Invited paper given at
1981 Nuclear Science Symposium
San Francisco, CA 10/21-23/81

MASTER

BNL 30248

OG 590

CONF-811012--32

Scintillating Optical Fibers
For Fine-Grained Hodoscopes

S.R. Borenstein, York College, C.U.N.Y.
Jamaica, NY 11451

and

R.C. Strand, Physics Department
Brookhaven National Laboratory, Upton, NY 11973

The submitted manuscript has been authored under contract DE-AC02-76CH00016 with the U.S. Department of Energy. Accordingly, the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for U.S. Government purposes.

SCINTILLATING OPTICAL FIBERS
FOR FINE GRAINED HODOSCOPES

S.R. Borenstein, York College, C.U.N.Y.
Jamaica, NY 11451
and
R.C. Strand, Physics Department
Brookhaven National Laboratory, Upton, NY 11973

Abstract

Fast detectors with fine spatial resolution will be needed to exploit high event rates at ISABELLE. Scintillating optical fibers for fine grained hodoscopes have been developed by the authors. A commercial manufacturer of optical fibers has drawn and clad PVT scintillator. Detection efficiencies greater than 99% have been achieved for a 1 mm fiber with a PMT over lengths up to 60 cm. Small diameter PMT's and avalanche photodiodes have been tested with the fibers. Further improvements are sought for the fiber and for the APD's sensitivity and coupling efficiency with the fiber.

Introduction

During the late 1980's at the proton-proton collider, ISABELLE, fine grained scintillating particle detectors will be needed to extract rare events for the study of new particles associated with the internal constituents of the proton. Up to ten million interactions per second are expected with an average of 20 charged secondaries going mostly forward where up to 2 x 10**12 particles per second per steradian are expected. Between 100 milliradians and 45 degrees, 80 Mhz per steradian is expected and between 45 and 90 degrees, 2 Mhz per steradian is expected.

Counting rate and space resolution of particle detectors influence the gross size of multiparticle spectrometers for proton colliders. Fine resolution allows short orbits and high rate capability permits tracking to start close to the origin. The volume and total cost of a spectrometer increase as the cube of its linear dimension. Track chambers and fine grained hodoscopes should facilitate efficient use of these costly volumes. High rate particle detectors can be made from new scintillating optical fibers and small PMT's.

Early attempts[1] to produce long bare scintillating filaments of one mm diameter yielded maximum useful lengths of about 15 cm, presumably due to optical imperfections at the bare surface.[2] During the 1978 ISABELLE Summer Study[3] an effort was begun to achieve a fine grained scintillating hodoscope. The experience and expertise of the fiber optics industry was applied to drawing and cladding of scintillating fibers. A fiber is drawn from a polished preform of PVT scintillator and is coated with a cladding of lower refractive index. Bare fibers capture more of the scintillation light but they acquire attenuating surface defects through handling and exposure. Clad fibers can fit into small spaces without extra material for their protection.

The geometrical optics of a scintillating fiber are illustrated in Figure 1. A photodetector is placed at one end of the fiber. A desirable candidate for photodetector is the avalanche photodiode (APD) which has the advantages of small size and insensitivity to magnetic fields. It has a quantum efficiency about four times that of a PMT, but the probability that a photoelectron will initiate a detectable signal is correspondingly lower. Thus the APD's and PMT's have comparable sensitivities.

A section of a hodoscope constructed from scintillating fibers is illustrated in Figure 1 as a bilayer of fibers imbedded in a protective isolating matrix. The centers of the fibers are offset by one radius from one layer to the next to assure that there are no cracks through which a particle might pass without penetrating enough scintillator.

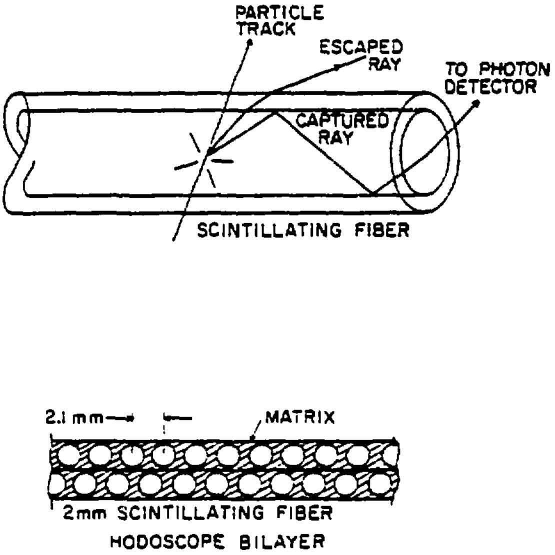


Figure 1a. Scintillating optical fiber, principle of operation; b) Bilayer of fibers, encapsulated in isolating matrix.

I. Properties of Scintillating Fibers

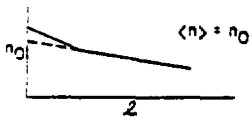
The fibers have been drawn by the Galileo Electro-optics Corporation from preforms purchased from Nuclear Enterprises. The drawing and evaluation of fibers have been reported.[4,5,6]

Fibers have been drawn from three PVT scintillators, NE102, NE110, and NE161. Cladding materials have been silicone, glass resin and several formulations of uv cured acrylic. Our evaluations are illustrated in Figure 2 as attenuation curves for equivalent 1 mm fibers. The rapid attenuation of unclad fiber is demonstrated. The longest attenuation lengths are obtained with NE161 coated with silicone or glass resin. The shaded region represents a range of performance of silicone clad NE161 or glass resin clad NE161. The silicone clad fiber performed closer to the top of this range than the fiber clad with glass resin. The new fibers and the available photodetectors allow us to construct hodoscopes of 1 mm fibers that are 50 cm long. Two mm diameter fibers can be used to build hodoscopes whose elements are 75 cm long.

We have characterized the quality of the cladding by an attenuation length, ℓ, where

$$1/\ell = 1/b + 1/r \; ; \; r = D/\ell n(p)$$

ATTENUATION CURVES FOR
1 mm diam. SCINTILLATING FIBERS



	SCINTILLATOR	CLADDING	ℓ_0	$\langle n \rangle$ AT $\ell = 50$ cm
a	NE 110	None	30	<< 1
b	NE 110	UV - Cured	80	2.6
c	NE 110	Silicone	100	4.5
d	NE 161	Silicone or Glass Resin (Composite curve, many trials)	115	4-4.8
e	NE 161	Glass and UV Buffer	115	4.0

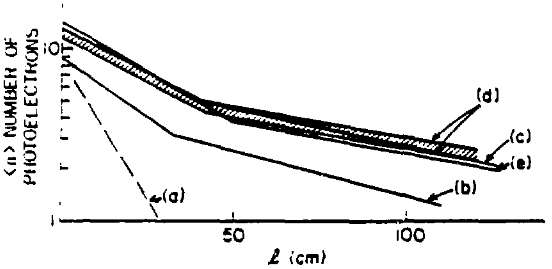


Figure 2. Attenuation curves for various fibers. Shaded region represents band within which many samples of silicone or glass resin coated NE161 fibers fell. In general, the silicone clad fibers performed near the top of the band, while the glass resin fibers were in the bottom.

where D is the diameter of the fiber, and p is the probability that a photon survives a reflection at the core-cladding surface. The results in Figure 2 are consistent with:

$b = 400$ cm, the bulk attenuation length from NE
$p = 0.999344$
$l = 115$ cm for $D = 1$ mm
$l = 175$ cm for $D = 2$ mm.

Some cladding materials are more tolerant of handling. The most fragile cladding, silicone, is soft, tacky, and in need of a protective outer coating. The hard, smooth glass resin is rather brittle. Sometimes pieces of it flake off the fiber. For this reason we have applied a buffer coating of uv acrylic to the glass-resin to improve its durability. The result is a durable fiber whose performance is only sightly inferior to the best performer, but whose resistance to damage by handling is significantly the best (Figure 2e).

The fibers acquire the curvature of the take-up spool for the drawing and cladding operation. The fibers must be cut, straightened, and encapsulated to make a hodoscope. A polygon shaped take-up spool or a method of cutting the fibers on line will be tried. This problem is more serious for larger diameter fibers.

II. Readout Options

Individual Fiber Readout

The photodetector's cost dominates the cost of a hodoscope.

Small PMT's which have outer diameters of 15 mm have been coupled to individual fibers. At best the PMT is an order of magnitude larger than the fiber. New cost reducing methods of production are unlikely, but the economies of scale in production can cut costs. Of course conventional PMT's are sensitive to magnetic fields. Multianode PMT's based on microchannel plate amplifiers are more tolerant of magnetic fields, but they have only half the needed quantum efficiency. The PMT option for individual fibers requires low magnetic fields and adequate space for the tubes.

The cost of the smaller APD is comparable to the PMT and it is insensitive to magnetic fields. Cost reducing methods of production are more likely for APD's and the economies of scale have yet to be achieved.

The most sensitive APD's are constructed in the reach-through geometry. Only RCA markets sensitive reach through APD's (RAPD's) with areas comparable to the cross-section of the fibers. These RAPD's operate in the linear mode below the breakdown voltage and in the saturated (Geiger) mode above the breakdown voltage. In the more sensitive saturated mode the RAPD must be cooled to near -70 degrees Centigrade. Here an electron has about a 20 percent probability of causing a discharge, when the bias is just beyond breakdown. This probability is an increasing function of the overvoltage so the probability for discharge depends on both voltage and the number of photons in the optical signal. Unfortunately afterpulsing introduces a dark counting rate that increases with overvoltage and true counting rate. An optimum overvoltage balances sensitivity with dark counting rate.

The Geiger operation of the RAPD is a new technology in which we are cooperating with RCA who is under contract to improve the sensitivity of the RAPD and to package the RAPD so most of the photons from a scintillating fiber can be captured.

Optically Encoded Readout

Under most circumstances, the high event rates and large multiplicities for which the fiber hodoscope is being developed would preclude any multiplexing schemes to reduce the number of readout channels. However for specific applications of low multiplicity it might be possible to effect considerable economies in readout electronics by the use of optical encoding.

Consider one of two layers of the hodoscope which contains n elements. Let r be the square root of n. At the upper end, the fibers are grouped in r bundles, each consisting of r adjacent fibers. At the lower ends the fibers are grouped in r bundles, but the groupings are such that the first bundle consists of the first fiber of each bundle at the upper end, the second lower bundle consists of the second fiber of each bundle at the upper end and so on. Thus a single fiber could be specified by a signal from one bundle at each end of the hodoscope. The number of readout channels has been reduced from n to twice r, the square root of n. Of course if more than one fiber is hit, the encoding is ambiguous. The level of ambiguity can be drastically reduced, by making use of the second layer of the hodoscope and by arranging the bundles in groupings which are distinct from those already used. An example of such an encoding scheme has been described elsewhere.[6]

Conclusions

We have developed a scintillating fiber for fine grained hodoscopes. The best results have been obtained with cores of NE161 and claddings of silicone, but this combination is too fragile and subject to deterioration with handling. We are seeking a buffer coat, to protect the silicone cladding, as well as other more durable cladding materials.

The preferred photodetector for single fibers is the RAPD. Efforts to improve its sensitivity and coupling to a fiber are being made. One mm fibers for 50 cm hodoscopes and two mm fibers for 75 cm hodoscopes have been developed. We have begun to construct hodoscopes.

This research was supported by the U.S. Department of Energy under contracts No. DE-AC02-76CH00016 and DE-AC02-81ER40035.

References

1. G.T. Reynolds and P.E. Condon, Rev. Sci. Instr. 28, No. 12, Dec. 1957; G.T. Reynolds, Nucleonics 16, No. 6, June 1958.
2. L. Reiffel and N.S. Kapany, Rev. Sci. Instr. 31, 1136-1142 (1960).
3. J. Marx and S. Ozaki, *Topic I: Detectors and Experiments, Summary of Activity, Proc. 1977 ISABELLE Summer Workshop*, BNL 50721, p. 4.
4. S.R. Borenstein, R.B. Palmer and R.C. Strand, Optical Fibers and Avalanche Photodiodes for Scintillator Counters, presented at the International Conference on Experimentation at LEP, Uppsala, Sweden, 16-20 June, 1980: Physica Scripta, 23, No. 4:1, pp. 550-555 (April 1981) Ed: Tord Ekelof, Vol. 1- Invited Papers; Pub: Alden Press, Great Britain.
5. S.R. Borenstein, R.B. Palmer and R.C. Strand, A Fine Grained Scintillating Optical Fiber Hodoscope for Use at ISABELLE, IEEE Transactions on Nuclear Science, NS-28, No. 1, pp. 458-460 (Feb. 1981).
6. S.R. Borenstein and R.C. Strand, Fine Grained Hodoscopes Based on Scintillating Optical Fibers, Proc. 1981 ISABELLE Summer Workshop, BNL 51443, Vol. IV, pp. 1538-1449.