Design and technology of a scintillating fiber sensor with silicon avalanche photodiode.

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ABSTRACT.

The results of work on design and technology of a novel fiber-optic sensor are presented. It contains an avalanche photodiode of the 1.5 mm diameter active area coupled with a scintillating plastic fiber of the 1 mm diameter. This fiber emits the light of 530 nm wavelength as a result of interaction with ionising particles. The developed technique of assembling not only have ensured high optical coupling between the fiber and photodiode structure but also secured total isolation of the photodiode against background radiation. The described sensor design ensures better isolation of an avalanche photodiode structure against nuclear radiation than the sensor with scintillating wafer directly attached to the active surface of the structure.

Keywords: scintillating fibre sensor, avalanche photodiode

1. INTRODUCTION

The performance of the scintillating fiber sensor with a silicon avalanche photodiode is based on following phenomena:

- generation of the optical radiation (scintillation) at the site of interaction between nuclear radiation and fluorescent dopants of the fiber core
- propagation of this radiation along the fiber into the photodiode that is coupled with the fiber
- detection of this radiation by the photodiode

The intensity of scintillation generated in the fiber is proportional to the exciting it external nuclear radiation (intensity of γ radiation or energy of particles). The scintillating fiber can also be excited by ionising radiation (X-rays). The photoelectric signal in the photodiode is proportional to intensity of scintillation radiation. Mechanical properties of the scintillating fibers allow to create (to weave) a matrix that can detect a trajectory of particles movement, their energy or the distribution of γ (X) radiation intensity. Scintillating fibre sensors may be applied in cosmic ray telescopes, neutron imaging, particle discrimination and real time imaging systems [1].

Because of necessity to detect very weak scintillation signals, the detectors that are used in scintillating fiber sensors are silicon avalanche photodiodes. [2]. The design and technology of that kind of sensor have been developed at the Institute of Electron Technology (Instytut Technologii Elektronowej – ITE). The project was inspired by CERN (CMS scientific program), where it is expected that described scintillation sensors will be used.

2. CONSTRUCTION OF SENSOR

A scintillating fiber, type of BCF-60 GREEN SCINTILATOR of 1mm diameter, manufactured at BICRON Saint-Gobain Ceramics, Inc. supplied by CERN and a BPYP 58 silicon avalanche photodiode of the 1.5mm diameter of

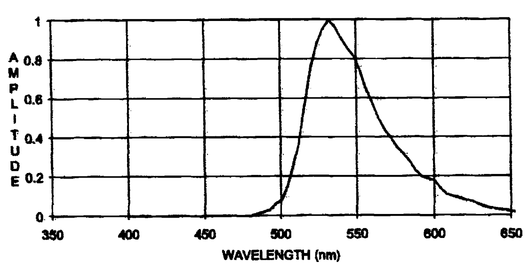

Fig.1 Relative spectral characteristic of the scintillating fiber emission

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an active area, made at the ITE, are used in the sensor. The length the fiber attached to the photodiode was 1.5m. The spectral distribution of scintillation radiation emitted by BCF-60 is shown in fig.1.
The numerical aperture of scintillating fiber is NA=0.58 that corresponds to value of the divergence angle of light beam going out of the fiber equals 35^0. Conditions of fiber to APD coupling were analysed. On the base of this analysis, tolerance of mounting dimensions was optimised to make sure that all light going out of the fiber reaches a photosensitive area of APD.

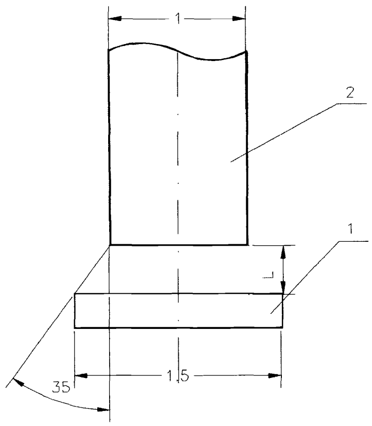

Fig.2 Illustration of coupling of BCF-60 fiber to a 1.5mm photodiode structure.
1 - photosensitive area of the avalanche photodiode
2 - scintillating fibre

The basic properties of the BPYP 58 photodiode at the wavelength of λ =500 nm are shown in table1.

Table 1.
The typical values of basic parameters of the BPYP 58 avalanche photodiode at wavelength of λ =500 nm.

Parameter	Symbol	Unit	Value	Test conditions
Reverse Operating Voltage	V_{R1}	V	185	M = 100
Sensitivity	$S_{1\lambda}$	A/W	25	$V_R = V_{R1}$
Dark Current	I_{01}	nA	4	$V_R = V_{R1}$
Reverse Operating Voltage	V_{R2}	V	186	$I_N = 1$ pA/Hz$^{1/2}$ *)
Gain	M		130	$V_R = V_{R2}$
Sensitivity	$S_{2\lambda}$	A/W	32	$V_R = V_{R2}$
Dark Current	I_{02}	nA	4,5	$V_R = V_{R2}$

*) I_N – spectral density of dark current

In fig.3, the principle of scintillating fibre sensor design is shown.

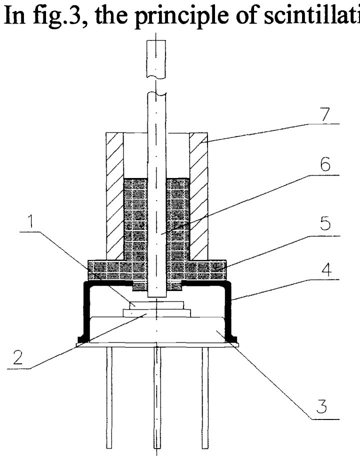

Fig. 3 Cross section of a scintillating fiber sensor.
1-photodiode structure
2-ceramic
3-TO-39 header
4-TO-39 cup
5-fiber fixing sleeve
6-fiber
7-plastic, light-tight fiber cover

3.TECHNOLOGY OF SENSOR ASSEMBLY

Assembly technology of sensor includes following operations:

1.Fiber preparing - finishing fiber-end surface.
2.Centric mounting of photodiode structure on ceramic, fixed on TO-39 header; wire bonding .
3.Fiber fixing in the sleeve.
4.Preparing of TO-39 cup.
5.Header to cup welding.
6.Header to sleeve fixing.
7.Cover fixing.

Fiber preparing

The method of cutting the fiber into pieces of a specified length was worked out. The method ensured an excellent smoothness of the fiber-end surface and its perpendicularity to the fiber axis. The method consists of cutting a fiber placed in a special handle with a heated edge. The principle of construction of that device is shown in fig.4.

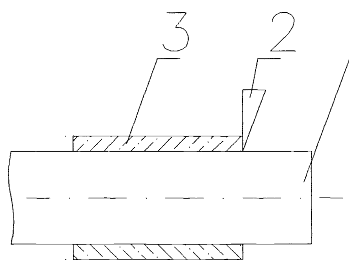

Fig.4 The scheme of plastic fiber cutting device.
1-fiber, 2-heated blade, 3-fibre fixing sleeve

The blade is led along precisely polished edge of sleeve.

Photodiode structure mounting. Cup sealing.

The developed at ITE, technology of mounting avalanche photodiode structures on TO-39 header with metalised ceramic, was applied. To guarantee fiber to photodiode coupling without the losses, it was secured that the centricity of the photosensitive area of the structure in relation to the header axis is not worse than +-0.04mm. In addition, the tolerance of distance between the surface of the structure and the surface of the TO-39 flange is smaller than 0.16mm (+-0.08mm). A header with a mounted photodiode structure was welded to a cup with a centric whole of a diameter fitted to a diameter of the fiber-fixing sleeve.

Fiber to sleeve mounting.

Fiber to sleeve fixing is proceeded in a special tighten splint. The same splint is used to final sensor mounting. In that splint 10 fibers (in final fixing case 10 sensors) are mounted simultaneously.

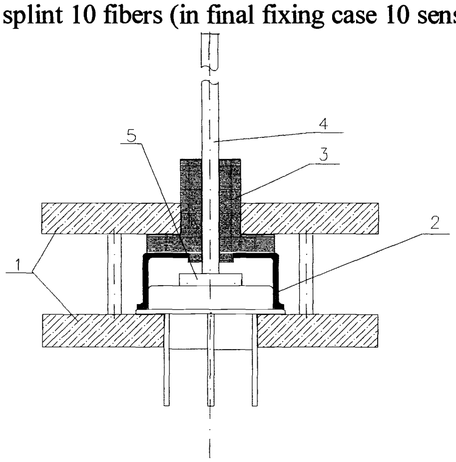

Fig.5 The scheme of tighten splint-fixing the fiber;
1-tightening surfaces, 2-TO-39 header,
3-sleeve, 4-fiber, 5-model plate

To ensure the right distance between a fibre and photosensitive surface, a special set including TO-39 header with model plate on it is used to fix the fibre to sleeve. The thickness of model plate is matched in such a way that the distance from the end of fiber to the photodiode amounts to 0.15+-0.08mm.The principle of fixing the fiber to sleeve in the tighten splint is shown in fig.5. The header 2 with the model plate 5 and the sleeve 3 are placed in the splint 1, after that the fiber 4 is fixed in sleeve 3 in a position in which the front surface of fiber touches the model plate 5. After fixing the splint is emptied and the sleeve with the fixed attached fiber is ready to the next operation.

Sleeve with fiber to header fixing.
A prepared, as described above, TO-39 header with a photodiode structure and a coat of epoxy in the proper position as well as a sleeve with the fiber are all placed in the tightening splint. The header and the sleeve are firmly tightened. When the epoxy has hardened, the sensor is taken out of the splint and a light-tight cover is put on the fiber. The epoxy with special filler, that ensures light-tight joints, is used for sticking the sleeve with the TO-39 header and for gluing the light-tight cover.

4.CONCLUSIONS

Presented sensors were examined at CERN in Geneva and the positive results were achieved. Recently, a new type of scintillating fibers with the peak of emission at $\lambda = 570$ nm appeared on the market. ITE avalanche photodiodes have much better detection characteristics at this wavelength [2], and using this type of fibers will enable the sensors to achieve much better parameters. The photo of the assembled sensor is shown in fig.6.

Fig. 6 The picture of an assembled sensor. The exposed part of the scintillating fiber is excited by diffused UV radiation from fluorescent lamp.

5. REFERENCES.

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