Devices, components and applications of low cost using polymer optical fibers

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ABSTRACT

Low-cost optical devices, components a polymer optical fiber (POF) are demonstrated using technical of polished. Potentially low-cost components fabrication processes are described. Several components and devices are proposed for applications in communications or industrial applications. Experimental results obtained with POF and diffraction grating are presented.

Keywords: Polymer Optical Fiber, Optical Sensor, Devices and Components.

1. INTRODUCTION

The increasing use polymer optical fibers (POF) for light wave communication, local area networks (LAN), or sensor require of devices and components that are compatible with solutions of low cost. Indeed, POFs are very attractive for the connections of short distances and they possess important advantages regarding the glass fiber [1]. The POFs is manufactured with a great diameter, large numerical aperture, they are easy to manipulate, the extremity components are of low cost and they have an excellent flexibility. The increase of the applications in communications and in the industry need components that can adapt to these necessities, particularly in optic sensors [2]. POF connectors and devices houstings can be made out of polymer [3]. The technology advancements in graded index polymer optical fibre (GI-POF) and low cost transceivers using red and green LEDs and cheap laser diodes are driving renewed interest in POF data links [4].
In this communication we present the design and the realization of a series of devices and components of low cost with the help of polymer optical fibers. These include couplers, distributors, filters and tapers in POF. The experimental results in different applications of measure of physical parameters are described. The realization of simple demultiplexing in wavelengths and heads sensors are also presented.

2. POLYMER OPTICAL FIBER

Polymeric materials have suitable properties for guiding light, which is why they can be used in the manufacture of optical fibers. An optical fiber is a guide for light waves. Cylindrical in structure, it is formed by two media: a central region or core, with a refractive index n_1 and an external medium or cladding which surrounds it, of refractive index $n_2 < n_1$ (Fig. 1a). These two regions are essential for guiding light. In cable form, the POF is protected by an outer sheath. The diameter of the fibers varies in magnitude, the most common ones being 1mm wide, where 980 µm corresponds to the core. The large diameter of the polymer fibers makes them multimodal, facilitating the study of the traveling of light in their interior. In fact, they can be studied in a simple fashion, using the theory of geometric optics [5]. The half-angle (θ_{max}) of the light cone that a fiber can accept is characterized by the numerical aperture (NA), which is defined by the difference in the refractive indices of the core and the cladding material (Fig. 1b):

$$NA = n_o \sin \theta_{max} = \sqrt{n_1^2 - n_2^2} \qquad (1)$$

where n_o is the medium refractive index (n_o=1, air). θ_{max} is referred to as the acceptance angle, and twice the acceptance angle is referred to as the aperture angle.

The light rays, which travel in the core of the fiber, can be of various types. For example, some may travel in a straight line, without hitting the core/cladding interfaces, others are totally internally reflected about the axis (meridional rays) whilst yet others do not pass through the axis (non-meridional rays). In addition to this, rays may also escape from the core, due to the fact that non-meridional rays are not necessarily totally reflected at the interfaces. In this case, part of the light may travel in the cladding. Another advantage of the large diameter of POFs is the ease of injection of light, using cheap sources like LEDs, where the rays entering at the incident face of the fiber satisfy the conditions for confining them to the core.

The properties of POF that are increasing its popularity and competiveness for communications are exactly those that are important for optical measurement, sensor, components and devices. Next, we will develop components and devices to base POF multimode and step-index of 1 mm of diameter.
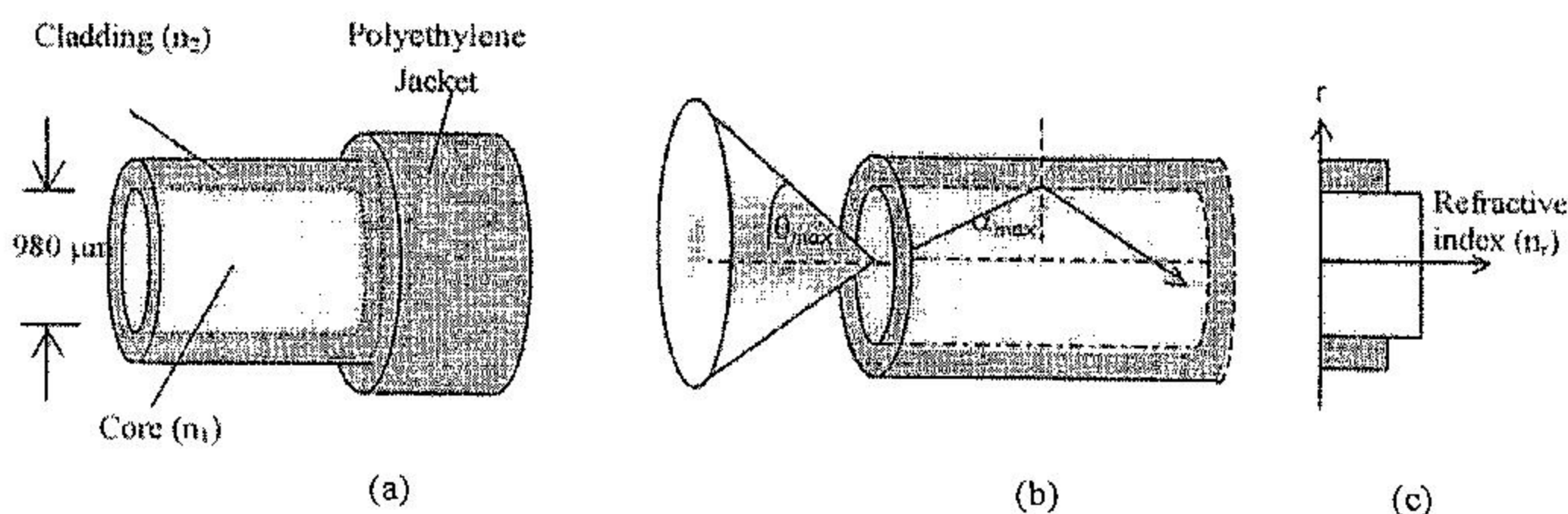

Figure 1. Polymer optical fiber (a) Structure and (b) acceptance angle, and c) step index profile.

3. PASIVE OPTICAL COMPONENTS

3.1. COUPLERS

We have carried out a series of passive components using strongly multimode POFs, where the design has been carried out using the theory of rays. The couplers based on POFs can be carried out in three ways: a) for coalition of two braided fibers, b) for abrasion of two curved fibers, and c) for cut in 45° of the extremity of fibers. We have carried out both last.

In the first case the coupling among the fibers is based on evanescent-wave. A fiber is bonded into a slot in a plexiglass block. The plexiglass block is prepared to contain the fiber inside a grove carried out by engraving mechanic. A slot of constant depth is cut into the top face. The bottom of the slot is then given concave-downward curvature in the saggital plane of the block by jeans of a wire saw. This imparts a curvature to the path of the fiber. The radius of curvature controls the length of the interaction region. The fiber is bonded while being stretched along the slot. The block and fiber are then ground and polished to within a few micrometer of the fiber core. The intersection forms an elongated oval pattern, whose width perpendicular to the fiber axis is used to determine the initial penetration depth into the fiber and thus the position of the fiber with respect to the bottom face. Measurement of the length of the oval pattern parallel to the fiber axis at several depths allows one to determine the radius of curvature of the fiber. Placing to such units in close proximity produces evanescent coupling of the guided light between the core regions. An important advantage of this coupling structure is that the coupling ratio can be controlled by small relative motions of the block with little effect on insertion loss or directivity. We fabricated low excess insertion loss couplers with multimode POF using lapping technique. This coupler is illustrated in the figure 2.

In the second case, the coupling among fibers is obtained by reflection and partial transmission. If a fiber endface is cut 45° to the axis the output beam is essentially perpendicular to the axis. This also means that light can be coupled in side-on. Putting two angled fiber ends together, leaving a small air gap as shown in figure 3, we have the terminal connected, either directly or via additional fibers. If the terminal has to be disconnected or bypassed it is only necessary to close the air gap. One could try to do this by moving

the fibers together or easier by filling the gap with a medium having the same refractive index as the fiber core. Thus there is no more total reflection at the endfaces, light passes directly through.
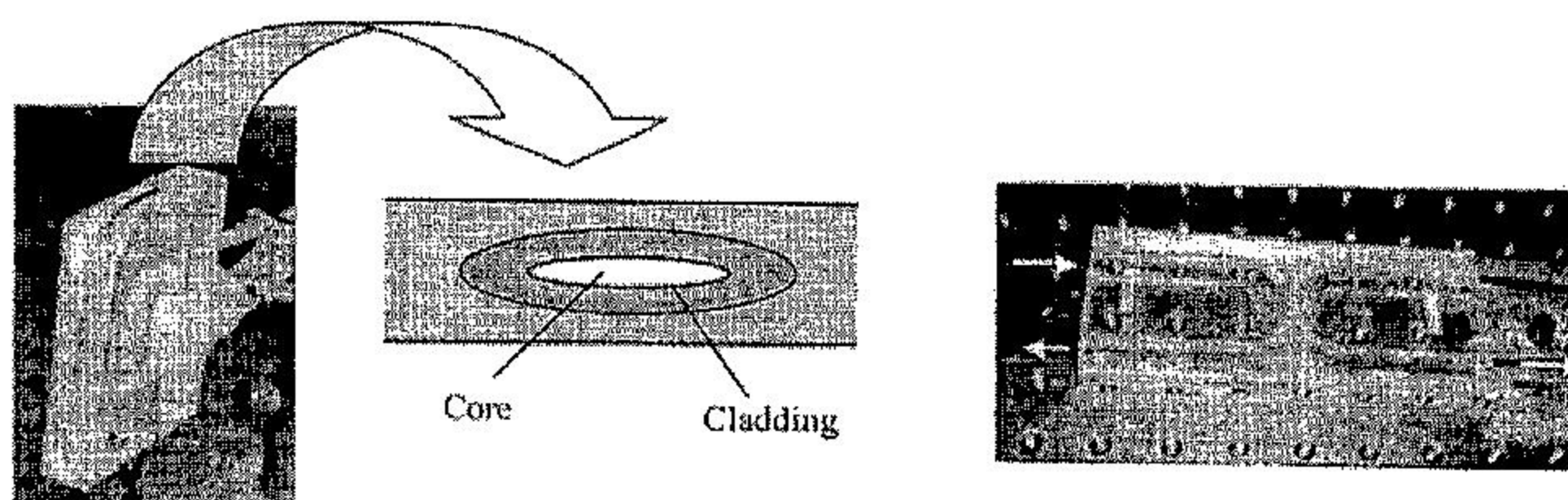

Figure 2. Evanescent-wave multimode POF coupler, a) polished fiber inside the plexiglass block, b) region of polished fiber, c) complete coupler.

To obtain the fiber extremities with angle of $\alpha=45°$, we have located the fiber inside a plexiglass block where the area of refined has this angle. α it is the cut angle with respect to the axis of the fiber. Fiber were cut with an unheated knife. Ends were then polished by hand using the stainless steel polishing tool and successively finer grit paper. The two fibers polished in angle of 45° are located carefully one in front of the other one inside a support in plexiglass that contain grove to house the fibers. These are aligned axially. Other two fibers, with right cut, they are located perpendicularly to the previous ones. Next, the group of fibers is fixed permanently with appropriate paste for the POFs. In the figure 3 the carried out coupler is illustrated. The operation of the coupler is reversible. This coupler type can be used in the installation of LANs at home because they can be located in the corners of the rooms. Another practical application can also the mixing two wavelength, that is to say a multiplexing operation.
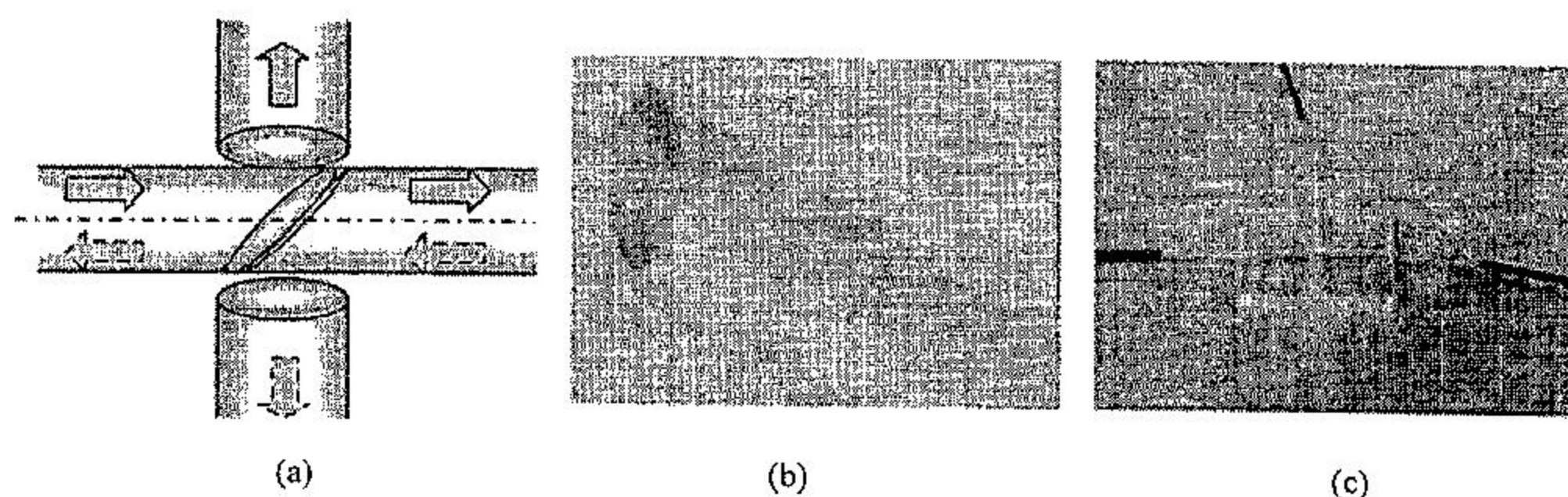

(a)　　　　　　　　　(b)　　　　　　　　　(c)

Fig. 3. a) Configuration of the coupler, b) POF polished in 45°, and c) Photo of the POF coupler achieved.

3.2. FIBER ENDFACE TILTED

To ensure optimal coupling, the end of the POF were cut with an unheated knife and polished. If the exit surface is polished with an oblique angle with respect to the fiber axis, the output will be deflected. If the critical angle for total internal reflection is reached, the light will leave the fiber through the cylindrical side. A fiber with a combination of a beveled and a flat polished tip can also be used for deflection as one part of the beam exits in the direction of the fiber axis while another part is guided sideways. To enable a larger range of steering angle, the beveled surface of the fibers can be alternatively be coated. All these forms of having finished of the fiber can be carried out with the technique described in the section 3.1. In the figure 4 some of these configurations of extremities of fibers are shown. These components can be

used as elements of probe of the sensors of chemical, biomedical or environmental type. An application example is described in the section 4.
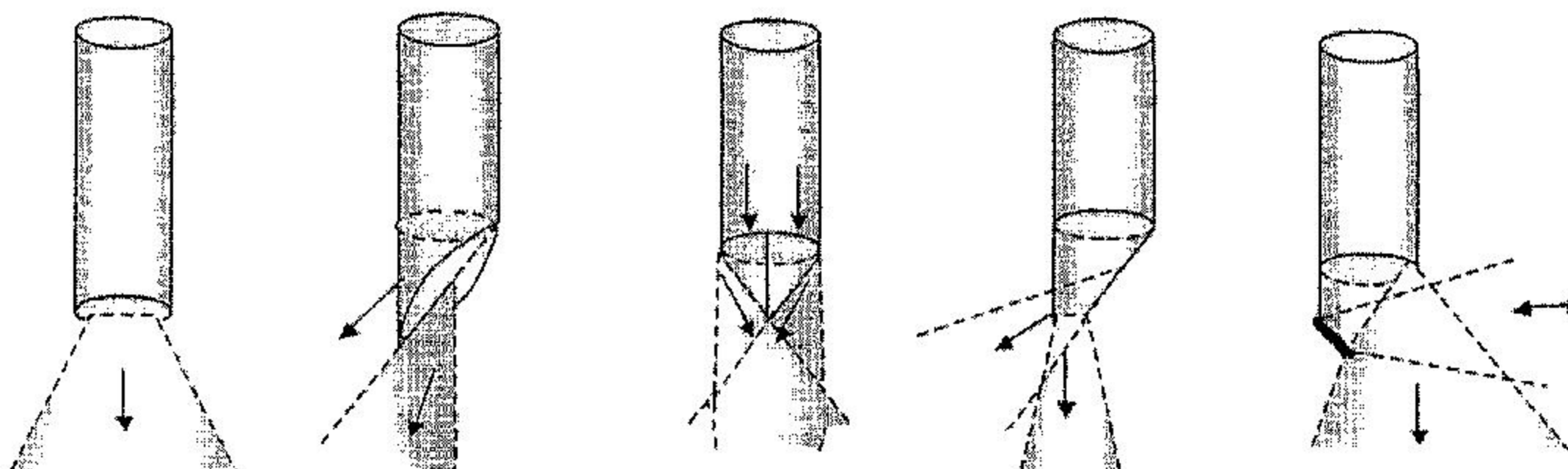

Figure 4. Different configurations of the extremities of polished fibers.

4. DEVICES IN POF

Using the POFs in different forms has carried out a series of devices for applications in optical sensors.

4.1. SENSOR HEAD FOR THE MEASURE OF CONCENTRATION OF LIQUIDS

A simple system of measure of the index of refraction of a liquid can be formed axially by one emitting and other one receiving fibers separate and submerged in a liquid. The variations of the index of refraction of the liquid modulate the intensity of spread light. In this case, the intensity of light coupled in the receiving fiber depends on the parameters of the liquid means, the propagation loss, the transmission coefficient Fresnel in the interfaces and of the geometric factor of the separation among the fibers. With the purpose of avoiding the influence of these factors and the inaccuracy of measure of the index, we have developed a system of three fibers. The outline of the measure system is shown in the figure 5. The receiving fibers displaced axially among them with regard to the axis of the fiber radio station allows to carry out a measure of differential optic power, annulling the undesirable factors that perturb the measure of the index of the liquid therefore. The device was successfully checked measuring refraction index changes of the water with different concentrations and refractive index of liquids [6][7].

4.2. DIFFRACTION GRATING IN POF END.

Diffraction gratings placed in the extremity of an optical fiber (Fig. 6a) are characterized by the grating equation given by [8]: $\sin\theta_d = n_1 \sin\theta_i \pm p\lambda/\Lambda$, where θ_d is the diffracted angle, θ_i is the incident angle, n_1 is the core refractive index, Λ is the grating period, λ is the wavelength and p ($\pm 1, \pm 2, ...$) is the order of diffraction. Diffraction orders of fiber end grating are distributed symmetrically around the axis when the gratings is placed in perpendicular position to the axial fiber axis on the end fiber face. But if the fiber end grating it finishes in angle, the diffraction orders can be properly managed. The spatial separation and the spectral resolution of the diffraction modes can then be improved. If α is the angle corresponding to higher order modes inside the fiber with axis, and θ_ℓ is the critical angle, the incident rays on the grating and that they will be transmitted they should be: $\theta_i < \theta_\ell = \sin^{-1}(1/n_1)$. If the angle α of inclination of the end fiber is important, for example for $\alpha=55°$, the angles of the rays transmitted for a POF they are between 35 ° and 42°. This new disposition of the grating in the fiber can improve the process of demultiplexing of wavelengths because they can be selected by appropriate positioning of the collecting device, placed at angles that match the diffracted angle of the desired wavelength. An portion of polymer optical fiber, of 1 mm A portion of polymer optical fiber, of 1 mm diameter type Super Eska-Rayon serie: SH4001, is laid on block of plexiglass and glued with an epoxy resin. Polishing is then performed upon in the final angle of interest the end fiber. After polishing, the surface end fiber trace

appear in ellipse form. This surface is characterized for; $S=(a.b)\pi$, where a, b are the radii of the means axes of the ellipse respectively. Consequently, the surface the end fiber passes from πa^2 to be characterized now by $\pi a^2/\cos\alpha$. A new displacement sensor has been proposed recently [9].
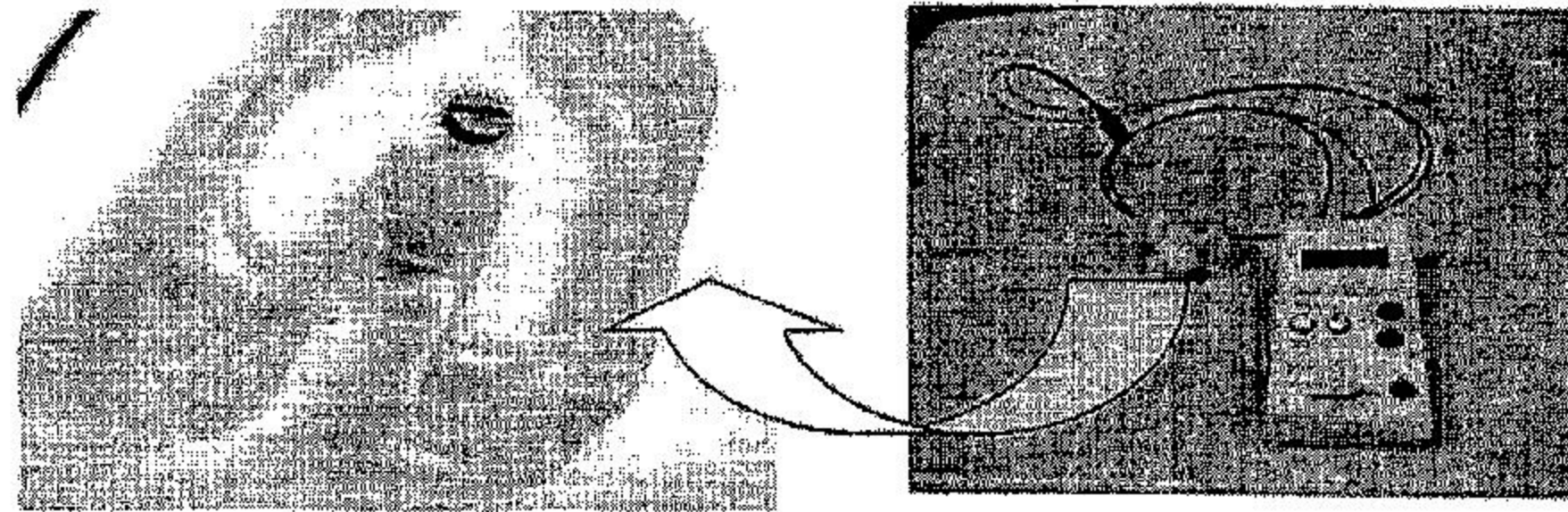

Figure 5. Sensor head assembly together with the electronic unit.

Grating diffraction available commercially and made in thin film, of 1.8 μm of period, it has been hit on the refined surface of the face of exit of the fiber. Notice that the grating surface is parallel to the fiber end-face. For an angle of α=55°, the surface occupied by the grating is of 1.3 mm², the grooves of the grating are willing parallel to axis 2a the surface elliptic (diameter of the fiber diameter). Results are shown in Fig. 6b. It can be note that the efficiency of the diffraction grating is higher for smaller wavelengths, although the angular separation decreases. To test the displacement sensor, the wavelength of 660 nm has been chosen. In this case, diffracted power in the order 0 is more important than in the order -1. The efficiency is also better for smaller wavelengths as it should be expected form basic physics.
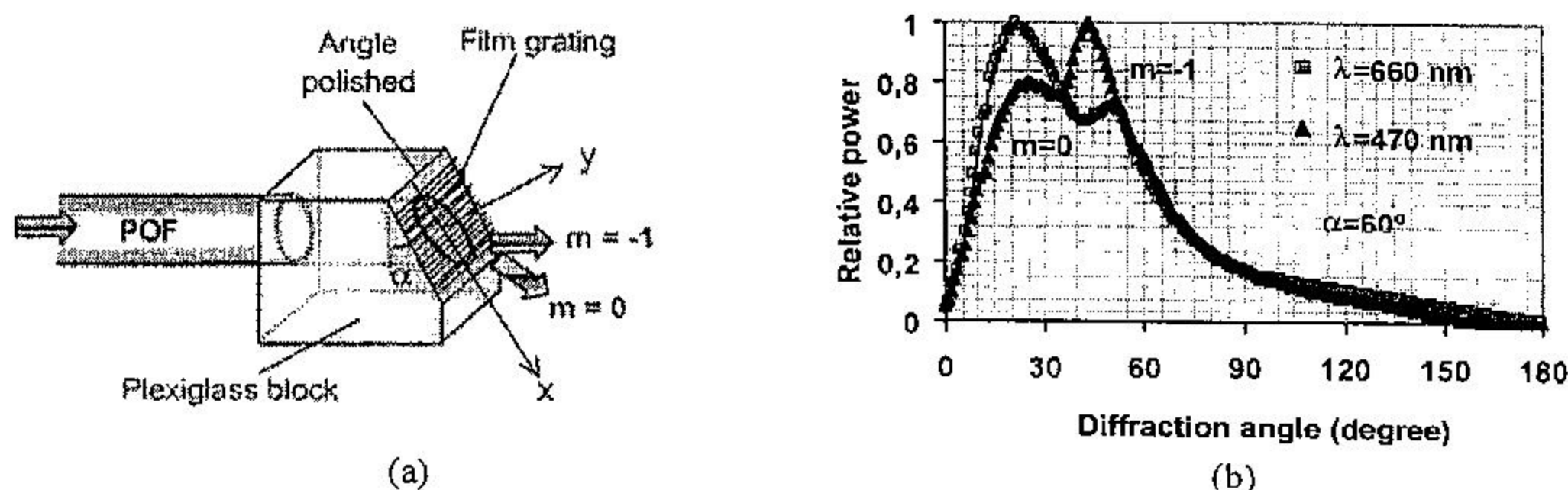

(a) (b)

Figure 6. Difraction grating in POF end. a) Schematic diagram of the device structure grating end fiber taper used in the experimental works, b) transmission of the diffracted light corresponding to order 0 and -1 for two different wavelength LEDs..

4.3. GRATING-FIBER COUPLER.

In similar way described in the section 4.2, a diffraction grating in film can be located in the polished region of a curved POF (figures 7a). It is known the application of the diffraction grating like element of joining of light. In this case, this device can act like spectral filter or like a sensor head based on evanescent wave. The measure of intensity diffracted in a range of 0° at 180°, on the curved surface of fiber-grating, for two wave longitudes is shown in the figure 7b. It is observed the action of the diffraction net well (Λ=1μm).
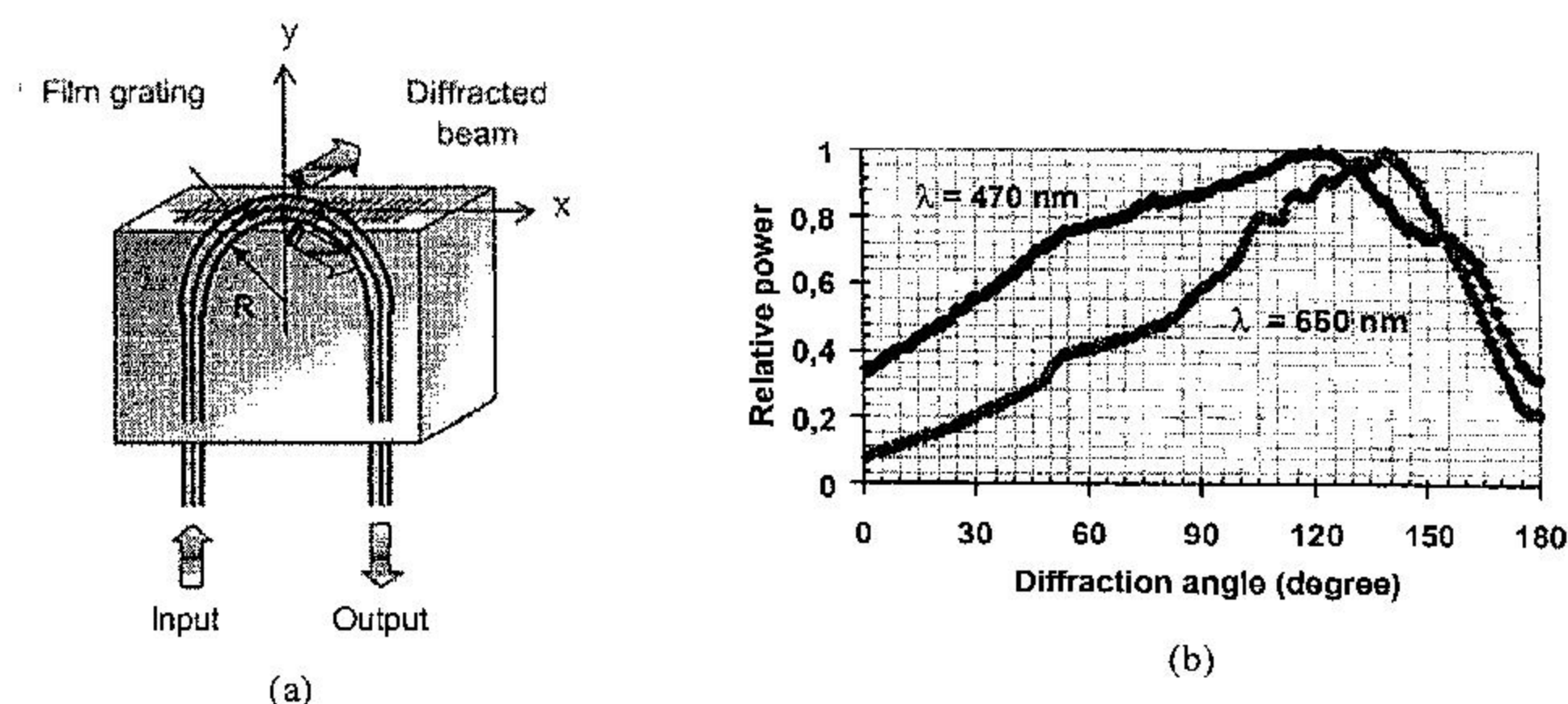
Figure 7. a) Structures of a device based on POF multimode and diffraction grating, b) intensity diffracted for two wavelength.

5. CONCLUSION

We have demonstrated the feasibility of making low-cost devices and components with POF. Two couplers types have been carried out using POFs and supports in polymer, these can also be used as multiplexing of wavelength. Combining the components in POF and diffraction nets has carried out sensor heads to measure refraction index and concentration in liquids, wavelength demultiplexing and displacement sensors. The advantages shown by POF over silica-based fiber, such as ease of termination, simple coupling to emitter and detector, coupled with ruggedness and low cost, combine with the ability to modify POF characteristics using inexpensive techniques, to enable low-cost development of POF devices and sensor.

6. ACKNOWLEDGEMENT

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