Proceedings of the International MultiConference of Engineers and Computer Scientists 2015 Vol II,
IMECS 2015, March 18 - 20, 2015, Hong Kong

An Optical Tunable Fiber Filter based on The Concatenated Single-mode Optical Fibers with Different Cut-off Wavelengths

Wanvisa Talataisong and Ratchapak Chitaree

Abstract—**In this study, an optical fiber tunable filter in visible wavelengths is studied. The structure of the proposed filter is simply fabricated by splicing different single-mode optical fiber having different cut-off wavelength together. The working principle of the filter is based on the cladding mode coupling to the high order mode introduced by disturbance on a single mode fiber in the filtering system. The experimental results clearly show that the concatenated single-mode optical fiber can act as the optical fiber tunable filter.**

Index Terms—**cladding mode, coupling, cut-off wavelength, optical fiber filter, tunable filter**

I. Introduction

THE development of optical fiber technology has become a necessary part of the innovation in telecommunications. In recent years, the fiber-optics technologies have much progress in the development of fiber grating, fiber amplifiers, and microstructure fibers. One of the new methods in fiber optics is controlling the propagation of radiation in optical fiber by means of cladding modes. [1]

The optical fiber filter is an optical fiber device used for wavelength selection, which allows desired wavelengths to pass and reject the others. Numerous applications relevant to the optical filter include dense wavelength division multiplexing (DWDM) systems for dynamic wavelength selection, field tunable optical noise filtering, and optical amplifier noise suppression. These applications are widely used in telecommunication and astronomy.[2-4]

Basically, the cladding mode can be supported by optical fiber. However, they can be easily scattered or escape from the waveguide due to relatively small deformations and strains on the fiber. The deformation of multimode fiber can couple the cladding mode to the high-order mode and the loss at that mode can occur. The experimental results obtained suggest that the high order mode in the single mode fiber can also be filtered out by the deformation with the operating wavelength less than the cut-off wavelength.

Manuscript received December 30, 2014; revised January 10, 2015. This work was supported in part by the applied optics research group. “An optical tunable fiber-filter based on concatenated single-mode optical fibers with different cut-off wavelengths”.

Ms. Wanvisa Talataisong is with the Department of Physics, Faculty of Science, Mahidol University, Bangkok 10400, Thailand (e-mail: wanvisaboo@gmail.com).

Dr. Ratchapak Chitaree is with the Department of Physics, Faculty of Science, Mahidol University, Bangkok 10400, Thailand (e-mail: rachapak.chi@mahidol.ac.th).

In the communication system that used an optical fiber as the medium, both signal and noise can propagate through the optical fiber. The noise rejection can be achieved by integrating the optical fiber filter into the communication system.[5, 6] The attenuated wavelengths of the optical fiber filter can be tuned by adjusting the environmental surrounding the optical fiber filter or selecting suitable optical fiber parameters such as the cut-off wavelength.

In this study, concatenated single-mode fiber with different cut-off wavelengths are investigated and shown to attenuate particular wavelengths. The range of the attenuated wavelengths is found to depend on the cut-off wavelength of the single mode fiber. The attenuation wavelength from the perturbed single fiber and the concatenated of fibers are also compared.

II. Theoretical Background

The light propagation condition for an optical fiber is determined by the *V*-number or normalized frequency. The fiber that is designed to allow only the fundamental mode (LP_{01}) to propagate at the required wavelength is called the single mode fiber. When the V-number is less than 2.405, only the LP_{01} mode can propagate through the fiber core. If the wavelength λ of the source is reduced sufficiently, the fiber can accommodate more optical modes as V exceeds 2.405. Therefore, the fiber has become multimode. Hence the cut-off wavelength λ_c above which the fiber becomes single mode is given by the normalized frequency V_c in Eq. (1).[7]

$$V_c = \frac{2\pi a}{\lambda_c} NA = 2.405 \qquad (1)$$

where $NA = \sqrt{n_1^2 - n_2^2}$ = Numerical aperture (2)

in which a is a radius of the fiber core, λ_c is the free space cut-off wavelength n_1 and n_2 are the refractive indices of the core and cladding, respectively.

A good approximation to the number of modes M in a step index multimode fiber is given by

$$M \approx \frac{V^2}{2} \qquad (3)$$

Given $k = 2\pi / \lambda$ the normalized propagation constant (*b*) is related to $\beta = \beta_{lm}$ by the definition

$$b = \frac{(\beta / k)^2 - n_2^2}{n_1^2 - n_2^2} \quad (4)$$

The radiation losses by the perturbation in the wavelength less than the cut-off wavelength is caused by the power-coupling coefficient of the cladding mode to discrete high-order mode.

III. Experiment

Two parts of experiment were performed. They are composed of the examination of the optical fiber deformation of the single mode fiber and the investigation of the fiber deformation of the concatenated fiber with different cut-off wavelength.

A. The deformation of single optical fiber with different cut-off wavelengths

The setup shown in Fig. 1 was used for obtaining the experimental results. It consists of a tungsten halogen lamp (Ocean Optics LS-1), and the Spectrometer (Ocean Optics USB4000). The force was applied by tightening one plate towards the other fixed plate. The deformation in the fiber was created by pressing the acrylic plate on to the fiber. In the experiment the force sensors (Economy Force Sensor CI-6746 PASCO) were used to measure the force magnitude. Note that, in this study, the force magnitude of 25 N was used for every perturbation.

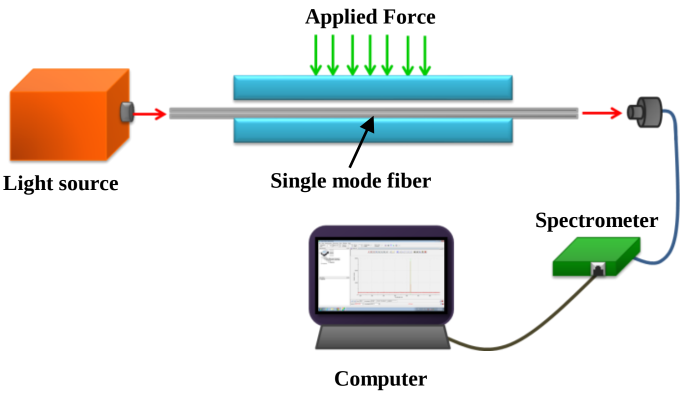

Fig. 1. Schematic diagram of the experimental setup used to measure deformation loss in a single mode fiber. The fiber placed between the two acrylic flat plates is perturbed.

In this experiment the 3 single mode fibers with different cut-off wavelengths (SM600 cut-off wavelength 600 nm, F-SF cut-off wavelength 800 nm, F-SBG cut-off wavelength 1,100 nm) were used to investigate the effect of cut-off wavelength to the attenuation spectrum. The light from tungsten halogen lamp was launched into the single mode fiber and the transmission spectrum was monitored using the Spectrometer (Ocean Optic USB4000). Firstly the transmission spectrum of unperturbed fiber was recorded. The fiber was then subject to deformation and its spectrum was recorded again and finally compared to the unperturbed spectrum. The difference gives the attenuation spectrum of the fiber due to the deformation.

B. The deformation of the concatenated optical fiber with different cut-off wavelengths

In this experiment the 3 single mode fibers with different cut-off wavelengths (SM600 cut-off wavelength 600 nm, F-SF cut-off wavelength 800 nm, F-SBG cut-off wavelength 1,100 nm) from previous experiment were spliced together by a fusion splicer. The splicing loss was measured to be less than 0.02 dB. The light from tungsten halogen lamp was launched into the concatenated fibers. Firstly the optical fiber with the cut-off wavelength of 600 nm was mounted on the perturbation plate. The fiber was then subject to the deformation and the attenuation spectrum of the concatenated fibers was recorded in real time. To observe other attenuation spectra from the concatenated fibers, the deformation position was moved subsequently to the fiber with the cut-off wavelength of 800 nm, and 1,100 nm, respectively.

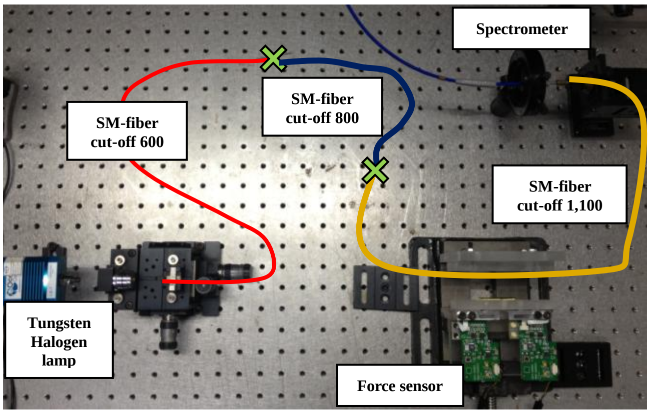

Fig. 2. Experimental setup used to measure deformation loss in the concatenated single mode fiber with different cut-off wavelength.

IV. Results and Discussion

The number of propagation mode in the optical fiber depend on the *V*-number. More than one propagation mode in the optical fiber can be found with the *V*-number greater than 2.405. From eq.(1), at the operating wavelength less than cut-off wavelength the *V*-number exceeds 2.405. So, when the fiber operates at the operating wavelengths less than the fiber cut-off wavelength, more propagation modes can be supported in the single mode fiber.

The attenuation spectra of the single fibers whose cut-off wavelengths include 600, 800, and 1,100 nm are shown in Fig. 3. It can be seen that the central wavelength of the maximum attenuation of the fiber with the cut-off wavelength of 600 nm is 547 nm while they are 670 nm, and 735 nm for the fibers with the cut-off wavelengths of 800 nm, and 1,100 nm, respectively. The results in Fig. 3 show that the attenuation wavelengths are less than the cut-off wavelength for each fiber. This is because the high order propagation modes in the optical fiber at the operating wavelength less than the fiber cut-off wavelength become extremely sensitive to the perturbation. The optical fiber with the cut-off wavelength of 1,100 nm in Fig. 3 possess more observable attenuation wavelengths than the attenuation wavelength of the optical fibers whose cut-off wavelength 600 nm, and 800 nm. This is because a fiber with a larger cut off wavelength can support more high order

ISBN: 978-988-19253-9-8
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

modes than a fiber with a lower cut off wavelength when being launched by the same range of wavelengths.

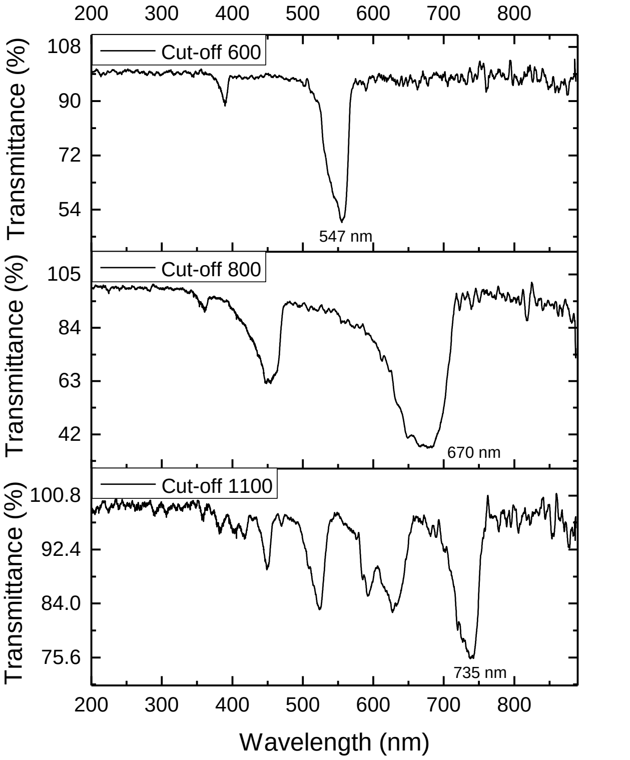

Fig. 3. The attenuation spectra of the single mode fiber with the cut-off wavelength 600, 800, and 1,100 nm when they were subject to the deformation.

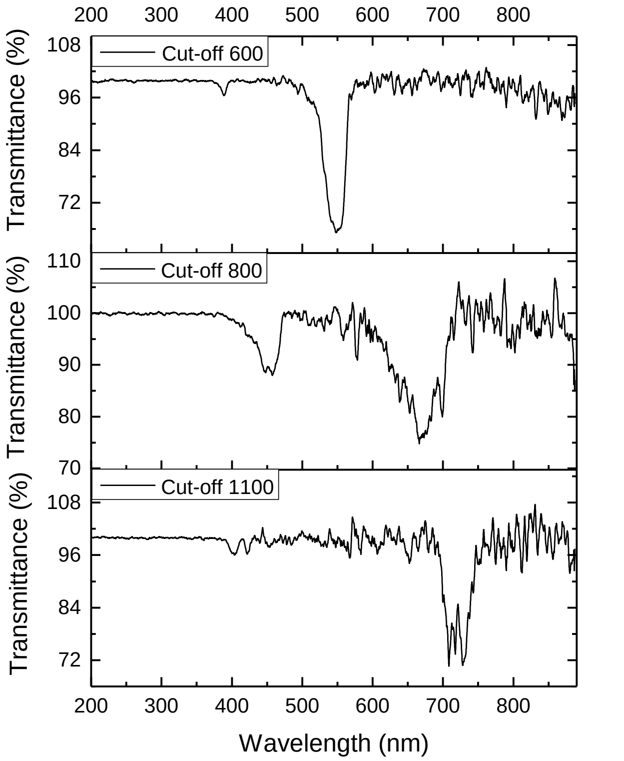

Fig. 4. The attenuation spectra of the concatenated fibers with the cut-off wavelengths 600, 800, and 1,100 nm when they were subjected to the deformation.

Figure 4 shows the attenuation spectra of the concatenated single mode fibers with the cut-off wavelengths of 600, 800, and 1,100 nm. Each graph shows the attenuation wavelength from the perturbation of each fiber. The results in Fig. 4 show that the central wavelength of the maximum attenuation of the fiber with the cut-off wavelength of 600 nm is 547 nm while they are 670 nm, and 727 nm for the fibers with the cut-off wavelengths of 800 nm, and 1,100 nm, respectively.

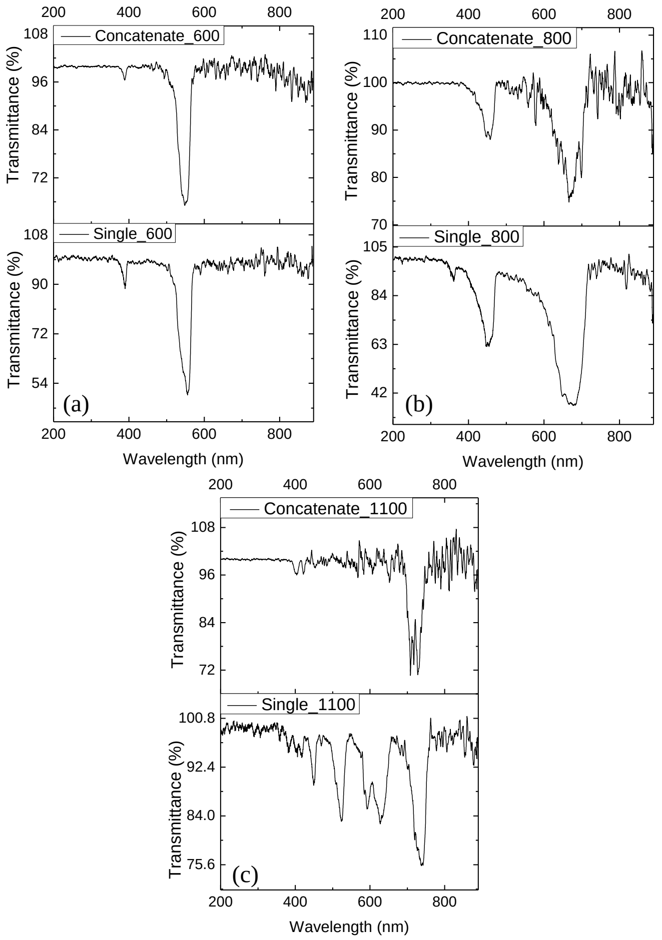

Fig. 5. The attenuation spectra of the concatenated fibers compare with the attenuation spectra of the single fiber when subject to the deformation.

The comparison of the attenuation spectra between the perturbations of the single fiber and the concatenated fibers are shown in Fig. 5. Figure 5(a) shows the attenuation spectra of the fiber cut-off wavelength of 600 nm. It can be seen that the perturbed single fiber and concatenated fibers have two similar attenuation dip wavelengths. The attenuation spectra of the fiber cut-off wavelength of 800 nm are shown in Fig. 5(b). The two attenuation wavelength occur when the fibers are perturbed and the attenuation dip wavelengths from the perturbed single fiber are the same as the perturbed concatenated fibers. Figure 5(c) shows the attenuation spectra of the fiber cut-off wavelength of 1,100 nm. The attenuation spectra of the perturbed single fiber display four attenuation dip wavelengths, whereas, the attenuation spectra of the perturbed concatenated fibers has only one attenuation dip wavelength. This is because the disappeared dip wavelengths experience the spectral loss due to the fusion splice. This is experimentally verified from the observed transmittance characteristics of the unperturbed concatenated fibers.[8]

The results from the perturbed single fiber with the cut-off wavelengths of 600 nm, 800 nm, and 1,100 nm show that the central wavelength of the attenuation increase with the

ISBN: 978-988-19253-9-8
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

increasing cut-off wavelengths and this phenomenon is also observable in the perturbed concatenated fibers. From this relation, the central wavelengths of the attenuation band can be changed with the changing of cut-off wavelength of the single optical fiber filter. This suggests that the concatenated fibers can offer a tunability of attenuation bands depending on which fiber section is disturbed.

V. Conclusion

In conclusion, we have demonstrated a possibility of using a single mode optical fiber as a fiber filter based on the cladding mode coupling in the perturbed single mode fiber. The attenuation spectra are observed in visible range. The tunable fiber filter can simply be fabricated by ways of splicing single mode fibers with different cut-off wavelengths together. In practical use, the proposed concatenated filter can simply be spliced with an optical beam carrying fiber. A combination of the attenuation wavelengths can be achieved by splicing the fiber based filter with different cut-off wavelengths together. The amplitude of each attenuation band can still be adjusted by changing the strength of the applied force. In this experiment, the optical fiber tunable filter was shown in this study to attenuate the central wavelength of the attenuation band up to 60% ($\approx$4dB). This suggests that the proposed fiber based filter is sensitive enough for various applications such as noise suppression (5dB).[9]

References

[1] O V Ivanov, S.A.N., Yu V Gulyaev, "Cladding modes of optical fibers: properties and applications." *Physics-Uspekhi*, vol. 49, pp. 24, 2006.

[2] Othonos, A., "Fiber Bragg gratings" *Rev. Sci. Instrum.*, vol. 68, 1997.

[3] Goh, C.S., S.Y. Set, and K. Kikuchi, "Widely tunable optical filters based on fiber Bragg gratings," *Photonics Technology Letters, IEEE*, vol. 14, pp. 1306-1308, 2002.

[4] Bland-Hawthorn, J., et al., "A complex multi-notch astronomical filter to suppress the bright infrared sky," *Nature Communications*, vol. 2, pp. 581-581, 2011.

[5] Mohammad, N., et al., "Analysis and development of a tunable fiber Bragg grating filter based on axial tension/compression," *Journal of Lightwave Technology*, vol. 22, p. 2001-2013, 2004.

[6] Sun, J., C.C. Chan, and X.Y. Dong. "A Wide Tunable Range Fiber Bragg Grating Filter," *in Lasers and Electro-Optics*, 2005.

[7] Kasap, S.O., *Optoelectronics and Photonics Principles and Practices*. 2001, United States of America: Prentice-Hall,Inc. 4.

[8] B. S. Wang, E.W.M., "Advanced Topics on Fusion Splicing of Specialty Fibers and Devices," *Passive Components and Fiber-based Devices (Proc. 6781)*, 2007.

[9] Estudillo-Ayala, J.M., et al. "Noise Suppression ASE of Erbium Doper Fiber Laser by Means of a Filter Optical Fiber Fattening," *in Frontiers in Optics 2008/Laser Science XXIV/Plasmonics and Metamaterials/Optical Fabrication and Testing.* 2008.

ISBN: 978-988-19253-9-8
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)