POINT-BY-POINT FABRICATION OF MICRO-BRAGG GRATINGS IN PHOTOSENSITIVE FIBRE USING SINGLE EXCIMER PULSE REFRACTIVE INDEX MODIFICATION TECHNIQUES

B. Malo, K. O. Hill, F. Bilodeau, D. C. Johnson and J. Albert

Indexing terms: Optical fibres, Laser applications

Optical fibre Bragg reflectors have been fabricated using a single pulse of high power 249 nm excimer laser light to photoinduce point-by-point each individual index element forming the grating. Bragg reflectors with a length of 360 μm and reflectivity of 70% have been made.

Introduction: Hill *et al.* [1] demonstrated the use of a KrF excimer laser to write point-by-point the index perturbations that can be used to configure in-fibre mode convertor gratings. In this waveguide-grating formation method, a small section (length W) of photosensitive optical fibre is exposed from the side to a collimated beam of ultraviolet light passing through a mask containing a slit of width W. The light irradiation increases slightly the refractive index of the core in the exposed fibre section (photosensitive response). The fibre is then translated in a direction parallel to the fibre axis through a distance Λ corresponding to the pitch of the grating and a second small fibre section of length W is irradiated. The length W of the exposed fibre section is typically of order $\Lambda/2$. By repeating the irradiation and translation process, a periodic sequence of index perturbations is written point-by-point to form a grating structure in the fibre core. The point-by-point writing technique is highly effective for fabricating spatial mode convertors [1, 2] and polarisation mode convertors [3, 4] that have periods Λ ranging from tens of micrometres to tens of centimetres. The principal advantage of writing gratings used the point-by-point technique is flexibility. The period of the grating is easily controlled and grating structures that have chirped periods or apodised coupling coefficients are possible [5].

We report extension of the point-by-point technique to the fabrication of efficient 1500 nm resonant fibre Bragg grating reflectors operating in the 2nd or 3rd order that have a grating pitch of $\Lambda \simeq 1$ and $1{\cdot}5\,\mu m$, respectively.

For point-by-point fabrication of Bragg gratings, we rely on photoinducing refractive index changes in the fibre core using a single pulse from an excimer laser [6, 7]. Each element of the grating is written by imaging a slit on the photosensitive fibre core and then using a single laser pulse to illuminate the slit at normal incidence. The process for photoinducing an index change at the fluence levels used in single pulse writing has been shown to be very nonlinear [8, 9]. Thus, the difficulties intrinsic to the point-by-point writing process that are associated with the need to align and translate the fibre through the image plane of the slit are reduced significantly. In single pulse writing with a focused light beam, photoinduced index changes occur only in the focal region where the light intensity is above a fairly sharply defined threshold [8, 9]. Furthermore, the size of the region in which the refractive index changes occur can be smaller than the spot size of the focused light beam.

We demonstrate point-by-point writing of in-fibre Bragg gratings using single-excimer-light-pulse irradiation. The devices we have made are short length (<0·5 mm) micro-Bragg fibre reflectors with high reflectivity.

Experiment and results: We write the point-by-point Bragg reflectors using ultraviolet light that is generated by an unstable cavity resonator Lumonics EX-510 KrF excimer laser and which has passed through a slit (with $\simeq 15\,\mu m$). A lens ($NA = 0{\cdot}25$, focal length 15 mm) images the slit on the core of the optical fibre with the long dimension of the image oriented perpendicular to the axis of the optical fibre. In the image plane, we estimate that the image size is $500 \times 1{\cdot}5\,\mu m^2$ and that the fluence level produced by a single 248 nm ultraviolet light pulse is $5\,J/cm^2$. With these irradiation conditions, the width W of the photoinduced perturbation in the fibre core is estimated to be $\sim 0{\cdot}7\,\mu m$. Bragg gratings can then be fabricated, using the point-by-point technique that we have described previously, by translating the fibre between each irradiation step with the aid of an interferometrically controlled translation stage. The whole point-by-point writing process has been automated so that the triggering of the excimer laser and the precision stepping of the fibre are carried out under computer control.

Using the point-by-point fabrication technique, we have made 1500 nm fibre Bragg reflectors in Andrew D-type polarisation maintaining fibre (cutoff wavelength 1200 nm, beat length $L_B = 7\,mm$ at 1300 nm, core/cladding $\Delta n = 0{\cdot}031$ and elliptical core size $2 \times 4\,\mu m^2$). The fibres are irradiated from the side through the flat cladding side of the D shaped fibre. The period Λ required for a grating in the D-fibre to reflect light in first order at 1500 nm is 530 nm. Because the width W, of index perturbation photoinduced in the fibre core using our experimental setup is larger than the 530 nm period, we are unable, at present, to fabricate first order 1500 nm Bragg using the point-by-point technique. Instead we have fabricated Bragg gratings which reflect light in the 2nd order or 3rd order at 1500 nm. Fig. 1 illustrates the spectral response of a 3rd order Bragg grating reflector in a wavelength region surrounding the resonator wavelength. In this case the grating period is $\Lambda = 1{\cdot}59\,\mu m$ and the grating contains 225 index perturbations resulting in a device length of 360 μm. The grating has a peak reflectivity of 70% at 1536 nm and an FWHM (full width at half maximum) of 2·7 nm. We calculate the refractive index modulation Δn_{mod}, for the third-order Bragg reflector at 1536 nm to be 0·006.

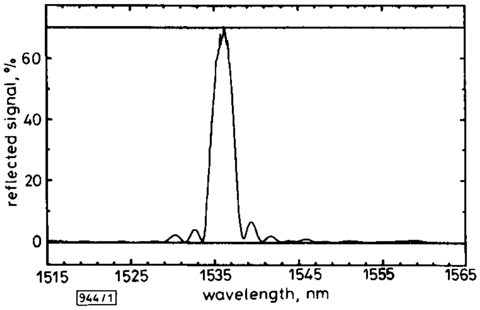

Fig. 1 *Reflection spectrum of third order Bragg grating*
Peak reflectivity is ~70%

These micro-Bragg reflectors also act as taps for light at wavelengths shorter than the first-order resonance wavelength. The spectral transmission response of the taps is similar to the response obtained for Bragg gratings fabricated using a phase mask and single pulse excimer laser irradiation.* At wavelengths shorter than the resonance wavelength, the Bragg grating couples the light out of the core into radiation modes of the waveguide. The effect is manifested as a light loss in transmission through the Bragg reflector. In the case of the Bragg reflector whose spectral response is shown in Fig. 1, the loss in the spectral region surrounding the resonance wavelength is too low to be measured directly. We are able however, to measure a transmission loss of 0·2 dB for 1536 nm light passing through a longer grating structure (700 steps, length 954 μm) having the same period. Thus, we estimate the insertion loss of the 360 μm micro-Bragg reflector in the spectral region surrounding the 1536 nm resonance to be less than 0·1 dB.

Another characteristic of the micro-Bragg reflectors is that light reflection can be obtained at wavelengths which satisfy

---

* MALO, B., JOHNSON, D. C., BILODEAU, F., ALBERT, J., and HILL, K. O.: 'Single excimer pulse writing of fiber gratings using a zero order nulled phase mask: Grating spectral response and visualization of index perturbations', submitted to *Opt. Lett.*

the Bragg resonance conditions for higher order reflections. The $1\cdot59\,\mu m$ period micro-Bragg grating has a strong 4th order resonance at 1150 nm which we have also observed.

Conclusions: Short length micro-Bragg reflectors have been made using the point-by-point fabrication technique by single excimer laser pulse irradiation. The reflectors are short ($< 0\cdot5$ mm) and have high reflectivity and may find applications as DFB reflectors for semiconductor lasers, point sensors and as fibre taps that appear promising for back plane interconnect using optical fibre waveguides. Furthermore the point-by-point fabrication technique is very flexible, thereby permitting the fabrication of gratings with a variety of different lengths, grating periods and spectral responses.

4th May 1993

B. Malo, K. O. Hill, F. Bilodeau, D. C. Johnson and J. Albert (*Communications Research Center, PO Box 11490, Station 'H', Ottawa, Ontario K2H 8S2, Canada*)

References

1 HILL, K. O., BILODEAU, F., MALO, B., JOHNSON, D. C., and SKINNER, I.: 'Efficient mode conversion in telecommunication fibre using externally written gratings', *Electron. Lett.*, 1990, **26**, pp. 1270–1272

2 BILODEAU, F., HILL, K. O., MALO, B., JOHNSON, D. C., and SKINNER, I. M.: 'Efficient, narrowband $LP_{01} \leftrightarrow LP_{02}$ mode convertors fabricated in photosensitive fibre: Spectral response', *Electron. Lett.*, 1991, **27**, pp. 682–683

3 HILL, K. O., BILODEAU, F., MALO, B., and JOHNSON, D. C.: 'Birefringent photosensitivity in monomode optical fibre: Application to external writing of rocking filters', *Electron. Lett.*, 1991, **27**, pp. 1548–1549

4 JOHNSON, D. C., BILODEAU, F., MALO, B., HILL, K. O., WIGLEY, P. G. J., and STEGEMAN, G. I.: 'Long-length, long-period rocking filters fabricated from conventional monomode telecommunications optical fiber', *Opt. Lett.*, 1992, **17**, pp. 1635–1637

5 MALO, B., BILODEAU, F., JOHNSON, D. C., and HILL, K. O.: 'Rocking filters written in photosensitive birefringent fiber: Suppression of sidelobes in filter wavelength response'. Proc. 1992 Optical Fiber Communications Conf., OFC '92, San Jose, California, 2nd–7th February 1992, Postdeadline Paper, PD-23, pp. 404–407

6 ASKINS, C. G., TSAI, T.-E., WILLIAMS, G. M., PUTMAN, M. A., BASHKANSKY, M., and FRIEBELE, E. J.: 'Fiber Bragg reflectors prepared by a single excimer pulse', *Opt. Lett.*, 1992, **17**, pp. 833–835

7 ARCHAMBAULT, J.-L., REEKIE, L., and RUSSELL, P. ST. J.: 'High reflectivity and narrow linewidth bandwidth fibre gratings written by single excimer pulse', *Electron. Lett.*, 1993, **29**, pp. 28–29

8 REEKIE, L., ARCHAMBAULT, J.-L., and RUSSELL, P. ST. J.: '100% reflectivity fibre gratings produced by a single excimer laser pulse'. Proc. 1993 Optical Fiber Communications Conf., OFC '93, San Jose, California, 16th–22nd 1993, Postdeadline Paper PD-14, pp. 60–63

ERRATUM

AKIRA, M., HIDETOSHI, N., and TOHRU, M.: 'Signal self-thresholding using wavelength-division multiplexed differential transmission for photonic ATM switches', *Electron. Lett.*, 1993, **29**, (15), pp. 1337–1338

Editor's corrections

The surnames and given names of the authors were confused: The names of the authors should therefore read

A. Misawa, H. Nakano and T. Matsunaga

The citation should read

MISAWA, A., NAKANO, H., and MATSUNAGA, T.: 'Signal self-thresholding using wavelength-division multiplexed differential transmission for photonic ATM switches', *Electron. Lett.*, 1993, **29**, (15), pp. 1337–1338; erratum, 1993, **29**, (18), p. 1669

The entry in the list of contents for issue 15 is correct

ESTIMATION OF LENGTH FOR *ELECTRONICS LETTERS*

Title + Abstract	4 col cm
Authors	2 col cm per address
Text	1 col cm per 165 characters Estimate number of characters (including spaces) per line and number of lines per page. Add 0·5 or 1 col cm for each equation unless it is well displayed; similarly for each line in a matrix
Tables	1 col cm for title, 0·5 col cm for each line (including blanks). Double up for wide (double column) tables
Figure captions	1 col cm for main caption. 0·33 col cm per line for subcaptions, including keys which would be moved from the graphics
Figures	These are usually reduced to single column width as per this table:

Width (inches)	Reduction (%)
Less than 3·5	95
3·5–4·4	75
4·4–5·3	62
5·3–6·1	54
6·1–7·0	47
7·0–8·9	37
8·9–10·6	31
10·6–12·2	27

If the figure needs to be reproduced over two columns the result of the above calculation must be multiplied by *four*

References	1 col cm each