Long Period Gratings Formed in Depressed Cladding Fibres

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Abstract: In a single mode fibre of a depressed cladding design, the LP11 mode is leaky but can propagate over a short length of fibre. This leaky LP11 mode instead of the conventional cladding modes can be used in long period gratings, with two extra benefits, I) a larger overlap, giving stronger coupling and II) coupling is insensitive to the glass-air interface therefore packaging is easier.

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There has been a significant interest in long period gratings, primarily due to their applications in gain-flattened erbium doped fibre amplifiers [1]. Up till now, cladding modes supported by the glass-air interface of an optical fibre have been used in a forward mode coupling scheme involving also the guided fundamental mode of the optical fibre. Here we propose an alternative technique. In a single mode depressed cladding fibre of an appropriate design (an example is given in fig.1), the higher order LP11 mode can be made to be a leaky mode in such a structure, i.e. it can propagate for a short length before being stripped off the high index region beyond the depressed cladding. This enables coupling between the guided fundamental LP01 and leaky LP11 modes, despite the fact that the optical fibre is single-moded. This coupling was first observed in [2], where a Bragg grating caused strong coupling into the backward-propagating leaky LP11 mode and much weaker coupling into a series of cladding modes. In a forward coupling scheme with a long period gratings (several hundred micrometres pitch), the LP01 mode can be coupled into the forward propagating leaky LP11 mode, therefore creating a loss peak in the transmission in the same way as when the LP01 mode is coupled into a cladding mode supported by the glass-air interface of the optical fibre which is subsequently stripped off over the coated section of the optical fibre. Two advantages are anticipated, I) potentially much stronger coupling due to the much large modal overlap possible and II), insensitivity to the glass-air interface as the LP11 mode is supported mainly by the core. It must be stressed that as the LP11 mode is an asymmetrical mode, the coupling from LP01 to LP11 will not occur if a circularly symmetrical grating is written over the core of the fibre, but this is not usually a problem when H_2 or D_2 loading is used, because of the asymmetry of the index change in such gratings due to strong absorption induced at the writing wavelength.

In the design in fig.1, the core will support two modes at 1.55 μm if the depressed region extends all the way to infinity. The presence of the high index region beyond the depressed cladding will strip off the higher order LP11 mode over a short length of fibre. The length over which the LP11 mode will propagate can be controlled by varying the normalised wavelength of the core and the thickness and depth of the depressed cladding, In general, the coupling between the LP01 and LP11 modes can be enhanced by having a large normalised wavelength for the core while keeping the structure single-moded. Also shown in fig.1 is the index profile in a grating written by a 248 nm KrF excimer laser. Such a structure has also been used to demonstrate suppression of coupling into cladding modes [3].

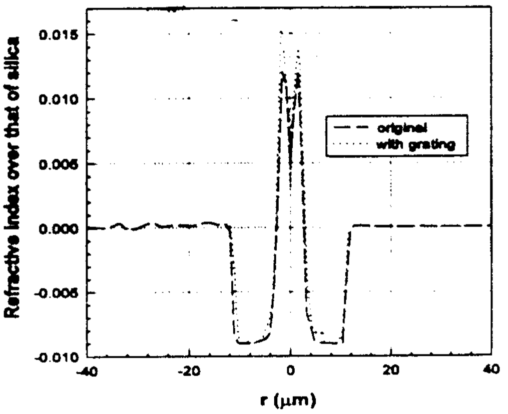

Figure 1 Index profile of a depressed cladding fibre.

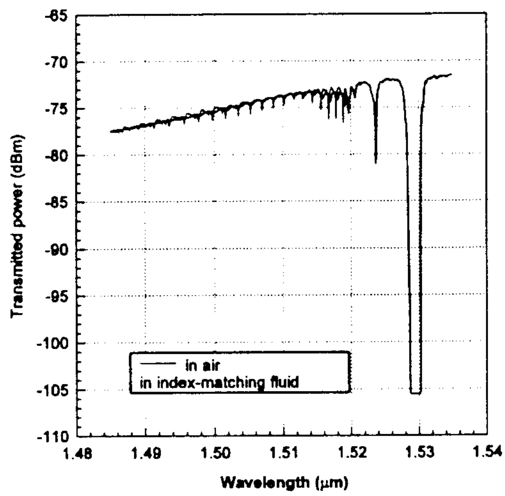

Figure 2 Transmission of a Bragg grating in a depressed cladding fibre.

To demonstrate the two advantages of the LP01/leaky LP11 coupling, a strong Bragg grating was written in a fibre with a similar refractive profile as in fig.1 but 1.26 times larger in overall dimension. This gives a measured cutoff wavelength of 1.47 µm compared to the 1.16 µm measured in the fibre in fig.1, using a standard bending technique (5 cm diameter). The fibre has a germania doped core and a boron doped depressed cladding. The fibre was H_2-loaded before a grating was written by a ArF excimer laser at 193 nm. Two transmission curves are shown in figure 2. One curve was taken while the fibre was in air and the other was taken while the fibre was in a silica-index matching fluid (n=1.452 at 633 nm). Immediately to the shorter wavelength side of the main Bragg grating band is the peak caused by coupling from LP01 mode to the leaky LP11 mode. Further to the short wavelength side are the coupling peaks caused by coupling from the LP01 mode to the cladding modes supported by the glass-air interface. The thicker line is the transmission taken while the fibre was in index-matching fluid. As can be seen, the coupling peaks for the cladding modes in the index matching fluid case are reduced due to a decrease in guidance and the peak wavelengths move towards longer wavelength due to an increase of the modal effective refractive index. Meanwhile, the peak for coupling into the LP11 mode is not affected by the changing environment of the fibre, strong evidence that this mode is a core mode which has virtually no power distribution at the glass-air interface of the fibre. Coupling into the leaky LP11 mode is also very much stronger than the strongest peak for the cladding mode coupling, ~5 dB in this case. Coupling into the leaky LP11 mode can be further improved by having a grating with strong non-circular symmetry and appropriate fibre design.

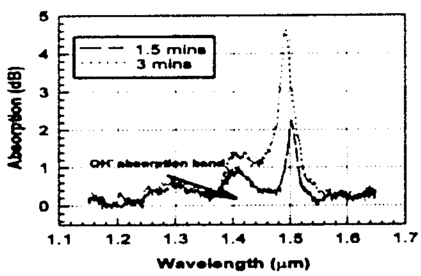

Figure 3 Growth of a long period grating in a depressed cladding fibre.

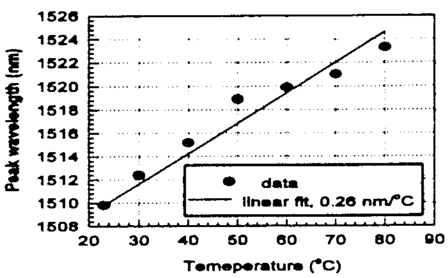

Figure 4 Temperature sensitivity of a long period grating in a depressed cladding fibre.

A long period grating was written into the fibre used above to demonstrate this method. The fibre was H_2-loaded before a ~2 cm grating was written by a 193 nm ArF excimer laser using an amplitude mask. The transmission of the fibre was monitored and then translated into absorption. This is plotted in fig.3. The temperature sensitivity of the grating is also measured and plotted in fig.4. The sensitivity was measured to be 0.26 nm/°C for this grating. This is typical for long period gratings.

To summarise, we have demonstrated a new method for use in long period gratings, which has enhanced coupling strength and is insensitive to the fibre glass-air interface.

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