Hypersensitisation in germanosilicate optical fibres

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Abstract: The process of hypersensitisation has been demonstrated with a number of ultra-violet wavelengths, the most recent being with a far-UV wavelength which is transmissive through the polymer coating. These results are presented. A further advancement in hypersensitisation through the use of a low-power UV lamp source is also demonstrated.

1. Introduction

Current methods employed for the fabrication of Bragg gratings in silica fibre involve a tedious hydrogen loading process, followed by mechanical stripping of the polymer coating and subsequent grating inscription with a chosen ultra-violet light source. The rapid out diffusion of hydrogen necessitates very low temperature storage of hydrogen-loaded fibres until UV exposure. The grating writing process is further complicated by the need to thermally anneal Bragg gratings to ensure long-term stability. All this contributes to the cost of grating based devices. Hypersensitisation is a process through which photosensitivity can be increased and permanently locked within optical waveguides.

This method allows the commonly used boron co-doped germanosilicate fibres to be pre-processed for room temperature storage and grating fabrication with the role of hydrogen completely removed from the actual writing process. Hypersensitisation through the polymer coating and with a low-power UV lamp source is also demonstrated.

The 355nm hypersensitisation process excites the partially forbidden, singlet-triplet transition band centred at 330nm [1]. The process involves a two-step mechanism [2-4] where two species are created one after the other. The two-step process identifies the involvement of a third species in the photolytic reaction. The following equation helps understand this better [4];

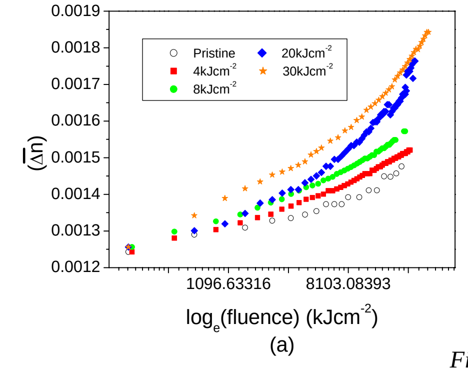
$$A \xrightarrow{h\upsilon, k_1} B \xrightarrow{h\upsilon, k_2} C \tag{1}$$

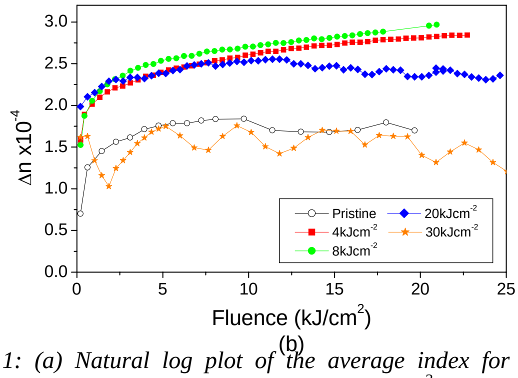
B is most likely a hydride species when hydrogen is present [4, 5], while *C* is formed independent of molecular hydrogen. Hydrogen is released at this point and recycled – this catalytic behaviour [2-4] is crucial for differentiating the two stages of the sensitisation process on timescales amenable to practical implementation. Species C is responsible for the permanent enhancement of useful photosensitivity, superior to pristine fibre. The use of near ultra-violet 355nm requires very large doses of fluence as the 330nm band is relatively weak and further 355nm is at the tail end of this band.

2. Experiments and discussion

The UV-cured coating used on the boron co-doped germanosilicate fibres was found to be 100% transmissive at the 355nm laser wavelength [6]. The transmission dropped to about 85% with hydrogen present. A number of boron co-doped germanosilicate fibres were hydrogen-loaded at 373K temperature and 100 atm pressure for a period of 24 hours.

In the initial experiments, hypersensitisation was performed with a frequency tripled Nd:YAG laser operating at 355nm and 5kHz repetition rate on fibres with and without the polymer coating over a length of 4cm for each fibre. The coated fibres were hypersensitised in a nitrogen filled chamber to prevent photo-oxidisation of the polymer during exposure. These fibres were then stored for a minimum period of two weeks, allowing all excess hydrogen to completely diffuse out. Gratings were then inscribed into each fibre incrementally with a frequency doubled argon ion laser operating at 244nm using direct writing through a phase mask. The reflection and transmission profiles were recorded in between each writing pass. The characteristic growth curves seen in figure 1 were derived from this data.





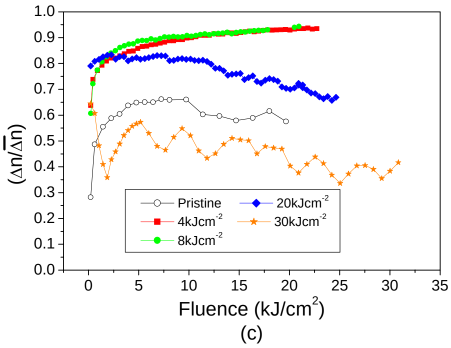


Figure 1: (a) Natural log plot of the average index for fibres with hypersensitisation fluences of 4, 8, 20 and 30 kJ/cm^2 and a pristine GF1 fibre (b) Plot of amplitude index modulation versus fluence. (c) Fringe contrast plots for fluences 4, 8, 20 and 30 kJ/cm^2. Note: the average value of the refractive index change, $\overline{\Delta n}$, used for the fringe contrast calculation (in plot (c)) was estimated to be the difference of the average index from the last grating writing pass to the first pass (from plot (a)), as the initial index of the core was not known. A standard value of the core index was subtracted for the purpose of the log plot and thus the initial value of $\overline{\Delta n}$ would be much smaller (10^{-4}) than shown in plot (a) (10^{-3}).

The 4 and 8 kJ/cm^2 cases show a linear average index modulation response over the total incremental range. A feature typical of hypersensitisation is linearity of the natural log graph of $\overline{\Delta n}$ vs ln(fluence) for optimally hypersensitised fibres. This indicates that the optimum hypersensitisation fluence is in the range of 4 to 8 kJ/cm^2. Comparing the 4 and 8 kJ/cm^2 cases with the pristine fibre case shows a striking similarity in the magnitude of the average index modulation, suggesting that the wavelength stability of a grating fabricated in an optimally hypersensitised fibre will be comparable to that of the pristine case. The 20 and 30 kJ/cm^2 cases show a much greater average index modulation for similar 244 nm writing fluences. However, Figure 4.2(b) indicates that the largest index modulations are attained only for the 4 and 8 kJ/cm^2 cases, despite much lower average index changes.

The plot of the fringe contrast, in Figure 1(c) further validates this claim. The plot shows a relatively high fringe contrast of almost 1 for both the optimally hypersensitised cases. The 20 and 30 kJ/cm^2 cases exhibit a high fringe contrast initially which quickly fades away with continued writing fluence as additional index contributions and changes due to excess hydrogen involvement, aided by variation in stress fields at the core/cladding interface and also in regions between grating writing fringes, come into effect [4]. Thus hypersensitisation for photosensitivity enhancement is about maximising the efficiency of the index change of the pristine fibre, and not allowing parasitic index changes, which can reduce the fringe contrast, thus producing poor quality gratings.

Given the performance at 355 nm, hypersensitisation of hydrogen-loaded fibres with a low-powered tube-light source such as those used in UV sterilisers was considered [7]. These lamps are designed to have a spectral peak at approximately 254 nm, the most effective wavelength for germicidal treatment. The low power output of these sources necessitated long exposure times. This could be significantly improved with high power excimer lamps. Nevertheless, the limits to hypersensitisation could be evaluated by the performance of a very-low-powered UV lamp. UV lamp hypersensitisation experiments were carried out with readily available gas filled fluorescent tubes (Philips G15 T8) with just 15 W of electrical input power. The broadband intensity at the surface of these lamps is estimated to be just ~0.054 W/cm^2. For optimal performance more specific lamps with higher power and lower relative costs (both purchase and running) compared with those of a UV laser are readily available.

In this experiment, the hydrogen loaded fibres were stripped of the polymer coating and placed in close proximity to the UV lamp source for 5 days, giving a cumulative hypersensitisation fluence of ~22 kJcm^{-2}. Gratings were then inscribed under the same conditions as for the previous experiment.

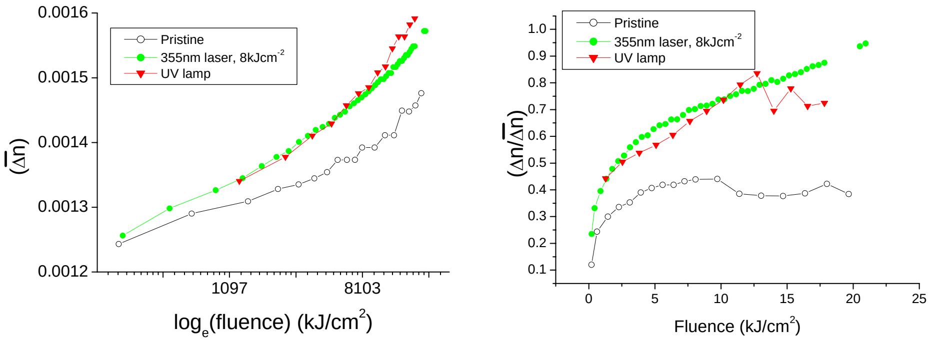


Figure 2: (a) Semi- log plots of grating growth for standard boron-co-doped germanosilicate fibres hypersensitised with a UV lamp and 355 nm laser and pristine fibre (b) Fringe contrast plots for lamp and laser hypersensitised and pristine fibres. Note: The average index , $\overline{\Delta n}$, used for the fringe contrast calculation (in plot (b)) was estimated to be the difference of the average index from the last grating writing pass to the first pass.

The maximum grating strength reached for a 5 day lamp hypersensitised fibre is ~22.5 dB whilst a 355 nm hypersensitised fibre yielded a maximum of 32 dB. The saturation of the grating strength in the lamp hypersensitised fibre occurred for much lower writing fluences (12.7 kJcm^{-2}) than the laser hypersensitised fibre (18 kJcm^{-2}). This indicates that the optimum hypersensitisation fluence has been exceeded and the exposure time needs to be reduced considerably. In comparison, the total cumulative fluence used is approximately 3-5 times that used for a single wavelength 355 nm laser source. This may seem surprisingly low given the optical power is distributed over a much larger spectral window outside peak absorption windows. However, this particular germicidal lamp has greater overlap with the 242 nm absorption band, which requires less fluence than at 355 nm.

3. Conclusions

The use of 355nm light to hypersensitise boron co-doped germanosilicate fibres provides a strong linear photosensitivity response in the characteristic curve (defined in this case as the index change versus ln(fluence); figure 1(a)) that is also permanent. The most obvious gain over using other shorter wavelengths is the ability to hypersensitise through the standard polymer coatings found on fibres.

The relatively strong grating fabrication demonstrated in UV-lamp-hypersensitised fibres shows that the process is quite effective, despite the out-diffusion of some hydrogen from the core. Thus it has been established that UV hypersensitisation does not require a high concentration of hydrogen in the core, with extremely cheap lamp sources utilisable for the hypersensitisation of fibres. The main advantage of using a UV lamp source is the ability to bulk hypersensitise reels of hydrogen-loaded fibres. The obvious disadvantage is the time required for the hypersensitisation process to be completed. However, much higher UV lamps are available (not just exciplex and excimer lamps) to cut back on the time required for hypersensitisation. By choosing more appropriate lamps centred at longer wavelengths we expect that practical hypersensitisation of fibre through the polymer coating is achievable without the requirement of special fibre coatings.

4. References

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