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ASYMMETRICALLY APODISED LINEARLY-CHIRPED FIBRE BRAGG GRATINGS WITH IMPROVED DISPERSION CHARACTERISTICS

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Abstract

Asymmetrically apodised linearly-chirped fibre Bragg gratings (FBGs) are shown to have highly linearised time-delay response. In simulations of a five-stage, 5-cm grating-based dispersion compensation system, asymmetrically apodised FBGs are shown to give over 60% reduction in the energy scattered from the main pulse body, for 16ps-60ps pulses propagated over 800km, as compared to a symmetrically apodised grating.

Introduction

It is now well established that in order to render fibre Bragg gratings (FBGs) suitable for high performance opto-electronic applications, proper apodisation, i.e. variation of the grating strength along its length, is needed [1-12]. It is also known that the apodisation requirements of linearly-chirped FBGs are quite different to the ones of the unchirped standard gratings [12]. However, in all the theoretical investigations and experimental implementations of linearly-chirped Bragg gratings to date, the apodisation profiles are always considered to be symmetric around the grating midpoint. In this paper, we present numerical results which demonstrate for the first time that, for high-reflectivity linearly-chirped fibre gratings, significant improvements in the linearity of the grating dispersion can be achieved through the use of asymmetric apodisation profiles with apodisation more pronounced towards the grating front (input) end.

Characteristics of Asymmetrically Apodised Gratings

For the purposes of the modelling presented here an apodisation profile based on the sine function was chosen for both the front and back end of the grating. The sine taper was then applied separately to each end of the grating structure over lengths defined by a percentage of the total grating length so that a different amount of the grating could be tapered at the front and back. The total effective length of the grating remains constant and, therefore, the maximum grating reflectivity, full-width half-maximum (FWHM) bandwidth and mean linear dispersion are retained.

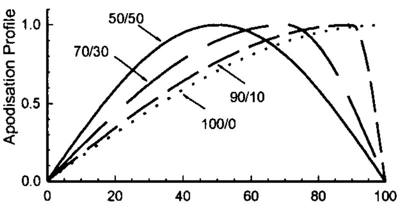

Figure 1: *Asymmetric apodisation profiles.*

Some representative asymmetric apodisation profiles are shown in Figure 1. The reflection characteristics of Bragg gratings with these tapers were calculated using coupled mode theory applicable to non-uniform aperiodic media [8]. To examine their effects in a practical grating, a length of 5cm and a central wavelength of 1550nm were chosen as typical of the photorefractive fibre gratings currently being written. In all calculations, the background refractive index variations and the resulting additional chirp have been ignored. Such an assumption is fully justified as recently developed phase-mask writing techniques [2-5] result in purely apodised gratings.

The various apodisation profiles were evaluated by calculating the mean linear dispersion D_m (in ps/nm) and average time-delay ripples $\Delta\tau_m$ (in ps) across the 10-dB reflection bandwidth. For each grating, both parameters were obtained from the corresponding time delay characteristics. The mean linear dispersion D_m was given by the slope of the best-fitted straight line. The average time-delay ripple $\Delta\tau_m$, on the other hand, was given by the mean value of the absolute differences of the actual time delays from the best-fitted straight line [12].

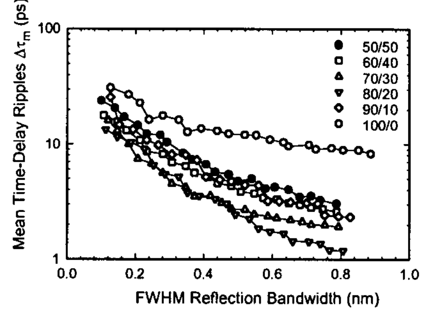

Figure 2: *Average time-delay ripples ($\Delta\tau_m$) versus FWHM reflection bandwidth, for sine apodisation profiles of different asymmetries. The grating length is 5cm and the peak reflectivity is 90%.*

Linearly chirped gratings with peak reflectivity of 90% and a FWHM bandwidth in the range of 0.05nm to 0.9nm were chosen. Although the mean linear dispersion D_m and FWHM bandwidth of the gratings remained almost unaffected by the taper asymmetry, the average time-delay ripples, shown in Figure 2, exhibited significant variations. It was observed that for FWHM bandwidths less than 0.4nm all the asymmetric profiles performed significantly better than the symmetrically apodised grating. However, for greater bandwidths the dispersion linearity of the 100%-0% taper profile was observed to deteriorate rapidly. This is to be due to the fact that the lack of apodisation at the grating far end gives rise to strong sidebands at the short-wavelength side of the affects adversely the in-band time-delay response (like in the unapodised case. Figure 2 shows that the optimum-asymmetry apodisation profile (~ 80/20) gave a reduction in the average time-delay ripples of ~40-60% across the whole range of the FWHM bandwidths considered.

The same calculations were then repeated for grating peak reflectivities in the range of 10% to 99.9%. The optimum profile asymmetry, i.e. the profile that resulted in an overall minimum $\Delta\tau_m$, was established for each reflectivity and the results are summarised in Figure 3. It is shown that the conventional symmetric (50/50) apodisation profile is close to optimum only for weak gratings (R < ~20%). As the peak reflectivity is increased, the optimum apodisation profile becomes gradually more asymmetric. For a peak reflectivity of 99.9%, the optimum asymmetry is ~ 85/15. The calculations were repeated for a number of different apodisation profiles, grating chirps and lengths with similar outcomes.

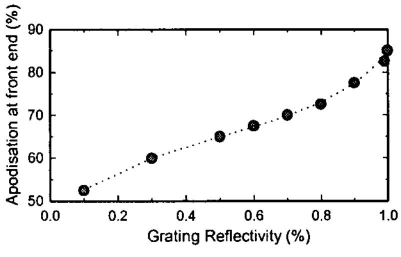

Figure 3: Optimum apodisation profile asymmetry as a function of the grating reflectivity. The grating length is 5cm, and the apodisation profiles are based on the sine function.

In-band residual non-linearities in the time delay response of apodised chirped FBGs originate primarily from the fact that the retarded wavelengths, which are progressively reflected from segments deeper into the grating, are suffering from the non-linear dispersion of the detuned preceding strong grating segments. Therefore, by increasing the degree of apodisation at the grating front (input) end, we minimise the in-band non-linear dispersion and obtain a highly-linearised overall time delay response.

Dispersion Compensation

In order to evaluate the effects of these gratings on a reflected pulse a simple transmission system was modelled. A single 16ps transform-limited $sech^2$ pulse was numerically transmitted over various lengths of SI fibre (17ps/nm/km dispersion) using 5cm, linearly chirped, 0.17nm 3dB bandwidth, 90% reflectivity gratings as dispersion compensators. Using a single grating a length of 130km could be compensated, resulting in the 35ps pulses. It was shown that, compared to the conventional, symmetrically apodised (50/50) grating, use of asymmetric (70/30 or 90/10) apodisation profiles results in a significant reduction in the pulse sidelobes, , even after a single reflection

In order to examine this further, the case of multiple reflections was examined, simulating a multi-stage fibre grating dispersion compensation system. A range of input pulse widths from 16ps to 120ps were propagated over a five-stage transmission line assuming that the power levels within the system remained in the linear regime at all times. For each input pulse width the length of step-index fibre in each stage was adjusted to give the minimum pulse width at the output. This varied from 160km/stage for the 16ps case giving a 56ps output pulse, to 174km/stage for the 120ps case giving a 130ps output pulse. Using a $sech^2$ fit to the main peak of the output pulse, an estimate of the energy scattered by the grating reflections was made. These results are presented in Figure 4 for gratings with 50/50, 70/30 and 90/10 apodisation profile asymmetries. It was observed that a reduction in the scattered energy by over 60% was achieved over almost the whole range of pulse widths studied for both the 70/30 and 90/10 asymmetries.

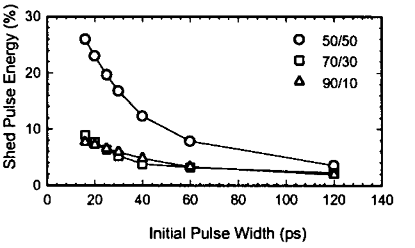

Figure 4: Shed pulse energy (in %) as a function of the initial pulse width.

Conclusions

In conclusion, we have proposed and numerically confirmed that the use of asymmetric apodisation profiles, with a pronounced tapering at the front (input) end of the grating, improves significantly the linearity of the time delay response of high-reflectivity linearly-chirped FBGs. These improvements were shown to translate to large reductions in the energy scattered after pulse reflection from such a structure (over 60% reduction after a five stage transmission system). Such taper functions would be simple to produce using many of the apodisation techniques reported in literature and could significantly improve system performance with no additional cost or complexity.

References

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