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RESEARCH PAPER

Fabrication of Polymer-SiO_2 Nanocomposite Optical fibers with a New Method

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ABSTRACT

At first step polymer optical fibers (POFs) are used in short distance for optical data transmissions. At second step SiO_2 nanoparticles were prepared by sonochemical-assisted method. Finally silica nanoparticles were added to polymer matrix to prepare polymer based nanocomposites. Most of the POF applications are in the medical and electrical devices. There are several methods for fabrication of POFs, description of which are given in this paper. We have designed a special co-extruder system for fabricating POF. The POFs fabricated by this device are very homogeny and their core and cladding have good viscidity.

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INTRODUCTION

Optical fiber communication systems are now matured systems for data transmission using light signals rather than electrical signals. In optical fiber higher capacities and bandwidths can be transmitted with less chance of interference [1]. In the last few years, interest in polymer optical fibers have increased significantly because of their ease of handling, flexibility, lower price, and applicability due to their large core diameter and high numerical aperture. In addition POFs have very low processing temperature than that of glass optical fibers [1-3]. Attenuation of commercial polymer fibers is very higher than that of glass fibers. Therefore, they are expected to be used as a short distant optical communication medium, such as computer-to-terminal data link in office automation systems, local area networks, signal links in medical devices, illuminating systems, air craft, fiber sensors and amplifiers [2-10].

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MATERIALS AND METHODS

Material properties of polymer optical fibers

In practice, the step index POF, composed of the known core and cladding polymers. Since high transparency is required for the fiber core, the polymer should be amorphous. Table 1 shows the possible high quality polymer materials for cores. Poly methyl methacrylate (PMMA) and polystyrene (PS) are normally used as core materials, because these polymers are easily purified at the monomer level and no condensation reaction is necessary in obtaining transparent polymers. Certain polycarbonates (PC) have higher amorphous characteristics and thermal resistance. Therefore application of these materials for the core is increasing gradually. The refractive index of the cladding material should be 2-5% less than that of the core material [11].

Material choice for POFs fabrication

Optical power acceptance and light guidance of POFs depend on the choice of the core and

Table 1. Optical Properties of Transparent Polymers

	Polymers*					
Property	PMMA	PS	SAN	PC	CR-39	TPX
Refractive index, (n_D)	1.491	1.590	1.579	1.504	57.8	1.466
Abbe number (ν_d)	57.2	30.9	35.3	30.3	57.8	56.4
Optical transmission, %	92	88	90	89	90	90
Usable temperature, °C	80	70	90	120	100	80
Thermal expansion Coef., 10^{-6}/°C	63	80	70	70	90	117
Specific volume	1.19	1.06	1.08	1.20	1.32	0.84

*SAN, styrene-acrylonitrile copolymer ; CR-39, diethylene glycol bisallyl carbonate ; TPX, Poly-(4-methylpentene-1).

cladding materials. The refractive index of the core material limits the choice of the necessary cladding material to create better waveguiding characteristics. However, refractive index is not the only intrinsic property that has to be considered. The other certain parameters that have to be considered when choosing the core polymer material are: morphology, molecular weight, molecular weight distribution, glass transition temperature, branching, cross linking, additives, repeating unit, and tacticity [1].

Methods of fabrication of polymer optical fibers

Several methods have been used to prepare glass optical fibers, e.g., ion-exchange, sol-gel leaching, and chemical vapor deposition. However, these methods are quite expensive and the production rate is low. Polymers have the advantages of excellent mechanical properties and good processibility compare to the glasses.

The most important fabrication of POF methods are: preform drawing, batch extrusion, and continuous extrusion [1,3,4,11,12].

In preform drawing method, the preform is produced and drawn to fiber, as shown in Fig. 1.

POF fabrication through batch extrusion is an efficient method to eliminate the extrinsic loss factors as organic impurities, water, dust, or bubbles from the POF core. A block diagram of an apparatus for POF fabrication is shown in Fig. 2. The method consists of a closed system, from monomer purification to fiber drawing [11].

In the continuous extrusion process, monomer containing polymerization initiator and chain transfer agent is continuously fed to the reactor and cladded fiber is continuously withdrawn from the die, as shown in Fig. 3. Since high production rates are possible, this is an ideal commercial process [11].

We have fabricated a simple apparatus for continuous fabrication of polymer optical fiber by co-extrusion method.

Design of an appratus for simple and fast fabrication of the POFs

We designed a special co-extruder for fabrication of POFs. This co-extruder produces the core and simultaneously coats it with cladding material. Due to the best of our knowledge, this is the first attempt for fast and simple fabrication of

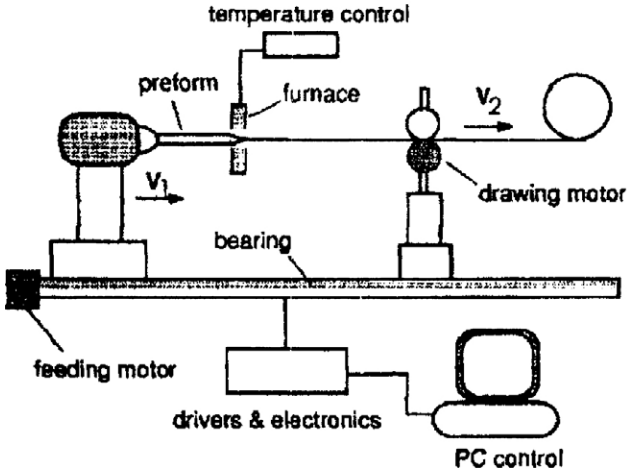

Fig. 1. Schematic diagram of fabrication rig for polymer optical fiber

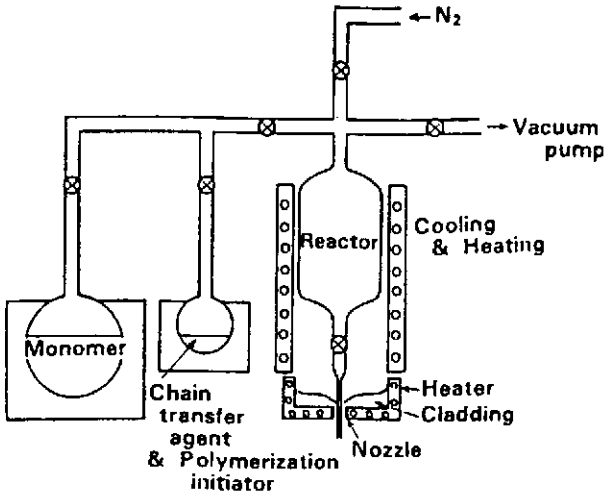

Fig. 2. Apparatus for POF fabrication by batch extrusion

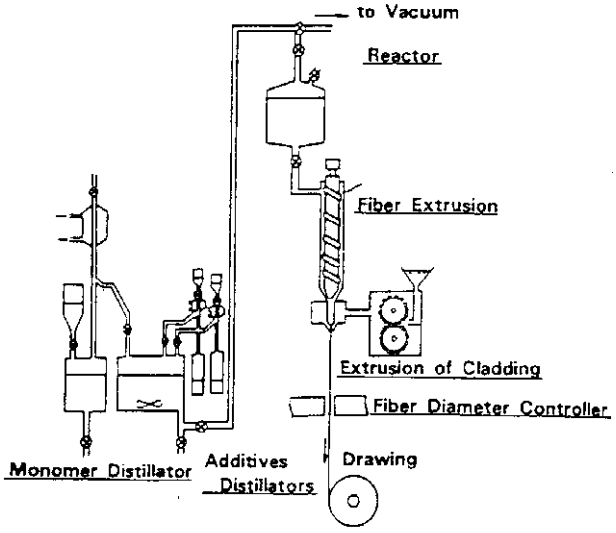

Fig. 3. Continuous extrusion process for fabrication of POFs

the POFs. The most critical part of the co-extruder is the design of nozzle die head. In the other words, a deep knowledge of the techniques of synchronous coating of the core with a certain amount of cladding materials is required. At the beginning the POFs were fabricated by polystyrene for core and Ethylene Vinyl Acetate (EVA) for cladding. These POFs are homogeneous and the core is completely in the center of the POF. The viscidity of the core and cladding is excellent. Fig. 4 shows the homogeneous and soft boundary of the core and the cladding of a sample of the manufactured POFs. This homogeneity and soft boundary is very important in fabrication of the POFs.

The loss of some fabricated samples was

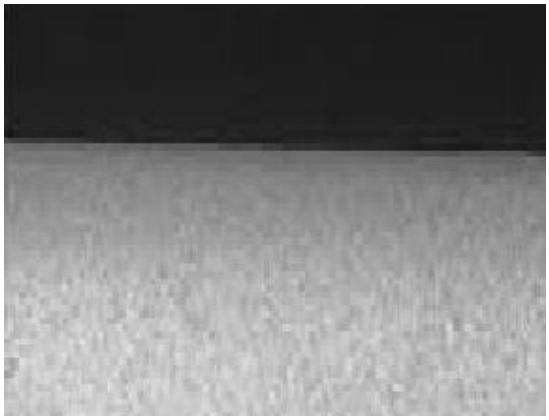

Fig. 4. Homogeneous and soft boundary of the core and the cladding of a sample of the fabricated POFs

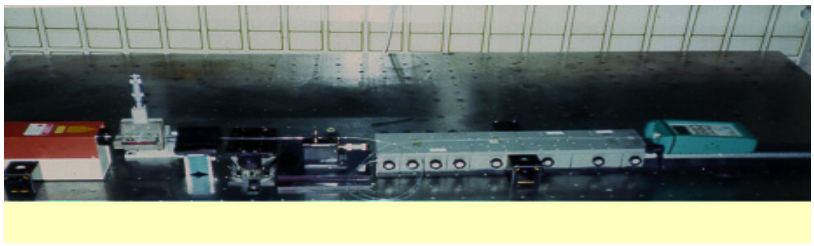

Fig. 5. Experimental setup for measurement of the POF loss by cut-back method

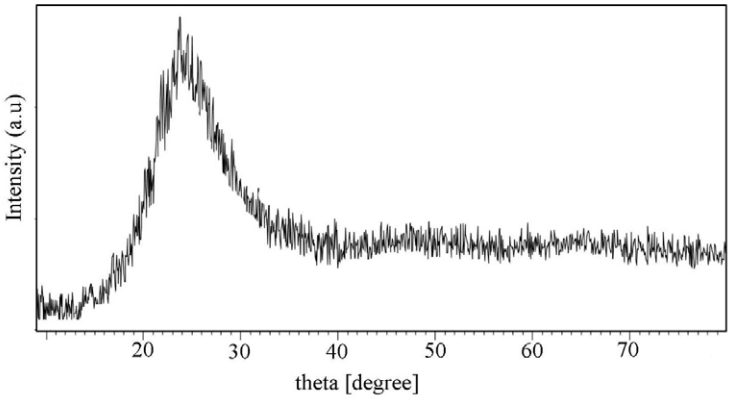

Fig. 6. XRD pattern of the SiO_2 nanostructure

measured by cut-back method with the experimental setup, shown in Fig. 5.

The light source was He-Ne laser with 632.8 nm of wavelength, but at the moment the available power meter can only detect light with 850 nm wavelength. The measured loss of a sample was about 32 dB/m. This value is much higher than that of commercial POFs, but for the beginning of the fabrication with a nearly designed and fabricated apparatus is acceptable. The next attempts will be for reducing the loss by choosing pure low loss materials and keeping the apparatus and fabrication environments clean as much as possible.

For Synthesis of spherical SiO_2 nanoparticles 25 ml of methanol and 10 ml of distilled water were sonicated. 4.5 mmol of TEOS was dissolved in 5 ml of methanol were added under stirring. 0.1 ml of ethylenediamine was then added into the mixture as precipitating agent, under ultrasonic. After 30 min, the precipitate was isolated by centrifuging and washed with methanol and water several times. The as-obtained products were dried at 80 ˚C under vacuum for 2 hours, then calcinated at 400 ˚C for another 2 hours.

At second step SiO_2 nanoparticles were prepared by sonochemical-assisted method. Silica nanoparticles were added to polymer matrix to prepare polymer based nanocomposite. For preparation of nanocomposite various percentages of silica nanoparticles were added to the polymer matrix and optical properties of amorphous silica were investigated.

The XRD pattern of spherical SiO_2 nanoparticles is shown in Fig. 6. The pattern of the as-prepared SiO_2 nanoparticles is indexed as an amorphous phase which is very close to the literature values (JCPDS No. 82-1557). The crystallite size measurements were also carried out by using the Scherrer equation,

$$Dc=K\lambda/\beta\cos\theta$$

Where β is the width of the observed diffraction line at its half intensity maximum, K is taken about 0.9, and λ is the wavelength of X-ray source used in XRD. The average crystallite size is estimated to be around 6 nm [13-15].

SEM images of SiO_2 obtained at different ultrasonic powers 100 and 150W are illustrated in Figs. 7 and 8 respectively. At 100W nanoparticles with average particle size less than 50 nm were synthesized. At 150W nanoparticles with mediocre size about 40 nm were prepared.

The purity of the nanostructures was also confirmed by energy-dispersive X-ray spectroscopy. EDS analysis of SiO_2 nanoparticles is illustrated in

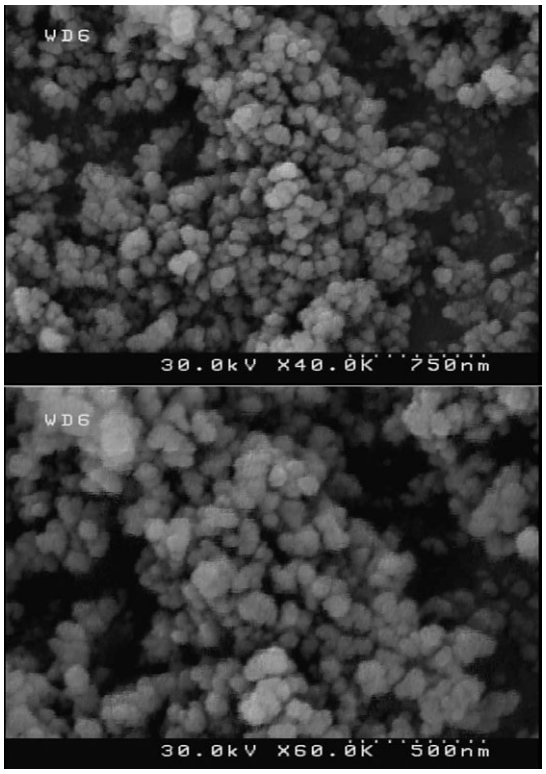

Fig. 7. SEM images of the SiO_2 nanostructure prepared at 100W

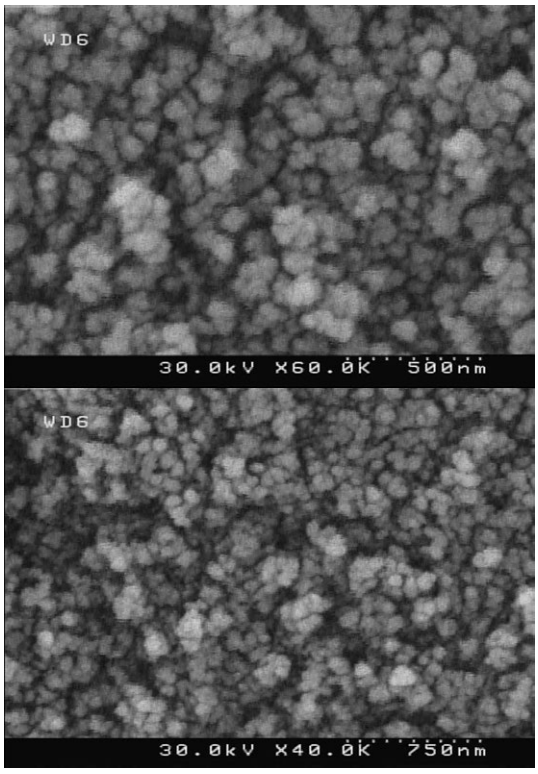

Fig. 8. SEM images of the SiO_2 nanostructure synthesized at 150W

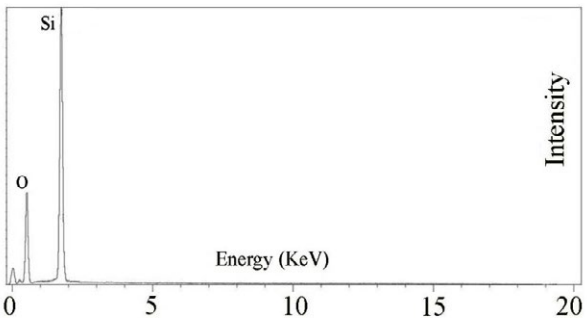

Fig. 9. EDS analysis of the SiO_2 nanostructure

Fig. 9. The lines of Si and O are obviously observed. FT-IR spectrum of as-synthesized product is depicted in Fig. 10. Absorption peak at 1063 cm^{-1} is related to stretching vibrations of Si-O bond. The result shows that the product does not have any major IR-active impurity.

CONCLUSIONS

An apparatus for fast and simple fabrication of the polymer optical fibers-SiO_2 nanocomposite by co-extrusion method was fabricated. A series of step index polymer optical fibers were successfully fabricated. Due to the author's knowledge, this is the first attempt for the fabrication of the POF in Iran. The loss of these POFs compare to the commercial ones is high. At the moment, we believe that the homogeneity of the core and cladding and their soft boundaries and specially lack of bubbles in them is much more important than their loss. However, optimization of the polymers use for fabrication of the POFs and clean lines of the device and environment will improve the characteristics of these fibers. Polymer granolas contaminants is one of the most important factors that dominate the attenuation loss, that must be improved. The best wavelength range for low

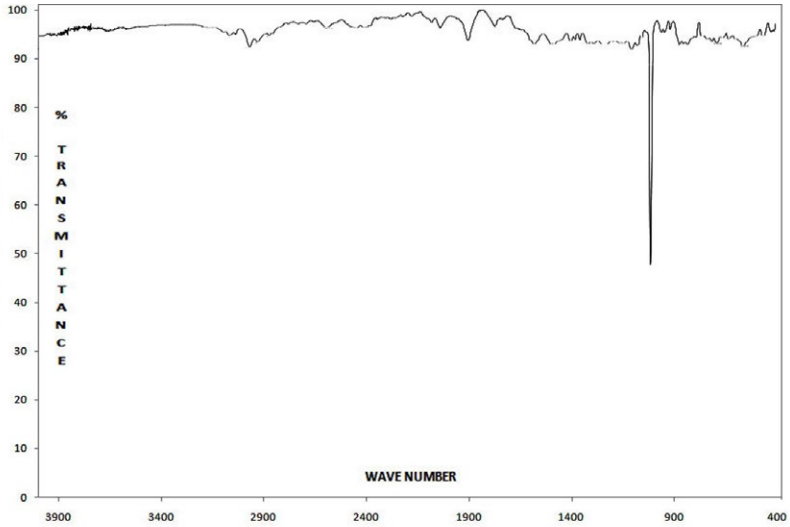

Fig. 10. FTIR analysis of the SiO_2 nanostructure

loss POFs is 400-800 nm, but due to the lack of a tunable source, the loss measurements have carried out by He-Ne laser. The measurement of the loss spectrum will show the low loss wavelength range of the fabricated POFs. The improvement of the apparatus, purifying the suitable polymer materials and clean lines of the apparatus and the environment will improve the characteristics of the fabricating POFs.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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