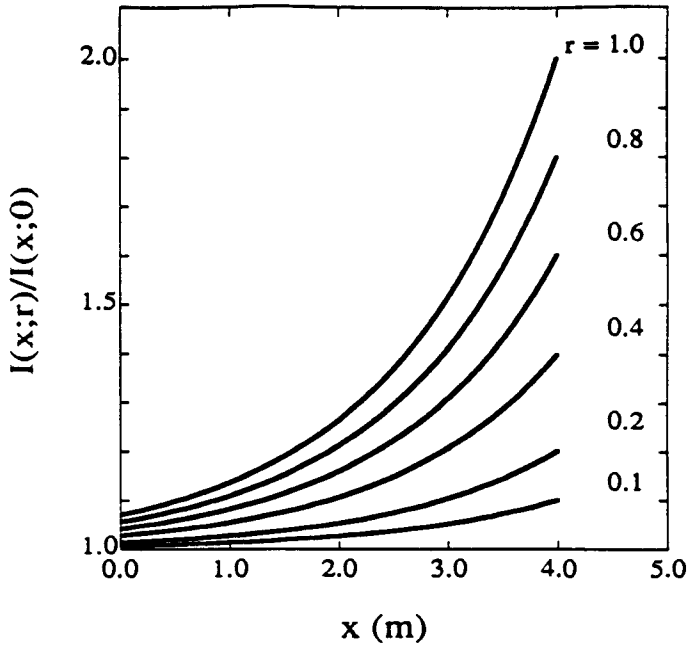

Figure 3. Variation of light enhancement, *I(x;r)/I(x;0)*, for various reflection coefficients, *r*, for a 4-m-long fiber with an attenuation length of 3 m.

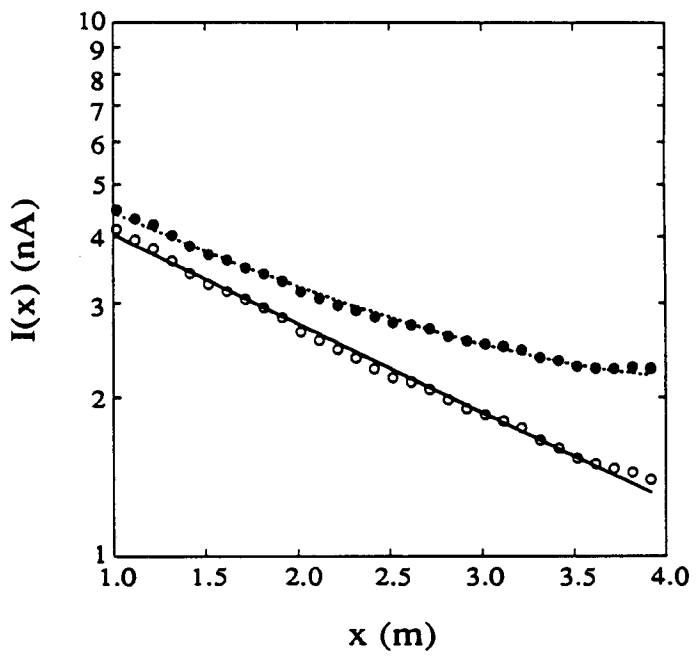

Figure 4. Measured light intensity as a function of excitation position for a 4.15-m-long Bicron BI-14 fiber. The open circles correspond to the far fiber end left "open"; the solid circles correspond to a front-surface mirror at the far end.