# Flexible optical fiber sensor based on polyurethane

Md Rejvi Kaysir[1], Alessio Stefani[1,2], Richard Lwin[1] and Simon Fleming[1]
[1]Institute of Photonics and Optical Science (IPOS), School of Physics, The University of Sydney, NSW 2006, Australia
[2]DTU Fotonik, Department of Photonics Engineering, Technical University of Denmark, DK-2800 Kgs. Lyngby, Denmark
simon.fleming@sydney.edu.au

*Abstract*— **Polyurethane (PU) based hollow core fibers are investigated as optical sensors. The flexibility of PU fibers makes it suitable for sensing mechanical perturbations. We fabricated a PU fiber using the fiber drawing method, characterized the fiber and experimentally demonstrated a simple way to measure deformation, in the form of applied pressure.**

***Keywords- Fiber optics sensor; polyurethane; fiber drawing and fabrication; pressure sensor; hollow core fiber sensor; flexible waveguides.***

## I. Introduction

Optical fiber sensors (OFS) are an existing technology, which offers many inherent advantages such as lightweight, resistance to electromagnetic interference, high sensitivity, high-temperature operation, immunity to corrosion and large bandwidth [1]. The commonly used materials in fiber optic sensing are glass or plastic (e.g. PMMA). However, due to their relatively high Young's modulus (> 1 GPa) they are not suitable for measuring small forces and large deformations without a complicated light detection system. An OFS made with a lower Young's modulus material, by comparison, allows for greater response to external perturbations.

Recently, there have been several demonstrations of applications that take advantage of flexible waveguides for soft robotics [2,3], wearable and human-friendly devices [4,5]. Such applications benefit mostly from the possibility of the waveguide to be stretched. Some other applications could instead take advantage from the waveguide to be highly compressible. An example could be monitoring the movement of bed ridden patients. This problem has been already investigated with the use of optical fiber sensors, but mostly using glass fibers and fiber Bragg gratings [6]. Both the material used and the costly detection method prevented utilizing this technology as solution for such a problem.

In this work, we report the fabrication of polyurethane (PU) optical fibers with low Young's modulus (~51 MPa [7]) to develop a simple deformation/pressure sensor. Given the high material loss, a hollow core design was used. The flexibility of PU allows high levels of deformation [8] that directly induce transmission losses. Thus, a simple power measurement is sufficient to obtain the desired information.

## II. Fabrication and Characterization Method

A PU optical fiber was fabricated using the "stack-and-draw" method [9], where the polymer capillaries were first arranged into a preform stack and then stretched to fiber using a combination of heating and tension in a fiber draw tower. The fabricated fiber cross section is shown in Fig. 1. The fiber has an outer diameter of ~2.1 mm and a core diameter of ~400 µm. The size of the fiber, together with the Young's modulus of PU and the air-filling fraction, determines the sensitivity and maximum working range of the sensor. As we are, at the moment, interested in applications where the pressure is induced by the human body, a large size and "rigid" (for this material) structure was first chosen.

The experimental setup used to characterize the PU fiber sensor consisted of a 532 nm laser focused using a 25X objective lens at the fiber input. The output radiation was measured using an Ocean Optics spectrometer (USB 4000) connected to a large core optical fiber, as shown in Fig. 1, and with a calibrated power meter (Coherent). The launched input power used for this experiment is in the range 4 to 28 µW. The level of power used can be easily achieved with a LED while the output power could be measured with a power meter, allowing a simple, cost effective and compact fiber sensor system. The PU fiber used for this experiment is 51.4 cm long. This fiber is quite flexible and can be easily bent to the centimeter level. The fiber was aligned on three XYZ stages, where the end stages (1) and (3) were used for coupling and the central stage (2) was used to support the fiber during the external force and bending experiments.

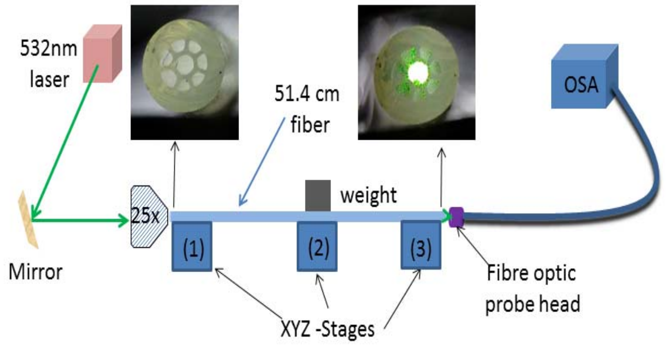


Figure 1. Experimental setup for characterizing the PU based hollow core fiber sensor. The diameter of the fiber core is ~400µm. Core guidance of the fiber is also shown.

The Australian Research Council under the Discovery Project scheme numbers DP 140104116 and DP170103537 (SF); Marie Sklodowska-Curie grant of the European Union's Horizon 2020 research and innovation programme (708860) (AS)

## III. RESULTS

We first characterized the guiding properties of the fiber. The PU fiber guides the light in the core as seen from the picture of the fiber output end facet (Fig. 1). The transmission loss of the PU fiber was measured using the 'cut-back' method and found to be 0.54 ± 0.20 dB/cm. The loss is still quite high (due to the fiber size) but not too high to prevent transmission along the meter long distance the application requires.

As we intend to measure power dependent deformations, loss due to bending were also measured. The bend loss of the PU fiber is shown in Fig. 2(a). The contribution of bending loss is, as expected, quite substantial (on the order of 0.95 dB/cm). However, we don't expect large bends to occur when the sensor is in place and, moreover, this allows using the same OFS for bending measurements.

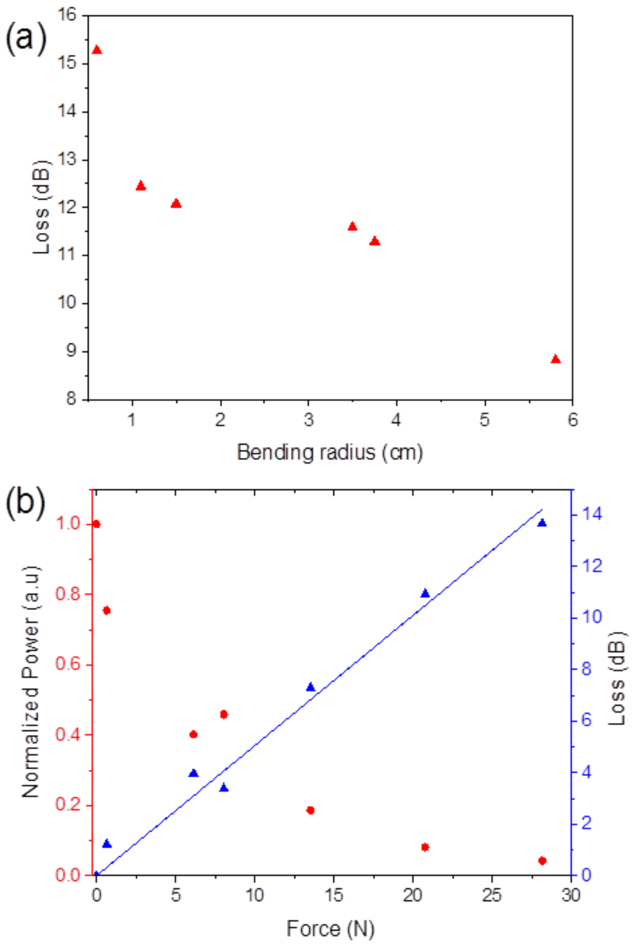


Figure 2. (a) Bend loss measurement. (b) Linear normalized output power against applied force (red circles) and the corresponding transmission loss in dB (blue triangles).

To determine the pressure sensitivity, a series of weights ranging from 0.1 to 3 Kg were placed on the top of the fiber at the stage (2) position. The dependence of the normalized power vs. applied force exerted by the weights is shown in Fig. 2(b). As expected, the power decreases exponentially with applied force. Full cycles of loading and unloading of the weights revealed negligible amounts of hysteresis (not shown here). Figure 2(b) also shows the transmission loss (in dB) of the fiber against the applied force. The corresponding sensitivity of the fiber was found to be 0.51 dB/N, which can be obtained through a linear fit of the above transmission loss data. Despite some measurement errors coming from the issue of balancing weights on a circular fiber, the results are quite promising and the system is expected to be compatible with measuring a person moving in bed.

## IV. CONCLUSION

We fabricated and characterized a simple mechanical sensing platform that can measure external force and bend radius using a flexible optical fiber made from polyurethane. This demonstrates the compatibility between low Young's modulus materials and the conventional fiber drawing technique. We show sensitivity to compression forces in the range intended for applications such as bed ridden patient movement monitoring. We also aim at scaling the fiber structure down in size for more compact and sensitive sensors.

## ACKNOWLEDGMENT


This work was performed in part at the OptoFab Node of the Australian National Fabrication Facility (ANFF), utilizing NCRIS and NSW Smart Sensors Network (NSSN) funding.


## REFERENCES


[1] B. Lee, "Review of the present status of optical fiber sensors," Optical Fiber Technology, vol. 9, pp. 57-79, 2003.

[2] C. Majidi, "Soft robotics: a perspective–current trends and prospects for the future," Soft Rob, vol. 1, no. 1, pp. 5-11, 2014.

[3] Y.-L. Park, B. Chen, and R. J. Wood, "Design and fabrication of soft artificial skin using embedded microchannels and liquid conductors," IEEE Sens. J., vol. 12, no. 8, pp. 2711-2718, 2012.

[4] C. Mattmann, F. Clemens, and G. Tröster, "Sensor for Measuring Strain in Textile," Sensors, vol. 8, p. 3719, 2008.

[5] B. J. Munro, T. E. Campbell, G. G. Wallace, and J. R. Steele, "The intelligent knee sleeve: a wearable biofeedback device," Sensors and Actuators B: Chemical, vol. 131, pp. 541-547, 2008.

[6] E. Al-Fakih, N. A. Abu Osman, and F. R. Mahamd Adikan, "The use of fiber bragg grating sensors in biomechanics and rehabilitation applications: the state-of-the-art and ongoing research topics," Sensors, vol. 12, p. 12890, 2012.

[7] H. J. Qi and M. C. Boyce, "Stress-strain behavior of thermoplastic polyurethanes," Mechanics of Materials, vol. 37, pp. 817-839, 2005.

[8] S. Fleming, A. Stefani, X. Tang, A. Argyros, D. Kemsley, J. Cordi, and R. Lwin, "Tunable metamaterials fabricated by fiber drawing," J. Opt. Soc. Am. B **34**, D81-D85, 2017.

[9] J. C. Knight, T. A. Birks, P. St. J. Russell, and D. M. Atkin, "All-silica single-mode optical fiber with photonic crystal cladding," Opt. Lett., vol. 21, pp. 1547-1549, 1996.