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ENVIRONMENTAL MONITORING OF SEA: OPTICAL FIBER SENSOR DESIGN

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Abstract: Major concerns arise about marine pollution due to human and industrial activities. The quality of sensing system response depends upon the materials used to realize sensors. There are different techniques used for the purposes of this kind of research that makes easier to reveal main parameters such as: temperature, salinity, waiving, wind, chlorophyll, oxygen, depth, etc. The paper presents an optical fiber sensor design using nanotechnology. The sensor will be used on floating buoys for autonomous marine detection. The sensor principle is based on photo-chromatography and to be realized using a waveguide for conducting light for multimodal approach.

Keywords: Fiber optic sensors, nanotechnology, sea pollution detection, pollutant measurements.

1. INTRODUCTION

The development of a dedicated station for detection of marine pollution is an interesting field of research involving different expertise. A good monitoring system requires the acquisition of different parameters regarding marine water such as temperature, salinity, current, wind, chlorophyll, oxygen, depth, etc. Different methods for monitoring the marine environment are presented in literature [1-4]. The biggest challenge for researchers is to have a system that ensures measurement accuracy and a measurement continuity over time in different environmental conditions. These requirements affect design choices as:

1) the desired level of detail in the measurements;
2) robustness to different climatic events;
3) autonomy of the apparatus;
4) continuous communication between mobile device and the station base.

Spectroscopy provides a good measurement accuracy, but a system of lenses positioned with high precision is necessary. Other systems that use sensors based on MEMS technology [5] are less accurate, or require support structures more bulky, unable to manage the collected data autonomously. Therefore in this work, the design of an innovative monitoring system based on optical fiber sensors is presented in order to contribute to the prevention and management of the marine environmental and of the coastal areas. For marine environmental monitoring it is appropriate to use a photo spectroscopy where an optical fiber, as a flexible waveguide [6-7], transfers the light from the source to receiver. An evaluation of the properties of transmission and absorption of light in a material can be carried out through a measurement of the spectrum of a source with and without the intervening material (e.g. glass, colored filter, or liquid solution) [8] .

2. PHOTOSPECTROSCOPY BY OPTICAL FIBER

The emission spectra in rows are typically associated with gaseous low pressure substances, or materials suitably excited that re-emit the light with characteristic wavelengths. If a substance is interposed between the source and the detector, it may preferentially absorb certain radiations. Therefore, in such conditions, it is possible to obtain an absorption spectrum for each substance, in which some wavelengths or some areas of the spectrum will appear missing (black). If the sample contains liquid solutions, we prefer to use the concept of absorbance, defined by the relation:

$$A = \log\left({}^{I_0}/_{I}\right) \qquad (1)$$

where I_0 and I are the intensity of incident and transmitted light through the substance measured at a given wavelength. A plot of absorbance in function of wavelength is called the absorption spectrum of the substance. The atomic absorption spectrum consists of isolated lines, while for a molecule the spectrum is more complex, structured in bands. An empirical law (Beer-Lambert Law) relates the absorbance A of a solution with the concentration of the solution c, the molar extinction coefficient.

$$A = \varepsilon\, l\, c \qquad (2)$$

The optical fiber (Fig.1) has been chosen to make the system stable for the transport of light on a non-inertial system. In fact, the use of optical lenses for normal spectroscopy requires a rigid system of large dimensions, and the possible fluctuations of the lenses could compromise the measurements.
The basic characteristics for an optoelectronics source in a system of optical fiber communication are the following:

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- Emission particularly efficient in three different transmission windows of an optical fiber;
- Adequate geometric profile to have an excellent source-fiber coupling;
- Reliability and cost such that the fiber optic system can be competitive with those in existence.

LED (Light Emitting Diodes) can be used as optoelectronic source to irradiate the sample. These diodes are able to irradiate a power of 10 ,100mW (-20 or -10 dBm) into a fiber optical.

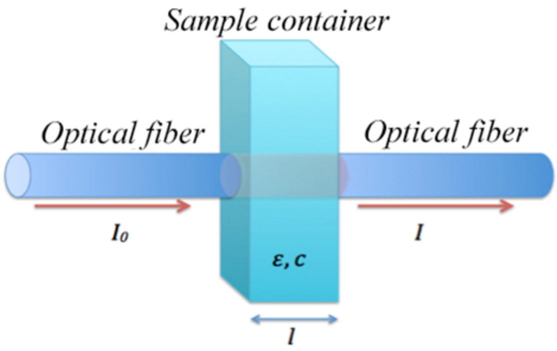

Fig. 1. The proposed structure

So, the radiant energy is produced for the phenomenon of spontaneous emission: for each electron-hole recombination, the emission of a photon occurs. So, the set of recombination in a semiconductor material will produce a large number of photons in all directions with different characteristics; the resultant radiation consists of a series of wave's trains of limited duration, without overlapping phase. In this case the radiation is incoherent. It is important to make a clarification: in general, the materials that emit radiation of a certain wavelength are also able to absorb it. Therefore, a part of the emitted radiation will be absorbed in the diode itself due to the breaking of a covalent bond with consequent passage of an electron from the valence band to the conduction band. The remaining part that arrives on the separation surface with the air, undergoes the phenomena of refraction and reflection, because the refractive index of the semiconductor material is greater than that of air, the phenomenon of total reflection occurs [9-10].

3. SOURCE-TO-FIBER COUPLING

The emission of the diode is relative only to rays and it is superficial as shown Fig.2. To have a good source-fiber coupling it is necessary that the area of emission of the radiation is not greater than the surface of the core.

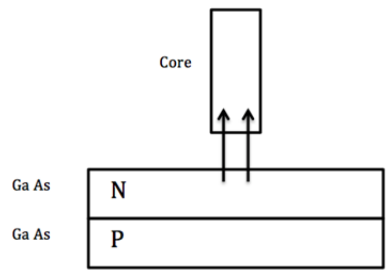

Fig. 2 Homojunction diode LED and its coupling with the core of the optical fiber

This is achieved by using of a homojunction diode LED (Light Emission Diode), the structure of Burrus, shown in Fig.3, in which the mask is performed with SiO_2. It reduces the injection zone of the current and therefore the area of emission of the photons. Furthermore, by chemical etching, it digs in N-type semiconductor, so to approach very (at a distance of 10μm) the fiber to the junction area in which the radiation is emitted spontaneously. Finally, the whole is blocked with an epoxy resin having the same refractive index of the fiber core.

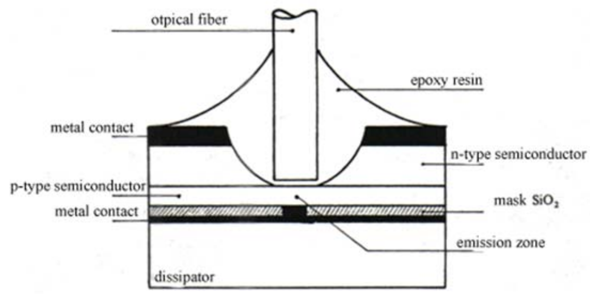

Fig. 3. Burrus structure

The same structure is applied to the fiber-junction detector in order to minimize the area of exposure of the photo-detector, and a lens is interposed between the fiber and the sensor because there is a difference in area between surface of the core and the surface of the photo detector. The type of the fiber is very essential. Multimode fibers are different from the single-mode primarily for the larger size: the diameter of the core is 50 μm and that of the cladding is of 125-150 μm. Moreover the refractive index profile may be: A step (step-index) and Gradual (graded-index). In the step-index fibers, the refractive index is constant throughout the core, and decreases abruptly in the cladding. However, unlike the single-mode fibers, multimodal fibers present a major modal dispersion, since the light rays with the same wavelength but with different angle of incidence (less than the angle of acceptance) propagate with the same speed inside the fiber, but through a zig-zag paths of different length (Fig.4). So, they arrive at destination in different times, producing a temporal extension of the transmitted light pulse. The number of propagation modes M for a multimode fiber can be evaluated with the following approximate formula, valid if $M >> 1$;

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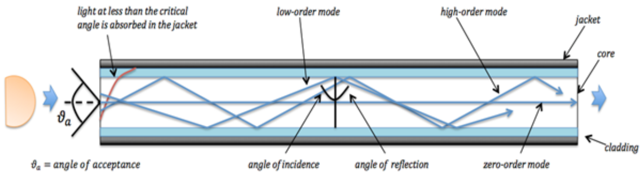

Fig. 4. Multimode optical fiber structure.

$$M \cong 0.5 * \left(\pi * d * \frac{NA}{\lambda}\right) \qquad (3)$$

where d is the diameter of the core, λ is the wavelength of the used radiation and NA is the numerical aperture of the fiber. Multimode fibers are used for very short distances (<10km) thanks to significant advantages over single-mode fiber. Plastic fibers are preferred because silica is suitable for lighting, medical, automotive, instrumentation and sensors that require very short fiber lengths. Plastic fibers (POF) are of step-index type with a typical diameter of 1 mm. These dimensions make it simple and efficient coupling of light from the source and economic connectors (10-20% less than standard).

They can have:

- Core: Polystirene, polymethyl methacrylate (PMMA)
- Cladding: Methyl methacrylate, copolymer.

The optical properties of the conventional POF are:

- Attenuation 0.15-0.2 dB / m @ 650nm
- High numerical aperture
- Bit rate limited by modal dispersion.

4. SIMULATIONS AND RESULTS

The software "TracePro Expert" developed by Lambda Research Corporation is used as the simulation environment, in order to display the light flux diffusion when crossing the sample holder within the optic fiber, and to see the attenuation of the signal with the light intensity for different wavelengths.

The system is depicted in Fig.5, where the source and the detector (a photomultiplier) will be placed at the two ends. In Fig.6 it is possible to see that the distribution of the flow on the detector placed at the output from the optical fiber is very homogeneous. This is an interesting feature for the flowmeter, that allows to the photodetector to work better. In Fig.7 the "Polar candela distribution" is shown. It represents the angular distribution for the source.

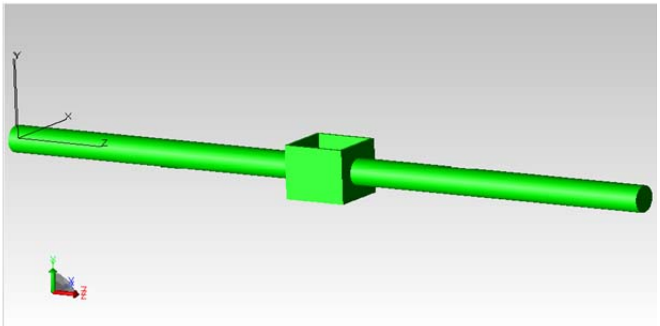

Fig. 5 3D view of structure.

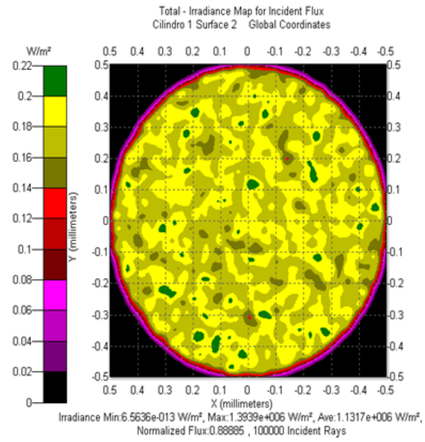

Fig. 6. Irradiance map of incident flux on sample.

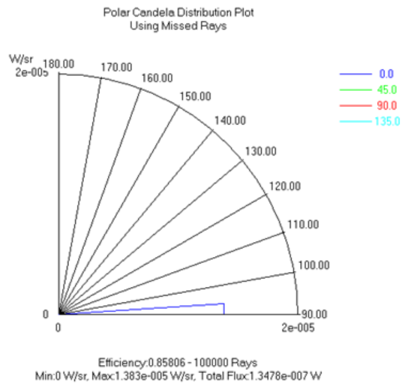

Fig. 7. Polar candela distribution using missed ray.

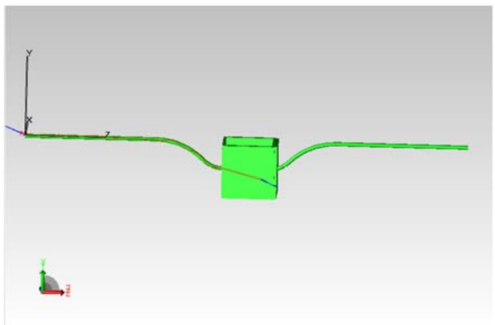

Fig. 8. Deformation of optical fiber of 1 mm to original position.

Fig.8 shows the system when a deformation occurs due to a shock or vibration of the motion marine. It corresponds to a displacement of about 1 mm with respect to its original position. Fig.9 shows instead how the rays of light are transported from one end of the system even after the deformation. The efficiency of the transported rays is lowered because the rays shut the sample with wider angles (Fig.10).

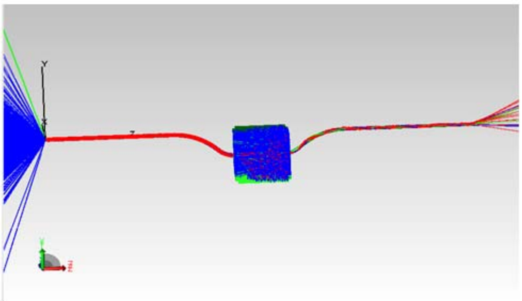

Fig. 9. Structure illuminated with 1000 rays with λ=640nm.

So, there is a reduction of the intensity of the incident rays on the IN-surface of the second optical fiber (Fig.11). The system requires fixed lens to focus better the rays and consequently to improve the efficiency.

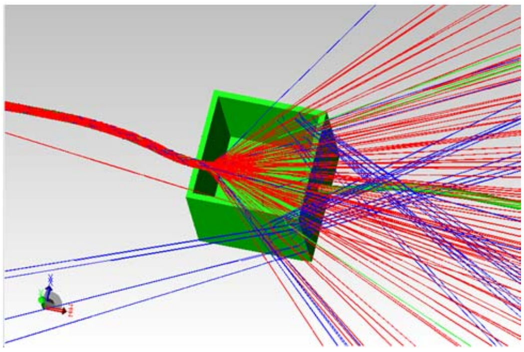

Fig. 10. Distribution of rays on sample container.

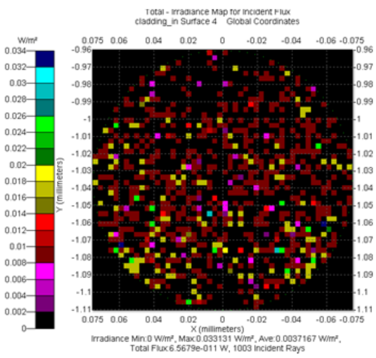

Fig. 11. Irradiance map of incident flux on input second fiber.

5. FINAL OUTLOOK

The data simulation show as a high efficiency and robustness of the designed sensor system can be obtained, because it can endure multiple external stresses caused by the environment [11] in which it must operate. An apparatus with precision optics could be more precise in stationary conditions, while it may not be practical and robust to external stresses for a Buoy system.

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