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CLADDING MOOE COUPLING SUPPRESSION IN FIBRE BRAGG GRATINGS USING FIBRES WITH A DEPRESSED CLADDING

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Abstract: We have demonstrated both theoretically and experimentally strong suppression of coupling of the guided fundamental mode into cladding modes in a Bragg grating by introducing a depressed cladding around the core region. We have also studied the effect for different depression depths.

Coupling of guided modes into leaky cladding modes can cause a series of loss peaks at the short wavelength side of a Bragg grating. This extra loss can be quite severe in strong Bragg gratings and renders these gratings unusable in wavelength-division-multiplexed systems or where the short wavelength side of gratings is used, e.g. pumping fibre lasers and strongly chirped gratings. So far two methods have been proposed to suppress coupling into cladding modes. The first one relies on having a photosensitive cladding [1], the principle being that the orthogonality of the modes will eliminate the intermodal coupling if a uniform refractive index change over the wave front of the guided mode is produced in a grating. In practice, it is very difficult to fabricate a fibre with equal photosensitivity over both core and cladding and, even if such a fibre can be made, it is also very difficult to write a grating with a uniform index change over a large photosensitive region since the writing light is strongly attenuated as it penetrates into the photosensitive region. The second method relies on the fact that in a fibre with a high NA, the coupling into cladding modes will start at a wavelength few nanometers shorter than the main Bragg wavelength and therefore leaves an usable wavelength range of operation. However, this range is only ~7 nm in a high NA fibre (0.24) [2].

We propose a new scheme based on a fibre with a depressed cladding. This depressed cladding has a strong effect on reducing the field strength of cladding modes over the core region. In fig. 1, we plot the effect of such a cladding on the LP_{09} mode distribution for different depression depths. In all of our simulations, the following parameters have been used: core radius of 2.8 μm, $\Delta n+$ of 0.01 ($\Delta+$ of 0.69%) and depressed ring thickness of 12.8 μm. It is clear that the field strength over the core region can be largely suppressed by introducing a strongly depressed cladding. In a fibre with a photosensitive core, the modal overlap over the core can serve as a good measure for the strength of the intermodal coupling. In our case, we are mainly interested in intermodal coupling between the guided LP_{01} mode and various cladding modes, and such a normalised overlap integral can be written as:

$$NOI = \int_0^{\rho}\int_0^{2\pi} \psi_{01}\, \psi_{mn}\, r\, dr d\varphi$$

where ρ, ψ_{01} and ψ_{mn} are core radius, field distribution of LP_{01} mode and field distribution of Lp_{mn} mode respectively. By reducing the field strength of the cladding modes over the core, we can substantially reduce this normalised overlap between the LP_{01} and Lp_{mn} modes over the core region and therefore suppress the coupling between the LP_{01} mode and the cladding modes. We first considered the first nine of the LP_{0n} modes. The NOI of the 9 modes is plotted in figure 2. The first mode is LP_{01} mode and the NOI measures the reflection strength of the LP_{01} mode into the back-propagating LP_{01} mode. As can be seen in fig.2, the NOI for this mode goes up slightly as the depressed depth increased. This is due to a better confinement of the LP_{01} mode in the core when a depressed cladding is introduced. The NOI between the LP_{01} mode and other LP_{0n} modes is substantially reduced as a depressed cladding with increasing depth is introduced. More than 30 dB reduction of the coupling strength to these modes compared to the case without a depressed cladding can be achieved with a depressed depth of 0.01 (0.69%). We also studied the coupling of the LP_{01} mode to LP_{1n} modes. The LP_{01} mode does not couple into these modes as dictated by the circular symmetry of the LP_{1n} modes, however, coupling can take place in a blazed grating. We consider the worst case where the phase variation of the field of LP_{1n} modes as φ is varied from 0 to 2π is completely compensated by the blazed grating. The NOI of the LP_{01} mode and the first 9 of the LP_{1n} modes are plotted in fig.3. A good suppression of the coupling to the LP_{1n} modes can also be achieved if a large depressed depth is used. As can be seen in fig.3, an increase of the NOI is expected for some LP_{1n} modes if a depressed depth of less than 0.006 (0.4%) is used. However, even in this worst case 20 dB suppression can be achieved with a depressed depth of 0.012 (0.83%). We fabricated a fibre with core radius of 2.8 μm, $\Delta n+$ of 0.01 (Δ +=0.069%), Δn-=-0.01 (Δ-=-0.069%) and cladding thickness of 12.8 μm. The fibre has a cut-off of 1400 nm and negligible bending loss at 1550 nm. For comparison, we also used a normal step index fibre with NA of 0.15 and core radius of 3.63 μm. A grating with a length of 15 mm and an index modulation of 0.001 was written by a 248 nm KrF excimer laser into each of the fibre. Fig. 4 gives the transmission spectra of the two gratings. We have plotted the curves on a linear scale to show clearly the coupling loss to cladding modes. The top figure is from the grating written in the step index fibre and shows the strong coupling into cladding modes which was obtained for gratings of this strength. The bottom figure shows the transmission of the grating in the depressed cladding fibre. Only small peaks of less than 10% are visible (less than ~0.45 dB insertion loss). This is possibly due to coupling into the LP_{1n} modes as the grating is slightly blazed and this should be able to be eliminated once zero blazing angle is achieved. The coupling into the LP_{1n} modes in a blazed grating will not be suppressed by any of the suggested schemes for cladding mode suppression.

To conclude, we have demonstrated a simple and effective way of suppressing coupling into cladding modes in Bragg gratings by introducing a depressed cladding layer around the core region. This depressed cladding very effectively reduces the field strength of cladding modes over the core region and therefore reduces the coupling from the guided fundamental mode to leaky cladding modes.

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Reference:

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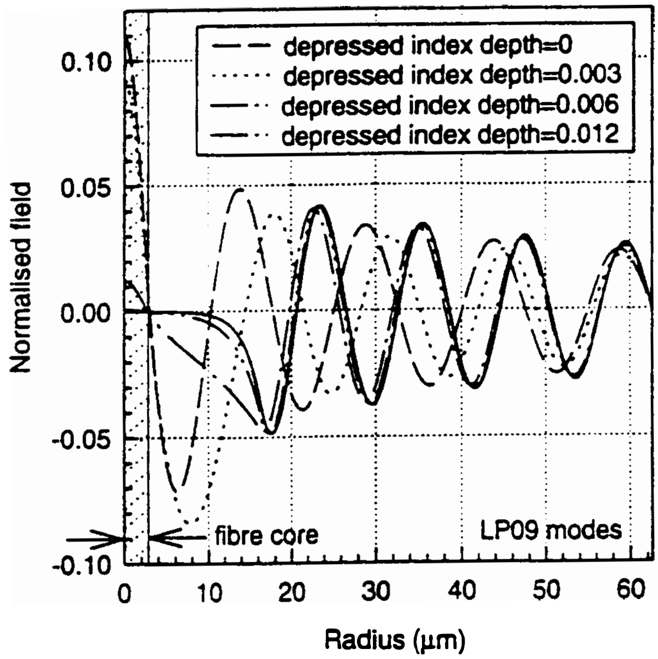

Figure 1 The effect of depressed cladding on the field distribution of the LP_{09} mode.

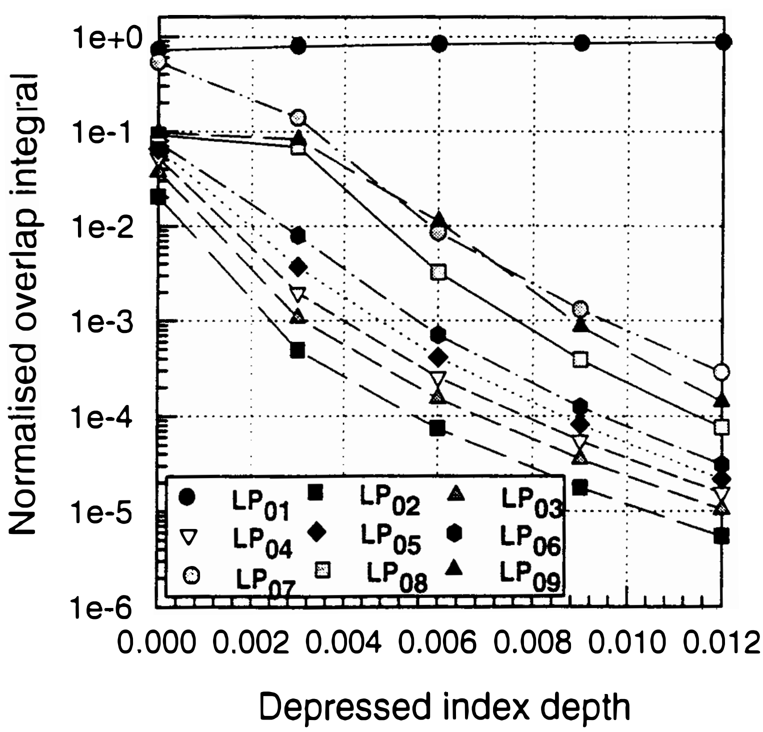

Figure 2 The dependence of normalised overlap of the LP_{01} mode and LP_{0n} mode over core region for the first 9 modes on cladding depression.

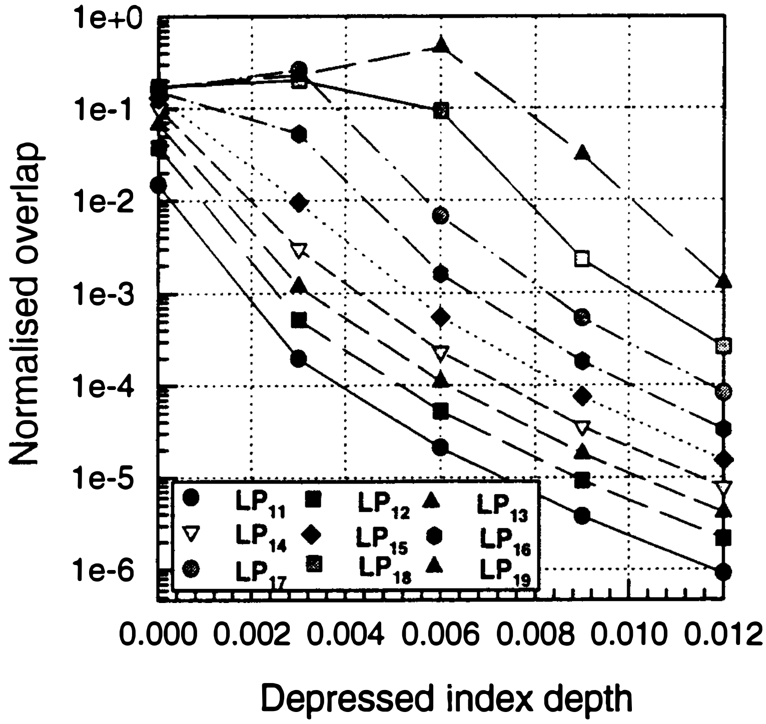

Figure 3 The dependence of normalised overlap of the LP_{01} mode and LP_{1n} mode over the core region for the first 9 modes on cladding depression.

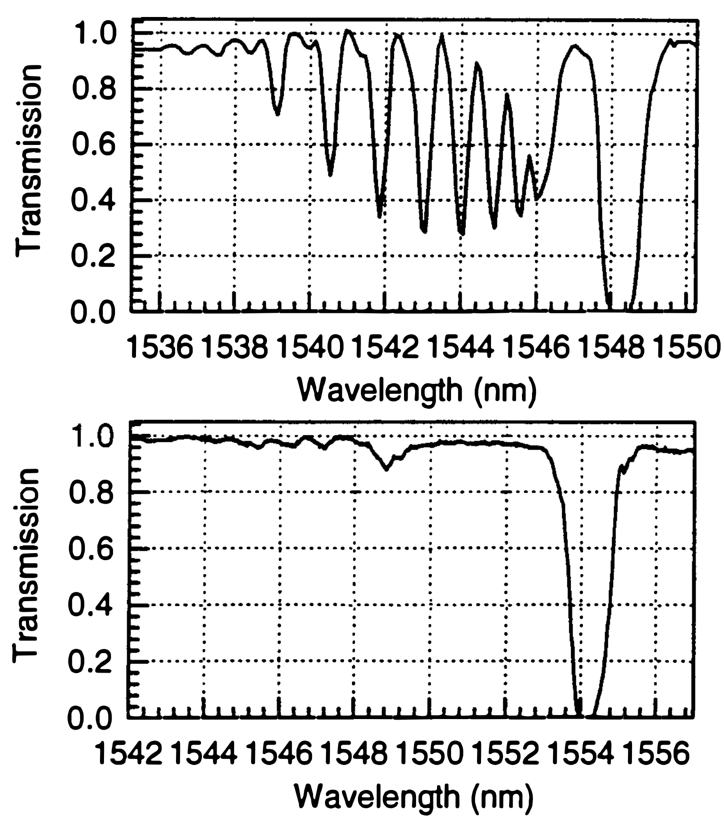

Figure 4 Two gratings of index modulation of ~0.001 and length of 15 mm written in two different fibres. Top: a step index fibre with 0.15 NA and core radius of 3.63 μm. Bottom: a fibre with depressed cladding with Δ+ of 0.69%, Δ- of -0.69%, core radius of 2.8 μm and a depressed ring size of 12.8 μm.