POST-IRRADIATION RESONANCE WAVELENGTH ADJUSTMENT OF LONG PERIOD GRATING BASED LOSS FILTERS

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Introduction:

Gain flattened EDFA amplifiers and cascaded Raman amplifiers are important devices in future WDM networks. In-fiber long period gratings [1] can be successfully used to shape the EDFA gain spectrum such that all wavelength experience the same gain [2] or to remove undesirable Stokes orders in the Raman amplifier. The grating resonance wavelength, the intensity of resonance peaks and the grating bandwidth can be chosen in accordance with the application requirements. These parameters are related to each other and are defined simultaneously selecting the amplitude of induced refractive index, grating length and period. In actual practice, the grating writing procedure is limited by the discrete set of available amplitude masks. Moreover, during the long-period grating fabrication there is a strong displacement of resonance peaks due to the increase of the mean refractive index of the fiber core [3]. For standard writing techniques the accuracy in positioning the loss peak for a desired peak intensity is limited to some nanometers.

In this work we present a simple technique to precisely and continuously adjust the resonance wavelengths of long-period cladding-mode-coupled gratings without strongly affecting the coupling strength. The main principle of this method is based on the strong dependence of the propagation constants and hence the peak positions of the cladding modes on the cladding diameter. Therefore, one can shift the grating resonance wavelength by changing the cladding dimension. In our case, this has been achieved by etching the fiber in a HF acid solution.

Experiment:

Long-period gratings have been written in a single-mode germanosilicate fiber with a GeO₂ core concentration of 12 mol%. The fiber has a step index profile with core and cladding diameter of 3.5 μ m and 125 μ m, respectively. Gratings were fabricated by irradiating the fiber with a KrF-Excimer laser (1 = 248 nm) through an amplitude mask with a period of L = 200 mm. An energy density of 85 mJ/cm²/pulse, a pulse repetition rate of 50 Hz, and an irradiation time of typically 1 hour were used. The gratings were characterized using a halogen lamp and a monochromator with a typical resolution of 1 nm. For fiber etching HF solutions with different molar concentrations ranging from 2 to 22 mol/l were used.

Results and discussion:

Figure 1 shows a typical transmission spectrum of a 17 mm long grating with a period of 200 μ m (solid line). Eight resonance peaks due to the coupling between the fundamental (HE₁₁) and the radially symmetric cladding modes (HE_{1m}, m = 2, ..., 9) were observed in the measured wavelength range. The experimental curve is compared with model calculations based on measured fiber parameters and an assumed rectangular profile for the index distribution in the fiber core. A linear correlation between the irradiation induced refractive index change, Δn^{ind} , and the mode coupling coefficient has been assumed [4, 5] and Δn^{ind} has been used as a fitting parameter. A very good agreement between the theoretical and the experimental spectrum is obtained for $\Delta n^{ind} = 4.7 \cdot 10^{-4}$. The slight deviations in bandwidth might be due to grating non-uniformity.

a) Institute of Applied Optics, Swiss Federal Institute of Technology, CH-1015, Lausanne, Switzerland b) Fiber Optics Research Center, General Physics Institute of the Russian Academy of Sciences, 38, Vavilov Street, 117942, Moscow, Russia Fiber etching leads to a change of the initial transmission spectrum. Using a HF solution with a concentration of 22 mol/l (40% HF), a mean etching rate of 1.9±0.1 mm/min was evaluated by measuring the fiber diameter with the aid of an optical microscope at regular time intervals. Figure 2 shows the spectra of the grating before and after five minutes of fiber etching using this HF solution. The resonance wavelength peaks are shifted towards higher wavelengths. The total shift depends strongly on the cladding mode order. The resonance wavelength of the highest cladding mode in our spectrum, HE₁₉, was displaced by about 130 nm. The bandwidth of the resonance peaks exhibits a slight broadening possibly due to variations of the diameter induced by inhomogeneous etching. The intensity of the peaks increases slightly during fiber etching. This phenomenon can be explained by the increase of the overlap integral between fundamental and cladding modes due to compression of the cladding mode field and should be taken into consideration for grating spectrum design.

The wavelength shift of the resonance peaks due to the change of the cladding diameter is presented in Fig. 3. The experimental results (open circles) are in excellent agreement with the theoretical predictions. The sensitivity of peak position to the diameter change increases with increasing radial mode order, m. For the first cladding mode this sensitivity is almost constant with a value of 0.05 nm/mm, while the highest observed cladding mode (m=9) exhibits a value ranging from 10 nm/mm up to 25 nm/mm depending on the fiber diameter. In these first experiments, the etch time could be controlled to about 10 sec. This allows to achieve a precision in the position of the resonance peak for the lowest cladding mode of below 0.02 nm. Such values are in most cases below the precision necessary for telecommunication applications. However, by changing the etch solution the etching rate could be easily reduced. This would allow to achieve picometer precision, potentially of interest in sensor applications. An increased sensitivity for higher mode orders was also observed in the case of peak position sensitivity on external influences, such as temperature, bending and refractive index of surrounding medium [6]. Both, the sensitivity increase with increasing mode order and with decreasing fiber radius are due to the waveguide properties of the fiber.

The normalized intensities of the resonance peaks of five cladding modes is plotted as a function of the cladding diameter change in Fig. 4. Qualitative agreement between experiment and theory is observed. The good agreement between theory and experiments, and the high precision in controlling the wavelength shift on the other hand allows conception and realization of wavelength loss filters tuned precisely to any desired center wavelength in an industrial production environment.

Conclusion:

The resonance wavelength of long period loss filters can be permanently adjusted after the irradiation. The post-irradiation peak adjustment has the advantage to decorrelate the peak position and intensity. By changing the cladding diameter using HF acid the resonance peaks can be shifted by more than hundred nanometer. A rapid peak displacement of up to 50 nm per etching minute can be achieved using a high concentration of HF acid. On the other hand a precise wavelength positioning can be performed reducing the molarity of the HF solution.

References:

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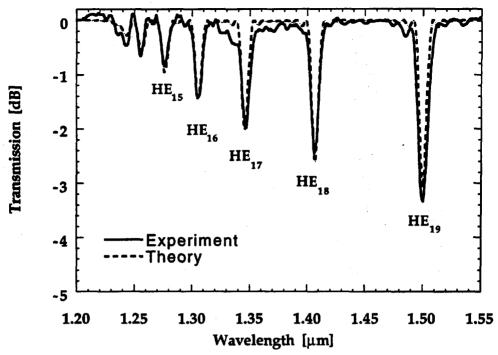


Fig. 1: Transmission spectra of a long-period grating.

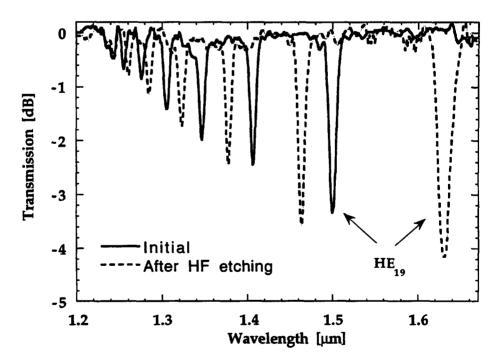


Fig. 2: Long-period grating transmission spectra before and after etching.

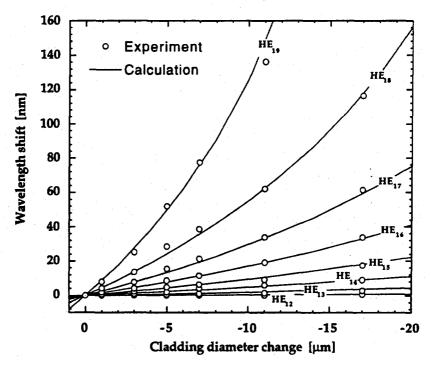


Fig. 3: Resonance wavelength shift as a function of cladding diameter change.

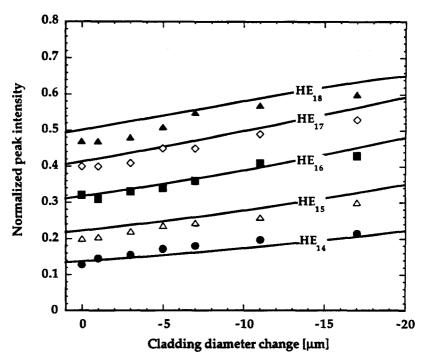


Fig. 4: Normalized loss peak intensities as a function of cladding diameter changes.