Short-wavelength, transmission-loss suppression in Fibre Bragg Gratings

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Introduction

Fibre Bragg Gratings (FBG's) are known to suffer from short-wavelength, transmission losses due to resonant coupling into backward-propagating cladding modes [1,2]. Figure 1 shows a typical transmission spectrum of a 10cm standard FBG. The cladding mode losses increase with grating reflectivity and could eventually impose severe limitations in the use of FBG's. The problem can be quite acute in the case that FBG wavelength-multiplexing is required. So far, several attempts have been made to eliminate the short-wavelength, transmission losses and improve grating performance [2-5]. In all cases, the resonant coupling of the forward-propagating core mode to the backward-propagating cladding modes is minimised by reducing the coupling strength.

In this paper, we report on a novel method for reducing cladding-mode transmission losses in standard FBG's. We show that short wavelength, transmission losses can be practically eliminated by *damping* the resonant excitation of the cladding modes. The damping is achieved by properly introducing a substantial propagation loss into the cladding modes. For maximum effect, the core mode should experience no extra propagation losses. By applying a thin lossy layer on the fibre cladding surface, a reduction of cladding-mode-losses of about 12dB was achieved.

Transmission-loss suppression

The cladding mode attenuation can be easily achieved by depositing a thin lossy layer on the cladding surface. Alternatively, the same effect can be accomplished by introducing one or more lossy layers into the fibre cladding during the fabrication process. The latter will result in a stronger cladding-mode/lossy-material overlap and, therefore, produce higher propagation losses.

A. Theory

The presence of losses in the cladding modes renders their propagation constants complex, i.e. $\beta'_n = \beta^{cl}_n + i\alpha^{cl}_n$ ($\alpha^{cl}_n < 0$). The core mode is supposed to remain lossless ($\alpha^c_0 = 0$). The transmission coefficient of a grating which couples the forward-propagating core mode into the *n*th-order backward-propagating cladding mode is given by:

$$t_{0n} = \frac{s_{0n}}{s_{0n}\cosh(s_{0n}L) + i\dfrac{\delta_{0n}}{2}\sinh(s_{0n}L)}\, e^{-i(\beta^c_0 - \frac{\delta_{0n}}{2})L}$$

where κ_{0n} is the coupling coefficient and δ_{0n} is the complex momentum mismatch, given by:

$$\delta_{0n} = \beta^c_0 + (\beta^{cl}_n + i\alpha^{cl}_n) - K_0 \qquad \text{and} \qquad s_{0n} = \sqrt{\kappa^2_{0n} - \left(\frac{\delta}{2}\right)^2}$$

Figure 2 shows the transmission spectra of the grating-assisted coupling between the forward-propagating core mode and the backward-propagating n^{th}-order cladding mode, for various propagation losses. The grating length (L) is 10cm and the normalised refractive index perturbation ($\Delta n/n_0$) is 2 x 10^{-6}. The n^{th}-

cladding-mode loss (α^{cl}_{n}) varies between -1.0 and -20dB/cm. The lossless case ($\alpha^{cl}_{n} = 0$) is also shown for comparison. It is observed that as the cladding mode loss is gradually increased, the resonant coupling between the forward-propagating core mode and backward-propagating cladding mode is severely damped, resulting in a dramatic reduction of the grating transmissivity. However, as expected, the reduction of the peak transmission loss is attained at the expense of an increased transmission-loss bandwidth. Figure 2 shows the transmission loss corresponding to only one of the cladding modes. It is obvious that the rest of the cladding modes will show similar transmission-loss reductions, provided they experience comparable propagation losses.

The amount of transmission-loss reduction, achieved by a certain lossy material, depends on the initial maximum transmission loss of the grating. Figure 3 shows the required cladding-mode loss that should be applied in order to achieve a certain level of final (residual) transmission loss, as a function of the initial maximum transmission loss. The grating length is 10cm.

B. *Experimental Results*

Several strong Bragg gratings where written in different fibres exhibiting a number of short-wavelength sharp notches due to coupling into different backward-propagating cladding modes. Figure 4 shows part of a typical transmission-loss spectrum (dashed line) of a 10cm grating. The grating reflectivity was about 30dB. The solid line shows the transmission-loss spectrum after the grating was coated with a thin ink layer. A dramatic reduction in the short-wavelength transmission loss from about -14dB to about -2dB was observed. According to Figure 3, such a reduction implies that the thin ink layer introduces a cladding-mode propagation loss of about 1dB/cm. The broadening of the damped transmission resonance is also apparent (cf. Figure 2). Similar thin ink layers were applied to weaker gratings, with maximum short-wavelength transmission losses of about 1dB, resulting in a complete restoration of the transmission spectrum.

Figure 5 shows the variation of the transmission loss as a function of the grating length over which the lossy ink layer has been applied. The grating length was 10cm. It was shown that the transmission loss was decreased quasi-linearly with the coated length (or equivalently, with the total applied cladding-mode propagation loss). The maximum transmission-loss reduction was achieved when the entire grating was coated with the lossy layer. According to Figure 3, a reduction of transmission losses from about -4.5dB to about -0.5dB implies again that the thin ink layer introduces a cladding-mode propagation loss of about 1dB/cm. Figure 5 also suggests that control of the cladding-mode propagation losses can be used as a means of achieving a variable strength and bandwidth grating notch filter.

Discussion - Conclusions

In this paper, we have shown that short-wavelength transmission losses in standard FBG's can be practically eliminated by *damping* the resonant excitation of the cladding modes. By applying a thin lossy layer on the fibre-cladding surface, a reduction in cladding-mode-losses of about 12dB was achieved. Such a film induces a moderate cladding-mode propagation loss (about 1dB/cm). Using different lossy materials and/or including them into the cladding can provide higher cladding-mode propagation losses and result in stronger reduction of grating transmission losses. The initial narrow-band transmission notches are significantly reduced and spread evenly over a much wider bandwidth. When such a grating is used in WDM applications will provide an insignificant wide bandwidth loss. The proposed method can be used in conjunction with any of the other proposed methods [2-5] for the total elimination of cladding mode losses.

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References

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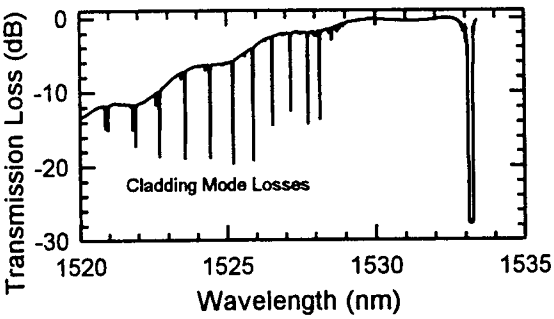

Figure 1: Typical transmission sprectrum of a 10cm Fiber Bragg Grating.

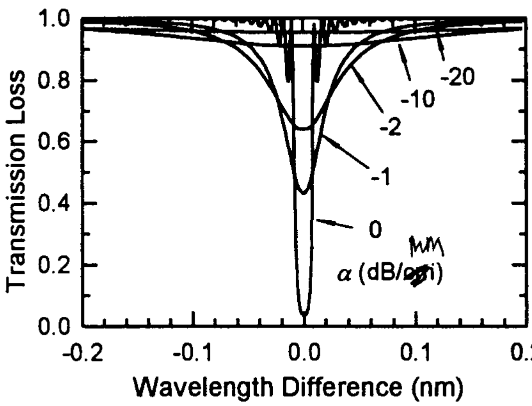

Figure 2: Transmission spectra of the coupling to the backward-propagating n^{th}-order cladding mode, for various propagation losses.

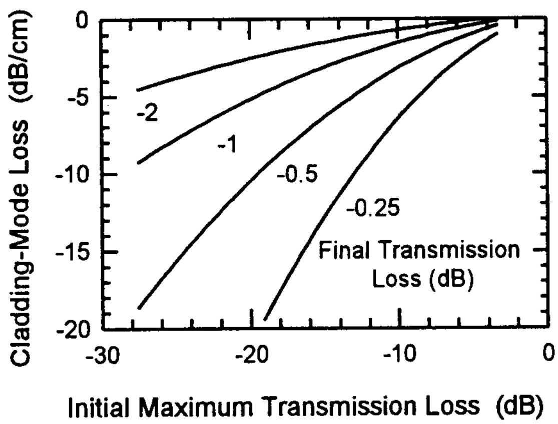

Figure 3: Required cladding-mode-loss in order to achieve a certain level of final transmission loss, as a function of the initial maximum transmission loss.

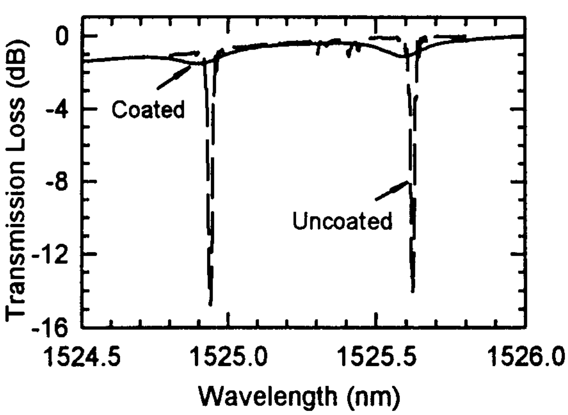

Figure 4: Part of a typical transmission-loss spectrum of a 10cm uncoated and coated FBG.

corresponds to α ~ 13dB/cm

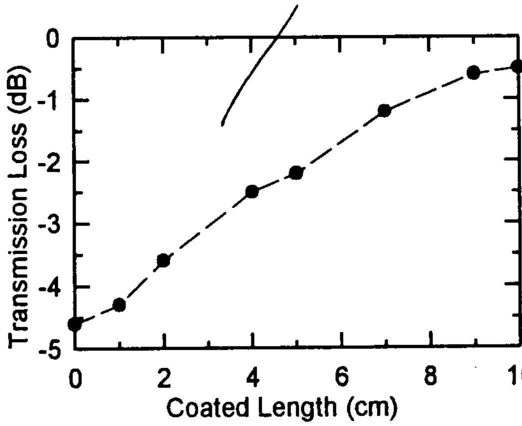

Figure 5: Variation of the transmission loss as a function of the coated grating length.

* Do with blazed gratings.