Characterisation of the effects of different lasers on the tensile strength of fibres during laser writing of fibre Bragg gratings

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ABSTRACT

Fibre Bragg gratings (FBGs) continue to be used in a wide variety of different telecommunications products such as filters, pump stabilisers and dispersion compensators. The increased specifications being demanded by successive generations of FBG components mean that higher manufacturing controls are needed to ensure high quality performance. One of the key areas of concern has been the effect of the laser exposure on the tensile strength of the fibre, since this affects yield, quality and lifetime of the FBG device. No comparative study has, to the best of our knowledge, so far been conducted to measure the relative merits of different exposure conditions. We present measurements of the degradation of the strengths of Corning SMF28 and intrinsically photosensitive fibres from laser exposure with the following lasers: excimer lasers at 193nm and 248nm and argon-ion laser at 244nm. A comparison is presented of the fibre pull strengths under varying illumination conditions with the different laser systems and a methodology established for favourable exposure conditions for FBG writing with reduced fibre strength degradation.

Keywords: FBGs, lasers, fibre strengths.

1. INTRODUCTION

The diversity, functions and specifications of fibre Bragg grating (FBG) devices used in telecommunications and sensor applications have grown rapidly over past few years. Although the most common established writing method for FBGs – the proximity phase mask technique [1] – has not altered, there have been numerous refinements which have been developed to access differing grating functions [2-3]. These developments in the exposure methods have concentrated on grating properties, on the whole, and no previous study has been conducted, to the best of our knowledge, on the comparative strengths of different optical fibres under varying illumination conditions. The amount of damage to the fibre while writing FBGs has become an increasingly important factor since it affects the long-term stability of FBG-based devices and ultimately their lifetime.

Different lasers have been used for the manufacture of gratings in fibres, ranging from excimer lasers at 248 and 193nm, fluorine lasers at 157nm, copper vapour lasers at 211nm, fourth harmonic neodymium-based lasers at 262nm and near UV lasers at 334nm [4-9]. The individual process parameters have been optimised for the different lasers but no clear comparison exists for the determination of amount of damage caused by the different lasers. We present a comparative experimental study which quantifies the respective damage caused by three commonly-used laser wavelengths using realistic conditions for grating writing. Following the assessment of the damage and the selection of exposure conditions, exposures have been made in the selected fibres to demonstrate that the chosen conditions are sufficient for the production of high quality gratings.

2. METHODOLOGY

All fibre exposures were conducted using three separate Exitech laser exposure systems: the GWS-200E tool for 248nm, the GWS-200I tool for 244nm and the S7000 tool for 193nm. The GWS-200E and GWS-200I tools are automated FBG writing systems (for excimer laser and argon ion lasers, respectively) which allow the production of highly reproducible gratings. These systems have a high level of diagnostics (such as beam profilers, dose controllers, fluence monitors, fibre and mask positioners and laser beam alignment aids) which were required to ensure that all the exposures, fibre tests and FBG writing were performed under consistent and reproducible conditions.

The pull testing of the fibres was carried out in the GWS-200E tool, which had an integrated automated pull testing station. The pull testing station consisted of a system where a length of fibre was clamped securely with one end attached to a Mecmesin PFI 200N portable force indicator (with a resolution of 0.004kgf) while the other end was fixed to a movable linear translation stage. The fibre break strength was measured by pulling the fibre at a speed of 16.6mm/sec and noting the tensile strength at which it broke. Ten fibres were exposed and pull tested for each of the exposure conditions at each wavelength.

The fibres which were used were: (i) Corning SMF28 fibre; (ii) Fiberlogix BGF004 intrinsically photosensitive fibre; (iii) Corning SMF28 fibre, hydrogen loaded (>165bar @ 70°C for days).

All fibres were mechanically stripped to give a mid-span stripped section of ~50mm in length. The fibre was cleaned gently with isopropan-2-ol after stripping before being exposed. The fibres were held and transported in between the different stations on specially constructed holder trays.

2.1. Excimer laser exposure at 248nm

Exposures were performed using a Lambda Physik FIBEX laser operating at a wavelength of 248nm coupled to the GWS-200E tool. The laser, which has an external unstable resonator, gives a spatial coherence length of >1mm. The beam was apertured and focussed using a cylindrical lens to give a beam size of 8mm (along the fibre axis) by 0.338mm at the fibre plane. The exposure fluence at the fibre was altered by CNC dielectrically-coated attenuator plates. The stripped area of the fibre was exposed to the desired laser fluence at a laser repetition rate of 25Hz and with a total dose of 500J/cm^2. After exposing and measuring the break strengths of ten fibres, the fluence was changed to the next desired setting and the procedure repeated.

Tensile strength measurements were also made for unstripped fibres to quantify the strength of pristine (unexposed) fibre. The break strength of mechanically stripped (but unexposed) fibre was also measured so that the effect of mechanical stripping could be accounted for.

2.2. Excimer laser exposure at 193nm

Exposures were performed using a Lambda Physik LPX210 laser operating at a wavelength of 193nm coupled to the S7000 tool. The pulse length of the laser was 25ns (FWHM). The beam was apertured and focussed using a cylindrical lens to give a beam size of 10mm (along the fibre axis) by 0.7mm at the fibre plane. The exposure fluence at the fibre was altered by CNC dielectrically coated attenuator plates. The stripped area of the fibre was exposed to the desired laser fluence at a laser repetition rate of 25Hz and with a total dose of 500J/cm^2. After exposing and measuring the break strengths of ten fibres, the fluence was changed to the next desired setting and the procedure repeated. After exposure in the S7000 tool, the fibre was transferred to the GWS-200E for pull testing. The additional strength degradation caused by the transfer was quantified by mechanically stripping, transferring and pull testing the fibre.

2.3. Argon ion laser exposure at 244nm

Exposures were performed using a Coherent Innova 300C MotoFRED cw frequency-doubled argon ion laser operating at 244nm. Following stripping of the fibre, the laser beam was scanned along the length of the fibre by translating a mirror mounted on an Aerotech FG-1000-50-LN air bearing stage. Various scanning speeds were used to give different exposures to the fibre.

After exposure, the fibre was extracted from the GWS-200I and loaded onto the fibre-handling tray and transferred to the GWS-200E system for strength testing. The preparation, exposure, transfer and pull testing was repeated for 10 samples of each type of fibre at the different scanning speeds. Tensile strength measurements were also made for mechanically stripped fibres loaded into the GWS-200I, extracted from the GWS-200I, loaded onto the fibre-tray and transferred to the GWS-200E such that the reduction in strength due to the transfer step could be quantified.

3. RESULTS

Each of the data points plotted in figures 1-8 represents the average of four separate measurements and the standard deviation of the range of values within each data set has been included. The plots for the exposed fibres in figures 1-8 have been corrected to remove the effects of mechanical stripping, manual handling and transfer between the different systems.

3.1. Excimer laser exposure at 248nm

The exposure of standard Corning SMF28 fibre at 248nm is shown in figure 1. The total dose applied to the fibre at each laser fluence was 500J/cm^2. Since this fibre was neither hydrogen loaded nor doped to be intrinsically photosensitive, it was expected that there would be little absorption of the UV 248nm laser in the silica. This was observed, as shown, and there was no significant degradation in the break strength of the fibre.

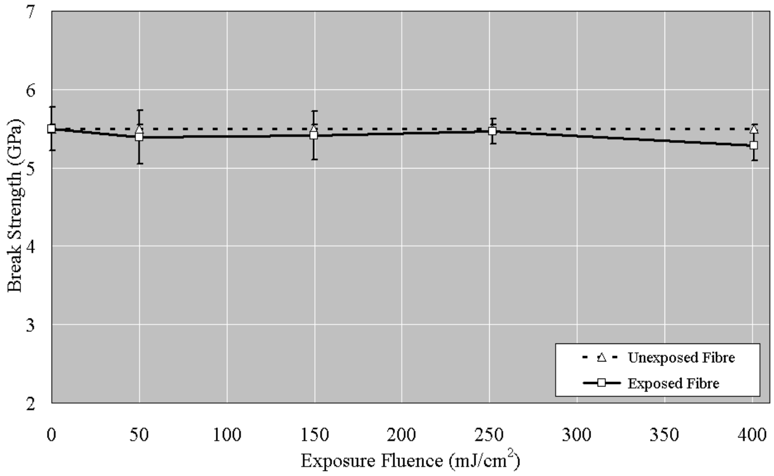

Figure 1. Standard Corning SMF28 fibre exposed using 248nm laser light from an excimer laser.

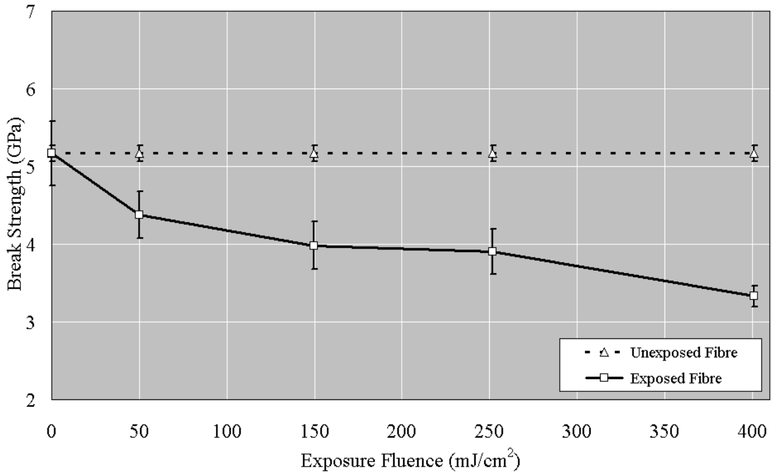

Figure 2. FiberLogix BGF004 photosensitive fibre exposed using 248nm laser light from an excimer laser.

Figure 2 shows the exposure of FiberLogix intrinsically photosensitive BGF004 fibre under the same conditions as the SMF28 fibre in figure 1. As expected, the higher absorption in this fibre due to its photosensitivity leads to a higher degradation in the strength of the fibre. It can be seen that the fibre becomes increasingly weaker as the incident laser fluence is increased, even though the total dose which the fibre receives is the same. This is in general agreement with previous work although we observe substantially less fibre damage than was the case in Limberger et.al. [8], although the total dose in that case was 1000J/cm^2.

The break strength of hydrogen loaded Corning SMF28 fibre is shown in figure 3. The same exposure conditions as the data in figures 1 and 2 were used and it can be seen that the mechanical strength of the hydrogen loaded fibre is slightly lower than that of standard SMF28 fibre (as in figure 1).

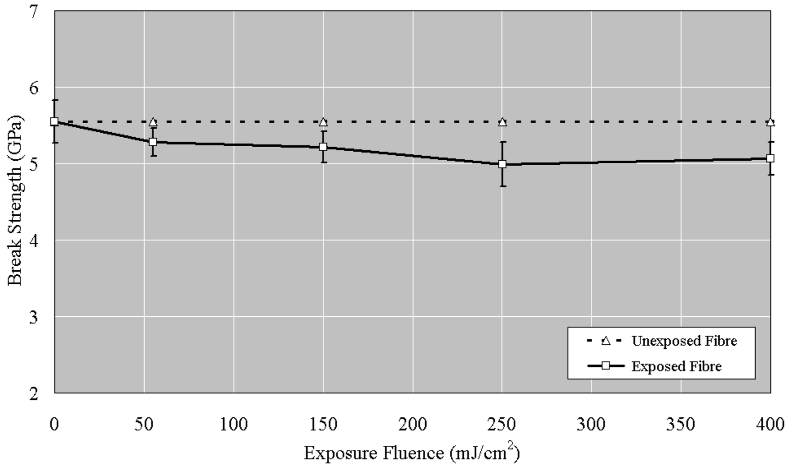

Figure 3. Hydrogen loaded Corning SMF28 fibre exposed using 248nm laser light from an excimer laser.

3.2. Excimer laser exposure at 193nm

Figures 4 and 5 show the exposures of standard Corning SMF28 and FiberLogix BGF004 photosensitive fibres, respectively, at 193nm. As can be seen from figure 4, there is increased damage to the standard SMF28 fibre at 193nm as compared to 248nm (as in figure 1), which is due to the higher absorption of 193nm light in the silica. The noticeable degradation in the fibre might be due to impurities in the fibre composition which absorb the 193nm light strongly and lead to a strength reduction.

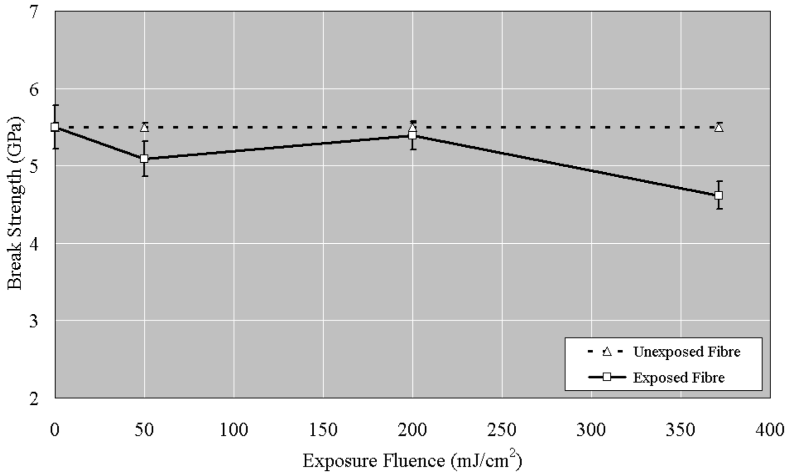

Figure 4. Standard Corning SMF28 fibre exposed using 193nm laser light from an excimer laser.

The damage to the BGF004 fibre is higher at 193nm than with 248nm. It is also noted that there is a larger spread in the break strength data of the exposed BGF004 fibre at 193nm as compared with 248nm, indicating that the interaction of the shorter wavelength light with the fibre causes more damage sites leading to a higher variation in the break strength and a less reproducible exposure.

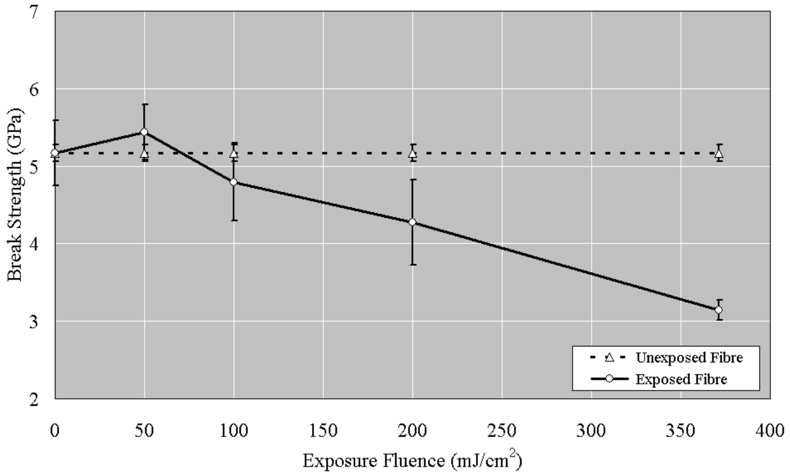

Figure 5. FiberLogix BGF004 intrinsically photosensitive fibre exposed using 193nm laser light from an excimer laser.

3.3. Argon ion laser exposure at 244nm

Figures 6-8 show the effects of argon ion laser exposure on the strengths of standard SMF28, BGF004 and hydrogen loaded SMF28 fibres. As can be seen, there is relatively little reduction in the break strengths of the fibres following exposure. This is attributed to the fact that the argon ion laser is a continuous wave laser and so does not induce pulsed shocks leading to increased damage as in the case of other pulsed laser sources such as excimer lasers, copper vapour lasers or other UV solid-state lasers.

3.4. Grating writing at 248nm

Figures 9 and 10 show the spectra from gratings written in hydrogen loaded SMF28 fibre and BGF004 fibre, respectively, using 248nm laser light. The exposure conditions are listed in Table 1. In both cases, an exposure fluence of ~100mJ/cm^2 was selected because the reduction in the break strengths for these fibres, as shown in figures 2 and 3, was modest and the aim was to determine whether a high quality FBG could be written at these fluences, thereby providing a process for the writing FBGs while still minimising the reduction in mechanical strength of the fibre.

	H-loaded SMF28 Fibre	BGF004 Fibre
Exposure Wavelength	248nm	248nm
Laser Repetition Rate	25Hz	25Hz
Total Dose	400.97 J/cm^2	200.9 J/cm^2
Exposure Fluence	104.2 mJ/cm^2	102.6 mJ/cm^2
Fibre-Mask Separation	50μm	50μm

Table 1. Exposure conditions of FBGs written using 248nm laser.

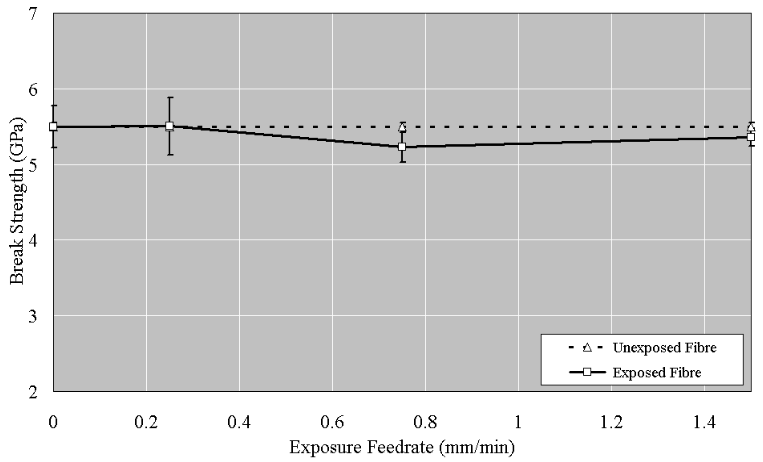

Figure 6. Standard Corning SMF28 fibre exposed using 244nm laser light.

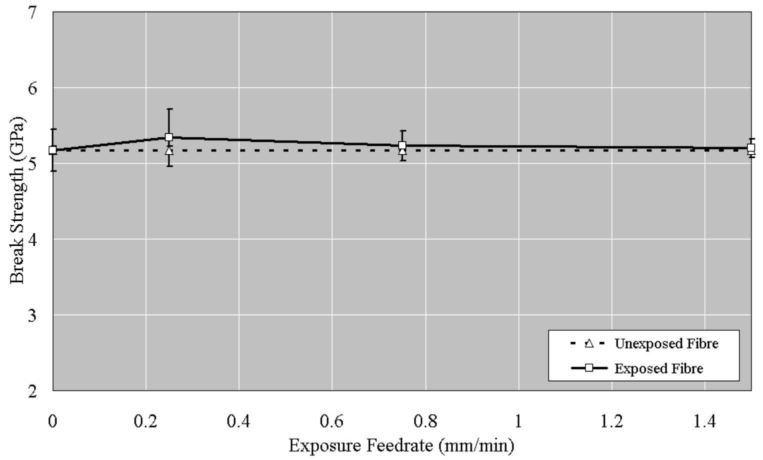

Figure 7. FiberLogix BGF004 fibre exposed using 244nm laser light.

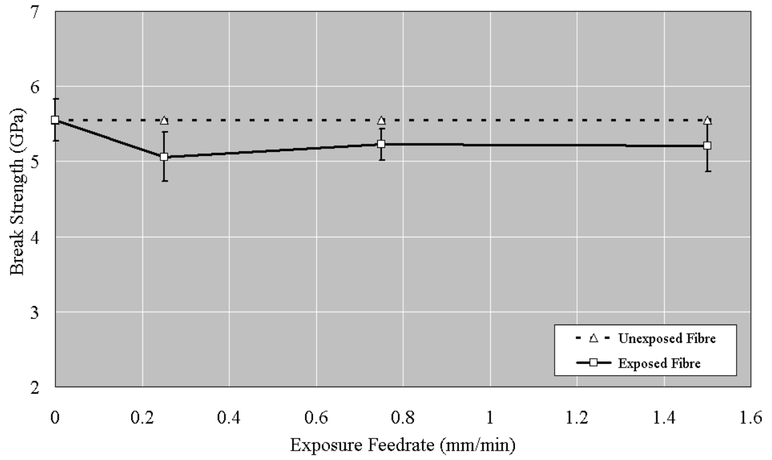

Figure 8. Hydrogen loaded Corning SMF28 fibre exposed using 244nm laser light.

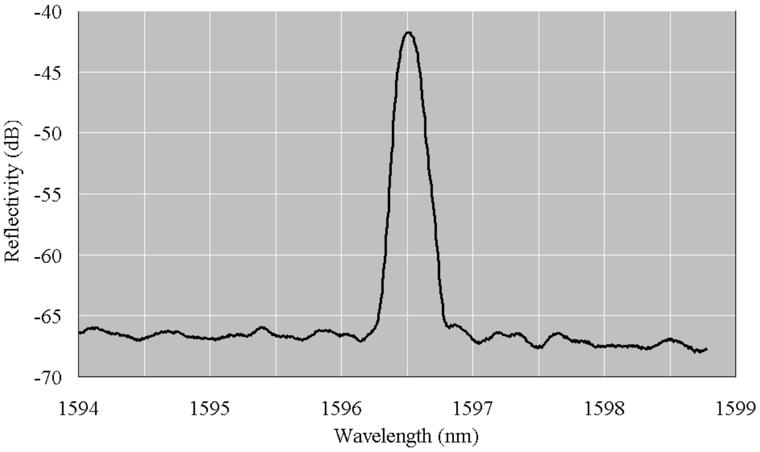

Figure 9. Spectrum of FBG written in hydrogen loaded SMF28 fibre using 248nm laser.

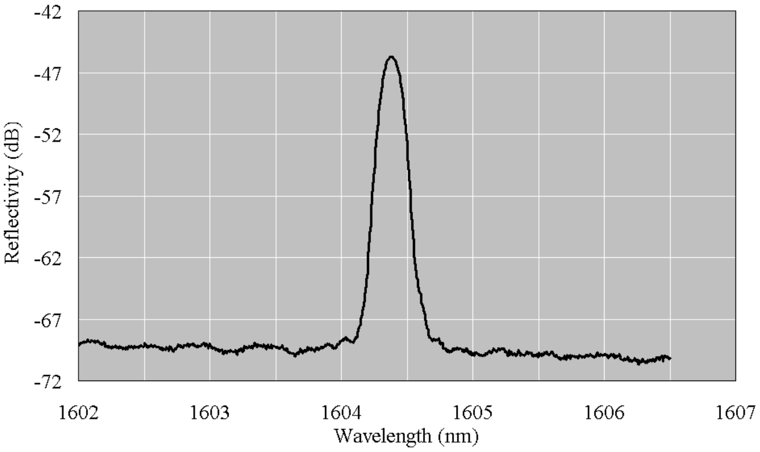

Figure 10. Spectrum of FBG written in BGF004 fibre using 248nm laser.

Figures 9 and 10 show high quality FBGs which would be ideal for applications such as sensors and narrowband filters.

3.5. Grating writing at 244nm

Figure 11 shows the spectrum of a FBG written with an argon-ion laser in hydrogen loaded SMF28 fibre and Table 2 lists the exposure parameters. The high quality of grating which is attainable in this fibre with the writing conditions used here is noted.

	H-loaded SMF28 Fibre
Exposure Wavelength	244nm
Scan Speed	0.75mm/min
Fibre-Mask Separation	125µm

Table 2. Exposure conditions of FBGs written using 244nm laser.

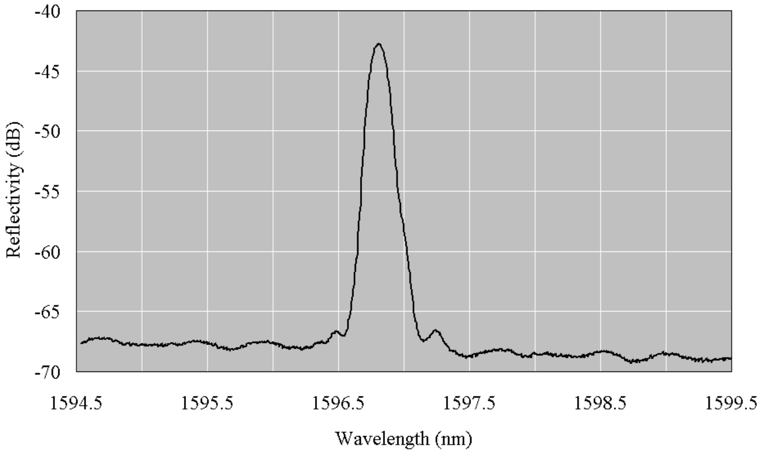

Figure 11. Spectrum of FBG written in hydrogen loaded SMF28 fibre using 244nm laser.

4. DISCUSSION

In the case of excimer laser exposures, there is a trade-off in the writing time at different fluences for a fixed total dose, i.e. more shots are required at a lower fluence than for a higher fluence exposure. Hence, comparing exposures at 248nm with hydrogen loaded SMF28 fibre, although an exposure at 400mJ/cm^2 would be faster than one at 100mJ/cm^2, it would also degrade the strength of the fibre by ~0.5GPa more (see figure 3). Similarly, for the case of the BGF004 fibre, the strength would be degraded by ~1Gpa less for an exposure at 100mJ/cm^2 compared to one at 400mJ/cm^2. Bearing this in mind, FBGs were written in these two fibres with 248nm laser light at an exposure fluence of ~100mJ/cm^2, as shown in figures 9 and 10. This shows that when considering excimer laser FBG writing, exposure conditions can be optimised to produce high reflectivity, high quality FBGs where the damage caused by the pulsed laser light is minimised while still maintaining a relatively fast write time. Work is currently being completed to characterise the FBG exposure parameters further [9].

The other main parameter which has been shown to have a significant bearing on the exposure damage is the photosensitivity of the fibre. This sensitivity, whether due to hydrogen loading or the intrinsic composition of the fibre, causes different amounts of laser absorption and therefore leads to varying damage. The balance of sufficient photosensitivity to produce high quality FBGs while still minimising the amount of damage should be possible such that it becomes another variable in the FBG production process. Work to optimise the manufacture of fibres to provide photosensitive and damage-resistant fibres is currently in progress and will be presented in the near future.

5. SUMMARY

Three commonly used lasers in the production of FBGs have been used to quantify the effects of laser exposure on the strengths of the fibres. A comparative study has been made which shows that (i) the exposure of cw argon-ion lasers at 244nm does not significantly degrade the mechanical strength of any of the fibres (within experimental error), (ii) the use of excimer lasers at 248nm has a greater effect on the strength of intrinsically photosensitive fibre (BGF004) than it does on hydrogen loaded SMF28 fibre and (iii) the use of excimer lasers at 193nm causes more mechanical damage than 248nm. The strength of the fibres has also been shown to decrease with increasing laser exposure fluence for a constant total exposure dose.

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