

Sampled phase-shift fiber Bragg gratings

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A phase-shift fiber Bragg grating (FBG) with sampling is proposed to generate a multi-channel bandpass filter in the background of multi-channel stopbands. The sampled moiré fiber gratings are analyzed by Fourier transform theory first, and then simulation and experiment are performed, the results show that transmission peaks are opened in every reflective channel, the spectrum shape of every channel is identical. It can be used to fabricate multi-wavelength distributed feedback (DFB) fiber laser.

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The phase-shift fiber Bragg gratings (FBGs) are widely used in optical fiber communications and optical fiber sensors. The insertion of a π phase-shift at the center of FBG opens a bandpass peak within the stopband^[1]. This is used in distributed feedback (DFB) fiber laser to generate narrow line-width and stable output^[2]. Sampled grating offers reflections of multi-wavelength, and the sampled grating distributed Bragg reflector lasers have been developed to extend the tuning range of semiconductor lasers^[3]. Sampled chirped fiber gratings^[4,5] have attracted wide attentions for their applications in multi-wavelength dispersion compensation. The chirped fiber grating which is added period sampling index modulation along the fiber axis is called sampled chirped fiber gratings, it has multi-channel reflection spectra, every wavelength channel inherits the group delay characteristics of the initial chirped fiber grating, so that the same group delay is achieved in every channel. The sampled phase-shift FBG are similar to sampled chirped fiber gratings in theory, under sampling, phase-shift bandpasses are opened in every reflective channel just like time delays in every channel of sampled chirped gratings.

Fourier transform (FT) theory is efficient to analyze FBGs with weak refractive index modulation^[6]. It is the main approach for analyzing sampled fiber gratings. Although most phase-shift index modulation functions are difficult to be analyzed by FT, FT is powerful to illustrate the grating's reflection characteristics. Moiré FBG^[7] is the simplest phase-shift grating. The index modulation is sinusoidal function. The Fourier integral of sinusoidal function along the grating (0, l) is shown in Fig. 1(b). The sampled phase-shift fiber grating coupler coefficient is

$$k(z) = p(z) \cdot s(z) \cdot k_0, \quad (1)$$

where $p(z)$ is the phase-shift function, $s(z)$ is sampled function. According to Ref. [7], the length l of moiré fiber grating is defined by

$$l = \frac{2\Lambda_1\Lambda_2}{\Lambda_1 - \Lambda_2}, \quad (2)$$

where Λ_1 and Λ_2 are the periods of two superimposed fiber gratings.

$$p(z) = \sin\left(\frac{2\pi}{l}z\right), \quad (0 < z < l), \quad (3)$$

$$s(z) = \sum_{n=1}^N \delta(z - np) \otimes \text{rect}\left(\frac{z}{s}\right), \quad (4)$$

where $\delta(z)$ is a Dirac delta-function, and \otimes is a convolution symbol, $\text{rect}(z)$ is a rectangular function with width s , and the sampled period is p . According to Kogelnik^[6], the reflective coefficient is the FT of coupler coefficient

$$\rho = \text{FT}[k(z)] = k_0 \text{FT}[p(z)] \otimes \text{FT}[s(z)]. \quad (5)$$

The relationship between refractive index modulation and reflectivity of phase-shift sampled fiber gratings is shown in Fig. 1. The three parts of Fig. 1(a) respectively indicate the phase-shift, sampled index modulation and their co-modulation. In Fig. 1(b) the FT according to Fig. 1(a) is shown. By the FT characteristics, phase-shift sampled grating's reflection is the convolving of phase-shift with sampled grating's reflectivity, sampling bandpass in every stopband could be achieved. The channel separation $\Delta\lambda$ is determined by sampling period

$$\Delta\lambda = \frac{\lambda_B^2}{2 \cdot n_{\text{eff}} \cdot p}. \quad (6)$$

The identity of every channel's reflectivity is determined by sampling duty cycle. The smaller sampling duty cycle leads to more useable channels. Under the condition of duty cycle of 1/8, if the sampling period is 2 cm and

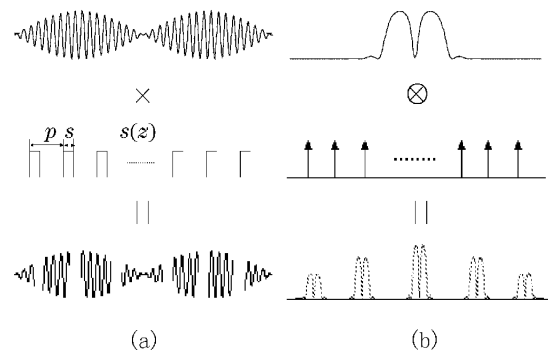


Fig. 1. The refractive index modulation of moiré sampled fiber grating (a) and its reflectivity got by FT (b).

with the index modulation of about 5×10^{-3} , about eight usable channels can be achieved.

The FT analysis of FBGs is very efficient, but not accurate. It is the first order Born approximation, only adapted to low reflectivity, but almost all FBGs work at high reflectivity. The most popular accurate calculating method is the numerical calculation using transfer matrix to solve the coupled-mode equation^[8]. As an example, the device parameters are: total grating length 2 cm, sampled period 1 mm, refractive index modulation 1×10^{-3} . The reflectivity spectra of phase-shift sampled fiber gratings are shown in Fig. 2(a). The multi-channel

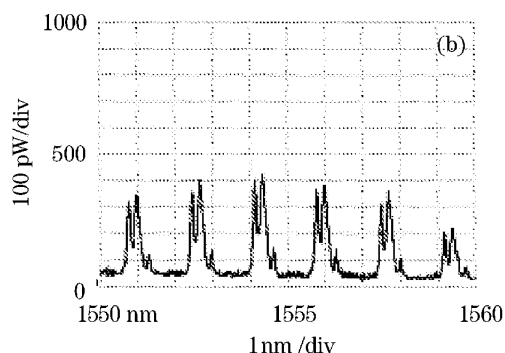
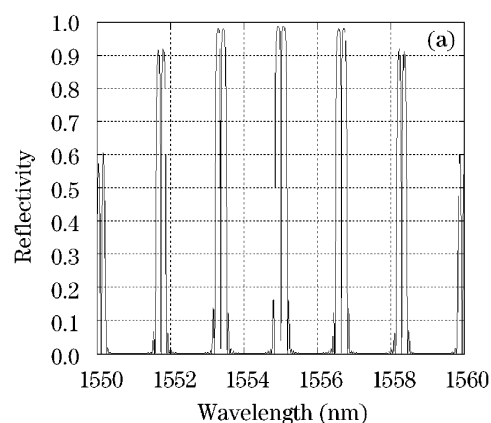


Fig. 2. Reflectivity spectra of sampled moiré fiber gratings with $l = 2$ cm, $p = 0.5$ mm, $s = 0.12$ mm, (a) by simulation, and (b) by experiment.

optical filter is achieved, in the center of every stopband, a narrow transmit peak is opened.

We take the experiment according to the simulated result, two sampled FBGs with equivalent amplitude and different periods Λ_1 and Λ_2 are superimposed in same fiber area. From Eq. (2) the wavelength difference of 2-cm moiré grating is about 0.078 nm, it is formed by slightly tension and superimpose. The sampled moiré FBG is imprinted using phase mask side writing and sampled with amplitude mask, the sampled period is 2 mm, the grating segment length is 0.12 mm. In the experiment, the photosensitive fiber was cladding mode suppress (Coreactive INT) loaded with hydrogen at 130 A for 240 hours at 25 °C so as to increase the photosensitivity and suppress the loss of cladding mode. The experimental result is shown in Fig. 2(b).

By sampling the phase-shift fiber grating, multi-channel bandpasses filters in the center of multi-channel stopbands are formed. The computer simulation and experiment of sampled moiré fiber gratings are performed, the results show that transmission peaks are opened in every reflective channel, the spectrum shape of every channel is identical. This structure will be useful to made narrow linewidth multi-wavelength DFB fiber lasers.

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