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Technical Note

Fabrication and characterization of low-cost polarimetric fiber-optic pressure sensor

G. C. CONSTANTIN[a], G. PERRONE[b], S. ABRATE[c], N. N. PUŞCAŞ[d*]
[a]*University "Politehnica" Bucharest, Physics Department, Splaiul Independentei, 313, 060042, Bucharest, Romania*
[b]*Politecnico di Torino, PhotonLab & Department of Electronics, C.so Duca degli Abruzzi, 24, 10129, Torino, Italy*
[c]*Istituto Superiore Mario Boella, PhotonLab, V. Boggio, 61, 10138, Torino, Italy*
[d]*University "Politehnica" Bucharest, Physics Department, Splaiul Independentei, 313, 060042, Bucharest, Romania*

Polarimetric optical fiber sensors exploit the variation in the polarization state of light transmitted from a single-mode fiber with external factor, such as pressure, temperature, etc. to estimate these physical quantities. In this paper we present the principles, fabrication and operation of a low-cost polarimetric pressure sensor that is based on the coupling between the two orthogonally polarized fundamental modes in a standard telecommunication fiber.

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1. Introduction

In the last few years, fiber optic sensors (FOS) have gained an increasing attention due to their superior characteristics mainly in terms of the capability of operating in hostile environments in comparison with their electro-mechanical counterparts. Thus, different implementations based on various physical principles (such as light amplitude, phase, frequency or polarization modulation) and for a wide range of applications have been reported in the literature.

Among them, polarization–based FOS are extremely attractive thanks to the possibility of being used for distributed high sensitivity sensors and of being configurable in many different shapes. Quite a number of polarimetric sensors have already been developed and studied; they typically use interferometric setups based on the coupling between the two orthogonally polarized fundamental modes of single mode highly birefringent fiber. These sensors have been used for the measurement of various physical parameters such as: pressure, strain, stress and temperature [1-6].

Most of the polarimetric fiber sensors presented so far in the literature are based on interferometric schemes making use of high-birefringent (HB) polarization maintaining (PM) fibers that is fibers in which strong asymmetries are purposely introduced in order to avoid the quasi-degeneracy of the two orthogonally polarized modes and thus to force a single polarization mode under normal operations. A pressure sensor using polarization maintaining optical fibers for a light with wavelength of 1300 nm has been successfully developed by Jiahua Chen and W. J. Bock [7]. In this case the sensor consists of five segments of optical fibers, spliced together with 45^o axis rotation at each consecutive splicing point between the fiber segments.

In this paper we report the experimental realization of a polarimetric pressure sensor that uses a standard single-mode fiber for optical telecommunications. To keep the overall basis, the measurement system was not based on an interferometric setup but on the direct evaluation of the power variation along a predefined linear polarization.

2. Theoretical considerations

Polarimetric fiber optical sensors, relate the variations in the polarization state of light transmitted by a single mode optical fiber with the influence of external factors, such as stresses, pressure, temperature, etc. In order to understand their working principle we first review few concepts about polarization. The polarization of an electromagnetic wave is defined as the orientation of the electric field vector and can be changed along the propagation path as a consequence of reflection, refraction, material birefringence, scattering etc. For sensing applications with optical fibers, the polarization variation is obtained by exploiting the induced birefringence due to micro-bending or other tensile/compressive strains.

It is well known that also single-mode optical fibers actually support two quasi-degenerate modes with orthogonal polarizations, given the unavoidable imperfections that slightly perturb the circular symmetry and produce anisotropy in the distribution of the refractive index. The effect is further enhanced by stresses due to curvatures or externally applied forces such as strains or pressures. This induced birefringence, while being a nuisance for optical telecommunications applications, it is what is used in polarimetric sensors since it can be directly related to the applied force. For example in our case the induced birefringence in a standard optical fibers for telecommunications is exploited to detect the pressure applied on the fiber (Fig. 1).

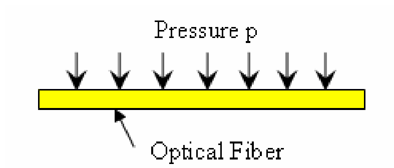


Fig. 1. Schematic representation of the optical fiber transducer used to detect a pressure.

3. Fabrication of the sensor, principle and results

The objective of this work has been to design and realize a low-cost distributed deformation sensor based on the change of polarization in a standard single-mode fiber normally used for optical telecommunications. The schematic representation of the sensor is shown in Fig. 2 and is composed by a laser source, a mechanical polarization controller, a fiber polarizer and an optical receiver that is connected to a PC (not shown in the figure) via a digital acquisition card (DAQ).

The laser source operates in CW and is made of a laser diode plus the biasing circuit; in our prototypes we used a telecommunications laser diode mounted inside a butterfly package. Although a thermistor and a Peltier cell are available within the package of the selected laser diode, we found that a proper temperature control was not necessary for our application and we just used one of the DAQ card to acquire the diode temperature and monitor its temporal evolution. We also acquired the reading from the monitor photodiode built into the package in order to have the possibility to compensate for the laser amplitude fluctuations.

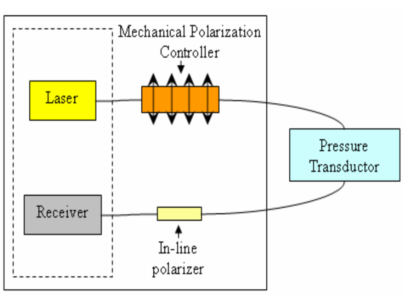


Fig. 2. Schematic representation of the polarimetric fiber-optic pressure sensor.

The mechanical polarization controller allows the selection of the polarization state entering the sensing region and provides complete Poincaré sphere coverage by adjusting the angles of three wave plates with fixed retardation and variable orientation angle. The pressure transducer is made by few loops of fiber sandwiched between two plexiglass plates (Fig. 3). This pressure transducer is place on two metallic supports.

At the receiver side the fiber optic polarizer transmits the light component polarized along a predefined direction while rejecting the orthogonal polarization.

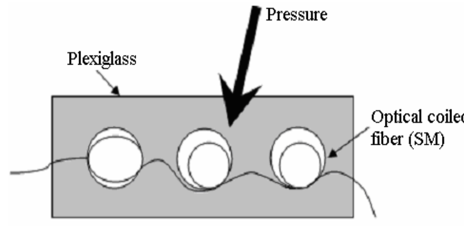


Fig. 3. The principle of the pressure transducer.

The receiver is a common one built around a photodiode with built-in a transimpedance amplifier, a filter stage and another final amplifier.

The working principle of the polarimetric fiber-optic pressure sensor is the following: the light emitted by the laser source feeds the pressure transducer via the mechanical polarization controller that is used to align the incident polarization orthogonal to the transmission axis of the polarizer in absence of the applied pressure stimulus. This way, the receiver reads a null voltage in the idle state. Alternatively it is possible to align the light polarization in order to maximize the receiver reading in absence of any perturbations. When a pressure acts on the transducer the polarization state in the single-mode fiber is perturbed and so changes the value of the power transmitted from the fiber polarizer. Therefore, if an orthogonal input polarization has been selected in absence of perturbation, upon application of the pressure stimulus an optical power different from zero is obtained at the receiver. A similar situation but with a reduction in the received power occurs if a parallel input polarization has been chosen. So, based on the above-mentioned considerations we can conclude that the principle of the presented polarimetric fiber-optic pressure sensor is very simple and uses very common components but also does not require a complex mechanical setup. The data acquisition has been performed with a program developed using the language LabView 7.0 from National Instruments. This software allows also for the creation of user friendly graphic interfaces like that presented in Fig. 4.

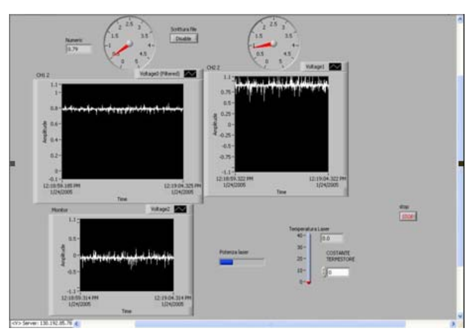
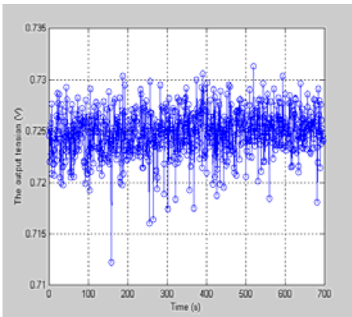
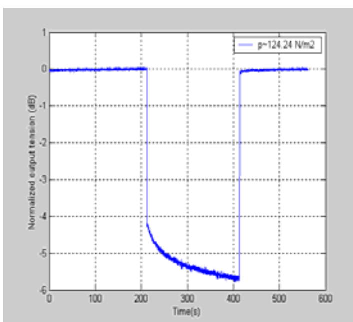


Fig. 4. The graphics interface for data acquisition and elaboration.

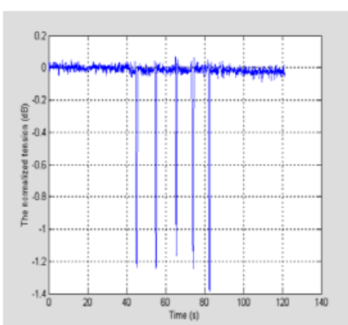
In Figs 5 a-f we present the main results obtained using the polarimetric fiber-optic pressure sensor. From the figures are observed a good reproductibility of the measurements and a good stability in time of the sensor. The pressure operated on the transducer is a pressure which we assume to be constant because the system is not equiped with a mechanical device to act the pressure on the transducer. The sensitivity value of the sensor is 1.15 dB/kg.



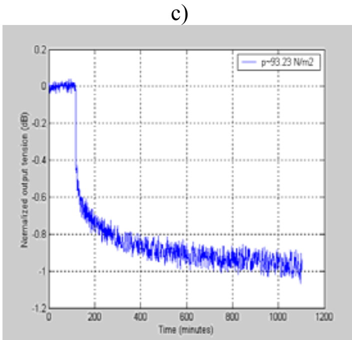
a)



b)



c)



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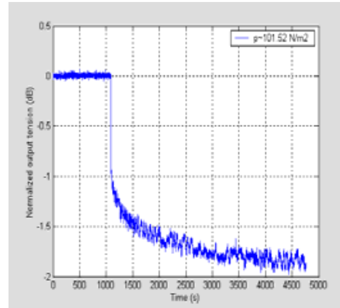
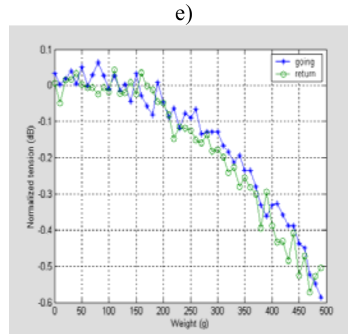


e)



f)

Fig. 5 a), b), c), d), e) and f). The dependence of the sensor output on time (a)÷e)) and weight (f)). Fig. 5 a) shows the output voltage (V) versus time in the absence of deformation, Figs. 5 b), d) and e) show the output normalized voltage (dB) at constant pressure. Fig. 5 c) presents the output normalized tension for different values of the pressure.

The output of the receiver is a voltage and its normalized value has been calculated with the following expression:

$$V_{norm} = \frac{V_{out} - V_{\inf}}{V_{out(0)} - V_{\inf}} \tag{1}$$

where V_{norm} represents the output normalized voltage, V_{out} is the value of the acquired voltage, $V_{\inf} = -0.5V$ is the lower limit of the output voltage and $V_{out(0)}$ is the output voltage in the absence of deformation.

When we have put a third metallic support at the pressure transducer the deformation of the plexiglass plates was very small and the main results in this case are presented in the Fig. 7 a), b). The value of sensitivity in this case is 7.21 dB/kg. A schematic view of the pressure transducer with a third metallic support is presented in the Fig. 6. This third metallic support permits to vary the deformation height of the plexiglass plates.

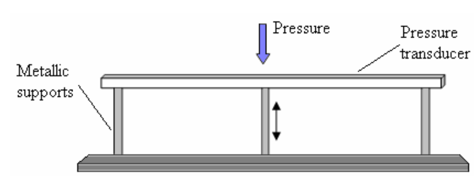
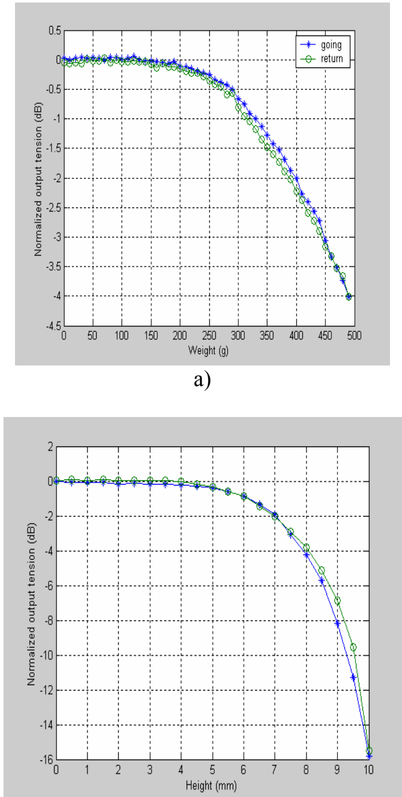


Fig. 6. Schematic view of the pressure transducer with the third metallic support.



b)

Fig. 7. The normalized output tension vs: a) weight and b) height using the third metallic support.

4. Conclusions

In this work we report the principle, design, fabrication and some experimental results which characterize a polarimetric fiber-optic pressure sensor. The design of the sensor is based on the change of polarization of electromagnetic field launched into a single-mode fiber. The above presented pressure sensor has the advantages of simplicity and low-cost.

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*Corresponding author: pnt@physics.pub.ro