The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 2023

Volume 26, Pages 641-647

IConTES 2023: International Conference on Technology, Engineering and Science

Plastic Fiber Low Light Measurement Method

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Abstract: Paper describe researches performed to develop a method for checking the light transmission through plastic scintillating fiber. Such fibers are used in different industrial or research application but for our purpose are main components of a flexible detector. Such detector use photon scintillating signals read by higly sensitive detectors and special measures taken to get such sensitivity. We present in paper a method and algorithm developed for measurement of light transmission through plastic fiber when signals are at level of nW. We develop a stand to implement and verify this method. We use fibers with connectors at each fiber end. Fibers are previously polished at each end in order to allows to pass the signal through surface with low losses. Using the stand we perform measurements to analyse the feasibility of method. We present the results that demonstrate the feasibility of method. We succeed to measure signals at level of nW using special measures. Our results shows that method and stand can be used to measure low level signals through fibers. Using this method, it is possible to check the quality of plastic fiber polishing. A fiber with end surface well-polished allows to pass the signal at such low level (nW)..

Keywords: Low light optical signal transmission, Plastic fiber testing, Fiber optic

Introduction

The purpose of the paper is to present research aspects in the field of fiber optic. Domain of flexible detector is relative new in photonic. Such flexible detectors appear because of special need, for special application were a flat detector do not offer enough information. There are situations in the domain of industry, medical, research, border control, smuggling monitoring, were this type of detector can be used as supplementary detector to offer more date and information. One of such flexible detector is presented in figure 1. In figure 1 we see fiber matrix. There is a zone, active area were stimuli can interact with fibers and following this interaction photon are emitted. At both ends of plastic fibers there are silicon photomultiplier - SiPMs. Fibers are fill in with scintillating material specially that allows to emit photons when are excited. Matrix of fiber are immersed in a resin. Resins used to build matrix are made from silicon or epoxy with purpose to became flexible after construction. We implement the method and we measure the signal transmitted through fiber.

We use for experiments plastic scintillating fiber from Kuraray (Kuraray, n.d.) with 1 mm diameter made from polymer. Fiber has core and clad. Fiber core is made from polystyrene material and clad is made from polymethyl methacrylat - PMMA. We present our concept for developing a method for testing light transmission through plastic scintillating fiber. Fibers are manual polished at both ends. All tests and measurements are performed in a special conditions to eliminate environment light influence on fiber sensitivity wavelength range. Due to low level of scintillating signal even a reduced level of influence is important and can modify the results.

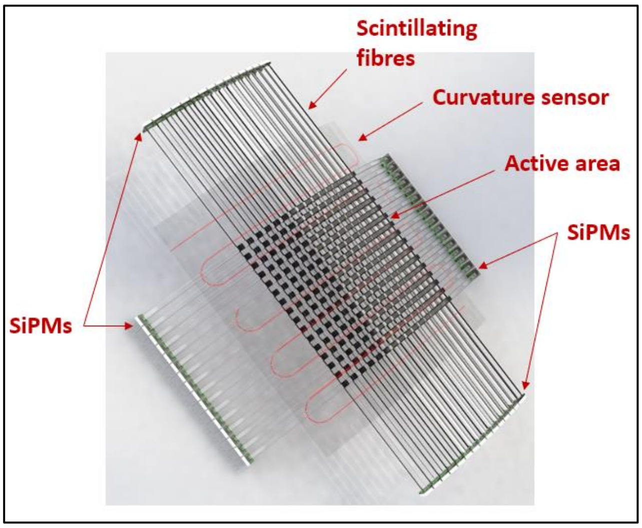

Figure 1. Flexible detector (Wibur et al.,2021)

Method

To define the method for testing the quality of signal transmission through plastic scintillating fiber it is need to start from light propagation through fiber. On same type of the plastic scintillating fiber, depending of the polishing quality, the light propagates on same way through the fiber because other influence factors can be controlled in order to minimize or eliminate their influence. We start our method design from definition of fundamental constant of speed of light. Speed of light (c) definition represents “the speed at which light waves propagate through different materials (Oxford Reference, n.d.). In our case is the speed at which light at known wavelength pass through fiber. Wavelength represents wavelength on which fiber is sensitive and this is a parameter set by manufacturer .

Speed of light in vacuum, “c” is defined by formula (1)

$$c = 299{,}792{,}458 \text{ m} * s^{-1} \quad (1)$$

Wavelength - frequency equation is defined by formula (2)

$$c = \lambda * \nu \quad (2)$$

were
λ - wavelength of light, [nm]
ν - frequency , [Hz]
According with formula (2) , when frequency increase, the wavelength decrease because speed of light” ***c “*** is a fundamental constant.
In our case the scintillating fiber is dedicated to transmit photons on blue domains of light spectra, especially on 440 nm. For example, a photon of light has a frequency “ ν” = 638 THz (terahertz) and will have wavelength “ λ ”.
Based on formula (2) we can wrote the formula of wavelength function of speed of light and frequency

$$\lambda = c / \nu \quad (3)$$

We introduce values in formula (3) and we obtained the value of wavelength:

$$\lambda = 3*10^{8} m*s^{-1} / 638*10^{12}*m*s^{-1} = 460 \text{ nm} \quad (4)$$

We know that the energy of a photon can be obtained by multiplying Planck constant by frequency, as is expressed by formula (5) :

$$E = h * \nu \tag{5}$$

Were

h - Planck constant, $h = 6,626 * 10^{-34}$ J*s

ν - vibration frequency

We fill in values in formula (5) and we obtain the value of energy:

$$E = h * c / \lambda = (6,626 * 10^{-34} \text{ J*s})*(3*10^{8} \text{ m*s}^{-1}) / 4,6*10^{-7} \text{ m} \tag{6}$$

For a photon with wavelength $\lambda = 460$nm, placed in blue region of optical spectrum, the energy value is

$$E = 4,32 \text{ x } 10^{-19} \text{ J} \tag{7}$$

Of course this results need corrections because in real situation there is more photons that pass through fiber not just a single photon. From this reason the result (7) should be multiplied by the number of photons. Scintillating photons appeared in plastic fiber are transmitted from one end to the other end were is a Multi-Pixel Photon Counter (MPPC), that convert optical photons in electrons. An electronic PCB receive electronic signal converted from photons, amplify signal using an amplifier integrated in PCB and send it further. For our researches we use a MPPC from Hamamatsu, type S13360 with a gain 4 x 10^{6} or a Silicon Photomultiplier (SiPM) from ONSEMI with gain 3 x 10^{6}.

With such high gain we are able to measure energy of photons in the range of pJ:

$$E=4,32*10^{-19} *4*10^{6} =1,632*10^{-12} \text{ J} =1,632 \text{ pJ} \tag{8}$$

Experiments

In the Figure 2 is a scintillating plastic fiber polished with metallic ferule at both ends. In the figure we have a fiber support made from plastic used for fixing fiber and metallic ferule. We have a plastic scintillating fiber with metallic ferule at both ends.

Figure 2. Plastic fiber polished

We design a method of testing the transmission of photons through plastic scintillating fiber using a special developed stand. his surface is manufactured by polishing. This method can be used to check the quality of fiber end surface because of this surface quality depend the signal send it. In order to investigate our assumption, it is need to implement a method into a stand. Developed stand (figure 3,4) is composed by following components:

- LED :
    - producer Wurth Electronik
    - wavelength $\lambda = 460$ nm
    - maximum illumination 25 Lm for 350 mA

- Regulated Power Supply :
    - model DC QJ 3003 C
    - DC tension is variable from 0 - to 30 Vcc
    - DC current is also variable from 0 - to 3 Vcc

- Rezistance :

- 100 Ohms
- max. 0.1A
- accuracy class 0.01

- Digital multimeter:

- producer UNI-T
- model UT 70A
- DC tension from 0.2 to 1000 V
- DC current 20 µA - 10A

- Plastic scintillating fiber:

- model Kuraray SCSF - 78
- 1 mm diameter
- wavelength peak 450 nm
- fiber is polished at both ends

- Detector

- model Ophir PD300R
- sensitivity spectre 200 - 1100 nm
- power range
  - 20 pW - 3mW
  - 2µW - 300 mW
- error ±2% for 420 nm - 980 nm
- noise ±1%

Detector meter:
- Laserstar

capable to measure: power, energy, pulse power, pulse energy
- command screen
- detect automatic the detector head

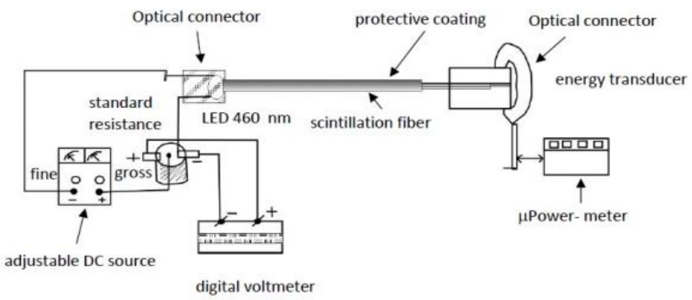

Figure 3. Measurement scheme

In Figure 3 is the schema of measurement stand. This schema is implemented by Figure 4. Implementation of method from Figure 3 is presented in Figure 4. In figure can be identified all parts of the measurement stand:

- output detector
- plastic fiber
- DC current measurement device
- power supply unit
- tools
- resistance

Fiber is inserted in tube for mechanical protection and and to avoid influence of environment. We increase slowly the input voltage applied at entrance of LED using coarse and fine knob from power supply. When on display it is indicated 2,2 V, we noticed that LED has emission on 460 nm wavelength. We increase slowly tension at LED entrance in small steps and we read the indication on multi meter display. The light emitted by LED is transmitted in fiber and is read with detector at output fiber. Fiber has both ends polished. Radiation pass through plastic fiber and reach a photosensitive detector, PD300UV from OPHIR. Such detector is very sensitive and was chosen from this reason. Each value of input and output is written and a graphics is prepared and shown bellow. Influence of environment is eliminated using few methods:

- protect fiber with a plastic jacket as in Figure 4
- coat fiber with protective paint
- perform measurements inside of a protective box.

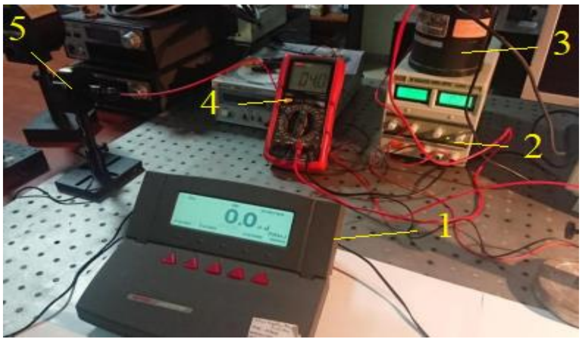

Figure 4. Measurement stand

1 -Laserstar; 2 - power supply; 3 - precision resistance; 4 - multimeter; 5 detector

In the Figure 4 are presented all components of stand used for testing measurement method:

- computing unit - Laserstar - position 1
- power supply - position 2
- precision resistance - position 3
- multimeter - position 4
- detector - position 5
- plastic scintillating fiber - red tube

In experiment we prefer to coat plastic scintillating fiber by black paint. Fiber is painted in black color to avoid external bad influence and perform measurements in a black box as in Figure 5. The box is a standard box painted with black paint. During measurements plastic scintillating fiber are inside of black box with LED and detector. Such protection avoid possible fake input stimulation's and possible error.
Possible errors on the results appear because of:

- mounting fiber and detector in supports,
- detector errors.

We do not consider errors appeared due to external influence because we consider that we take needed measures to eliminate them.


Figure 5. Black box

In Figure 5 is presented black box for protection against environment influence.

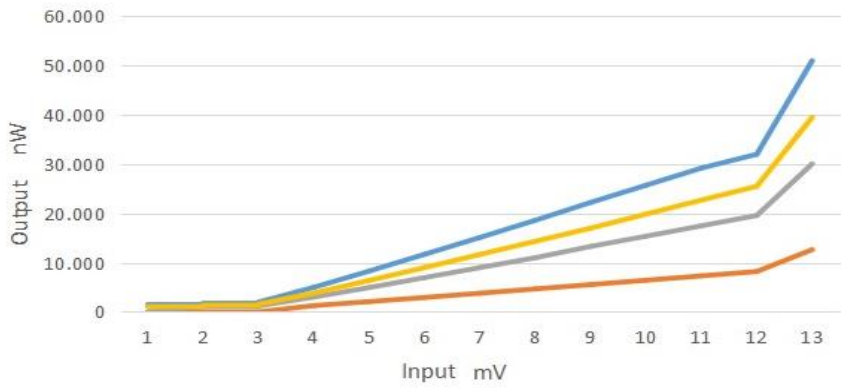

Figure 6. Measurements using method

Measurements are performed as were described earlier. After we obtain from LED output light, the value from multimeter and laserstar are written in a table. We measure 5 fibers and we obtain the graphic from Figure 6. We notice that if the fiber is well polished the output value increase with increase of input. We can claim that fiber is well polished using another method, an video microscope with 100x magnification from Edmund Optics. We noticed that for low input values, the output is not increasing. It is not plotted this situation in graphic because we do not considered. This is normal situation because for low level of measurements, we are in the range of errors given by tools and instruments used. When we increase the input value the output value increase also, there is a direct correlation between input and output. In conclusion method and stand associated are feasible to use them for testing plastic scintillating fiber polishing quality. Method and stand are is easy to implement and use it.

Abbreviations and Acronyms

PMMA - polymethyl methacrylat
MPPC - Multi-Pixel Photon Counter
SiPM - Silicon photomultiplier

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgments

* This article was presented as an oral presentation at the International Conference on Technology, Engineering and Science (www.icontes.net) held in Antalya/Turkey on November 16-19, 2023.

* We develop our experiments under the project " *Flex-Ray - Inherently Flexible X-Ray Imaging Detector using Single Photon Avalanche Photodiodes and Scintillating Fibres*", project funded from the European Union's Horizon 2020 research and innovation programme under grant agreement No 899634.

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To cite this article:

Comanescu, B.., Schiopu, P., Vladescu, M., & Vlad, M. (2023).Plastic fiber low light measurement method. *The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 26,* 641-647.