行政院國家科學委員會專題研究計畫　成果報告

新型光纖通訊光纖與半導體元件(I)

計畫類別：個別型計畫
計畫編號：NSC91-2215-E-002-030-
執行期間：91 年 08 月 01 日至 92 年 10 月 31 日
執行單位：國立臺灣大學光電工程學研究所

計畫主持人：楊志忠

報告類型：精簡報告
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中　華　民　國 92 年 10 月 27 日

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中文摘要：
我們以週期性凹槽結構施壓於光纖，產生長週期光柵的效果，由上下凹槽的齒凸相對位置變化所帶來長週期光柵不同的效果，我們斷定週期性凹槽結構施壓效果乃為產生微彎曲，而非壓力產生折射率變化之效果。

Abstract:
Periodical perturbations along an optical fiber can cause power coupling between the core mode and cladding modes for the applications of spectral filtering and derivative operations. Such perturbations can be generated through periodical loading on fiber. By applying loading onto fiber with two face-to-face, identical groove structures, it was found that the long-period grating effects were dependent on the relative phase of the two periodical corrugations. Particularly, when the relative phase was zero (crest-to-crest), spectral filtering effects disappeared completely. The comparisons of such results between the cases of jacketed and un-jacketed fibers led to the conclusion that geometric deformation, instead of direct pressure-induced effect, was the dominating mechanism for generating spectral filtering functions in the double-sided loading configuration. The same conclusion can be applied to a single-sided loading device.

1. Introduction

Spectral filtering and its derivative operations, such as gain flattening, are important functions for fiber communication applications. Spectral filtering can be implemented with long-period fiber gratings of various forms. In a long-period fiber grating with phase matching, the core-mode signal in the fiber can be coupled into cladding modes, resulting in spectral depressions. Effective long-period fiber gratings can be realized with permanent modification of fiber, such as etching and UV-induced refractive index change, and temporary alteration of fiber propagation characteristics. The method of temporary alteration has the advantage of dynamically controlling the function of spectral filtering. Dynamic long-period fiber gratings can be implemented through the application of either an acoustic wave to fiber, or periodical loading onto fiber. In the loading technique, two possible mechanisms may result in the aforementioned phase matching process, including geometric deformation (micro bending) and pressure effect for periodical refractive index variation of the fiber.

We report the spectral filtering results of effective long-period gratings implemented by double-sided loading with two identical blocks of periodical grooves. Also, the dominating mechanism for effective grating effects is discussed. In our experiments, it was found that the positions and depths of transmission spectral depressions varied with the relative phase of the two periodically grooved structures. When the two periodical structures are exactly in phase, i.e., crests exactly matched, all spectral depressions disappear. This is true no matter the plastic jacket is removed or not. This observation leads to the conclusion that geometric deformation is the dominating mechanism for phase matching between the core and cladding modes. The conclusion is further confirmed with the results of single-sided loading on fiber, which manifests that loading without plastic jacket is less effective than the case with jacket in the loading range that fiber is not broken. The jacket is supposed to provide the means for micro bending, which results in effective mode coupling. In addition, a theoretical study on the coupling behaviors induced by micro bending shows reasonably consistent results with the experimental data.

2. Experimental Procedures and Results

For double-sided loading, two identical copper blocks of 3 x 3 x 0.5 cm (L x W x T) with periodical corrugations on the L x W plane were prepared. Square grooves of 400 μm in depth, 50 % in duty cycle, and 700 μm in period were fabricated with mechanical process. Commonly used communication fiber (Corning, SMF-28) was placed between the two corrugated copper blocks. Loading was applied by moving one of the blocks toward the other with a translation stage. The relative position, corresponding to the relative phase of the two face-to-face corrugated blocks, was controlled by a translation stage moving along another direction. The fiber was aligned along the normal to the groove lines. The transmission spectrum of the fiber under loading was recorded with an HP spectrum analyzer (HP 70004A) with spectral resolution of 0.08 nm.

We show the normalized transmission spectra of two loading levels: 0.15 and 0.2 mm stage displacements for the upper and lower curves, respectively. In this situation, the relative phase of the two blocks was about $\pi/2$. Note that zero-phase is defined as the situation when crests of the two corrugated blocks are exactly matched. The spectra were normalized to the level of zero loading (completely loose). Three depressions around 1500, 1560 and 1620 nm can be clearly seen. A deeper depression corresponds to stronger coupling between the core mode and a cladding mode.

The wavelengths and depths of the spectral depression minima were recorded when the relative phase of the two corrugated blocks was varied. We also show the variations of depression wavelength and depth with the relative phase when the loading level is about 0.22 mm stage displacement. Here, the relative phase is also displayed with the stage displacement in mm. Only two coupling wavelengths are shown because the one near 1500 nm is unclear. One can clearly see that near the phases of integer numbers of 2π, all the induced spectral depressions disappear. It is noted that the depression wavelength reaches the largest value when the relative phase is an odd number of π. In this situation, coupling is expected to be strongest because the depression depth increases as the relative phase moves away from integer numbers of 2π. The tuning range in varying the relative phase is about 10 nm. Such wavelength variations can be attributed to the change of effective fiber propagation constant in loading with different relative corrugation phases. The spectral depression depth drops fast when the relative phase approaches an integer number of 2π. The minimum features of depression depth near odd numbers of π relative phase may originate from the saturation effects of loading.

We then show the comparison of spectra between the cases without loading (the lower curve) and with loading (the upper curve, with 0.22 mm stage displacement loading level – a relatively high loading level) when the relative phase is an integer number of 2π. We can see the almost identical spectra (even without a significant difference in background level), which do not have any significant spectral depression. The ratio of the two curves results in < 7 % noise fluctuation within the spectral range from 1.4 through 1.7 μm. Such results confirm the insignificant effect of loading when the relative phase is an integer number of 2π.

3. Discussions

The insignificant loading effect in the case that the relative phase is an integer number of 2π has an important implication. Application of loading onto fiber may produce two mechanisms for inducing mode coupling: geometric deformation and pressure-induced elasto-optical effect. The former forms micro bending and the later produces periodical refractive index variation. From the results described above, we may conclude that geometric deformation is the dominating mechanism for mode coupling in our loading configuration. Here, one can see that the loading effect is essentially the periodical application of pressure onto fiber. Such a pressure may not be effectively applied to the glass portion of the fiber because the plastic jacket may absorb the pressure. On the other hand, the loading effect on fiber with π phase is essentially geometric deformation, i.e., micro bending. Such a geometric deformation produces significant coupling between the core mode and cladding modes. When the relative phase moves from π to zero, the micro bending amplitude is reduced and the effective grating period is decreased. Therefore, the coupling strength, i.e., spectral depression depth, is reduced. Also, the depression wavelength becomes shorter when the relative phase moves from π to zero.

As mentioned, one may wonder that the insignificant loading effect in the case of zero relative-phase may originate from the pressure absorption of the fiber jacket. To understand the jacket effects, we removed the jacket and conducted the loading experiments. We observed almost the same results, except that the loading level could not be too large; otherwise the fiber was broken. Particularly, insignificant loading effect could again be observed in the case of zero relative-phase. The transmission spectra of the un-loaded and loaded (loading level 1.2 mm) cases look almost identical.

The observations described so far may bring about a doubt about the effects of single-sided loading. By intuition, single-sided loading cannot create micro bending of fiber and its grating effects must come from periodical pressure distribution. To clarify this point, we also conducted single-sided loading with jacketed and un-jacketed fibers. We did observe the grating effects with single-sided loading, either with jacket or without jacket. However, the loading effect with jacket was much more significant. Our results ruled out the possible effect of periodical pressure in loading because the existence of jacket, which was supposed to absorb pressure, resulted in much stronger grating effects. Such a result can only be explained with the conclusion that even in the case of single-sided loading, the dominating mechanism for mode coupling is micro bending. The elasticity of jacket can help the fiber to become curved when the corrugated structure is applied. When the jacket is removed, it becomes difficult to produce micro bending on rigid glass.

To further make sure that the spectral depressions were really due to the coupling of the core mode and various cladding modes under micro bending, we conducted a theoretical study on the coupling behaviors in a fiber with micro bending. The coupling behaviors between the core and cladding modes due to micro bending are quite different from those in a long-period fiber grating with a periodical effective refractive index variation in the core. With a perturbation method, it can be shown that a $HE_{\nu\mu}$ cladding mode with $\nu = 2$ leads to a longitudinal coupling coefficient variation of the same period as micro bending. However, a $HE_{\nu\mu}$ cladding mode with $\nu = 1$ results in a coupling coefficient variation of one-half the period of micro bending. Such results are due to the odd and even nature of the cladding modes with $\nu = 2$ and 1, respectively. The detailed discussions of the coupling behaviors will be presented in another publication. Here, we simply demonstrate a result simulating the experimental data. We assumed a 3-cm long-period fiber grating of micro bending with period 700 μm and 10 % bending (the fiber axis deviates from the un-perturbed situation by 10 % of the core radius). The radii of the fiber core and cladding were assumed to be 4.1 and 62.5 μm, respectively. The refractive indices of the core, cladding and jacket were 1.44919, 1.44408 and 1, respectively. It was found that the coupling results with the low-order cladding modes were weakly dependent on the refractive index of the jacket. With little effect on the results, we set the jacket refractive index as 1 (free space). The results of normalized transmission spectrum from numerical calculations are shown. Here, three major depressions can be clearly seen, with the depression minima at around 1510, 1560 and 1620 nm. These three major depression wavelengths are quite consistent with those of the three depressions from experiment. Also, the relative depths basically agree well between the experimental and numerical results. From this comparison, we can identify that the three depressions observed in the experiment originate from the coupling of the core mode (HE_{11}) with the cladding modes HE_{17}, HE_{21}, and HE_{22}, respectively. Note that the coupling of HE_{17} mode is phase-matched with the coupling coefficient period of 350 μm. Those of HE_{21} and HE_{22} modes were phase-matched with the coupling coefficient period of 700 μm.

4. Conclusions

In summary, we have demonstrated the spectral filtering effects of fiber with double-sided loading of periodical corrugations. It was found that the filtering wavelength and strength were dependent on the relative phase of the two periodical corrugations. In particular, when the relative phase was zero (crest-to-crest), spectral filtering effects disappeared completely. Such results and other evidences led to the conclusion that geometric deformation, instead of direct pressure-induced effect, was the dominating mechanism for generating spectral filtering functions in the double-sided loading configuration. Such a conclusion should also be true for the configuration of single-sided loading.

Related Publications:

1. Tsung-Yi Tang, Pao-Yi Tseng, Chung-Yi Chiu, Chih-Nan Lin, Yean-Woei Kiang, C. C. Yang, and Kung-Jen Ma, "Long-period Fiber Grating Effects with Double-sided Loading on Fiber," to appear in Optical Engineering. (SCI)
2. Horng-Shyang Chen, Shun-Lee Liu, and C. C. Yang, "Below-band-gap Waveguiding Behaviors of a Weakly Index-guided GaAs/AlGaAs Quantum Well Laser," Optics Communications, Vol. 220, pp. 383-388, 2003. (SCI)
3. Chih-Nan Lin, Yean-Woei Kiang and C. C. Yang, "Wavelength Switching in a Mixed Structure of a Long-period and a Bragg Fiber Gratings," Chinese Optics Letters, Vol. 1, No. 1, pp. 42-44, January 2003.
4. Jyh-Yang Wang, Yean-Woei Kiang and C. C. Yang, "Band Structure Calculations of Photonic Crystals with Dispersive Materials," SPIE Proceeding, Vol. 4905, 2002.
5. Horng-Shyang Chen, Shun-Lee Liu and C. C. Yang, "Below-band-gap Linear and Nonlinear-optics Waveguiding Characteristics of a Weakly Index-guided Semiconductor Laser," SPIE Proceeding, Vol. 4905, 2002.
6. Tsung-Yi Tang, Pao-Yi Tseng, Chung-Yih Chiu, Chih-Nan Lin, Yean-Woei Kiang, and C. C. Yang, "Long-period Fiber Grating Effects with Double-sided Loading on Fiber," SPIE Proceeding, Vol. 4904, 2002.
7. Nai-Ren Kuo, Yean-Woei Kiang and C. C. Yang, "Numerical Studies of Wavelength Conversion with Cross-Gain/Phase Modulation in a Multi-mode Interference Semiconductor Optical Amplifier," revised for publication in Optics Communications. (SCI)
8. Chien-Hung Lin, Qun Li, Pedram Z. Dashti, Amy A. Au, Ivan Tomov, C. C. Yang and Henry Lee, "Alignment of Birefringence Axes of Polarizaton-maintaining Fibers by Pressure- induced Periodical Micro-bending," submitted to Optics Communications. (SCI)