Interaction of uniform phase picosecond pulses with chirped and unchirped photosensitive fibre Bragg gratings


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Since its initial discovery [1], photosensitivity in optical fibres has been extensively investigated and developed with particular relevance to photoinduced Bragg gratings and their varied applications [2, 3]. In this Letter we report theoretical and experimental verification of the interaction of picosecond pulses of constant phase with fibre grating reflectors which to our knowledge has not been previously described.

A simple experimental scheme was used to investigate the spectral and temporal response to picosecond pulses reflected off the Bragg fibre gratings. To avoid any effects of inherent chirp the source of pulses was derived from a stabilised, picosecond 'figure of eight' erbium fibre soliton laser. This laser was tunable throughout the erbium gain band and was arranged to produce eight soliton pulses of 1.5ps duration with an associated bandwidth of 1.7nm. These were coupled with an average power in the milliwatt regime, via an optical isolator into a 3dB coupler, which had the Bragg grating fused to one of the output ports. The other output port was used to monitor the input pulses, while on reflection, the pulses were amplified in a diode pumped Yb:Er fibre amplifier (IRE-Polus FA-3L) and detected by a scanning autocorrelator and spectrum analyser. The gratings examined were manufactured using the technique of holographic replication using a phase mask [2]. The particular grating examined and which is reported here, was nominally 4mm long and exhibited a reflectivity of 85% centred at 1.5437μm. The response of the grating was theoretically modelled by taking an analytic approach and assuming a sinusoidal variation of the refractive index in the fibre core. Only in the ideal situation can the complete grating be described as such. In the manufacture of the gratings, some chirp can arise, for example due to non-uniformity in the illumination. This leads to a quadratic chirp, in that both the average core refractive index and peak amplitude refractive index change along the fibre length. A close approximation to the experimental situation can be found by assuming that variations in the average and peak indices and the grating period symmetrically follow a Gaussian profile. Chirp in the grating is not significant when the grating length is much less than the 1/e width of the Gaussian profile. By cascading short sections of ideal (sinusoidal) gratings (approximately 10 periods long) a complete transfer matrix of any grating structure can be found.

Theoretical reflectivity of a 4mm long Bragg fibre grating exhibiting 15% chirp and corresponding autocorrelation trace (inset)

Fig. 2 Experimental reflectivity of a 4mm long Bragg fibre grating (see text) and autocorrelation of reflected pulse for incident 1.5ps soliton (inset)

Experimentally, Fig. 2 shows the measured reflectivity and the associated autocorrelation trace for a 1.5ps soliton incident on the 4mm grating. The measured autocorrelation width deconvolves to a reflected pulsewidth of 18.9ps, assuming the 1.52 factor determined above for the unchirped grating. By comparing Figs. 2 and 3 it can be seen that qualitatively and quantitatively the agreement between theoretical prediction and experimental measurement is reasonable, considering uncertainties in, for example, the experimental grating length and the peak amplitude index.

The presence of chirp in the grating can significantly modify the reflected pulse profile of a uniform phase input pulse. This is clearly demonstrated in Fig. 3 which shows the theoretical response of a 1.8ps soliton in a 4.6mm long grating as described above, but exhibiting an approximate 16% chirp. The effect of the chirp is to broaden the reflected bandwidth and reduce the reflectivity of the sidelobes. In the time domain, the reflected pulse shape is changed, becoming more rectangular, as can be seen inset in Fig. 3. The autocorrelation however remains relatively unaf-
affected in the recorded half width, with only the wings of the auto-
correlation trace becoming suppressed. Also shown in Fig. 3 is the
response of the chirp is increased further, by a factor of ~2.5, the pulse
distortion increases, giving a pulse with a half width of 18.6ps and a de-
convolution factor from the autocorrelation of 1.34. In the corre-
the chirp was increased. However, if the chirp is
and spectra recorded for incident 1.5ps solitons. The theo-
demonstrated in a series of cut-back experiments, where the initially
rectangular as the chirp was increased. However, if the chirp is
increased further, by a factor of ~2.5, the pulse distortion increases,
giving a pulse with a half width of 18.6ps and a de-
convolution factor from the autocorrelation of 1.34. In the corre-
sponding autocorrelation, the wings are reduced relative to that of
Fig. 3. These examples clearly indicate that simply from experi-
mental autocorrelation data alone the reflected pulse duration and
shape are indeterminate as is the magnitude of the grating chirp.

Where the grating is linear or effectively unchirped, theoretical
predictions of the reflected pulse shape and spectrum can be deter-
mined quite accurately. This was demonstrated in a series of cut-
back experiments, where the initially 4mm long Bragg grating was
cut back, in 1 and 0.5mm steps and the corresponding auto-
correlations and spectra recorded for incident 1.5ps solitons. The theo-
retical and experimental data are shown in Fig. 4, and demonstrate a reasonable agreement.

In conclusion, we have examined the reflection of picosecond constant
phase (soliton) pulses off chirped and unchirped Bragg fibre
gratings. Theoretical and experimental data are in good
agreement and allow us to confidently predict the behaviour for
unchirped gratings and pulses. These experiments are the subject of
our current investigations.

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Fig. 4. Theoretical prediction and experimental measurement of reflect-
on of picosecond solitons, both spectral and temporal, from linear fibre
Bragg gratings of varying length, all other parameters being constant.

Step-chirped gratings

Introduction: There is considerable interest in transversely written
photoinduced all fibre gratings [1] using UV radiation for applica-
tions in telecommunications [2]. Chirped fibre gratings have been
proposed for chromatic dispersion compensation [3] for long-haul
telecommunication systems. Several methods for the fabrication of
chirped gratings have been reported which rely on using the inten-
sity distribution of the writing beam [4], mechanical bending [5] or
a temperature gradient [6] along the length of the fibre during
writing of the grating. Methods reported in [4, 6] produce small
chirps, and although bending [5] can produce large chirps, the
method produces blazed gratings which may be undesirable
because of induced radiation loss. In all cases, the drawback is in
the repeatable production of more than one grating with identical
characteristics. Recently, there have been several reports [2, 7, 8]
of direct holographic replication of a constant pitch phase mask
into the core of a photosensitive fibre to produce reflection grat-
tings. This Letter reports for the first time the use of 'stepped-
chirp' phase masks for the replication of chirped gratings;
unblazed linear and quadratic wavelength chirped gratings with
bandwidths between 3 and 15 nm with reflectivities up to 95% are
demonstrated. The results agree well with theoretical predictions.

Fig. 1. Step-chirped grating.

Step-chirp' phase-masks: The method of fabricating the phase
mask used for the fabrication of gratings relies on the exposure by
electron-beams (e-beam) of photosensist, spun coated on UV-trans-
mittng silica, to define small features (order 0.5mm). The beam
is stepped sequentially with a minimum step size to produce a
series of exposed lines. This works well for a constant period grating.
It is impossible to produce a continuously chirped grating
using this method because the step size is not infinitesimal. The
step-chirp method builds the chirp in the phase mask in short, \( \delta \) \( \mu \) long sections (see Fig. 1). Thus, for a chirped grating with
minimum reflection at a wavelength \( \lambda_1 \), length \( L \) and chirp \( \Delta \lambda \), \( \delta \mu \) sections are fabricated with each section differing in period from the
previous by \( \Delta L/\delta \). The section length depends on the chirp
and also the step resolution. There is a certain amount of random
variation in the final periods owing to the jitter in the writing
process, which help reduce the overall phase discontinuities at the
section boundaries. Using this method, both linear and quadratic
wavelength chirps of between 3 and 15nm were incorporated into
phase masks. By simply changing the step size, phase widths
of the chirped grating, it is possible to fabricate chirped phase masks for

References
1. HILL, K.O., FUKU, Y., JOHNSON, D.C., AND KAWASAKI, B.S., 'Photonsensitivism in optical fiber waveguides: Application to reflec-
tion fiber fabrication', Appl. Phys. Lett., 1978, 32, pp. 647-
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8-14