ISSN 1991- 8690 الترقيم الدولي ١٩٩١ - ٨٦٩٠

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Fabrication and Characterization of Dye-doped Polymer Optical Fiber

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Abstract

This paper is concerned with the design a special perform drawing system for fabricated Step Index-Single Mode Polymer Optical Fiber (SI-SM POF). The POF has been fabricated by this device based on a highly crosslinked poly methyl methacrylate (PMMA) as a core material and a dye-doped PMMA cladding layer. The refractive indices of the core material and the cladding are 1.49 and 1.35, respectively. The physical and optical properties of POF have been studied, which fabricated at different diameters. Laser light (633 nm) was coupled in to the POF using standard prism coupling techniques. From the morphological analysis of the POF it has been shown that the homogenous and the viscidity of the core and cladding is suitable. In additional to the core is completely in the center of the POF.

Keywords: polymer optical fiber, refractive index, perform drawing, polymethylmethacrylate.

تصنيع ودراسة الخصائص الليف البصري البلاستيكي المطعم بالصبغة

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كلية العلوم – جامعة بغداد

الخلاصة

يهتم هذا البحث بتصميم وتصنيع بطريقة خاصة لمنظومة سحب التشكيل لليف البصري البلاستيكي ثابتة معامل الانكسار ذات نمط منفرد وهذا اليف البصري المصنع بشكل مترابط اساسا مادة القلب من بوليمر مثيل ميثا اكريلايت ومادة القشرة من صبغة الرودامين 6G المطعمة باللبوليمر. معاملات الانكسار لمادتي القلب والقشرة كانت 1.35, 1.49على التوالي. تم دراسة الخصائص الفيزيائية والبصرية للالياف البصرية المحضرة وباقطار مختلفة. استخدم الليزر ذو الطول الموجي 633 nm في عملية الاقتران بواسطة تقنية اقتران الموشور. ومن خلال دراسة الشكل المظهري للالياف لوحظ ان التجانس واللزوجة بين القلب والقشرة كانت مثالية اضافة الى ان موقع القلب كان تماما في مركز الليف البصري البلاستيكي.

1- Introduction

The last few years has witnessed a remarkable attention to develop polymer optical fiber (POF). POF are often used in telecommunication, consumer electronics and automotive applications [1]. The working principle of POF is based on the phenomena of total internal reflection; POF consists of a highly transparent core with a refractive index, ncore, and a surrounding cladding with a refractive index, nclad. To ensure that a light ray has passed through the fiber can be guided along it, the condition must be true: ncore > nclad. [2]. The first commercialized poly methyl methacrylate (PMMA) based POF, exhibited an optical loss of more than 1000 dB/km [3,4]. One of the main causes of high optical loss of PMMA, PS and PC based POFs is the C-H vibrations absorption, which can be substantially reduced by replacing hydrogen atoms with heavier atoms [5,6]. The POFs are more flexible than glass and so, POF can be manufactured with larger diameters. Also polymers allow for a wide range of refractive indices, which means that POF can be designed with a larger numerical aperture (NA) compared to the NA of glass fiber. POF has been demonstrated to achieve high-band width (> 2GHz.km). in additional POF have very low processing temperature than that of glass optical fiber [7]. The total number of light modes which can be coupled in is defined by the NA, generally, NA is related to the difference of refractive indices of the core and cladding. NA is thereby related to the angle of acceptance, θa is given by the following formula [8].

$$NA = (n_{co}^2 - n_{cl}^2)^{1/2} = n_o \sin\theta a \qquad (1)$$

Where: no, nco and nclad are refractive indices of outer medium (usually, no =1), the core and the cladding respectively.

Using the definition for the relative refractive index differential Δ [9].

$$\Delta = \frac{n_{co}^2 - n_{cl}^2}{2n_{co}^2} \qquad (2)$$

It is possible to represent the NA as follows [9]:

$$NA = n_o\sqrt{2\Delta} \qquad (3)$$

Now, the optimum profile exponent, αopt in which the modal dispersion is minimal and thus the delays of all modes are approximately the same [9].

$$\alpha_{opt} = 2 - 2\Delta \qquad (4)$$

The normalized frequency or V number can be written by the formula [9].

$$V = \frac{2\pi}{\lambda_o} a\sqrt{n_{co}^2 - n_{cl}^2} = \frac{2\pi}{\lambda_o} a n_{co}\sqrt{2\Delta} \qquad (5)$$

Where: a, fiber core radius and λo, operating wavelength.

Dye – doped polymer were first demonstrated by Havinga and Van pelt [10,11]. In these studies, the dye chromophores are aligned with an electric field when the polymer is softened at an elevated temperature.

Laser dyes used to dye – dope POF included rhodamine 6G, rhodamine B and fluorescein. Innovative device have been designed based on single – mode core dye-doped POF [12]. In the present work, we improve the method used to manufacture POF based on PMMA. The feature characteristics are studied through morphological analysis.

2- Experimental

In practice, the step index POF, consists of the core and gladding polymers. The fiber core is required high transparency, therefore we used PMMA as core, and optical properties for PMMA are listed in Table 1.

Table 1 optical property for PMMA [13].

Property	**PMMA**
Refractive index, (n_D)	1.491
Abbe number (v_d)	57.2
Optical transmission (%)	92
Usable temperature, ^oC	80
Density ρ (kg/m^3)	1170
Thermal expansion Coef. $10^{-6}/^oC$	63

In preform drawing method, the preform is produced and drawn to POF, as shown in Figure 1. The mechanical system consist of Electrical heater working as a power supply supplying DC voltage of 65 volt and varying current in the range of (5-7) amp. This heater consists of two half cylindrical pieces with series connection bordering the preparation cylinder. Preparation cylinder which is an iron (Carbon steel) made cylinder placed in its lower part a disk containing a central hole to permit the exit of the polymer, and its upper part is connected to a Compress working by gas pressure. The designed preform drawing for fabrication of POF, is shown in Figure 2.

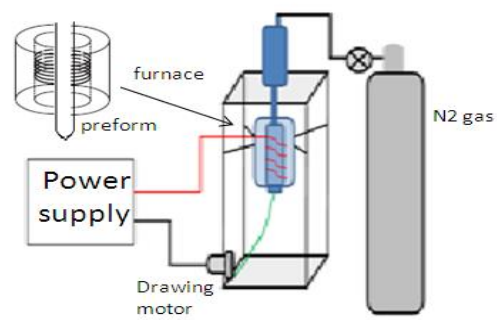

Fig. 1 Schematic diagram of apparatus perform

Fig. 2 Photograph for system used drawing POF.

Different – diameter polymerized optical fibers have been prepared by dissolving (PMMA) in chloroform solvent and the Rhodamine 6G laser dye in ethanol solution of 10^{-3} M after which the two solutions were mixed together and left for a while to allow mixture to become more viscous. After that, the mixture is put in a cylinder and once its temperature reaches 65^0C, the polymer is pulled out of the cylinder following the compression on the cylinder by means of a rod and nitrogen gas pressure.

3- Results and discussion

The perform drawing is very good method for manufacturing POF due to the contactless treatment. Moreover, low cost of production. The POF were fabricated by PMMA for core and Rhodamine 6G dopbed Polymer for cladding with different diameters. These POFs homogenous and the core is exactly in the center of POF as shown in Fig. 3. The viscosity of the core and cladding is optimum. Fig. 4 shows the homogenous of the core and the cladding of the samples POF manufactured.

Fig. 3 illustrated the core in the center of abricated POF.

Fig. 4 homogenous of the core and the cladding.

Fig. 5 shows one of the many fiber geometries achievable with this process. In this fiber a 0.2 mm diameter step-index doped Rhodamine 6G. A series of single mode fiber (SMF) step index polymer optical fibers were successfully fabricated.

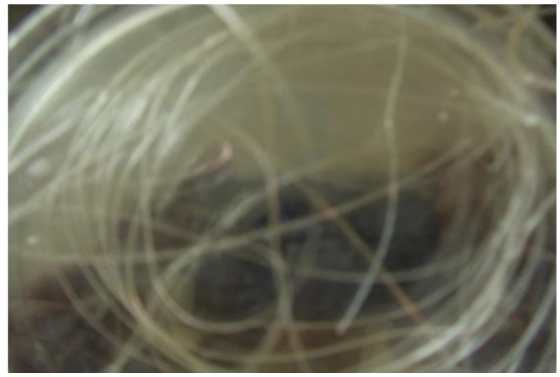

Fig. 5 illustrated fabricated POF with 0.2 mm diameter.

The NA, is a function of the refractive index (n), then if both values n_{co} and n_{cl} were known NA, could be calculated accurately from Eq. 1.therefore it is easy to calculate θ_a, of POF. Therefore, if the value of λ_o were known by empirical procedure, they could estimate normalized frequency from Eq. 5. Table 2 lists values of NA, θ_a and V for fabricated POF with diameter 0.2mm.

Table 2 physical properties of fabricated POF.

n_{co}	n_{cl}	NA	θ_a	v	α_{opt}
1.49	1.34	0.64	40.5	645	1.82

It is noted from the above table a large NA, generally more modest than the NA of 0.14 of optical glass fiber. The light source was a He-Ne laser (wavelength, 633 nm). The measured loss of a sample was about 28 dB/m. This value is suitable than that of commercial POFs.

4- Conclusions

In this work, all calculations were done in order to find more appropriate polymer for using as core material of POF. An apparatus for fast and simple fabrication of the POFs perform drawing method. This process can produce POF with higher NA, than the NA of optical glass fiber. It has been found that when a dye is doped into a polymer optical fiber, some of its optical properties can change. The results indicate that the homo geneity of the core and cladding and their soft boundaries are good. In additional to the more suitable wavelength range for low loss POFs is 400-800 nm. Therefore POF can be used in short distance optical data transmissions, especially are in the medical devices applications. Moreover, this method which is fairly acceptable, considering that it is the first attempt to manufacture POF in Iraq.

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