Equalisation of Spectral Non-Uniformities in Broad-Band Chirped Fibre Gratings

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Abstract
The authors present a novel application of apodisation to equalise the spectral non-uniformities caused by cladding-mode losses in broad-band chirped fibre Bragg gratings.

Introduction
The use of chirped fibre Bragg gratings (FBGs) in a dispersion compensating role has been shown to be a successful technology with great promise for future network upgrades [1, 2]. A natural consequence of using FBGs in a negative dispersion sense is that although the structure is designed to phase-match forward- and backward-propagating LP01 modes, the phase-matching condition for coupling from the forward propagating fundamental mode to a higher order cladding-mode is also met for wavelengths just below that of the fundamental Bragg reflection. Because propagation in cladding-modes is extremely lossy there is a significant out-coupling of this shorter wavelength light. The chirped nature of FBGs designed for broad-band (> 5nm) dispersion compensation means that this cladding-mode loss is integrated along the length of the grating with the result that the reflection spectrum has a slope extending from the short wavelength edge of the useable bandwidth. In a practical transmission system this in-band variation of reflectivity is unacceptable. In this paper the authors present for the first time a demonstration of spectral equalisation of cladding-mode losses by exercising control over local apodisation along the length of a 8.5nm 75cm long continuously-written chirped FBG. No post-processing was used.

Experiment
The longitudinal distribution of the spatial frequencies that comprise the structure of a chirped FBG means that a localised change of coupling constant converts directly to a narrow-band modulation of spectral response. Although it is possible to temper the coupling constant by regulating the fluence of the UV writing beam, this leads to a change in background refractive index and hence induce an undesirable chirping effect. The technique of apodisation [3], in contrast, allows the direct control over the index modulation of a FBG without altering the background index and hence the dispersion characteristic of the device remains unaffected. In this paper the authors describe an experiment where the dispersion-friendly process of apodisation is turned to face and overcome the problem of non-uniform spectral response in chirped FBGs caused by short-wavelength cladding-mode losses.

Figure 1 shows the effect of cladding-mode loss on a 8.5nm 75cm long high-quality chirped FBG designed to compensate 50 km of step index fibre with a dispersion of 17 ps/nm/km when characterised in a negative dispersion sense. The grating was fabricated with the 100 mW 244 nm output of a CW laser in a fibre of ~ 0.2 N.A. using a variation on the moving-fibre/phase-mask scanning technique [3] and was characterised with 5pm steps using a wavemeter accurate to 0.15pm. The loss induced as a result of coupling to cladding modes is ~ 2.5dB, with the first...
cladding mode (associated with longest structural period) observed at a wavelength approximately 3nm short of the corresponding Bragg phase-matching condition.

By using a suitable apodisation profile it is possible to reduce the coupling constant of the grating at the long wavelength end and thus both lower the coupling of short wavelengths to lossy cladding-modes and compensate for any remaining spectral non-uniformity. Figure 2 shows a 8.5nm 75cm long chirped FBG made with an apodisation profile designed to counteract the effects of cladding-mode loss when the grating is used in a negative dispersion sense; it is clear that the effects of short wavelength cladding-mode loss have been successfully equalised. This figure also confirms that the dispersion is not unduly affected when apodisation is used to locally vary the coupling constant of a grating.

The use of apodisation to vary the local coupling constant of the grating inevitably means that there will be a decrease of maximum reflectivity, but in many applications the demand for spectral uniformity outweighs the need for very low insertion losses. The fibre used in this experiment exhibited undesirably strong coupling to cladding-modes and hence the insertion loss of the spectrally-equalised device is more than would be ideal; the use of fibre with a higher N.A. or
Figure 2. A chirped FBG fabricated with an apodisation profile designed to compensate for the effects of cladding-modes can be seen to have a flat reflection spectrum when used in a negative dispersion sense (b). The shaping of the grating is evident when viewed in transmission (c) and the dispersion is still clearly linear (d).

depressed cladding would help minimise this effect by suppressing the coupling to cladding-modes somewhat [4].

Summary

This demonstration of spectral equalisation of cladding-mode effects shows that the use of apodisation should not just be considered as a tool to reduce unwanted coherence effects, but rather as a method of tailoring the spectral response of FBGs without affecting their dispersion. The successful flattening of a broad-band chirped FBG will be crucial for dispersion compensation in fibre link where there is either significant drift of the carrier wavelength or several WDM channels. The application of apodisation to spectral shaping is not just limited to this example and, by the time of the conference, the authors hope to show spectral flattening of FBGs designed for combined 2nd and 3rd order dispersion compensation [5], and also FBG devices for combined dispersion compensation and EDFA gain flattening.
References


