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Fabrication of Chirped Fibre Gratings Using Etched Tapers

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Abstract: A technique for fabricating fibre gratings with an accurately controlled chirp profile is demonstrated. It involves writing a grating over a section of fibre, the cladding of which has been tapered by etching in HF acid. A strain gradient along the taper is used to produce the chirp either during or after writing. Linearly chirped gratings with bandwidth up to 4.8nm have been demonstrated. Transmission filters have also been demonstrated when a step is made in the taper.

Background: The numerous applications of in-core fibre gratings have attracted much interest in recent years. Recently, chirped gratings have been proposed to compensate for dispersion in optical fibre telecommunication links. There are many other applications for chirped gratings such as pulse shaping, fibre DFB lasers, filters, etc. A chirp in the grating can be introduced during grating writing using several demonstrated techniques [1,2,3,4] and extremely large chirps (44nm) have been obtained [4]. It is, however, generally very difficult to control the chirp profiles. For applications such as dispersion compensation and pulse shaping, gratings with relatively small chirps (several nanometres) but very well defined chirp profiles are required. The technique using a chirped phase mask [3] produces gratings with such well defined chirp profiles, but is very inflexible and so far can only produce stepped chirps. A temperature or strain gradient can be applied in order to chirp gratings after they are written, however a high temperature is required to obtain a usable chirp. A strain-chirped grating was demonstrated recently using a cantilever [5], but the method is potentially polarisation sensitive. It is difficult to produce nonlinear chirps using post-processing, and packaging can be a problem.

Very recently, a technique was proposed by Putman *et. al.* [6] where a HF etched taper was used to create a strain gradient over a grating. A chirp of 2nm was achieved. This technique is potentially capable of accurately producing any arbitrary chirp profiles in fibre gratings. In this paper, we have demonstrated that a larger chirp can be produced by a stronger taper and that accurately defined taper profiles can made by the etching technique. Linearly chirped gratings with bandwidths up to 4.8nm have been made. We have also demonstrated that a transmission band can be created in the middle of the grating reflection band by making a step in the taper. This kind of structure is very useful in applications such as band-pass filters and DFB lasers.

Theory: A taper with the desired profile is made first in the cladding of a section of fibre by differential HF etching. The core of the fibre is not affected. A grating is then written into the taper in the normal manner using either an interferometer or phase mask. Two methods of writing are possible. In method A, no tension is applied during writing. The chirp is created when tension is applied to the fibre. This is due to a strain gradient over the taper (local strain depends on fibre diameter), which causes a refractive index gradient along the length of the taper through both the stress-optic effect and the variation of the grating pitch through fibre lengthening (the strain gradient stretches different parts of the fibre differently). Tapers can be made to give any desired chirp profiles, *e.g.* linear, quadratic, etc.

In method B, tension is applied to the fibre during the writing process. The grating is chirped during writing due to the stress-optic effect caused by the strain gradient along the fibre. The grating pitch, however, does not vary over the taper in this case. When the tension is removed, the chirp due to stress-optic effect disappears, but another chirp is developed as different parts of the taper relax differently from the initial strain gradient (a reverse of the lengthening effect). Using this method, the chirped grating can be packaged strain-free. It also creates a larger chirp than in method A for the same applied force, because the stress-optic effect has an opposite sign to the lengthening effect, and some chirp cancellation takes place.

Experiment: The tapers are made by immersing an uncoated fibre in a HF solution contained in a beaker and moving the beaker down at a controlled rate. The etching rate is linear with time, therefore any desired taper profile can be produced by controlling the movement the beaker. Two buffer oils (decahydronaphtalene + 10% dichlorotoluene and trichloroethylene) can also be put both under and above the HF solution so that only the part of the fibre in contact with the HF solution is etched. This is also necessary to obtain good fibre diameter control at the ends of a taper. Batches of 6 to 8 tapers have been made at the same time with good repeatability and consistency. Three different tapers were made for this experiment, all 25mm long. Taper 1 had the profile shown in the inset of fig.1, which fitted well with the design to give a linear chirp (see the solid line). The profile of taper 2 is given in the inset of fig.2 and also agreed well with the design profile to give a linear chirp. Taper 3 has a step in the taper designed to give a linear chirp (see top graph in fig.3). The tapers took approximately 50 minutes to fabricate using a 32% HF solution at room temperature.

The first grating was made on taper 1 by method A. It was written by scanning a KrF excimer laser beam (λ = 248nm) through a phase mask. The beam was masked to obtain a beam width of 3mm. The excimer laser gave a pulse fluence of ~0.1J/cm^2 and was set at 20Hz. The scanning speed was 1.5mm/min. The length of the grating was ~19mm and was slightly less than that of the taper (25mm) in order to ensure good overlap. Fig.1 gives the reflection spectra of the grating at different tensions. The grating had a reflectivity of 30% and was slightly chirped when written, probably by residual chirp in the phase mask or fluctuation in the writing beam intensity. The grating bandwidth broadened and reflectivity decreased as expected when tension was applied to the fibre. A chirp of 2.1nm was reached at 87.9 grammes of tension, which fitted well with the theoretically expected chirp of 2.25nm. The variation in the reflection along the grating may have arisen from non-uniformity in the phase mask or intensity fluctuation in the writing beam.

A second grating was written on taper 2 by method B with 94 grammes of tension applied during writing. The excimer laser was set at 40Hz this time and the beam scanning speed was 3mm/min. The grating was again approximately 19mm long within the 25mm long taper. Fig.2 shows the reflection spectra from the grating as written and in its relaxed state. The peak reflectivity of the grating as written was 47%. The grating had a chirp of 1.1nm when written, as expected from the index gradient along the grating, which increased to 4.8nm when the tension was removed. This value fits reasonably well with the theoretically expected chirp of 5.5nm. The reflection along the grating again showed some variation.

Taper 3 was put in a H_2 chamber at 160bar for ~1 week at room temperature and then had a 19mm grating written over it while 16 grammes of tension was applied to the fibre (method B). The excimer laser was set at 40Hz and the scanning speed was 0.75mm/min. The grating had a reflectivity of ~100% when written. The transmission of the grating when tension was released is given in fig.3. A transmission band was opened up in the middle of the reflection band as expected.

Summary: We have demonstrated a simple and flexible method for fabrication of gratings with an accurately controlled chirp profile. Linearly chirped gratings with bandwidths up to 4.8nm have been produced to demonstrate the controllability of the technique. The HF etched tapers were found to have a similar strength to that of uncoated fibre. A grating was also demonstrated which had a transmission band opened up in the middle of the reflection band. This kind of structures is very useful in applications such as band-pass filters, DFB lasers etc. Recently 32nm compression tuning of fibre gratings has been demonstrated [7]. The compression technique can be used in our method to obtain much lager chirps.

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Figure captions:

Fig. 1 Experimental result for a chirped grating fabricated by method A. The inset gives the taper profile and design (solid line) to achieve a linear chirp. The grating reflection shows the expected response when tension is applied to the fibre.

Fig. 2 Experimental result for a chirped grating fabricated by method B using a tension of 94g. The inset gives the taper profile. The taper was again designed to give a linear chirp. The grating reflection shows the expected response when tension is released.

Fig. 3 Experimental result for a grating written over a taper while a tension of 16g was applied to the fibre (method B). The taper profile is shown in the top graph. The bottom graph gives the transmission spectrum of the grating when there is no tension applied to the fibre.

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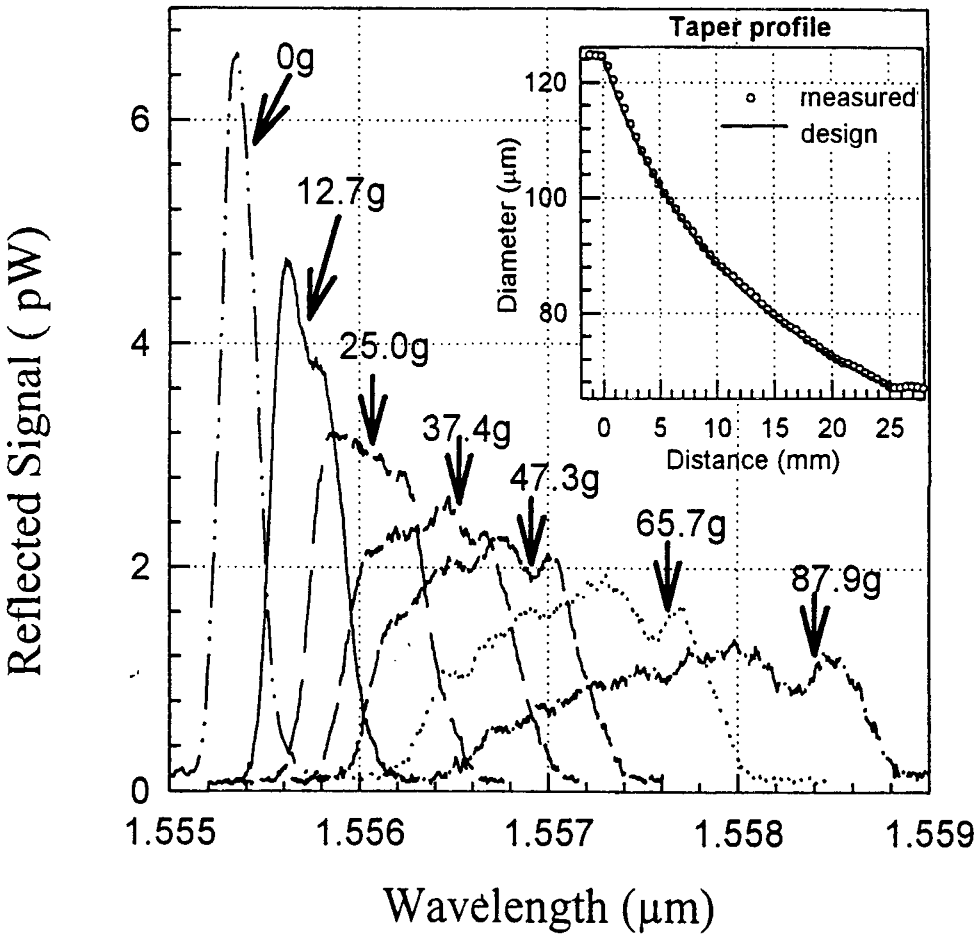

Fig. 1

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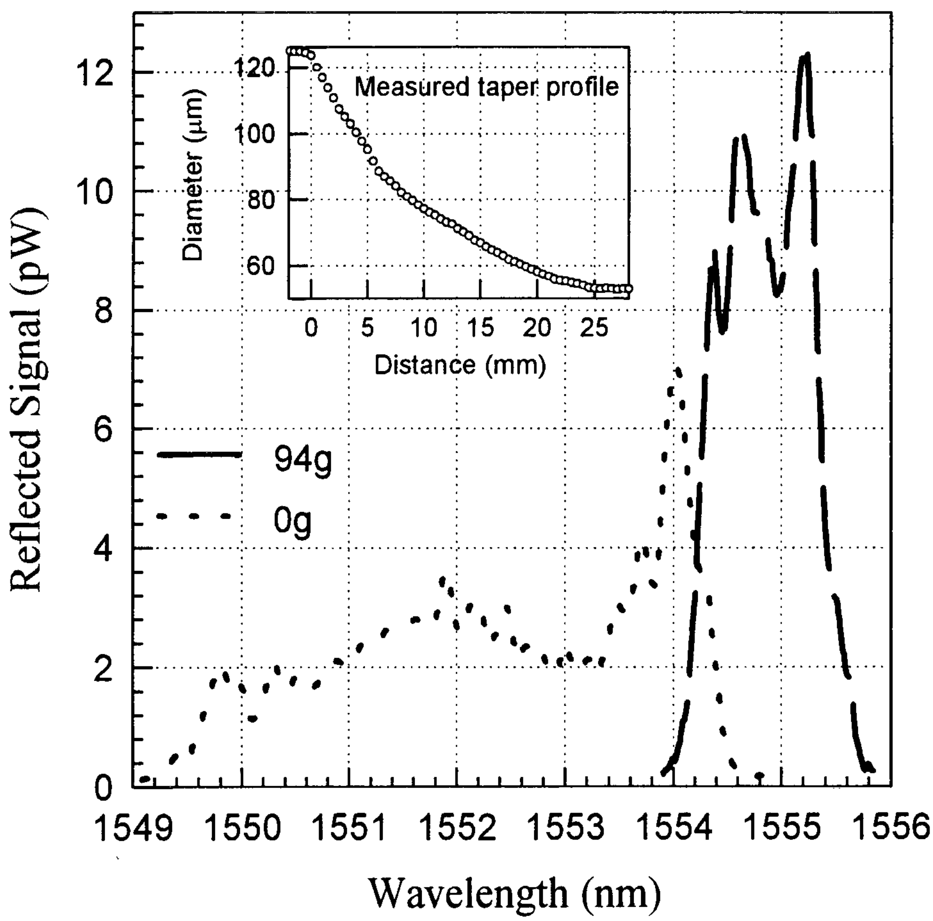

Fig 2

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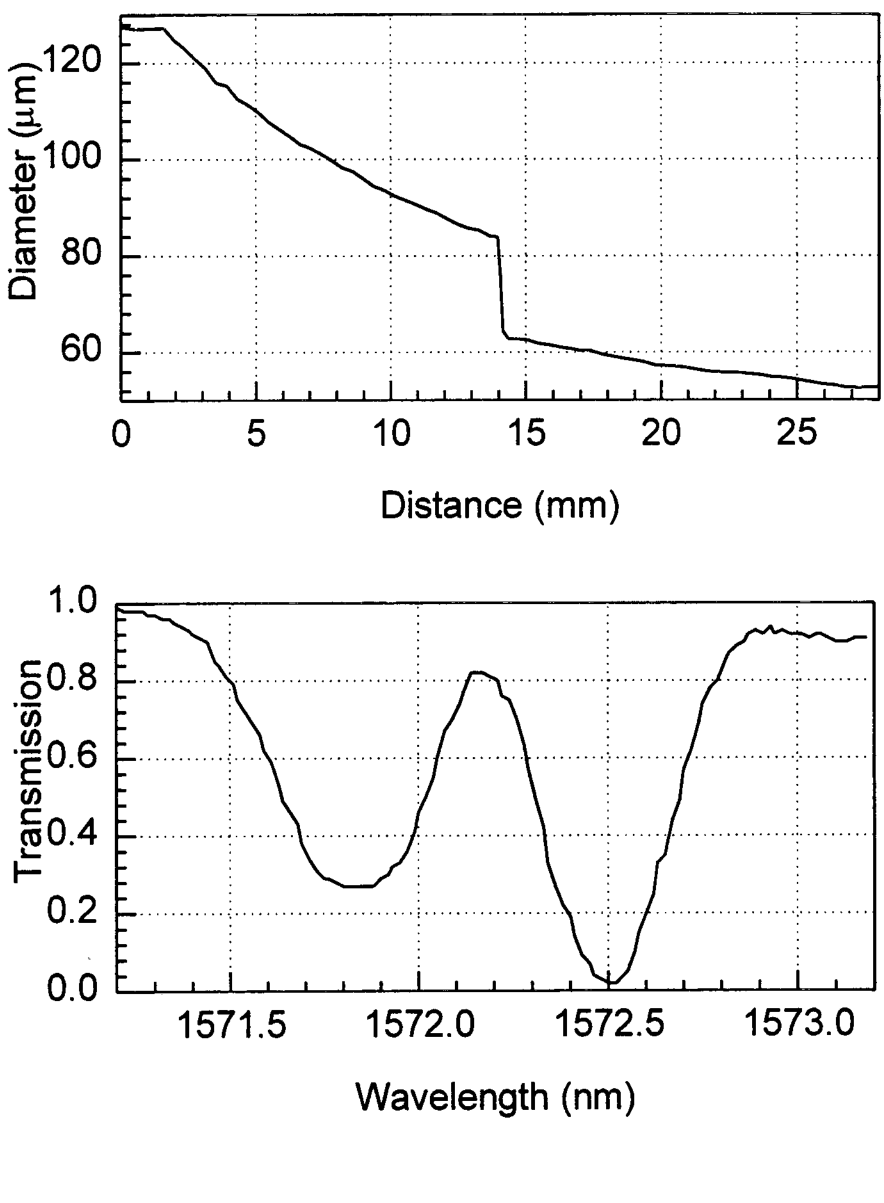

Fig. 3