Design and fabrication principles of uniformly side-emitting plastic optical fibers

Roya Gachiloo[1], Vladislav Ulitco[1], Codey Nacke[2], David Plant[2] and Maksim Skorobogatiy[1]

[1] Department of Engineering Physics, École Polytechnique de Montréal, Québec, Canada

[2] Department of Electrical and Computer Engineering, McGill University, Québec, Canada

Abstract

Polymer optical fibers (POF) have attracted much attention in science and industry. In comparison to the glass fiber or copper wire, POF systems are lighter and less expensive. Their great flexibility and resilience to bending, shock, and vibration make them good candidates for sensing and communication. Side emitting plastic optical fiber (SE-POF) is a special form of POF. In SE-POF different methods can be used to hinder total internal reflection (TIR) and as a result, light leaks out from their surface. This property makes them suitable for illumination purposes such as automotive or decorative lighting as well as different applications in the fields of medicine, optical communications and fiber-optical sensing. In this study, we fabricate PMMA fibers using fiber drawing technique. Then the surface of the fibers is modified using abrasive papers with different grit sizes and the effect of surface scratching on the side emission of PMMA fiber is investigated. The experimental results show that this method can be used to enhance the side emission of PMMA fibers.

Theory

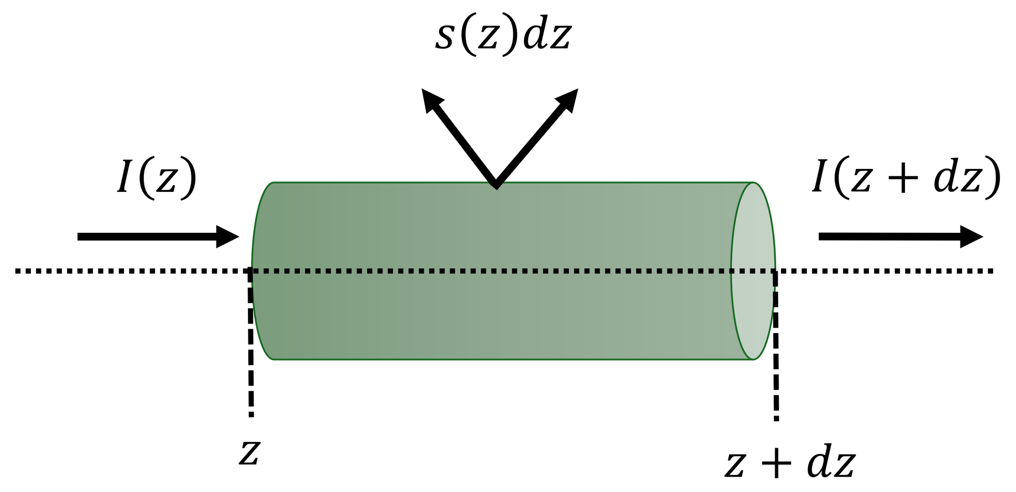


Fig.3. Light propagation in the side-scattering optical fiber.

From energy conservation, it follows that:

$$I(z+dz) = I(z) - A(z)dz - S(z)dz \quad (1)$$

Assuming:

$$A(z) = I(z)\alpha$$
$$S(z) = I(z)\delta(z) \quad (2)$$
$$\delta(z) = \delta_0 + \Delta\delta(z)$$

Design goal:
Constant side emission along the fiber

$$S(z) = S_0 = \text{const.} \quad (3)$$

A derivative from (1) and considering the condition of (3) leads to the following solution:

$$I(z) = I_0 e^{-\alpha z} - S_0 z \quad (4)$$

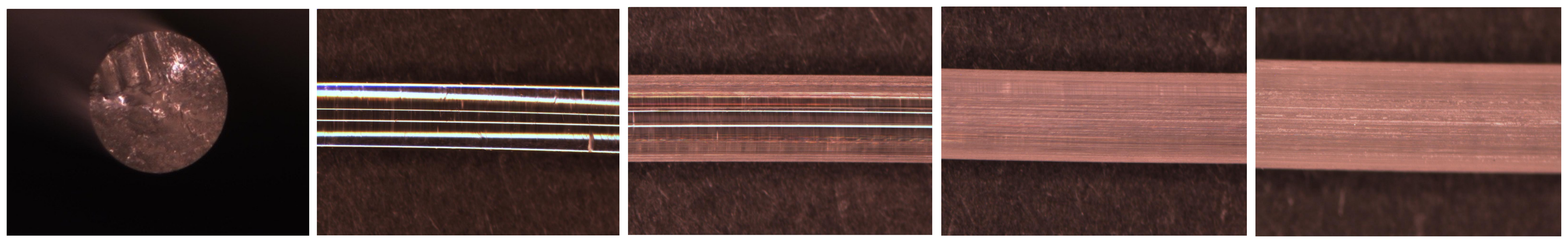
From (4), we derive the necessary condition for the existence of a uniformly side emitting fibers (5) and the maximal length of uniformly emitted fibers (6):

$$S_0/I_0 \geq \delta_0 \quad (5)$$
$$z_{max} = 1/\delta_0 \quad (6)$$

Parameters:

- $\mathbf{I(z)}$: Light power guided in the fiber core [W]
- $\mathbf{S(z)}$: side-scattered light power [W]
- $\mathbf{A(z)}$: Absorbed light power [W]
- $\boldsymbol{\alpha}$: Material absorption coefficient $[\frac{1}{m}]$
- $\boldsymbol{\delta(z)}$: Side scattering coefficient $[\frac{W}{m}]$
- $\boldsymbol{\delta_0}$: Intrinsic scattering loss of the material$[\frac{W}{m}]$
- $\boldsymbol{\Delta\delta(z)}$: Extrinsic scattering coefficient $[\frac{W}{m}]$

Experimental Measurement



(a) (b) (c) (d) (e)

Fig.1.a) Cross section of 1.5mm rod-in-air PMMA fiber b) Fiber surface before scratching c) Fiber surface after 2 times scratching d) fiber surface after 6 times scratching e) fiber surface after 14 times scratching.

In this study we work on 1.5mm rod-in-air PMMA fiber. Fiber is fabricated using fiber drawing technique. To achieve side-emitting fibers, modifications to the fibers are necessary. This modification involves treating the surface of PMMA fibers using abrasive papers with varying grit sizes. Fig.1.a-1.e show the changes of fiber surface after scratching. The side emission of fibers are measured with a detector placed close to the surface of the fiber. The experimental setup is shown in Fig.2.

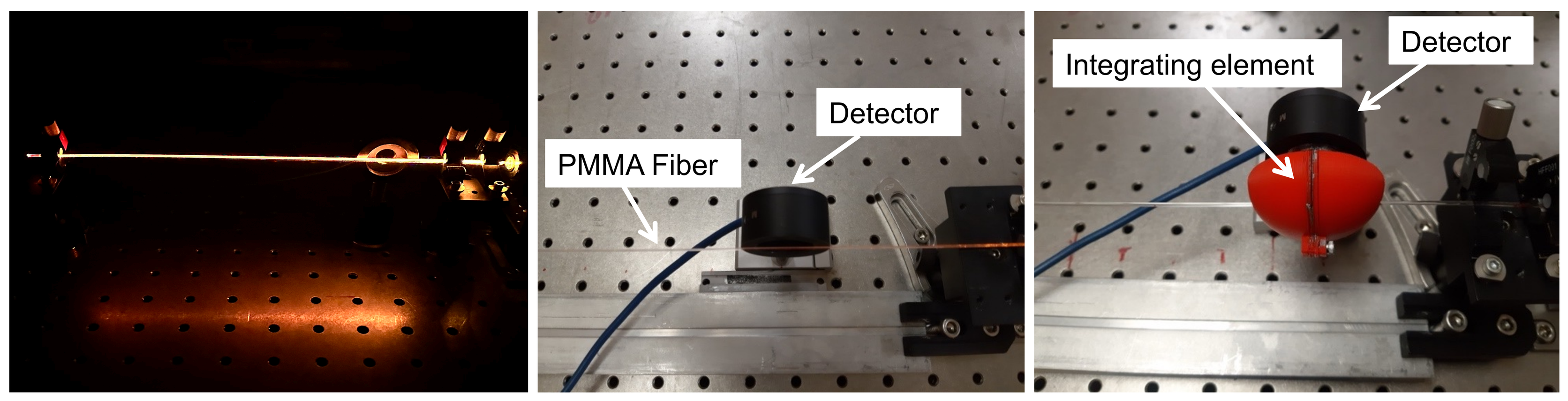
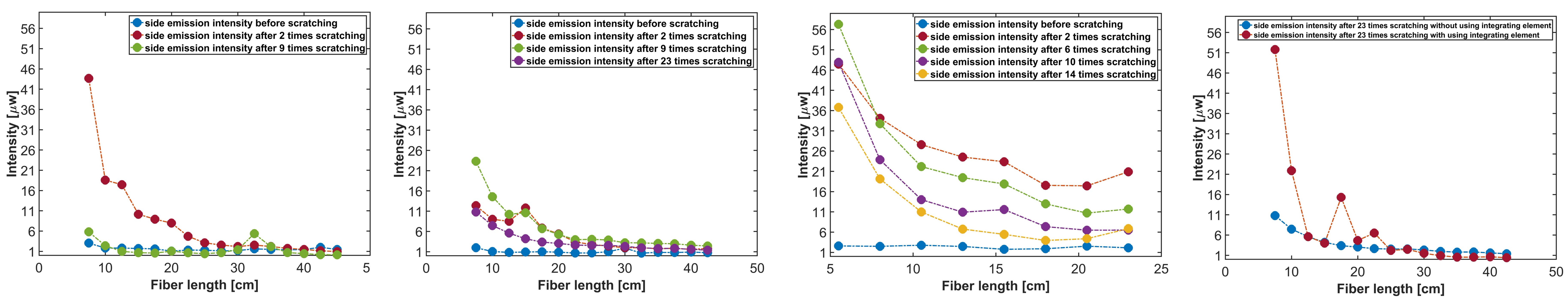


Fig.2. View of experimental setup.

To ensure a consistent method of measuring side emissions we designed and fabricated an integrating element to ideally collect all the side radiation from the fiber into the detector. Fig.3.d compares the measured side emission with and without using this integrating element.

Result and Discussion



(a) (b) (c) (d)

Fig.3. Side emission intensity of PMMA fiber before and after scratching with abrasive papers of grit sizes a) 240, b) 320, c) 400, d) Comparison of side emission intensity of PMMA fiber with and without using integrating element.

Results:

- Polymer fiber surfaces can be effectively modified using a simple technique involving abrasive papers. As shown in Fig. 3, this modification significantly enhances the side emission intensity from the fiber surface.
- Integrating element helps collecting all the side radiation from the fiber into the detector.
- While scratching significantly enhances the side emission intensity, after certain number of scratches the the side emission intensity decreases. This number is different for different grit sizes.

References

[1] J. Spigulis, "Side-Emitting Fibers Brighten Our World," Optics & Photonics News, OPN **16**, 34–39 (2005).

[2] J. Kallweit, M. Pätzel, F. Pursche, J. Jabban, M. Morobeid, and T. Gries, "An Overview on Methods for Producing Side-Emitting Polymer Optical Fibers," Textiles **1**, 337–360 (2021).