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A completely laser-based production method for fibre Bragg grating devices.

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Abstract

A completely laser-based procedure for the production of fibre Bragg gratings is demonstrated for the first time, including laser stripping, laser grating inscription, laser annealing and laser-assisted recoating. High reflectivity, stable gratings for telecommunications applications are produced. Future prospects for laser-based production methods are discussed.

Keywords: Bragg gratings, laser stripping, laser annealing.

1. Introduction

Fibre Bragg grating (FBG) devices are found in a multitude of telecommunications and sensing systems having widely varying specifications. Irrespective of the characteristics and functions of the device, however, the production of the FBGs usually involves a multiple stage process, including stripping of the fibre's outer coating [1,2], writing of the grating in the fibre [3], annealing of the grating properties [4-6] and recoating of the stripped region of the fibre. Partly due to this protracted procedure, much of the present manufacturing of FBG devices is labour-intensive and relatively slow. The disparate processing and handling steps also lead to a wide variation in reproducibility, which, in turn, mean that production yields can often be quite modest.

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Recently, a lot of attention has been given to the automation of various production techniques for photonics devices in an effort to increase manufacturing yields and device throughput. Although production lines for FBGs have been in place for many years at the production plants of major telecommunications companies, they have largely tended to be based on manually operated stations for the separate fibre processing steps. Fully automated production tools for FBGs have yet to emerge and make an impact on the market, although such a development is widely seen to be desirable in advancing the manufacturing of FBG devices. An effective production tool for FBGs needs to address various issues over existing production methods: (i) ease of use, (ii) high levels of automation (iii) high yields, (iv) high throughput, (v) greater flexibility and (vi) no increased safety or environmental concerns. There are many advantages to using laser techniques over existing methods, including simplicity, flexibility, lack of chemical (or other hazardous) substances and speed. Some of these advantages become particularly relevant when considering automated manufacturing platforms. It is therefore of major interest to develop a completely laser-based procedure for the production of FBGs and this is reported here, for the first time to our knowledge.

2. Laser Processing

A fibre was cycled through all the usual processing steps (stripping, writing, annealing and recoating) to produce a FBG device using only laser-based methods and the final quality and strength of the FBG was evaluated. In this demonstration of completely laser-based processing, it was not possible to establish an automated production line for the FBG manufacture. Instead, three separate processing stations were used with manual transfer in between each station. The effects of the manual handling and transfer were quantified so that the overall production merit could be assessed. Work is currently underway to transfer the acquired process knowledge into a linear production system incorporating automated handling procedures to eliminate the manual steps completely.

The fibre used throughout this work was FiberCore PS1250/1500 photosensitive fibre (9.6μm mode field diameter at 1500nm, 125μm cladding diameter, DSM dual layer acrylate coating of 245μm diameter) and discrete lengths of this fibre (typically around 1m in length) were mounted on a specially designed holder, allowing the fibre to be used in the different processing set-ups without excessive handling.

Fibre stripping: A Coherent-DEOS GEM-100 CO_2 laser operating at 9.6μm was used in the stripping station. The laser beam was split into two arms, each of which was then directed at a static fibre from opposite directions. Both beams were scanned in synchronism along the fibre to strip a pre-defined length of coating. The fibre was housed in a box constantly purged with helium gas and the coating debris was removed by a vacuum extract in close proximity to the exposed region of fibre. The laser conditions for stripping were 1kHz repetition rate, 0.5ms pulse width, powers of 43W and 45W in each arm and a beam scan speed of 10mm/s. Strip lengths of 25mm were produced with this set-up. The stripped fibre was either pull-tested *in situ* or was transferred (on its holder) to the separate FBG writing station. A section of laser-stripped fibre is shown in the inset of figure 1. The ends of the stripped region can be tailored to be tapered or not depending on the stripping conditions and this has been done in subsequent work. In the work reported here, however, less tapered interfaces at the ends of the stripped region were used as shown in figure 1.

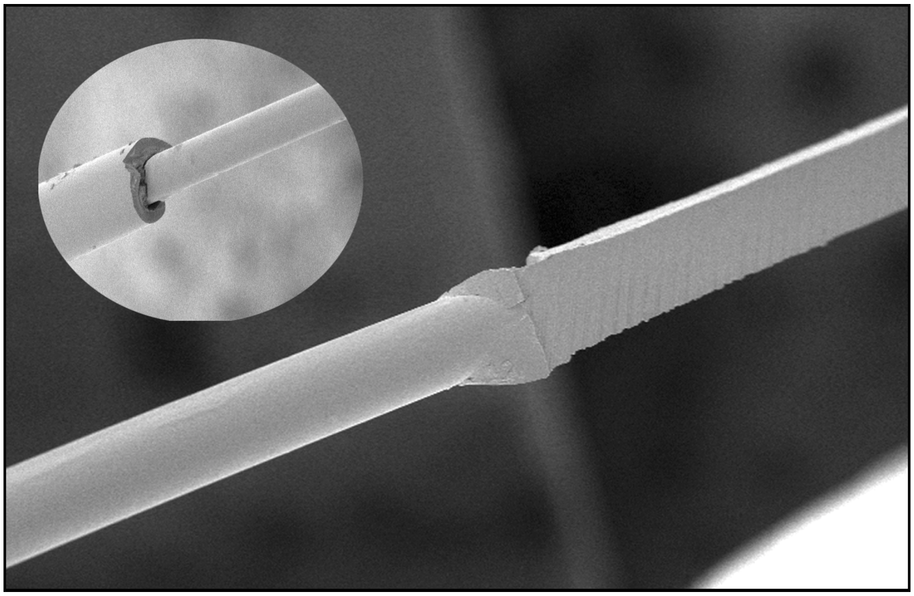

Fig. 1. Scanning electron micrograph of recoated fibre showing normal buffer layer on left hand side and recoated section on the right hand side. The irregular shape is caused by non-uniformities from the recoat mould. The inset shows a section of the laser stripped fibre.

FBG writing: An Exitech GWS-200E automated FBG writing tool, coupled to a Lambda Physik Fibex excimer laser operating at a wavelength of 248nm, was used to write reproducible FBGs in the laser-stripped fibre. The FBGs were inscribed at an exposure fluence of 250mJ/cm^2, total dose of 500J/cm^2 and a laser repetition rate of 25Hz using a Lasiris linear apodised 1" phase mask. The fibre-mask separation for all exposures was 50μm and the length of each FBG was 8.3mm. The FBG spectra were recorded on an Agilent 86152B optical spectrum analyser. Typical FBGs of ~35dB reflectivity were produced with this set-up. Following FBG inscription, the fibre was transferred back to the CO_2 laser set-up for annealing.

FBG annealing: The CO_2 laser beam was modified using spherical and cylindrical lenses to be approximately 9mm x 2mm. The FBG was exposed statically to the laser beam for periods of 1 minute, after which time the spectrum of the FBG was recorded. The laser conditions for annealing were 350Hz repetition rate, 5.6W average power and a pulse width of 0.1ms. Successive exposures were performed on the FBG until no further changes in reflectivity or wavelength were observed. After annealing, the fibre was transferred to the recoating station.

Recoating: Two halves of a plastic mould were clamped around the fibre and the recoating compound (DSM Desotech Inc. 950-250) was injected into the square cross-section cavity surrounding the fibre. A DPSS diode-pumped $Nd:VYO_4$ laser operating at a wavelength of 355nm was scanned over the mould to expose the recoating compound. The 355nm laser was operated at a repetition rate of 30kHz with 50mW of average output power. Four passes over the mould were used at a speed of 8.3mm/s, which resulted in a total time of 33s for the recoating. After recoating, the fibre was pull-tested to determine the final strength of the FBG. The recoated fibre is shown in figure 1.

4. Results

Figure 2 shows plots of the pull strengths of PS1250 fibre for the various process steps. (The full process sequence was strip, transfer, write FBG, transfer, anneal, transfer, pull test). It can be seen that the transfer of the fibre from the in situ pull testing to a separate pull testing station degrades the fibre strength by ~0.2GPa (~30kpsi). Taking this into account, the final pull strength of the annealed fibres would be ~0.6GPa (~90kpsi) higher if the three transfer steps were removed. The other aspect which is obvious from figure 2 is the significant reduction in fibre strength due to the excimer laser UV exposure, which is of the order of ~1GPa (~150kpsi).

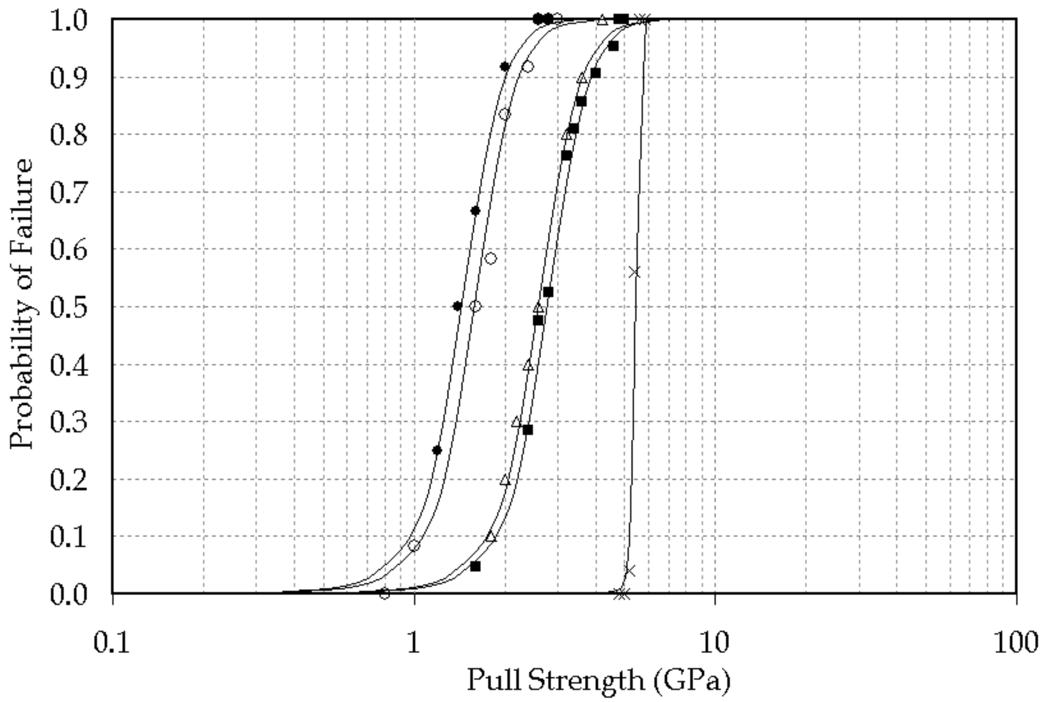

Fig.2. Pull strengths of pristine PS1250 fibre (x), after laser stripping and pull testing in situ (■), after laser stripping and transferring for pull testing (△), after laser stripping, transferring, FBG writing and pull testing (○), and after laser stripping, transferring, FBG writing, transferring, laser annealing, transferring and pull testing (●).

Following the recoating step, the fibres were pull tested and it was found that although the strengths were acceptable (with the majority in 1.03-1.38GPa, or 150-200kpsi, range), there was a change imparted on the centre wavelengths of the FBGs. This was attributed to how the fibre was seated inside the recoat compound after curing, which led to residual uneven tension in the fibre. Since the recoating did not change the reflectivity or quality of the FBG, and the strengths of the fibres were not degraded by it, it was decided to measure the FBG properties after the annealing step instead of after the final recoat. The recoating step is currently being improved to ensure that a change in wavelength does not occur.

To quantify the laser annealing process for the fibres being used, a thermal annealer was built and employed to heat the FBG to temperatures between 180-350°C for 20 minutes. A FBG spectrum was recorded every minute using the optical spectrum analyser to measure the properties of the grating. Figure 3 shows two spectra from a typical laser-processed FBG before and after thermal annealing at 300°C. The spectra from a FBG before and after laser annealing are shown in figure 4. It can be seen that the form of the change with laser annealing is very similar to that of thermal annealing. It was not possible to measure the temperature at which the laser annealing was performed but the laser exposure conditions were optimised such that the annealing characteristics matched those of thermal annealing.

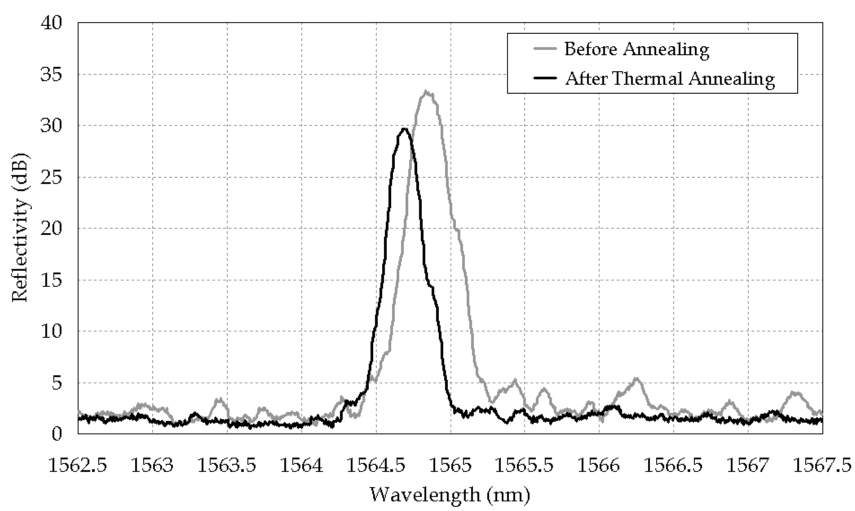

Fig.3. FBG spectra before and after thermal annealing at 300°C.

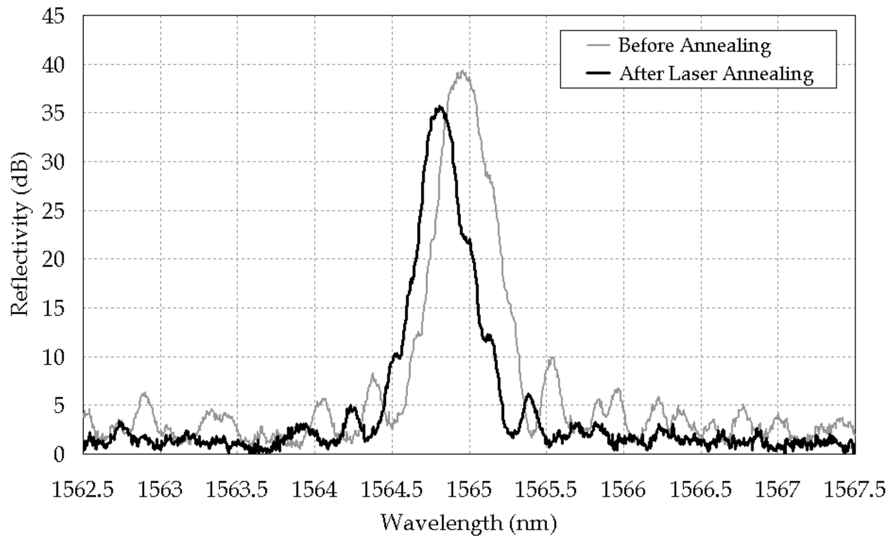

Fig.4. FBG spectra before and after laser annealing.

Figure 5 shows the change in centre wavelength and change in reflectivity with the thermal and laser annealing processes and it can be seen that the laser annealing matches very closely the behaviour of the FBG under thermal annealing.

This confirms the validity of using a laser to anneal FBGs. In both types of annealing, the centre wavelength was reduced by 0.15nm after annealing and the reflectivity dropped by 3.6dB. The rate of change in the centre wavelength was virtually identical for both thermal and laser annealing whereas the rate of change of reflectivity showed a larger initial decay for laser annealing than for thermal annealing. Further work is underway to characterise the laser annealing process in more detail and to quantify the laser annealing processes for different temperatures.

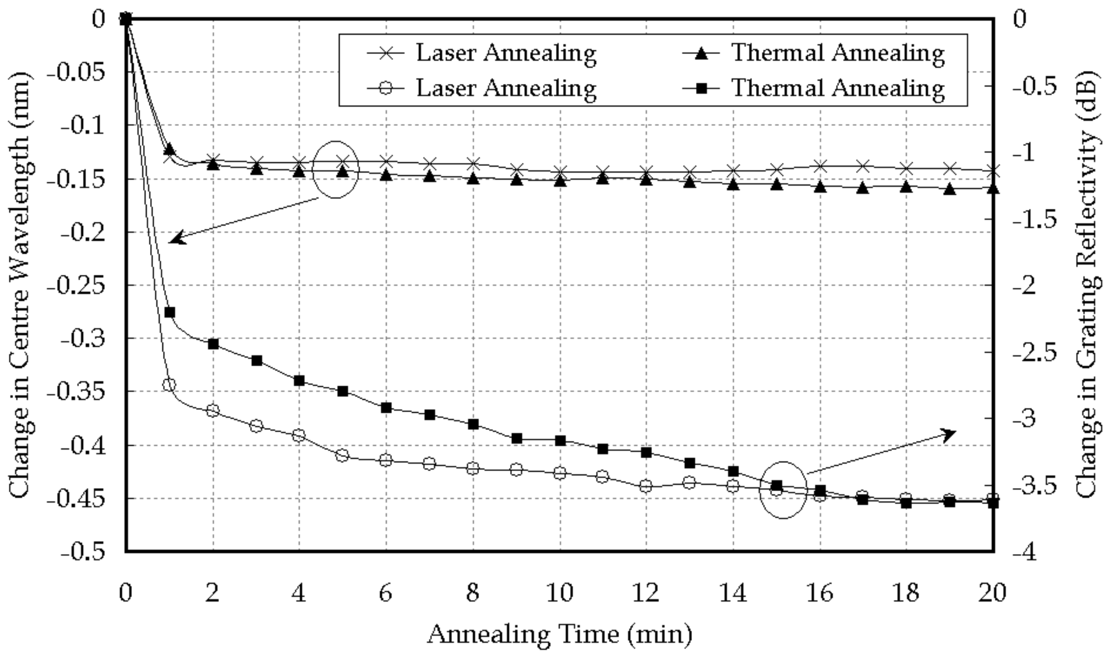

Figure 5. Response of FBG centre wavelength and reflectivity to laser and thermal annealing.

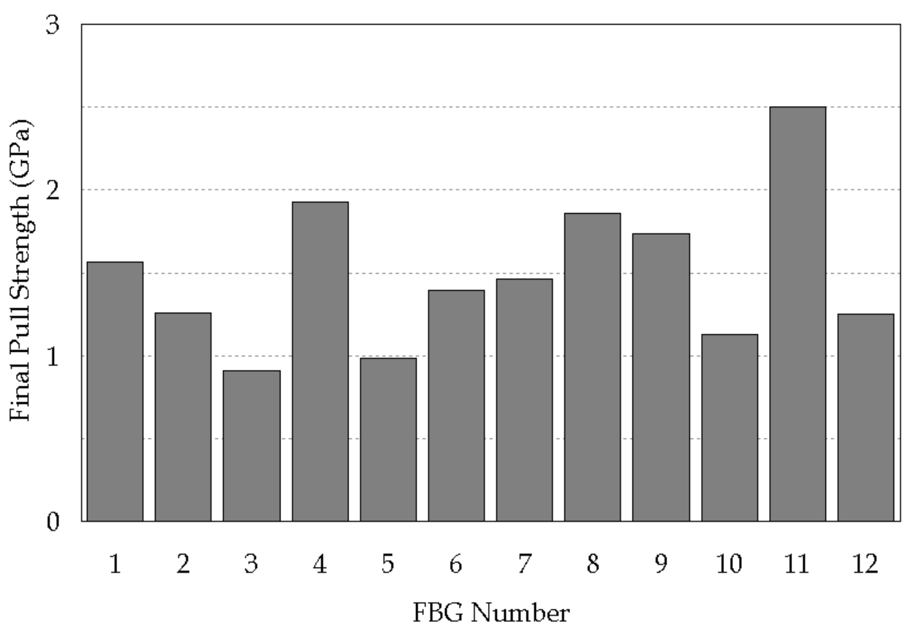

Figure 6. Final pull strengths of fibres after laser stripping, grating inscription and laser annealing.

The pull strengths of the fibres after laser stripping, grating writing and laser annealing were measured and figure 6 shows the distribution of the strengths. The large variation in the strengths is attributable to the manual handling steps involved but despite this, however, all the 12 fibres processed showed strengths above ~0.69GPa (100kpsi). The values of the final pull strengths as shown in figure 6 have not been corrected for the handling steps and so are the real final strengths of the actual fibres which were processed. The removal of the manual handling steps will, of course, improve the final strengths further. It is also to be noted that use of the argon-ion lasers for the grating writing, which do not affect the pull strengths of the fibres as much, should increase the final pull strengths by ~1.034GPa (150kpsi) compared to the excimer laser results shown here.

The 355nm laser-assisted recoating of the fibre was used here purely to demonstrate the possibility of this method. In this particular case, where a CO_2 laser was used for stripping, it is obviously excessive to employ a laser for the recoating. However, in some cases, the fibre's coating may be more efficiently and cleanly removed using a 355nm laser and we have observed this for non-acrylate coatings. In such a situation, it would be simple and efficient to use the 355nm laser for recoating, as demonstrated here.

5. Discussion

One of the main attractions of laser production methods is the ability to automate the procedures and the demonstration of completely laser-based manufacture of FBG devices presented here opens up this possibility for telecommunications devices. Inherent in this automation route is the opportunity to reduce the process time as compared with ‘conventional’ methods. In such methods, the fibre stripping is usually accomplished with thermal and / or chemical means and the annealing is performed using thermal annealers. The biggest decrease in the production time is gained by using laser stripping – typical chemical procedures can take between 10-15 minutes to produce a clean, 25mm long, mid-span strip of fibre whereas the laser stripping demonstrated here took under 3 seconds to produce the same strip length. Laser manufacturing also offers great flexibility in the processes which can be used, for example in the lengths of fibre which are stripped, the types of gratings which are written and the conditions for annealing which are used. All such processes can be easily held as recipes for different components in an automated workstation and so laser manufacturing enables simple, labour un-intensive, flexible, high yield and high throughout production options for future demands.

6. Summary

A completely laser-based process has been shown to be capable of producing stable, high reflectivity (30dB) FBGs in a photosensitive fibre where all steps have used laser-based techniques. Laser annealing of the FBGs has been validated against thermal annealing and the final pull strengths of the fibres have been measured to be acceptably high at >1.03GPa (100kpsi).

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8. References

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