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論　文　要　旨
Thesis Abstract

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※報告番号	甲　第　280　号	氏　名 (Name)	Ravivudh Khunin

主論文題名　(Title)

The Perturbation of 3D Printed Long-Period Fiber Grating Device for Tunable Optical Filter inside Single-Mode Fiber

内容の要旨　(Abstract)

The telecommunication by using an optical fiber as a transmission medium becomes widely popular in several commercial fields and applications. The attenuation of the fiber is possibly lower than 0.14 dB/km in which it is able to transmit the optical power to very long distance with very few losses. There are two major types of the fiber; single-mode and multimode fiber. Single-mode fiber carries only one mode of light to be transmitted through longer distance while multimode fiber can carry several modes of light, but they are transmitted in shorter distance. The fiber type is selected regarding to the appropriate factors of usage such as distance and environment. In addition, an optical fiber is capable for the sensor application to the surrounding environment for the specific measurement. Various sensor types have been developed to response the appropriate usage with the lower price.

One of an interesting sensor type by using an optical fiber is the fiber grating. The fiber grating is the fiber with its structure change at specific point with the period as a grating period along the fiber axis. Fiber grating consists of two main types; fiber Bragg grating (FBG) and long-period fiber grating (LPFG). FBG is also called short-period fiber grating where its period relies in submicron level while LPFG has its grating period between 100 to 1,000 μm. This research focuses only on the LPFG with the single-mode fiber type. The development of the LPFG fabrication techniques on the fiber has been studied all the time. The LPFG first observed as a mode coupling inside the fiber with its periodic perturbation structure along the fiber axis. The mode coupling was detected as the attenuation loss in the form of resonant wavelength. Later, an inscription of LPFG structure into the fiber by using UV irradiation was performed to permanently alter the periodic index of the fiber. The fabrication was then developed by using external device as a mechanically induced technique which temporarily altered the fiber structure only when the fiber was perturbed by that device.

The LPFG fabrication by the perturbation of a 3D printed LPFG device on to the fiber is carried out to observe the coupling characteristics in term of resonant wavelengths as conventional methods did. The modern technology of three-dimensional printing has been increasing and it is benefit to various applications with low cost, but high efficiency. The 3D printing technology inspires the creation of an LPFG device in which the design of the 3D printed LPFG device is controllable. The 3D printed LPFG device has a general dimension of 4.0 cm long, 2.5 cm wide, and 0.5 cm thick. The grating period of the LPFG device begins from 500 to 630 μm with an increment of 10 μm. The perturbation process was taken by direct pressing the LPFG device on to the bare single-mode fiber by using a digital force meter and the perturbation weight can be read as well. The broadband light source with the

maximum power at 1550 nm transmits the light pulse through the fiber and it is received by an OSA.

The spectral output shows the amount of three to four resonant wavelengths for a single perturbation and five resonant wavelengths for a simultaneous perturbation. Each resonant wavelength corresponds to each coupling mode. All resonant wavelengths shift to the longer one when the LPFG device with longer grating period is applied. The relationship between the resonant shift and the grating period is linear function. The constant value referring to that relationship is the differential effective refractive indices between core and cladding mode. From the single perturbation, three resonant wavelengths have the constant value of 1.2857×10^{-3}, 1.5287×10^{-3}, and 1.9406×10^{-3}, respectively. All resonant shifts have the linearity over 0.99 as determined from the coefficient of determination (R^2). In addition, the 550 µm grating period of the LPFG device is slightly expanded by tilting the device from its initial axis. Practically, the fiber is rotated with the support of fiber rotator every 5 degrees. The constant values of three resonant shifts are 1.2666×10^{-3}, 1.4843×10^{-3}, and 1.8194×10^{-3}, respectively and all of them have the linearity higher than 0.99 as well. Those constant values are lower compared with the single perturbation due to larger induced refractive index and smaller grating expansion from tilted LPFG device. The perturbation of the LPFG device with the different specification of the fiber or different surrounding environment especially temperature may result to different results of resonant wavelengths.

Besides the experiment, the characteristic of coupling mode is simulated to observe the electric field distribution through the grating structure along the propagation axis. The finite-difference time-domain (FDTD) technique is used to simulate an electric field in term of TE mode in FullWAVE (Synopsys Inc.) software. The dimension of the fiber is shrunk to few microns and the index difference is setup to very high to decrease the simulation time, but still remain the clear resolution of the simulation results. Four examples of grating period; 5.2, 5.5, 5.8, and 6.1 µm, together with an amount of three grating pitches. The simulation results show that the coupling begins when the light passes the first grating pitch, but not every grating pitches as seen from the contour. The coupling characteristic shows that when the coupling to cladding mode happens, the magnitude of the field inside core layer decreases. When the electric field is in phase with the position of the grating pitch, the coupling at that grating pitch occurs. This causes the LPFG to have many grating pitches to increase the coupling strength. If any parameters are changed such as refractive indices of core and cladding layer, even the grating pitch, the distribution of an electric field will be changed or no coupling occurs on that structure.

The fabrication of an LPFG structure by using 3D printed LPFG device has a potential to filter out partial wavelength from the broadband signal inside an optical link. The advantage of using the LPFG device is that it temporarily changes the fiber when it is only perturbed on the fiber in which the fiber is able to be used for another purposes. The perturbation of a 3D printed LPFG device can be applied to the tunable filter as it can control the resonant wavelength. Moreover, it is also suitable for weight sensor to the object or an intruder sensor when someone approaches the sensor area.