Bragg grating induced cladding mode coupling due to asymmetrical index modulation in depressed cladding fibers

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measured phase delay error for a similar but apodized grating. As
expected, apodization decreased the ripples.
Although this technique was demonstrated on short commercial
gratings, it is better suited to resolve the phase ripples in long dispersion-
compensating gratings.
4. K. Enns et al., presented at European Conference on Optical

TuA6 12:15pm

Bragg grating induced cladding mode coupling due to
asymmetrical index modulation in depressed
cladding fibers

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UV-written Bragg gratings find wide spread use as wavelength selective
components. In reflection high extinction ratios is routinely obtained.
However, coupling to cladding modes gives excess loss on the short
wavelength side of the main reflection. Different fiber-designs have been
proposed to reduce this problem.1-3 Neither of these designs seems to
give complete solutions. In particular, the otherwise promising depresed
cladding design gives a pronounced coupling to one LP_{m} mode,
this has been referred to as a Ghost grating.4

To find the modes of the fiber we have established a numerical
modesolver based on the staircase-approximation method. The Bragg
grating causes coupling between the fundamental LP_{01} mode and higher
order LP_{p} modes that satisfy phasematching. The coupling strength is
determined by the overlap integral of the LP_{01}, the LP_{p} mode, and the
UV-induced index perturbation. For LP_{01} the index perturbation is set to
one in the core and zero elsewhere. For LP_{m} it is simplified to the worst
case, i.e., opposite sign of the field.

Figure 1 shows measured transmission spectres along with normal-
ized overlap integrals (NOI) calculated for the fiber index profile. The
fiber used has a high core index (15·10^{-3}) and a depressed cladding ring

\[ n_{UV}(r,\phi,z,\theta) = n_{UV\max} \cdot \exp(-\gamma(\sqrt{a^2 - (r \cdot \sin(\phi))^2} + r \cdot \cos(\phi))) \cdot \alpha_{\text{blaze}}(r,\phi,z,\theta) \]

\[ \alpha_{\text{blaze}}(r,\phi,z,\theta) = \frac{a - r \cdot \sin(\phi)}{2a} \cos^2 \left( \frac{\pi}{\Lambda} z \right) \]

\[ + \frac{a + r \cdot \sin(\phi)}{2a} \cos \left( \frac{\pi}{\Lambda} z - \frac{2a}{\tan(\theta)} \right) \]

UV Fig. 1. Measured cladding mode coupling spectra and calculated NOI.

UV Fig. 2. Measured Ghost dip relative to Bragg dip as a function of blaze angle.

UV Fig. 3. Asymmetrical index volume (ASIV) as a function of blaze angel, left trace: 800 dB/mm; right trace: 50 dB/mm (note zero slope for zero blaze). Insert shows distribution of UV-induced index perturbation in a fiber cross section.

of depth -5·10^{-3} and width 5 \mu m. To fit the measured spectrum the
depth of the cladding ring was set to -6·10^{-3}.

At 1°, blaze of the phasemask a large dip is seen 4 nm from the Bragg
wavelength. This corresponds to the calculated LP_{10}, LP_{17} cladding
modes. Changing the depth and width of the depressed cladding ring
shifts the Ghost dip to other mode numbers but the size and spectral
position is virtually unaltered. When the blaze is reduced to 0° ± 0.02°
this dip is reduced to six percent of the Bragg dip. This behavior was
further investigated by writing four gratings under identical conditions
except for blaze angles ([Fig. 2]).

The UV-induced index change was deduced assuming cosine
squared longitudinal index modulation, blaze angel \theta and exponential
attenuation (coefficient \gamma) of the UV-beam entering the fiber core from
the side;

\[ n_{UV}(r,\phi,z,\theta) = n_{UV\max} \cdot \exp(-\gamma(\sqrt{a^2 - (r \cdot \sin(\phi))^2} + r \cdot \cos(\phi))) \cdot \alpha_{\text{blaze}}(r,\phi,z,\theta) \]

\[ \alpha_{\text{blaze}}(r,\phi,z,\theta) = \frac{a - r \cdot \sin(\phi)}{2a} \cos^2 \left( \frac{\pi}{\Lambda} z \right) \]

\[ + \frac{a + r \cdot \sin(\phi)}{2a} \cos \left( \frac{\pi}{\Lambda} z - \frac{2a}{\tan(\theta)} \right) \]
where \( n_{UV_{\text{max}}} \) is the maximum UV-induced index change, \( A \) is the grating period and \( a \) is the core radius.

The volume integral of \( n_{UV} \) subtracted a cosine squared index modulation is proportional to the NOI, assuming no radial field variation and step azimuthal variation, in the core. This integral we denote as the asymmetrical index volume (ASIV).

The analysis indicate two regimes [(Fig. 3)], namely a blaze-dominated \( \text{LP}_{01} \) coupling for small UV attenuation (<100 dB/mm) and a side illumination dominated behavior for large UV attenuation. The measurement in Fig. 2 seems to fall in between these extremes. For the fiber used, we estimate an UV attenuation of 400 dB/mm. Comparing this result with the residual Ghost dip for zero blaze and published measurements of index profiles after UV-sidewriting\(^5\) we conclude that asymmetry arising from side illumination is very important for the understanding of \( \text{LP}_{01} \) coupling. Design of fibers and writing setups, with the aim of reducing cladding mode coupling must be based on this new understanding.

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**TuB**  11:00am–12:30pm  Room A2

Vertical Cavity Surface-Emitting Lasers  
Connie J. Chang-Hasnain, University of California—Berkeley, Presider

**TuB1 (Invited)**  11:00am

Fusion bonding for vertical-cavity surface-emitting lasers

Dubravko Babić, Hewlett-Packard Laboratories, Palo Alto, California, 94304; E-mail: babic@hpl.hp.com

This talk summarizes current efforts in fusion bonding and the application of this technology to vertical-cavity surface-emitting lasers at Hewlett-Packard Laboratories. We discuss electrical characteristics, carrier-concentration profiling and SIMS analyses through InP/GaAs junctions, and the development of 1300 nm VCSELs.