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# A low-cost and highly integrated fiber optical pressure sensor system

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**Abstract**

This paper presents a simple, affordable, fiber-optic based pressure measurement system, in which both sensor and readout parts are constructed using batch micromachining techniques, supplemented with some straightforward assembly steps. Prototypes of relative and absolute pressure sensors parts and a readout part have been realized. Goal of this research is to enable deployment of such harsh-environment sensors in high-volume, low-cost applications.


*Keywords:* Optical sensors; Pressure sensors; Waveguides

## 1. Introduction

Fiber optical pressure sensors consist out of a 'sensor part' that is read out optically from a distance though optical fiber by a 'readout part'. As the 'sensor part' does not need to contain electronics, these systems are under investigation for use in harsh environments and medicine.

Most fiber optical pressure sensors in literature use the bending of a pressure-sensitive membrane to convert pressure into a mechanical displacement. The sensors can be differentiated according to the optical principle used to read out this deflection.

The simplest readout principle is deflection modulation [1,2]. In these sensors more or less light is deflected back into the fiber by the pressure-induced movement of a mechanical structure as for example a membrane. It is a simple solution that does not need coherent light. However, the sensitivity is lower than for other methods. Also, it is not inherently insensitive against light source intensity variations and fiber bending losses.

More advanced readout principles use interferometry. A so-called Fabry-Pérot type pressure sensor [3,4] uses a configuration where the fiber is positioned a small distance above the pressure-sensitive membrane. Light reflecting at the fiber–air interface interferes with light reflected by the membrane.

The Fabry-Pérot type is most common in recent literature. Versions have been built fitting on top of an optical fiber [5] or even by constructing a pressure-sensitive membrane directly on top of a cleaved fiber end [6]. Also, commercial versions are available, for example from Fiso Technologies.

For these Fabry-Pérot sensors, the conversion of the optical signal into an electric one can be more advanced than simple intensity measurement as for example used in [5]. One example is the so-called white-light interferometry, where the sensor is fed with low-coherence light from for example a LED [5,7]. A spectrometer is then used to detect the fiber-membrane spacing. This has the advantage that light attenuation, for example by fiber bending, does not disturb the measurement. The price of this is a lower sensitivity and a more complicated and expensive readout setup. Nevertheless do commercially available Fabry-Pérot pressure sensors use such a readout.

An alternative for these is so-called fiber Bragg grating (FBG) sensors. A FBG [8] is a section of an optical fiber core where the refraction index $n$ varies periodically. This part reflects a characteristic wavelength almost completely. As an elongation of the fiber causes the period of the grating to shift, the peak reflected wavelength is shifted as well. Thus, these fibers form sensitive and compact temperature and strain sensors. However, pressure sensitivity of a bare Bragg fiber is not high [9]. Therefore, mechanical structures converting pressure into fiber strain are used to enhance sensitivity [10].

In all these works, the emphasis has been on the sensor part (pressure-optical conversion in a possibly harsh environment),

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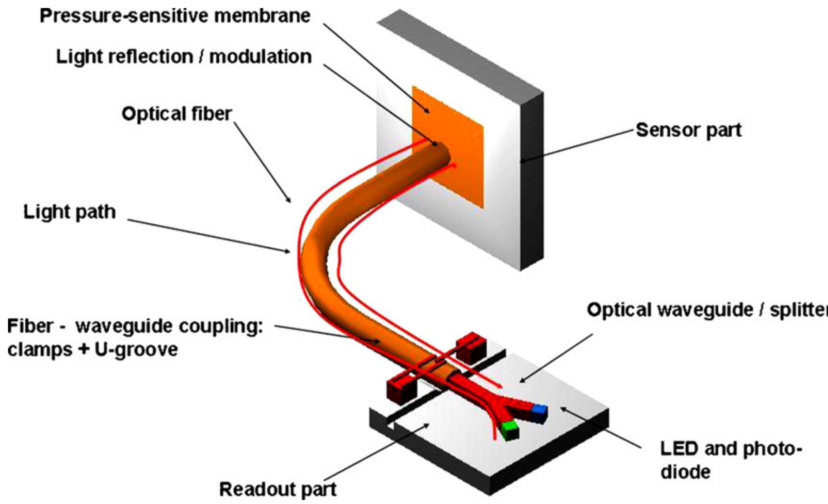


Fig. 1. Schematic overview.

whereas the readout part (optical–electrical conversion under non-harsh conditions) is traditionally constructed using discrete off-the-shelf optical components.

We present the design and initial characterization of a simple optical pressure sensor system (Fig. 1: schematic) where both readout and sensor parts are made by micromachining. Goal of the research is a low-cost batch produced system for harsh environments and high temperatures.

## 2. Readout part

For cost and simplicity reasons, light intensity measurement is selected over spectrometric methods as for example white-light interferometry. For the same reasons, multimode fiber and waveguide components are used. Also, a LED is used as light source.

The readout part presented features an integrated waveguide splitter, enabling emission to and reception of light from a single fiber. Another feature is a fiber holding structure for easy mounting of the optical fiber (Fig. 2).

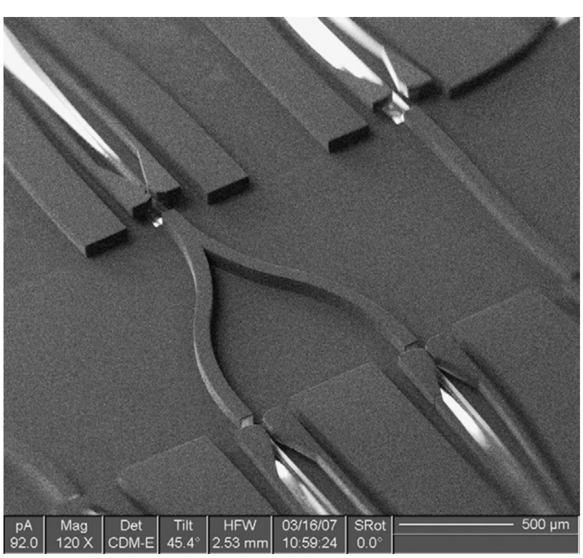


Fig. 2. Waveguide core, optical fiber and clamping structure. Upper waveguide cladding omitted for clarity.

Also, the possibility for differential readout is foreseen: by a double splitter structure, light from the LED can be sent into two fibers, one leading to the sensor membrane, another one leading to a membrane not exposed to the pressure nearby. By dividing the reflected intensities, this should enable to compensate for thermally induced membrane deformation, fiber bending-induced variations in the light intensity and LED intensity variations.

Fabrication is done in a simple three-layer surface micromachining process, using the thick optical photoresists Epocore and Epoclad. In a first version, the splitter waveguide core and the fiber holders were made of SU-8. However, optical stability was found to be poor (degradation from 0.4 dB/cm transmission loss to over 30 dB/cm in a month for 800 nm light). In the current Epocore/Epoclad no transmission degradation was observed over a period of 4 months. Performance figures are in Table 1.

The fabrication process can be summarized as follows:

(1) A 50 μm layer of Epoclad is spun and patterned using the standard process. The lower cladding of the waveguides and a fiber holding trench are formed in this layer.
(2) Then, the trench is filled with thick SPR220-7 photoresist that will be used as a sacrificial layer.
(3) The resist is covered with a 200 nm aluminum layer to protect it from the solvents in the next layer that will be spun on.
(4) A 60 μm layer of Epocore is spun and patterned. This forms the waveguide core and the fiber clamps.

Table 1
Optical properties

| | |
|---|---|
| Transmission loss | <0.4 dB/cm |
| Fiber-waveguide coupling loss | <1.85 dB |
| Photodiode sensitivity for light from fiber (open-circuit voltage) | 176 mV @ 42 $\mu W_{in}$ |
| Light power coupled into fiber | 8.8 μW (170 mW $P_{in,\ diode}$) |