Recent research on polymer optical fiber photosensitivity and highly tunable optical fibre Bragg grating

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ABSTRACT

Photosensitive optical fibres provide great potential for development of many important devices. The application of photosensitivity of optical fibres has profound impact to telecommunication at the 1550nm window and, increasingly, to optical fibre sensing as well as other systems. Large tunability in fibre grating is of great significance for future dense wavelength division multiplexing where channel selectivity and reconfigurability are of prime concern. The group in University of New South Wales has recently investigated the photosensitivities of various polymer optical fibres and has demonstrated that polymer optical fibre Bragg grating based on poly(methyl methacrylate) could be made and tuned over a range of more than 70nm, far exceeding that could possibly achieved in conventional silica fibre Bragg gratings. More recently, the photosensitivity of a low loss new polymer fibre material -- CYTOP has been demonstrated. These research activities and results unfold the great potential of realising a new class of fibre Bragg grating for various photonic applications. This paper will review the recent developments and will discuss some of the important prospects and remaining challenges in polymer fibre Bragg gratings and related topics.

Keywords: Photosensitivity, photostability, polymer optical fiber, fiber Bragg grating

1. INTRODUCTION

Fibre Bragg gratings have become essential photonic components since 1978 when K. O. Hill and his colleagues first observed a photo-induced grating in a germanium-doped silica optical fibre [1]. It has excellent wavelength selectivity in its spectral characteristics. In telecommunication systems, fibre gratings have found a wide range of important applications such as dispersion compensation [2], optical filtering, optical add-drop multiplexing in optical Dense Wavelength Division Multiplexing (DWDM) systems [3,4], frequency stabilization of optical fibre lasers or semiconductor diode lasers [5], and gain flattening of erbium-doped fibre amplifiers [6], etc. They are also increasingly popular in various sensors for measuring temperature [7], pressure and strain [8], hydro-sound [9] and industrial process [10].

Since fibre grating has such a great spectrum of applications, intensitve research on the photosensitivity and fabrication of gratings in optical fibres have been carried out in many research groups and companies all around the world in recent years. So far work in this regard are dominantly concentrated on the silica optical fiber gratings [11] more particularly on germanium-doped or rare earth-doped silica optical fibres [12, 13]. Significant advances have been made in fabricating photosensitive silica optical fibres. Also the fabrication techniques for silica fibre grating have been rapidly developed for commercial production and a range of silica optical fibre Bragg gratings are now commercially available.

No doubt Bragg gratings based on silica fibres have many attractive and unique features. Nevertheless they have also their limits. Most apparent limitation seems to be their limited wavelength tunability and stress responsivity. This could be a fundamental limit that restricts silica fibre gratings from being used in some of the important applications. Wavelength tunability will be a crucial feature required for future broadcasting and reconfigurable DWDM systems [14]. On the other hand, high stress responsivity is essential in various fibre sensor applications where stress related effects are utilised [15]. In fact, although considerable efforts are being made to improve the tunability, their success has been limited [16-22]. For example, the recent report of a magnetically tunable fiber Bragg grating (FBG) for fast reconfigurable optical add/drop multiplexers (OADM) demonstrated a 4nm shift of the Bragg wavelength [18]. A 0.4 nm tunable range has been achieved for an 8-channel tunable drop device by thermal tuning of silica fibre grating [19]. Using a PZT for fibre grating tuning, the tuning range obtained was 1.68 nm [20]. A larger tuning range was reported in a chemically etched cladding fiber grating, where wavelength tuning up to a failure point of 21.2 nm has been demonstrated along with repeated cycling over a 9-nm tuning range [21].

The prime reason for the poor tunability is clearly linked to the high rigidity of silica glass. Likewise the poor stress responsivity is related to its relatively large Young's modulus (~100GPa). Polymer optical fibre is highly flexible and elastic compared with silica fibre and, as far as flexibility and elasticity are concerned, POFs (typically ~3GPa,) have similar complementary properties to their silica counterparts. Apparently working on POFs could provide opportunities for high tunability or high stress responsivity components. Particularly important is its possibility to achieve high wavelength tunability if POF could be made significantly photosensitive and POF Bragg gratings could be fabricated. Based on these considerations, work on photosensitivity of POF and its application for fibre Bragg gratings were started recently [23-26].

POF was first developed in the early 1970s, about the same time as silica fibre. In the mid of 1970s, Schleinitz at duPont in the US demonstrated that poly(methyl methacrylate) (PMMA) based POF could have attenuation as low as 300dB/km [27]. Mitsubishi then developed a continuous casting process in manufacturing POF based on high purity acrylics [28]. This has since led to the development of various POFs at Mitsubishi Rayon in Japan. However, POF has long been neglected under the shade of the far more popular and superior silica fibres. Only recently, research and development of polymer optical fibre (POF) have been greatly boosted by an emerging and important market of high-speed (broadband) local area networks. In these networks polymer optical fibre is deemed to be able to compete with the conventional silica optical fibre. POF is attractive for its excellent flexibility, low cost and, ease of handling and connection [29,30]. Moreover, because of the excellent compatibility of base polymer optical fibre materials with many functional organics, special POFs are being targeted and developed for various active and passive photonic devices, such as all-optical switch [31-33], amplifier [34-37], electro-optic modulator [38], fibre Bragg grating [23-26] and fibre laser [39-41]. However this review is mainly restricted to work on photosensitivity of polymer optical fibres and its applications.

This paper will review the recent advances in research and application of photosensitivity of various polymer optical fibres. It is organised as follows: In Section 2, the experimental work on photosensitivities of PMMA-based polymer fibre preforms and polymer fibres are summarised; In Section 3, the tuning mechanisms and tunability of centre wavelength of POF Bragg gratings are discussed and experimental results are presented. In Section 4 recent research on photosensitivity of CYTOP and CYTOP POF is reported. In the final section, we briefly discuss challenges topics in research and development of photosensitivities of POFs as well as the feasibility of producing enabling photonic devices, especially tunable FBGs, for various applications.

2. PHOTOSENSITIVITY OF PMMA POF

Irradiation of the core of an optical fiber with ultraviolet light introduces a permanent change in the refractive index. This photorefractive effect, referred to photosensitivity, has great practical significance because it makes possible an ever increasing number of passive and active fiber devices [42]. It is well known that various single-mode silica optical fibres, especially germanium-doped or rare-earth-doped silica fibres, exhibit a certain photosensitivity. Photorefractive index changes as much as 10^{-2} have been obtained in germanium doped optical fibers. It is also well known that the photosensitivity of these fibers could be significantly enhanced by various post-drawn photosensitisation techniques such as flame brushing, or hydrogen loading.

Photosensitivity of PMMA has been discovered for about 30 year if not longer. The earliest report we found on photosensitivity of PMMA is the work of Tomlinson et al [43]. In their work, they found that properly prepared PMMA (through oxidation of monomer) exhibited a substantial increase in refractive index after irradiation with UV light at 325nm ($He\text{-}Cd^+$ Laser) or 365nm (Hg arc). A subsequent report related to photosensitivity of PMMA is a paper on dye-doped polymer laser [44]. The solid-state dye laser consists of a pair of Bragg gratings which were produced inside of a bulk sample of PMMA doped with rhodamine 6G by the permanent change of refractive index induced by irradiation of incident UV laser beams. The gratings had a dimension of $2 \times 2 \times 2$ mm^3 and a maximum reflectivity of 20%. The material preparation and fabrication processing of current POF are considerably different from these early works. Nevertheless they are helpful references.

In the recent research carried out at the University of New South Wales, photosensitivities of various PMMA-based POFs were investigated. The photosensitivities of several PMMA POFs made from undoped, dye-doped or oxidated preforms are examined, under varying irradiation wavelength, intenisty and time.

In the initial photosensitivity experiment, a simple interferometry setup is arranged as shown in Fig.1. In the first experiment, a dye-doped, single-mode, twin-core polymer optical fibres was tested. Both cores of the fibre are doped with typical laser dye, fluorescein (170ppm). The near-field pattern (endface) and far-field pattern (interference fringe) of this polymer fibre are shown in the insets of Fig.1. The near-field pattern directly shows the fibre structure. The particular far-field fringe pattern is formed when the fundamental modes in each core is launched equally with a He-Ne laser. Because the core separation is rather small, the fringes are very well separated. They can be clearly seen on a screen a few centimetres away from the endface of the fibre. The Ar laser output is launched into one of the cores of the fibre to induce the photosensitivity effect. To observe this effect, a He-Ne laser of output power 1mW at 633nm is launched equally into each core via a defocussing lens. Since the fibre cut-off wavelength is at 780nm, care must be taken to launch this 633nm He-Ne light into the cores so that fundamental mode only is excited. The fibre length is selected to be much shorter than the coupling length. Hence the power coupling between the two cores is negligible and a stable and uniform output far field interference fringe pattern can be obtained. The fringe (phase) shift as a function of the exposure time (at a certain Ar laser power level) is directly related to the photosensitivity.

In this first experiment, two types of photo-induced phase shifts have been observed. They are of quite different natures. The first type of phase shift is non-permanent and shows fast response. In this case, the phase shift is introduced when the Ar output is launched. It is lost when the Ar output is blocked. This fast response to the Ar irradiation is on a time scale of less than 0.1ms. This response could come from the thermal nonlinearity linked to the optical absorption of the dye molecules in the core, a factor which is not relevant to the present investigation. The second type of phase shift is permanent and has a fairly slow response (it takes time to build up). Thus the phase shift is not instantaneous and it may, in fact, take tens of minutes to build up. However, this phase shift will remain when the Ar laser is switched off. This is exactly the photosensitivity of our interest.

Fig.2 shows the photosensitivities as a function of the exposure time at 514nm for the two cores. The experiment on core 1 was carried out in two steps: (1) a 0.36mW Ar laser power was launched into the fibre for 9 minutes, and then (2) the Ar laser power was increased to 1.08mW and the fibre was illuminated for 53 minutes. The rate of phase shift was gradually reduced as the exposure time increased. In the second step, an explicit saturation behaviour can be seen. This behaviour could be understood from the material system. The photosensitivity must be associated with photochemical processes (eg. photobleaching) involving the active molecules of the laser dye. This has been verified by our observation. It is found that the absorption loss of the fibre at 514nm was reduced by 12dB after the first 9-minute illumination in step 1 of the experiment. At the end of step 2, the absorption loss was further reduced by 6dB. This saturation indicates that the active dye molecules have been depleted. In this experiment, a total phase shift of 15π is reached. For the fibre length of 14.5cm, this shift corresponds to a photorefractive index change of 3.3×10^{-5}.

Similarly the experiment on core 2 was carried out in two steps: (1) 0.26mW was launched into the fibre for 13 minutes, and then (2) the power was increased to 1.3mW and the fibre was illuminated for 24 minutes. Similar saturation behaviour was observed. In the first 13-min irradiation, the absorption loss was reduced by 12dB. The absorption loss was further reduced by 3dB under 1.3mW and 24 min irradiation. For the same length of fibre, a phase shift of 12π was observed, corresponding to a photorefractive index change of 2.6×10^{-5}.

A second experiment was carried out using the 488nm output of the Ar laser. This experiment was carried out in one step and under a constant launched power of 1.84mW. The maximum phase shift observed is 17π, which gives a photorefractive index change of 3.4×10^{-5}, for fibre length of 16cm. The experimental result is shown in Fig.3.

It is more important to examine the photosensitivity of POF under UV irradiation. Hence another experiment was carried out using the UV output from an OPO. The experiment was set in a different configuration as shown in Fig.4, where the fibre under test is illuminated transversely. The OPO generates 5ns pulses at a rate of 10Hz. Different UV wavelengths have been used, viz. 248nm, 280nm and 325nm. In this experiment, the net effect of photosensitivity depends on the orientation of the twin-core with respect to the illuminating light. Fig.5 shows the phase shifts as a function of the product of pulse energy-exposure time for two different orientations. It must be noted that the phase shift measured is the relative phase shift, since now both cores are illuminated. With the UV at 248nm, a (relative) phase shift as large as 10π was obtained when the two cores were in the same plane as the illuminating light. When the two cores are perpendicular to the incident light, the phase shift is much smaller. The reason for this is quite simple - now the cores are exposed at nearly same level and the photosensitivities produced in each core must be similar. The non-zero phase shift in Fig.5 for the latter case could come from the asymmetry of the cores and/or the uncertainties in orientation of the fibre. From the experiment, the difference of the photo-induced index change between the two cores could be evaluated. For an effective 3mm spot size of the UV beam and a phase shift of 10π, the photoinduced index difference is 1.1×10^{-3}. Although accurate photoinduced index change could not be directly worked out from this value, it could be concluded that the net photo-induced index change must be larger 1.1×10^{-3} under 248nm irradiation and 8×10^{-4} under 280nm irradiation, respectively. It is obvious that photosensitivity is wavelength dependent and has larger value at shorter wavelength.

From these experiments, it was revealed that significant photosensitivity can be introduced to POF with appropriate doping materials, eg, laser dyes at relevant wavelengths. Later it was also demonstrated that the base material, ie. undoped POF, could have significant photosensitivity at UV wavelengths [24,38]. These findings provide important evidence that POF grating may be fabricated by making use of these photosensitivities.

3. FABRICATION OF POF BRAGG GRATING

Now the immediate task is to create a grating in POF and to evaluate its performance. Along with the development of silica fibre Bragg grating, various grating writing techniques have been introduced, including an interferometer of the type proposed by Meltz et al [45] and a simpler technique based on phase mask made from holographic relief grating [46].

A Sagnac type of interferometer was set up to imprint Bragg grating into POF as shown Fig.6. The phase mask used, which has a period of 1.064μm, is designed for a writing beam of 248nm wavelength. At this wavelength, the zeroth order diffraction from the mask is less than 1% and the two main orders (±1) have the largest powers (~44%). The writing beam is from a frequency-doubled OPO pumped by a frequency-tripled Nd:YAG laser. With a 3-prism combination, the Sagnac interferometer has the two first-order beams from the mask to form the required interference pattern for the grating. One particular advantage of this system is that one may select a different writing wavelength away from the 248nm wavelength, without the influence of an increased zero diffraction order. The phase mask together with the POF can be transversely shifted by a stepping motor. In this way, a grating may be made with the same length as the mask. A spectrum analyser is used for on-line monitoring of the grating-writing process.

The first POF grating was written on a few-moded POF with a writing wavelength of 325nm [24]. The reflection spectrum recorded by the spectrum analyser is shown in Fig.7. Since the fibre is few-moded, it has a broadened reflection bandwidth of about 10nm. Later gratings are made from a single mode POF with a reduced bandwidth of ~1nm, an improved reflection of about 80% [47].

4. TUNABILITY OF POF BRAGG GRATING

The reflection wavelength of a fibre Bragg grating, λ_{Bragg}, can be expressed in a simple general form [42],

$$\lambda_{\mathbf{Bragg}} = \frac{2\Lambda n_{eff}}{N}$$

where Λ is the grating period which is determined by the period of interference pattern (fringe) of writing light beams. n_{eff} is the effective refractive index of the guided mode. N is an integer representing the order of the interaction. In most practical cases of our interest, N=1. From this expression, we can see that the Bragg wavelength of a grating can be tuned, if a particular mechanism is used to introduce changes in the grating period, Λ, and / or the effective index n_{eff}. At least two simple mechanisms can be easily used for tuning investigation. The first mechanism is applying longitudinal stress to a fibre Bragg grating. The wavelength shift from applying stress to a fibre grating comes mainly in two factors: a change in Λ due to stress-induced strain and a change in n_{eff} through the photo-elastic effect. By definition, strain is related the applied stress σ

$$\varepsilon = \frac{\Delta L}{L} = \frac{\sigma}{E}$$

with E the Young's modulus of material. Hence the stress-induced Bragg wavelength shift can be easily expressed as

$$\frac{\lambda_{Bragg}}{\lambda} = (1 - P_e)\varepsilon = \frac{1 - P_e}{E}\sigma$$

where P_e is the effective photo-elastic coefficient and ε longitudinal strain. Thus the amount of tuning of the Bragg wavelength is determined by the modulus of the material. Materials with greater modulus, such as silica, have less strain sensitivity which in turn means higher stress needed to produce the same strain in comparison to low modulus materials such as PMMA. Moreover, rigid materials have usually low breakdown strain, for silica it is about 1%. This sets a limit to the maximum achievable tuning range. For polymers such as PMMA because of its great flexibility in material synthesis, however, 10% or more breakdown strain could be readily achieved.

Similarly, a change in the fibre temperature, ΔT, could also lead to the shift of Bragg wavelength that can be expressed by

$$\frac{\lambda_{Bragg}}{\lambda} = (\alpha - \beta)\Delta T$$

where α is the thermal expansion coefficient and β is the thermo-optic coefficient of the fibre material.

In the experiment of POF grating, the tuning of Bragg wavelength was realised by a simple mechanical stretching setup (Fig.8). Before the grating was written, the POF was mounted on a glass slide with both ends glued to it. The slide was then cut using a diamond saw in the middle after the grating was created and the two sides were fixed on two steel blocks which were connected to two micro-positioners. One of the micro-positioners was fixed and the other was attached to a translation stage to allow for stretching. The tensile strain was loaded by rotating the lead screw with a longitudinal displacement of 1 mm per turn.

The reflection spectra for a piece of 25.3 mm POF containing a Bragg grating of 3 mm are shown in Fig.9. The trace in Fig.9(a) shows the spectrum with no tension on the fibre (the original position for the mobile micro-positioner), and the resonance wavelength is 1561.12 nm. The traces in Fig.9(b)-(e) are the spectra with strain from 1.22 to 4.84%, where the fibre longitudinal expansion is 1.225 mm and the Bragg wavelength is 1634.22 nm, which was the longest wavelength we achieved without significant shape change in the reflection spectrum. The strain values were estimated by dividing the fibre expansion by the original fibre length. The total wavelength shift from Fig.9(a) to (e) is 73 nm. As mentioned above, the fibre has a cutoff wavelength around 1580 nm, so the sidebands in Fig.9(a) and (b) are due to the higher order modes in the fibre. Note that the intensity at the Bragg wavelength is not uniform over the shift range. This is mainly due to the following facts. First of all, the launched white light source has a spectral distribution and the wavelength response of the optical spectrum analyser used to detect the grating decreases with the wavelength. Secondly, the multi-mode fibre coupler employed to launch the grating with a white light source and collect the reflection spectrum has a wavelength-dependent coupling ratio. Finally, as the strain increases, the fibre becomes smaller. This is firstly to eliminate the higher order mode (as shown in (a) and (b)) and in turn to increase the intensity of the fundamental mode as a result of energy transfer from the higher order mode. Then the guided intensity in the fundamental mode should decrease as the core size is further reduced.

The preform that was used to draw the polymer optical fibre was fabricated following the procedure described in [48]. In order to increase the thermal stability and strength, however, higher temperature was used for core polymerization. A hollow polymer preform filled with core monomer mixture (MMA+EMA+BzMA) was thermally polymerised in an oven. The temperature of the oven was increased gradually from 65°C to 85°C for three days. Note that the temperature used here was still well below the cladding's glass transition temperature that is usually around 100°C. Polymer optical fibres were drawn at 270°C from the preform. The diameter of the fibres is 105 μm with a core size of 7.6 μm. The difference in the refractive index between the core and the cladding is 0.0086, which was measured using the transverse interference method with a microscope after the fibres were drawn. The cutoff wavelength is around 1580 nm. The fibre Bragg grating was prepared using the technique described in [24]. In order to increase the intensity of the 325 nm UV laser beams, we added to the setup a pair of cylindrical lenses with focal length of 150 mm and 50 mm respectively in front of a phase mask used for the grating writing. The beams on the phase mask were reduced from 6mm to about 2 mm in the perpendicular direction to the fibre.

This efficiently shortened the grating preparation time. For example, the time for saturation of grating reflection decreased from 85 min to 15 min. The grating with a length of 3 mm created in the higher temperature-prepared POF has reflection of 50%, which is compatible with that of our previously reported value. This shows that the higher temperature used here did not degrade the photosensitivity of the POF to the UV light.

The change in Bragg wavelength with strain applied to the fibre is shown in Fig.10. The circles are the experimental results and the line is the least-square fitting to the results using $\lambda_b = 1560.61(1+0.966\varepsilon)$. The photoelastic constant was deduced to be $P_e = 0.034$. This result shows that the contribution from photoelastic effect is insignificant on the wavelength tuning and that the wavelength shift is linearly proportional to the strain.

So far a wavelength tuning of 73 nm, the largest range ever reported, in fibre grating has been successfully demonstrated. The Bragg wavelength can be tuned linearly with the tensile strain up to nearly 5%. The result is significant because its tunable range is about 10 times greater than that achieved in a silica optical fibre grating and it would be sufficient to cover the whole bandwidth of erbium doped amplifiers used in optical WDM communication systems.

5. PHOTOSENSITIVITY CYTOP POF

More recently the photosensitivities of a novel perfluorinated polymer material, CYTOP™, and in POFs made from CYTOP have been investigated, jointly by the researchers of the University of New South Wales, Keio University and Asahi Glass Co. It is revealed that there are also considerable photosensitivity of the perfluorinated polymer [49].

CYTOP is developed by Keio University and Asashi Glass Co Ltd in Japan. It has similar chemical, thermal, electrical and surface properties as conventional fluoropolymers such teflon. In addition, it is characterised by its high optical transparency This work represents a significant recent breakthrough in the development of low-loss material systems for POF. The most attractive feature of CYTOP is its very broad transmission window, ranging from the 650nm right up to 1300nm. Within this window, a graded-index POF has been made with loss less than 100dB/km; it bottomed out at 50dB/km at 1300nm [50]. It is even predicted that it could possibly reach a theoretical attenuation limit of 0.3dB/km [51], ie. lower than that of silica glass at this wavelength. This very promising prospect opens up various opportunities in developing novel very low loss photonic devices based on CYTOP POFs.

Due to the fact that there is no single mode CYTOP polymer optical fibre available yet, the initial work was carried out on slab samples made from graded-index multimode CYTOP polymer fibres, provided by Asahi Glass Co. The core diameter of the CYTOP fibre is 120μm. It is made with two layers of claddings: an inner cladding to about 210μm in diameter and an outer cladding to about 500μm in diameter. The core and inner cladding are made from CYTOP and perfluorinated materials. The outer cladding is from PMMA. To test the photosensitivity of CYTOP, the outer cladding was removed and fibre samples (~210μm in diameter) consisting of CYTOP core and inner cladding were obtained. These fibre samples are not particularly convenient for the test. Therefore they were squeezed into fibre slabs at an elevated temperature. Then slab samples were made with about 100μm thickness.

The phase mask technique was used to imprint Bragg grating into thin CYTOP slab samples. This is a very simple way of quickly testing photosensitivity of a material, by placing a sample right behind a phase mask. The sample is directly exposed with diffracted beams from a silica phase mask under UV illumination. The UV writing beam at 355nm wavelength was output from a frequency-tripled Nd:YAG laser. The laser outputs 5ns pulses at a repetition rate of 10Hz and the pulse energy is 280mJ. Since the phase mask with a period of 1.061μm is designated for operation of at a wavelength of 248nm, it has significant zeroth-order diffraction at the 355nm wavelength. As a result, this would make the period of the interference fringe and therefore the period of grating written to double (1.061μm) [52].

The grating of CYTOP fibre samples are tested using a simple setup shown in Fig.11. A He-Ne laser at 6328nm was used to test the gratings. When illuminating the He-Ne laser light to the UV light exposed region of the fibre slab, a diffraction pattern was observed as shown in the top of Fig.11. This indicates that a grating is successfully written into the CYTOP slab. The diffraction angle, θ, of the first order was measured to be 36° in the experiment. The grating period can be calculated by taking the grating diffraction equation as follows. $\Lambda = \frac{m\lambda}{\sin\theta}$, where m is the diffraction order, and Λ is the gratings period.

λ is the incident light wavelength. The period of the CYTOP slab grating is calculated to be 1.07μm, agreeing well with the prediction of the period doubling in the presence of the zeroth diffraction. By measuring the power of the first orders (P_{-1}, P_{+1}) and the zero order (P_0), the diffraction efficiency η can be calculated from $\eta = \frac{P_{-1} + P_{+1}}{P_{-1} + P_0 + P_{+1}}$. The diffraction efficiency of several gratings formed in varying UV exposure time was measured and the results are shown in Fig.12 (solid line).

In order to ascertain whether the grating written in a CYTOP sample is of a surface relief type or of a bulk type, diffraction efficiencies were also measured when a refractive index matching oil was spread onto the slab surfaces. The difference in diffraction efficiency were compared to determine whether the diffraction contribution is from a surface relief grating, a bulk grating or a combination of both. If it is a surface relief type of grating, the diffraction would disappear when index matching oil is spread. The experimental results with index matching oil are included in Fig.12 (dashed line). It is clear that the diffraction efficiency changes little and that the gratings written are of the bulk type, ie. they are the result of the change of refractive index, not due to material ablation. This proves the existence of the photosensitivity of CYTOP. From Fig.12, one can see that the efficiency increases as exposure time increases up to 20 minutes and that a maximum diffraction efficiency was obtained. It must be noted that underlying mechanisms associated with photosensitivity remain to be further investigated.

6. FINAL REMARKS

As the development of telecommunication, internet, fibre sensing, etc, the demand on a wide range of photonic components have been growing rapidly. The timely development of enabling photonic components are essential.

Photosensitivity in POF has been investigated for developing highly tunable POF Bragg grating -- an enabling technique that would add significant flexibility as well as capability to future photonic applications such as intelligent all-optical network or IP over WDM networks. Work in this area have been driven largely by the prospect that polymer optical fibre has superior elasticity in comparison to that of silica fibres and that this excellent elasticity could be duly utilised to build highly tunable fibre Bragg gratings. Some initial work have been successfully carried out in demonstrating significant photosensitivities of POF materials and in exploring the potential of manufacturing Bragg gratings in POFs.

In particular, PMMA-based POF was first investigated and it had been shown to have useful photosensitivity and Bragg gratings can be inscribed onto them by UV irradiation. As expected, POF grating is shown to have great potential in providing wide tunable range that no existing techniques could possibly achieve. Also optical diffraction grating has been imprinted into CYTOP samples and significant diffraction efficiency have been observed. Based on these research, the inscription of Bragg grating in CYTOP POFs to produce low loss POF grating can be achieved. Work in this aspect is now continuing. These results suggest unambiguously the feasibility of creating Bragg grating CYTOP POF.

On the other hand, all the work done so far are still preliminary. There remain a fairly long list of important issues to be addressed in the future. They include physical property issues (such as long term thermal, optical, chemical and mechanical stabilities, attenuation and dispersion), material issues (photoinduced processes and underlying principles, photosensitivity enhancement, elasticity tailoring, synthesis techniques, etc), grating fabrication issues (optimal writing wavelength, optimal exposure intensity and time, desirable fabrication scheme) as well as component techniques (practical tuning mechanism, packaging, connection, etc). All these topics would be challenging and important for bringing new and enabling POF photonic components to practical applications.

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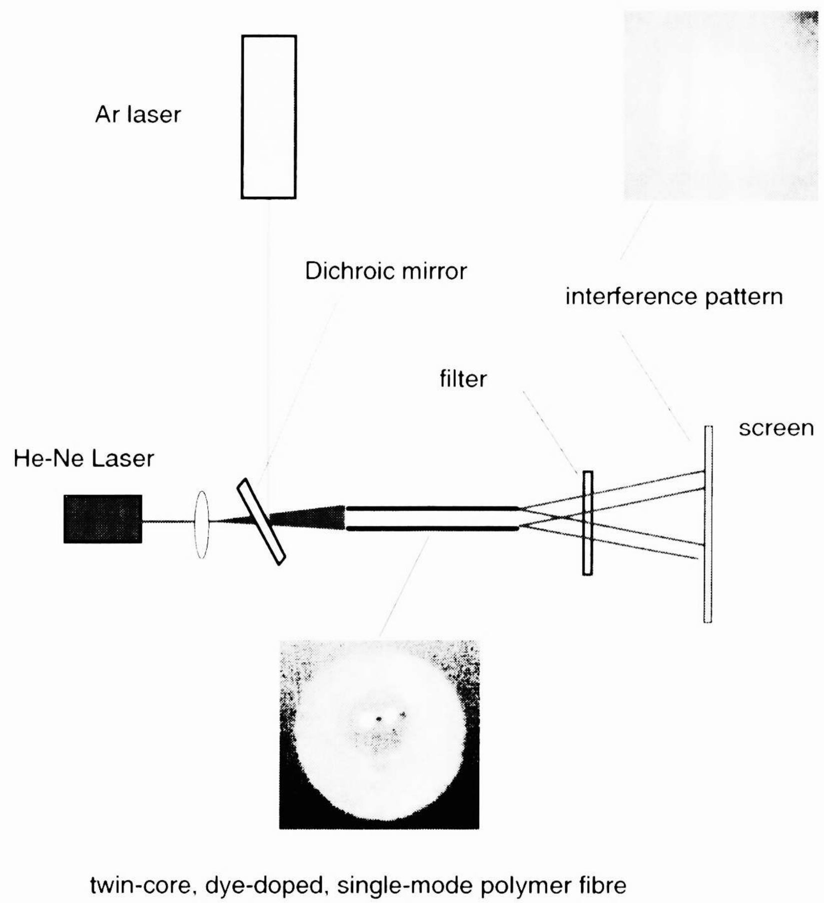

Fig.1 Schematic diagram of the photosensitivity experimental setup, where the insets are the near-field (endface image) and far-field pattern (intereference fringe) of a twin-core polymer fibre.

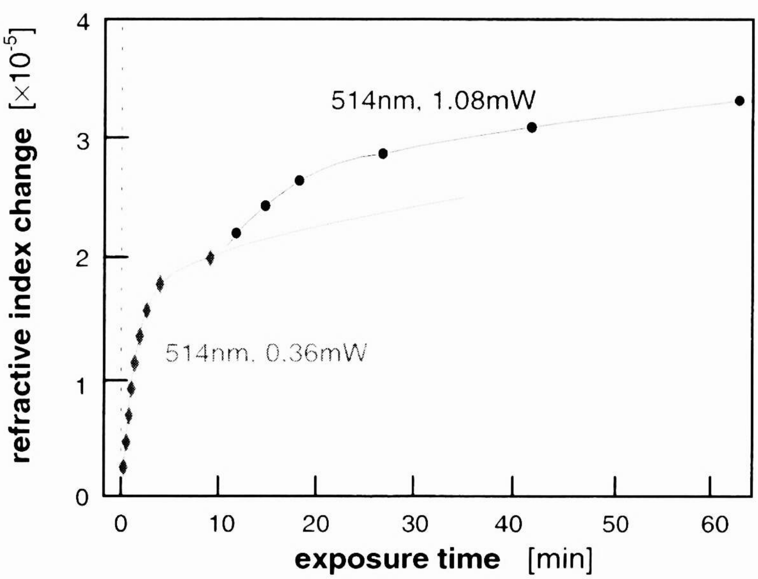

Fig.2(a) Result from core 1.

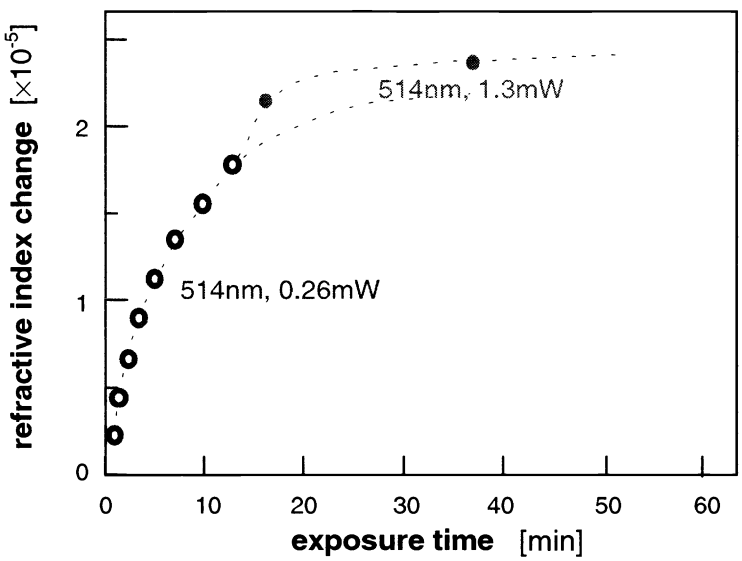

Fig.2(b) Results from core 2.

Fig.2 Photosensitivity of a fluorescein-doped twin-core POF under the exposure of 514nm.

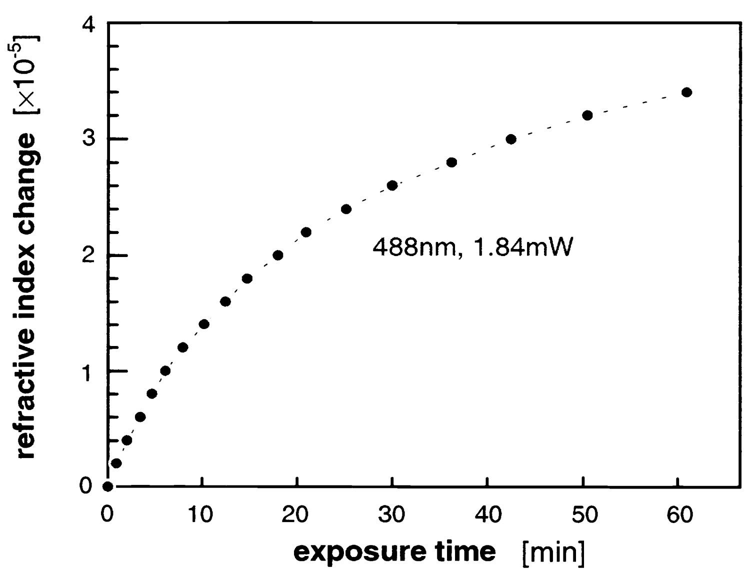

Fig.3 Photosensitivity of a fluorescein-doped twin-core POF under the exposure of 488nm.

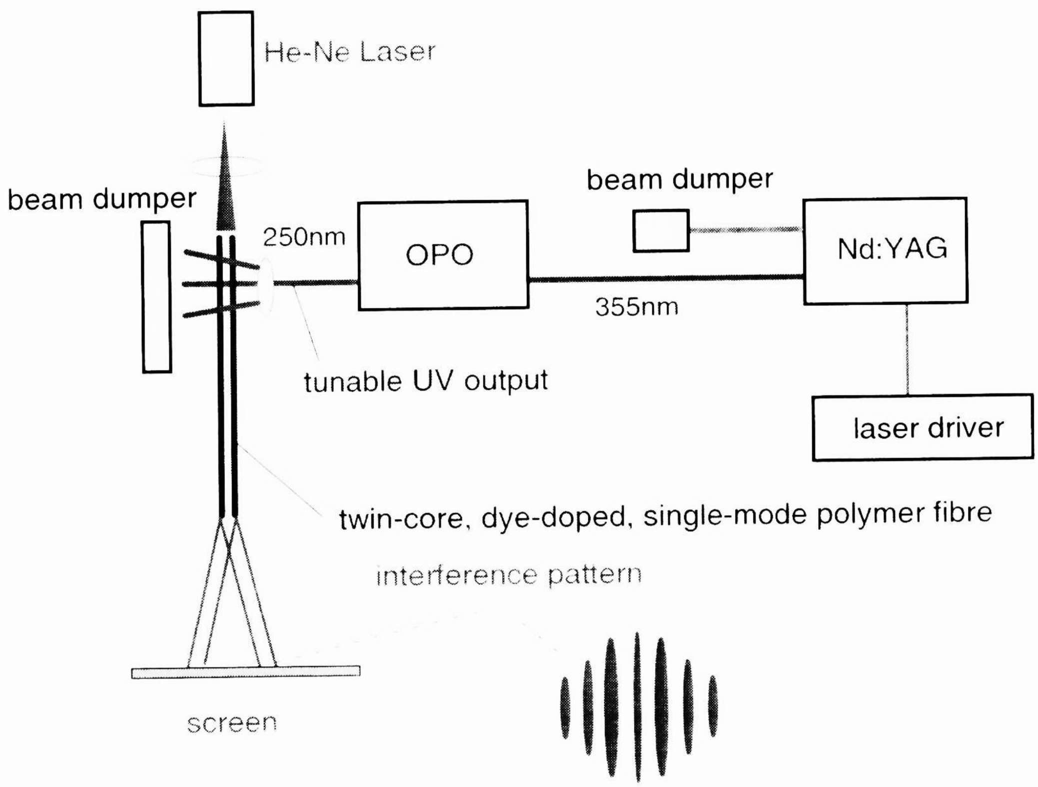

Fig.4 Schematic diagram of the photosensitivity experimental setup for UV wavelengths.

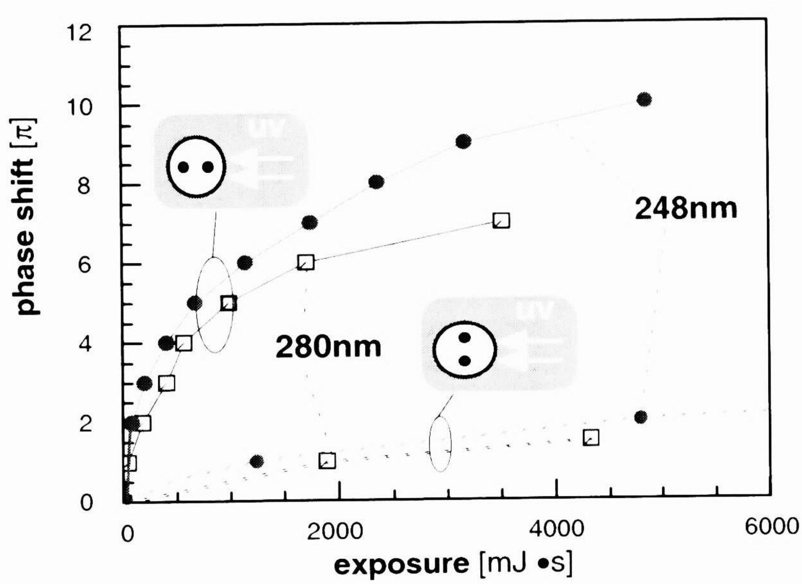

Fig.5 Photosensitivity of a twin-core POF under side-illumination of 248nm and 280nm.

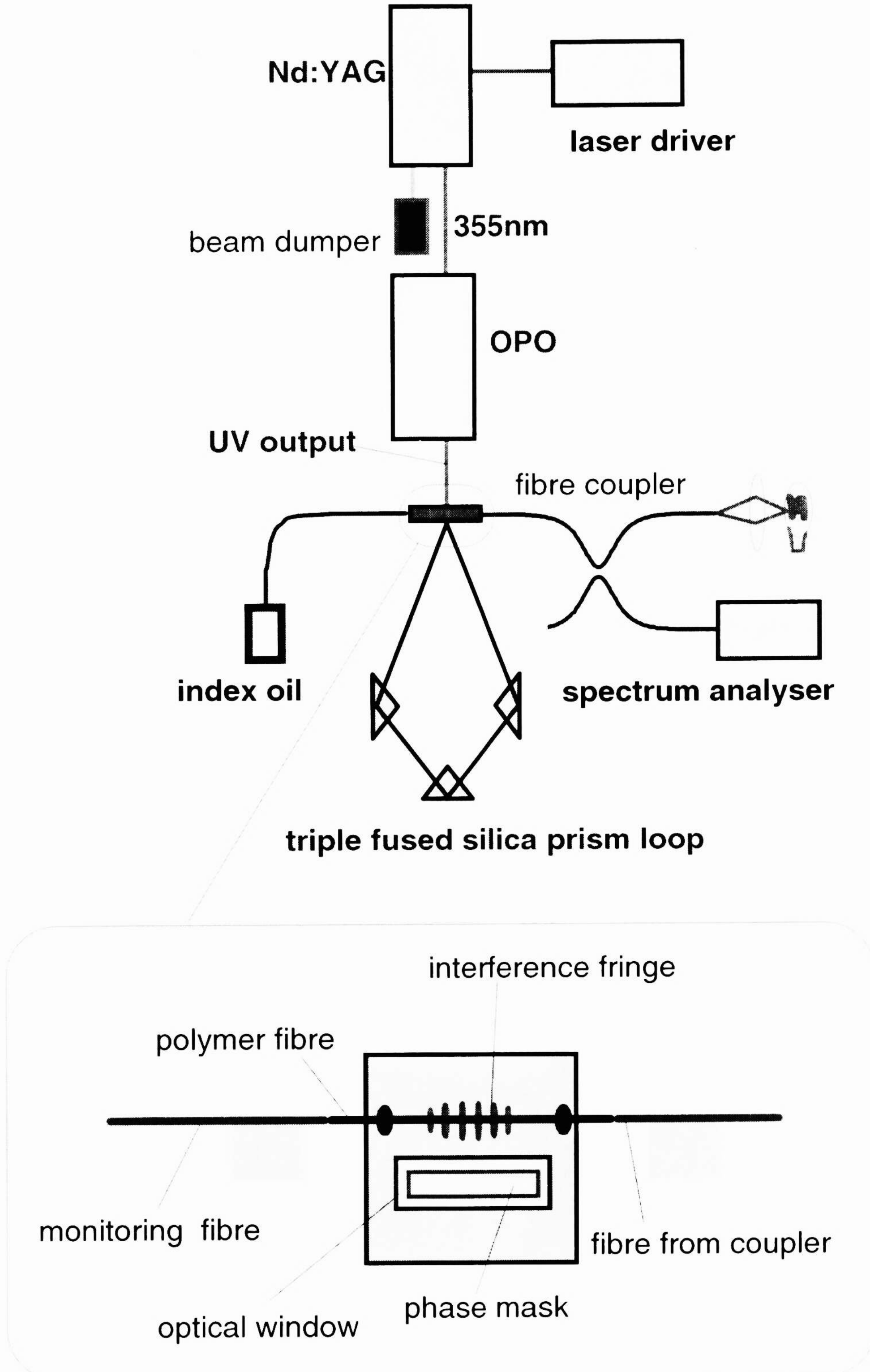

Fig.6 Experimental setup for writing POF grating.

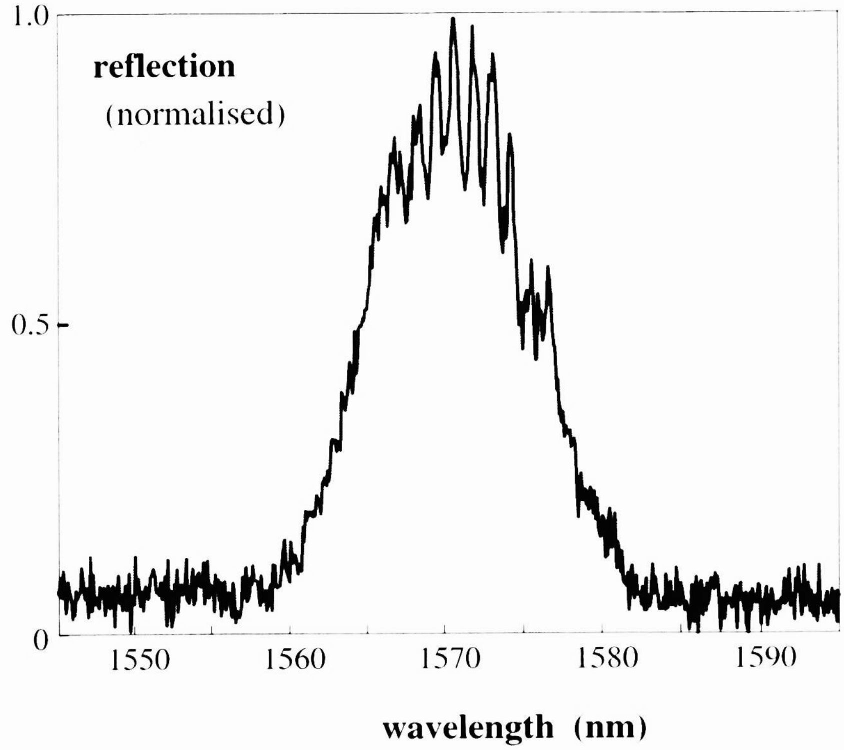

Fig.7 Reflection spectrum of a Bragg grating made in a few-moded POF.

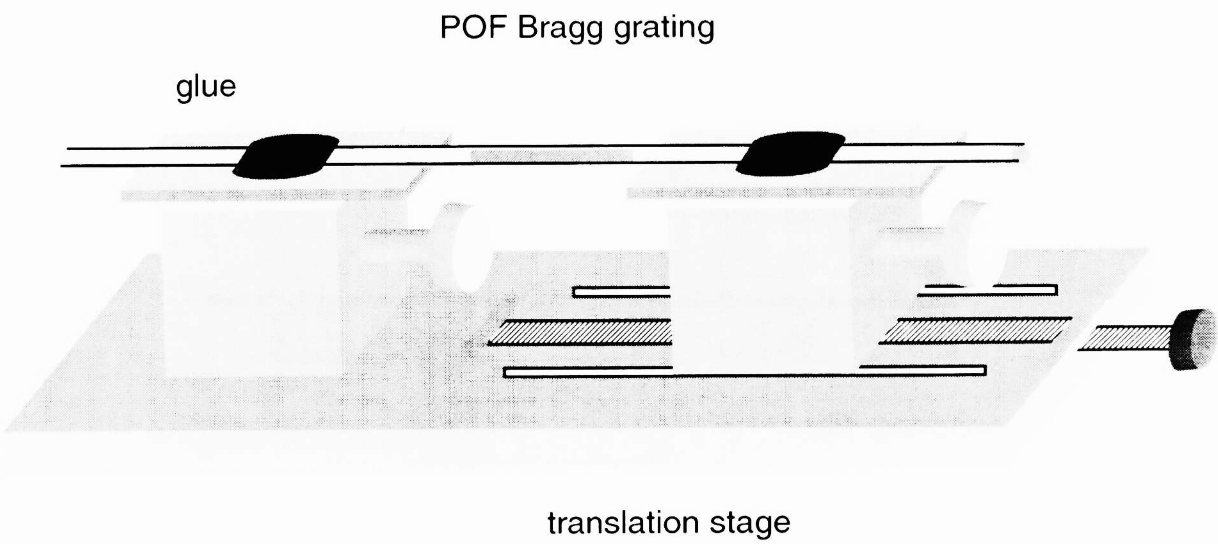

Fig.8 A simple mechanic setup fro wavelength tuning of POF grating.

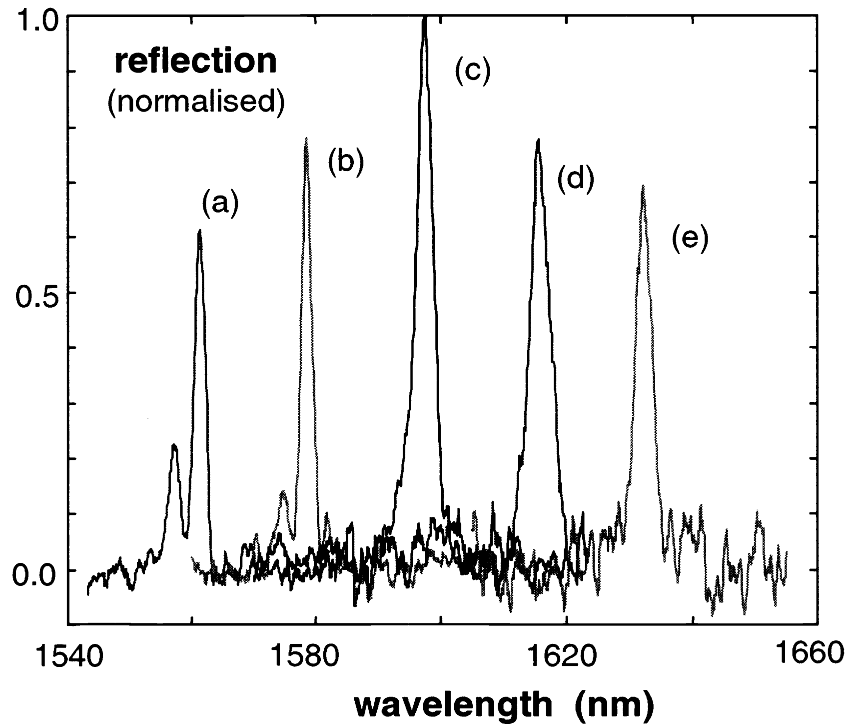

Fig.9 Wavelength tuning of a POF grating by mechanical stretching.

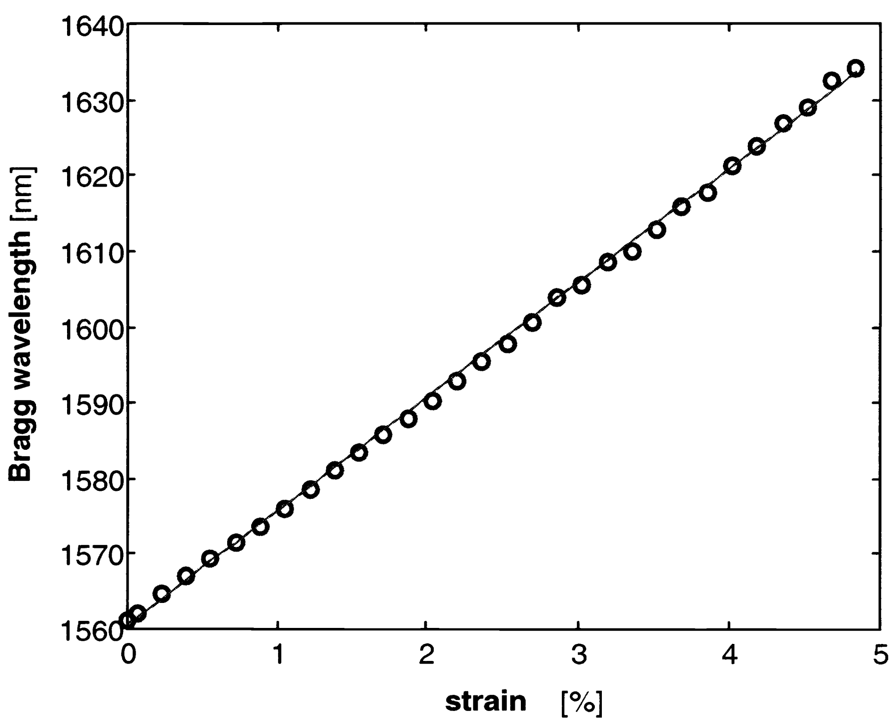

Fig.10 Wavelength tuning of a POF grating versus strain.

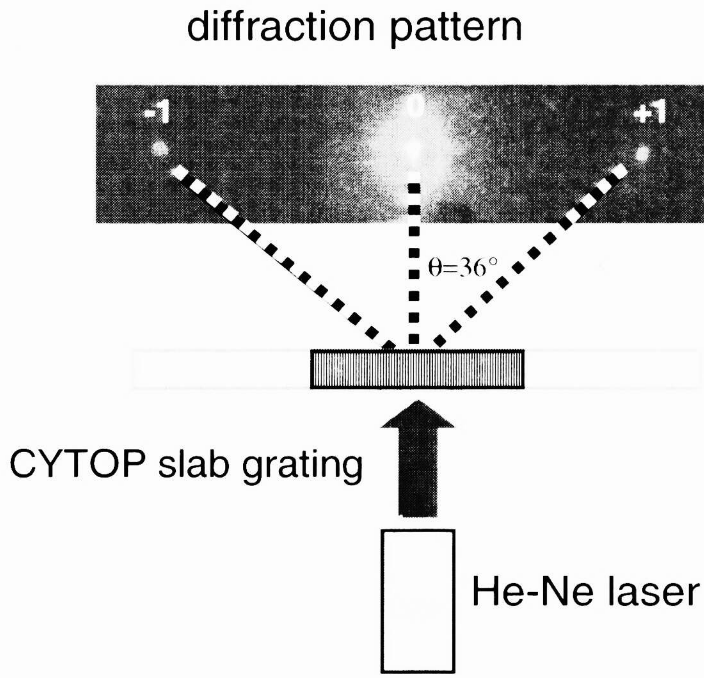

Fig.11 Arrangement for grating testing, including a diffraction pattern from a CYTOP grating.

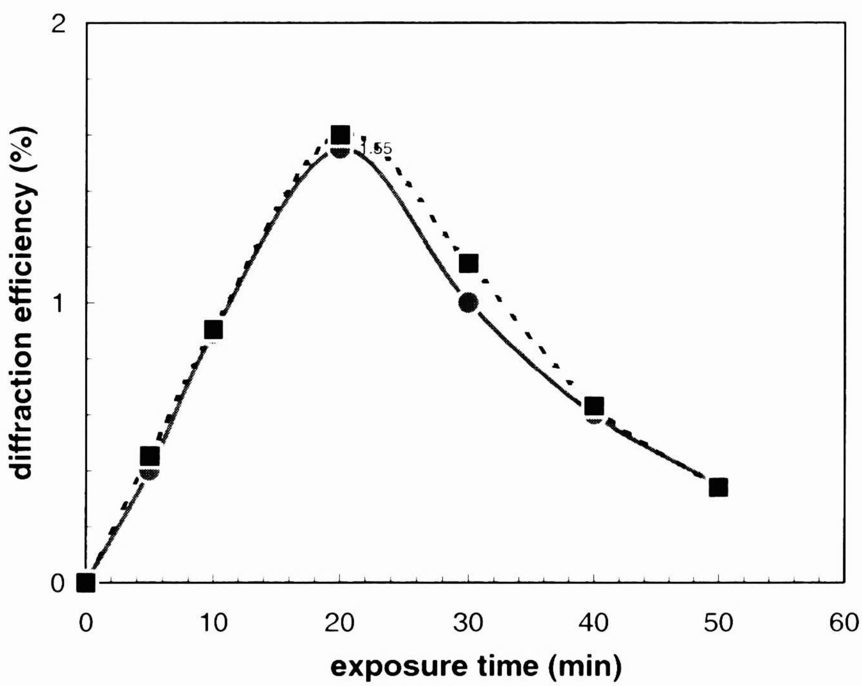

Fig.12 Grating diffraction efficiency versus UV exposure time with the PMMA jacket removed.