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Photonic Measurement System for Load Detection in a Neuro Interventional Training Model

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Summary:

A measuring system based on flexible silicone waveguides is presented in this work. A proof of principle of the bending-loss sensing unit was performed in a previous work [3]. The subject of this paper is to report different sensor designs, fabrication, as well as the linear response of the sensing unit in a predetermined force range. The linear behavior was achieved by a multimode waveguide design and the associated fabrication method for the waveguides of the sensor unit.

Keywords: PDMS waveguide, flexible pressure sensor, photonic pressure sensor, multimode photonics

Introduction

A common medical practice for the treatment of intracranial aneurysms is coiling [1]. In the procedure, several coils are inserted into the aneurysm in order to fill the void and hence stop blood flow. It is crucial to control the forces coils exert on the walls of the aneurysm. A neuro interventional training model (NTM) with 3D printed phantom aneurysm has been developed in order to eliminate the need of animal testing for the practice of the interventionalists performing the procedure described [2]. This work presents a measuring system that can be integrated into the phantom aneurysm of the NTM to detect and measure exerted loads during the training, making this key performance indicator available to the practitioners.

Description of the System

The pressure sensing system consists of an electronic and a photonic unit. The electronic unit acquires and processes the sensor data while providing an adjustable light source for the exchangeable photonic sensor unit. Detected loads were displayed in real-time. The sensing unit is made out of a flexible multimode waveguide array. In order to maximize the covered sensing area straight, curved, and split waveguide designs are investigated. The interface to the electronic unit is designed as a plug, assuring easy exchangeability and thus adaptability to different settings.

Fabrication of the PDMS waveguide

The sensing unit is a flexible fiber-optic system made of a Polydimethylsiloxane (PDMS) based waveguide array. The waveguide cladding and carrier, made out of silicone from Dow Corning (SYLGARD 184), were manufactured using nanoimprint lithography (NIL) as described in [3]. The cores of the waveguides were filled with a different PDMS (LS-6257 - NuSil) which has a slightly higher refractive index than the surrounding cladding. Comparing to [3] a new method based on an approach shown by Missine et al. [4] is developed with enhanced reproducibility of the cores. The waveguide carrier is cut in a way, that core trenches are opened on the two ends, generating an inlet and outlet for the core material to be filled into the trenches. The sensor carrier is then placed on a coated wafer with the core trenches being on the bottom side. This is done in a Cleanroom, to assure a dust particle free on surfaces. Even small particles would lead to enclosed air bubbles between the wafer and the carrier material, having a negative impact on light transmission in the waveguide subsequently. Next, core material is applied on the inlet side of the trenches to be soaked in due to capillary action forces. To ensure continuous supply of core material, a reservoir is necessary. It takes around 20 to 40 minutes for the trenches to be completely filled, dependent upon trench size. Lastly, the setup is baked to cure the core material and bond it to the cladding.

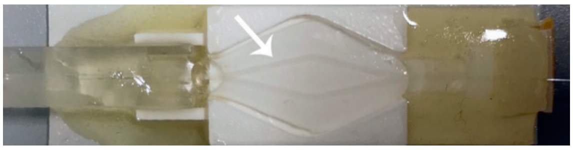

Fig. 1. Flexible PDMS mat with integrated curved waveguides (→).

Sensor units fabricated this way were then glued on a 3D printed support structure (Norland Optical Adhesive 68). To establish a link between the waveguide array and the light source and detector, glass fibers were used, which were aligned using a 3D printed v-groove adapter. After proper alignment, fibers were butt-coupled to the waveguide array. To ensure easy and fast replacement of the sensor unit, LED as light source and photodiode as detector were connected to the electronic unit by removable wire connectors. Figure (1) shows a flexible sensing unit glued to the support structure.

Experimental Setup

The system evaluation was performed using two different sensor designs. The first sensor includes an array of four straight waveguides with a fixed core height of 230µm and a variable core width (100µm, 200µm, 300µm, 400µm). This sensor was used to evaluate the effect of core width on the sensitivity and sensing range. The second sensor was designed with a single waveguide (width: 600µm, height: 230µm) splitting into two diverging waveguides (width: 600µm, height: 230µm) and being recombined at the end. The impact of splitting and uniting waveguides was investigated with this sensor. Measurements were performed placing the sensor unit including the support structure on a precision scale. Loads were exerted perpendicularly on the sensor surface using a metal rod with a spherical tip.

Results

To investigate the tunability of the system three measurements were performed with the source LED being at high, medium, and low intensity. Thus, the photodetector was fully saturated, just in saturation, and unsaturated. Figure (2) shows a shift of the measurement range to higher loads with increasing source intensity. Same is true for the linear range, shifting from 0 – 5 grams for low source intensity to higher values for high source intensity.

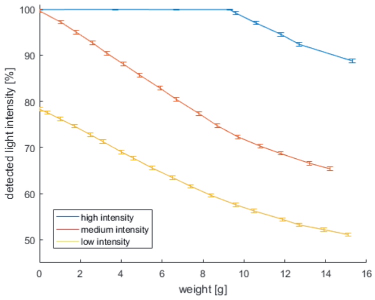

Fig. 2. Output light intensity as function of force exertion. Force is exerted three times at the same position but with different input intensities.

The impact of the channel width on the sensitivity and linear range was investigated using the first sensor. The light source of each channel was tuned to give all channels a matching starting value for the detected intensity at zero load. In Figure (3) the wider waveguides with 300µm and 400µm width responded linearly from the beginning while the waveguide with 200µm just behaved linearly after approximately 2 grams.

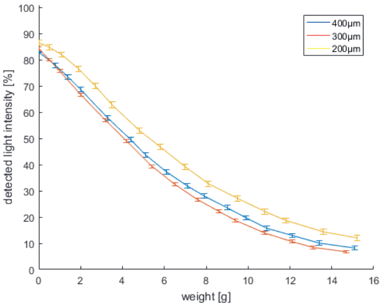

Fig. 3. Light intensity during force exertion. Force is exerted to straight waveguides with different width (200µm, 300µm, 400µm).

Figure (4) shows the impact of the Y-splitter and the curved waveguide geometry on the sensitivity and overall performance of the sensing unit. The load was applied at three sensor surface positions as indicated, with the light signal being transmitted from top to bottom. Position 1 and 2 showed slightly different sensitivity with loads > 5 grams, indicating that the source light was not split uniformly into the two channels by the Y-splitter. Also, the bending of the core seems to have a significant light loss as the curve for position 3 is shifted towards lower forces.

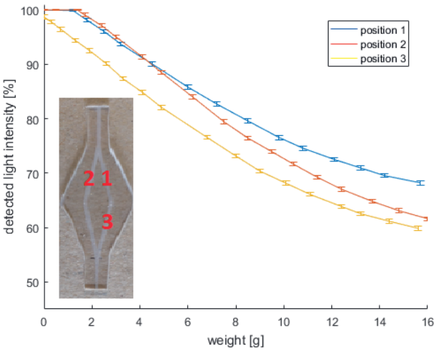

Fig. 4. Output light intensity as function of force exertion. Force is exerted at three different positions.

Conclusion

In this work we demonstrated a sensor system with a linear measurement range that is tunable within the limits of the detection range. Straight waveguides turned out to be the best waveguide design for this application since Y-splitters and curved waveguide geometries lead to falsified measuring results depending on the position of the load exertion. Furthermore, the whole measurement system is robust, transportable, flexible, and straightforward to produce, making the system simple to integrate in different settings.

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