Mechanically Induced Chirped Long Period Gratings

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ABSTRACT
Long period fiber gratings (LPFGs) in single mode fibres have been induced by creating periodic microbending in the fiber in an array made of graphite rods. The transmission spectra of the resulting LPFGs is studied. Wide tunability of the loss peaks in the transmission spectrum is observed. Introducing a small chirp in the LPFG leads to considerable broadening of loss peaks. Finally, it has been shown that transmission spectrum of mechanically induced LPFGs show very little polarisation dependence.

Keywords: Long period fiber gratings, microbends, chirped grating.

1. INTRODUCTION
Long period fiber gratings (LPFGs) are devices with a periodic refractive index perturbation written in the core of the optical fiber that couples a forward propagating core mode to forward propagating cladding modes. They operate as wavelength dependent loss elements and find extensive applications in wavelength division multiplexing systems (WDMs) as gain flattening filters for erbium doped fiber amplifiers (EDFAs), as well as fiberoptic sensors 1-3. These gratings are fabricated using several techniques such as UV exposure using excimer lasers 1-3, point by point writing using CO₂ lasers4, or using fiber fusion splice machine5,6. Mechanically induced periodic microbends in optical fibers are also known to induce mode coupling 7,8. In a recent study7, the authors induced periodic microbends in an erbium-doped optical fiber and demonstrated gain-flattening with a gain variation of less than 0.93 dB over a wavelength range from 1525.3 nm to 1558.3 nm. While such a set-up is useful in realizing gain-flattening in EDFAs, a study of properties of LPFGs induced by such periodic microbends in itself is interesting. In this paper, we report tuning characteristics of such periodic microbend gratings using different fibers and show for the first time, the possibility of realizing chirped LPFGs with such a scheme. Effect of polarized light on transmission spectrum of LPFGs is also explored.

2. EXPERIMENTAL
A set-up for periodic microbends was fabricated similar to the one reported in7. Arrays of graphite rods of diameters 0.5 mm, 0.7 mm, and 0.9 mm were used to create microbends at those periods. We refer to such an array as ‘grating’. A single mode optical fiber (Corning SMF-28) was placed over this array and was held taut so that it was normal to the array of graphite rods. The fiber could be stressed against the graphite rods from the top using a flat plate. White light was launched into this fiber and the transmitted light analysed by an optical spectrum analyzer (HP 70004A). Experiments were carried out with and without the fiber jacket. Spectral data was stored on a computer using HP-IB interface. The experimental setup is shown in Fig. 1. We also carried out experiments in which, the fiber was pressed between two identical arrays of graphite rods, with the graphite rods of the top array resting between those of the bottom array. We refer to this as double-side grating in this paper. The LPFG was tuned by placing the fiber at an angle with respect to the grating array and varying the angle while chirp in the LPFG was induced by placing the fiber along a curved arc on the array.

3. RESULTS AND DISCUSSION
The transmission spectra of LPFG with a period of 0.5 mm for (a) jacketed and (b) unjacketed fiber, where the fiber is pressed on the grating from the top using a flat plate is shown in Fig. 2. In both the cases, we see four loss peaks which occur at about 1396.5 nm, 1430 nm and 1500 nm and 1646 nm respectively. This indicates that the presence or absence of fiber jacket does not really affect the performance of the device. Therefore, one could also induce an LPFG without removing the jacket that also enables one to handle the fiber easily. In our experiments, we found that
an unjacketed fiber required much less pressure to produce the same amount of loss at a given phase matching wavelength compared to that in a jacketed fiber.

\[
\text{Pressure} \\
\text{Optical fiber} \\
\text{White light source} \\
\text{OSA}
\]

Figure 1: Experimental set-up for mechanically induced LPFGs. OSA : Optical Spectrum Analyser

This is due to the fact that the effective applied pressure in an unjacketed fiber is directly transmitted to the optical fiber, unlike the case of jacketed fiber where the actual pressure seen by the fiber is much less.

\[\text{Fig. 3(a) shows the arrangement of graphite rods to create a double-side grating as mentioned in the experimental arrangement above. The transmission spectrum corresponding to this arrangement is shown in Fig.3(b). An interesting observation in this case is the appearance of new peaks. There are eight peaks in all, appearing at 1380.9nm, 1396.0nm, 1413.6nm, 1429.2nm, 1479.9nm, 1497.0nm, 1611.4nm and 1642.2nm. In addition to loss peaks obtained using a single-side grating, the additional peaks that we see here appear at 1380.9 nm, 1413.6 nm, 1479.9 nm, 1611.4 nm. In this configuration, one clearly induces microbends in the fiber as shown in Fig. 3(a) which is different from the case where the fiber is pressed with a flat surface on one side.}\n
\[\text{Fig. 2: Transmission spectrum of a 0.5 mm period LPFG produced using the array of graphite rods (a) fiber with plastic jacket, (b) fiber without plastic jacket}\n
\[\text{Fig. 3: (a) Arrangement of graphite rods for double-side grating (b) corresponding transmission spectrum. Fiber used in this study was SMF-28}\n
\[\text{The periodic refractive index perturbations in the first case (single-side grating) could be primarily stress induced since the points of stress would be those where the flat plate presses the fiber against the graphite rods, while the}\]
second case (Fig.3b) is due to periodic microbend, leading to clearly different spectral characteristics in both these cases.

When the fiber is placed at an angle with respect to the graphite rods, we observe a shift towards longer wavelengths in the peak loss positions which is expected. This happens because the effective grating period in this case is larger than the original grating period by a factor of $(\cos \theta)^{-1}$. Fig. 4. shows the shift in peak loss wavelength for all the three peaks as shown in Fig. 1 as a function of grating period, where the original grating period is 700 µm.

![Figure 4](image-url)  

**Figure 4:** Tuning characteristics of the three observed loss peaks of the induced LPFG as a function of grating period for Corning SMF-28. The original grating period was 700 µm.

As it can be seen from the figure, the loss peaks are broadly tunable. For example, the loss peak corresponding to 1542.5 nm at 700 µm period can be continuously tuned upto 1685 nm which corresponds to a period of 808 µm. This indicates a peak loss wavelength tunability of over 140 nm with a change in period of about 108 µm. Therefore, it becomes possible to use this set-up as a tunable long period grating which has a unique advantage over LPFGs that are fabricated using other techniques mentioned in the introduction. In those LPFGs, the period is fixed once the grating is fabricated except for small variations that could be induced by longitudinal strain.

In order to induce a chirp in the LPFG, we curved the fiber on the grating array as mentioned earlier. In such a configuration, if $\theta$ is the angle made by a tangent to the fiber at a given point, then the period $\Lambda(z)$ at that position is given by,

$$\Lambda(z) = \Lambda_0/\cos \theta \quad [1]$$

where $\Lambda_0$ is the grating period without any chirp. Since the angle $\theta$ continuously changes along the fiber, this leads to continuous variation of the grating period. As $\cos \theta \leq 1$, the grating period $\Lambda(z) \geq \Lambda_0$ in the fiber at any point. In this case, the grating has a negative chirp, since the grating period gradually increases along its length. Fig. 5 shows the transmission spectra of chirped gratings. For reference, corresponding spectra of an unchirped grating is also shown.

The grating period in (a) varied from 500.0 µm (initial grating period) to 500.5 µm (final grating period) which corresponds to a chirp parameter of $-1.69 \times 10^{-5}$ while that for (b) varied from 500 µm to 501.2 µm, corresponding to a chirp parameter of $- 4.06 \times 10^{-5}$. In both the cases, all the three loss peaks broaden considerably even with a small chirp. A larger chirp broadened the spectrum considerably. A properly designed single chirped grating can be thus be employed in gain-flattening EDFAs rather than using concatenation of LPFGs.

We also recorded transmission spectrum of LPFGs where Corning’s large effective area fiber (LEAF) fiber and a dispersion shifted fiber (DSF) were used. The transmission spectrum of LPFG using IEAF is shown in Fig. 6(a). Even in this case, three peaks are clearly observed at 1363.2 nm, 1455 nm and close to 1520 nm. The grating period in this case was 500 µm.
Figure 5: Transmission spectrum of chirped LPFG where the chirp parameter $C$ is (a) $-1.69 \times 10^{-5}$, and (b) $-4.06 \times 10^{-5}$. Transmission spectrum of unchirped grating is also included for reference. The fiber used was Corning SMF-28.

However, in the same fiber with the same grating period, when one creates tilted gratings with a tilt angle of $17^\circ$, a remarkable change in the spectral features of the grating is seen, which is shown in figs 6(b) and (c). Here the tilt angle is with respect to the fibre axis.

Figure 6: Transmission spectra of LPFG in SMF-28 with a period of 0.5 mm with tilt angle (a) 0° (b) 17° (c) 43°.
It can be seen from Fig. 6(b) that with a tilt angle of 17°, the main loss peak located at 1363.2 nm shifts to 1403 nm. With further increase in tilt angle, the peak shifts further to 1583.6 nm as seen in Fig. 6(c). The changes in the transmission spectra due to the grating tilt is being investigated further.

Finally, response of LPFGs to incident light polarizations were investigated. The experimental setup for this consisted of an external white light source. Using a polarising prism and a microscope objective, light of a given polarization was launched into the fiber and its transmission spectrum recorded. Light of orthogonal polarization was then launched in the fiber, and the transmission spectrum of LPFG recorded again. Fig. 7 shows the transmission spectrum of LPFG in Corning SMF-28 with the two polarizations.

![Figure 7: Transmission spectrum of LPFG with unpolarised light (top). The middle and the bottom traces are for the two orthogonal polarisations.](image)

From the figure, it can be seen that there is a very small polarisation dependence seen in the transmission spectrum. Further investigations on this are under progress. This indicates that the LPFGs are not very sensitive to polarisation of light propagating in the fibre, which is an important feature.

## 4. CONCLUSION

In conclusion, we have demonstrated mechanically induced long period grating by pressing an optical fiber on a grating made of uniform graphite rods. The ‘single side’ and ‘double side’ gratings show primarily different transmission spectra, which indicates in the former the periodic refractive index change could be stress induced, while in the latter, the observed spectrum could be due to periodic microbends. The peak loss wavelength of the gratings is continuously tunable over a large wavelength range. Chirping the grating by even a small amount results in considerable broadening of the loss peaks. This arrangement could be suitable to generate complex transmission spectra and for flattening the gain of EDFAs.

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## REFERENCES


