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A polarization-maintained, ultranarrow FBG filter with a linewidth of 1.3 GHz

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Abstract: A polarization-maintained ultranarrow FBG filter with a linewidth of 1.3 GHz has been successfully fabricated by using a 15 cm-long phase mask. A maximum reflectance of 65% and a side lobe suppression of 13 dB were obtained by employing an apodization technique with slits.

Keywords: optical filer, fiber Bragg grating, narrowband filter, polarization-maintained filter, apodization
Classification: Photonics devices, circuits, and systems

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1 Introduction

A fiber Bragg grating (FBG) is an attractive optical filter device because of its narrow wavelength selectivity, low insertion loss, compactness, low cost and ease of fabrication, therefore it is useful for dense wavelength-division-multiplexing or coherent optical communication systems. This excellent wavelength selectivity is also useful for realizing a fiber laser that operates in a single longitudinal mode, since the oscillation of fiber lasers is usually multimode due to the existence of Fabry-Perót modes. In addition, if we can fabricate a polarization-maintained (PM) ultranarrow FBG for such a laser, DWDM systems, and coherent lightwave transmission, their performance of the lasers [1] and systems would be much improved. A polarization-maintained (PM) ultranarrow FBG filter is necessary for the single polarization mode operation and strongly required for their desirable performance.

An FBG with a long length is important because it allows us to realize a narrower linewidth. A 0.04 nm (5 GHz) linewidth has been achieved using a 10 cm-long FBG [2]. A linewidth of 4.6 pm (0.58 GHz) and a side lobe suppression ratio of 8.7 dB have also been reported in a 20 cm-long FBG [3]. However, these are not PM FBGs. A 1.6 mm-long PM FBG was reported in [4], but it has a linewidth as broad as 1.6 nm (200 GHz).

In this letter, we demonstrate the first PM ultranarrow FBG filter with a linewidth as narrow as 1.3 GHz.

2 Fabrication of PM FBG

We fabricated a 15 cm-long PM FBG by using a conventional phase mask method [5]. The setup we used for fabricating the PM FBG is shown in Fig. 1. The UV laser light was the fourth harmonic of a 1.06 μm Q-switched YAG laser. The PM fiber was irradiated with 266 nm-wavelength UV light reflected by a mirror through a 15 cm-long phase mask. The mirror was scanned from one end of the phase mask to the other so that a 15 cm-long FBG was fabricated in a similar way to that reported in [6, 7, 8]. An appropriate scanning velocity was selected to generate a narrow linewidth because high index modulation causes significant linewidth broadening.

We also employed an apodization technique [8, 9] to suppress the side

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lobes using a slit with an aperture of sinusoidal shape as shown in Fig. 1 (i). In this figure, the aperture of the slit faces forward, but it was actually placed perpendicular to the UV beam. Additional exposure designed to adjust the average refractive index was carried out by inserting another slit with an inverse aperture. This exposure process was undertaken after removing the phase mask as shown in Fig. 1 (ii).

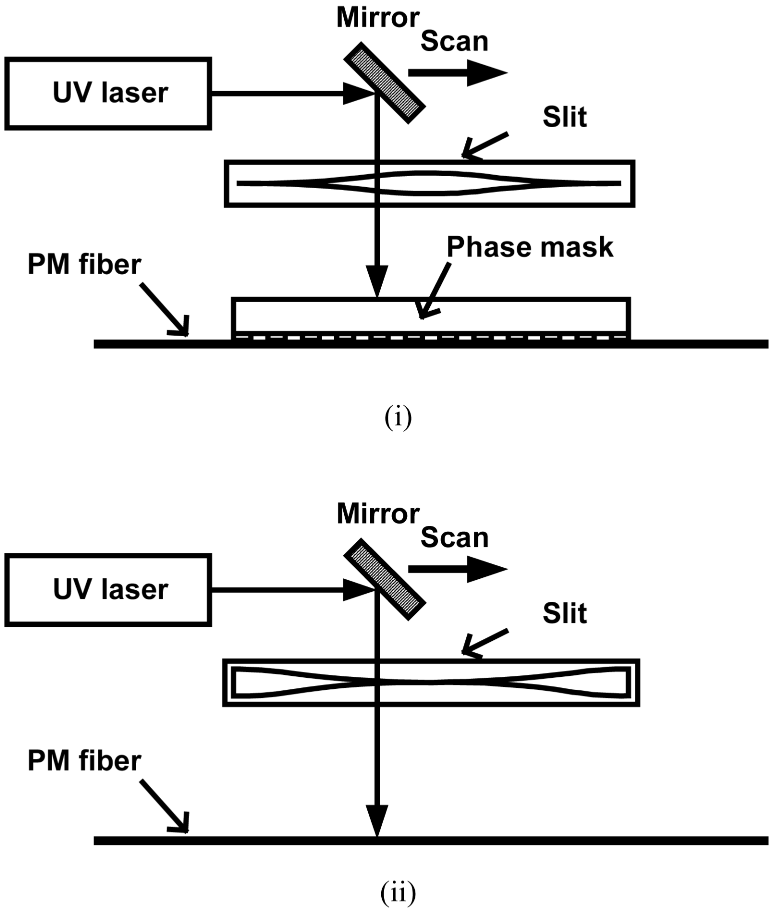

Fig. 1. Setup for fabricating PM FBG.

3 Measurement of PM FBG

The reflection spectrum of the fabricated PM FBG filter was measured by using an optical network analyzer with a spectral resolution of 40 MHz. The PM FBG was spliced to a PM circulator by selecting the slow axis. Then, the polarization of the input signal from the optical network analyzer was adjusted to the slow axis by using a polarization controller. Thus, we measured the reflection spectrum of the PM FBG with the slow axis. We also carried out a similar measurement by fusion-splicing a PM FBG to the PM circulator and selecting the fast axis.

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4 Results

Figure 2 (i) and (ii) show the reflection spectra of the fabricated PM FBG with the slow and fast axis, respectively. The FWHM linewidth is as narrow as 1.3 GHz, a maximum reflection of 65% is obtained at a wavelength of 1538.21 nm, and the side lobe suppression ratio is 13 dB with the slow axis as shown in Fig. 2 (i). Almost the same reflection spectrum was measured with the fast axis as that shown in Fig. 2 (ii) but the maximum reflectance wavelength was shifted to 1537.81 nm. The wavelength difference of 0.4 nm is caused by the modal birefringence of the PM fiber. The measured birefringence Δn_{eff} by wavelength-sweeping technique is 4×10^{-4}, which gives rise to a Bragg wavelength difference $\Delta\lambda_B$ of 0.4 nm from the following equation.

$$\Delta\lambda_B = 2\Delta n_{eff}\Lambda \tag{1}$$

Here, Λ is the grating period, which is 0.5 μm in the present PM FBG.

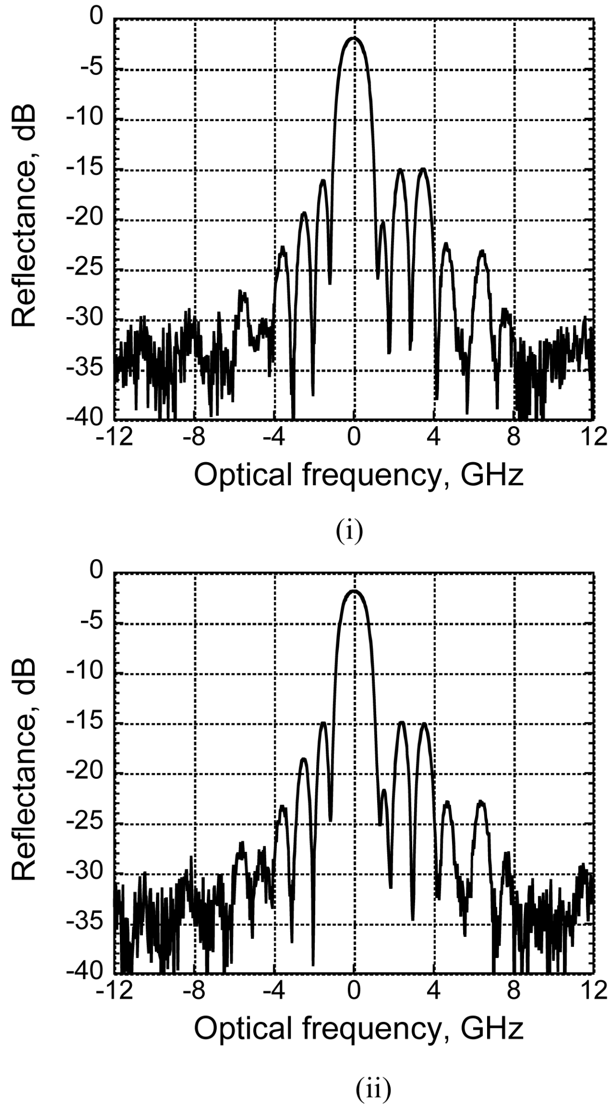

Fig. 2. Measured reflection spectrum of PM FBG with slow axis (i) and fast axis (ii).

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The insertion loss of the fabricated PM FBG filter is 1.9 dB and slightly higher than that of the conventional FBG filter because of its lower reflectivity. The high reflectivity is incompatible with the narrow linewidth when the length of a FBG is a constant as explained next.

Figure 3 shows the linewidth of a raised-cosine apodized 15 cm-long FBG as a function of reflectance calculated by the transfer matrix method [10]. The linewidth increases significantly with increases in the reflectance as shown in this figure. A narrow linewidth of less than 2 GHz can be obtained only in the low reflectance regime even in a 15 cm-long PM FBG. The filled circle in Fig. 3 represents the measured reflectance and linewidth of the fabricated PM FBG filter. The measured linewidth agrees well with the numerical result. However the simulation shows that the ideal side lobe suppression ratio is expected to be 32 dB. We attribute this difference to the disturbance of the UV irradiation caused by the stress-applied parts of the PM fiber and the imperfect optical alignment.

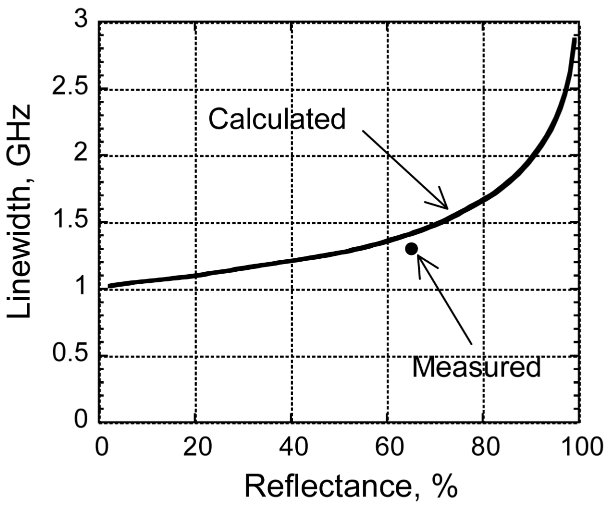

Fig. 3. Calculated linewidth versus reflectance of raised-cosine apodized 15 cm-long FBG. (The filled circle indicates the result for the fabricated FBG.)

5 Conclusion

We successfully fabricated a polarization-maintained, ultranarrow FBG filter with a linewidth of 1.3 GHz. The maximum reflectance and the side lobe suppression ratio of the FBG were 65% and 13 dB, respectively. The obtained linewidth and reflectance agreed well with the numerical calculation. The origin of the excess side lobes needs further investigation.

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