A filter array based on the variable period grating array and Fabry-Perot resonator*

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An integration method of grating array with different periods and Fabry-Perot (FP) resonator with an all-dielectric single-cavity is proposed. It is based on the capacity of spatial separation of spectral component by the grating and band-pass characteristics of filter to achieve the multi-pass band filtering. The filtering response can be tuned by changing the period of the grating rather than the cavity length of the filter. Theoretically, the relationship of the grating period and the peak wavelength is obtained by using the transfer matrix method (TMM). The device is analyzed by adopting the finite-difference time-domain (FDTD) method. The filter array can cover the wavelengths ranging from 850 nm to 950 nm with the full-width at half-maximum (FWHM) of 11−28 nm, and is suitable for the integration of the micro-filter array and the detectors.

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Optical filters have wide applications in optical detectors[1-3]. In tunable optical filters, excellent transmission tuning was achieved by spatially modulating the physical length of the cavity[4-8]. An array of 16 Fabry-Perot (FP) resonators with different fixed cavity spacings can achieve tunable multi-pass band filtering[1]. Another method is to change the effective refractive index by controlling the fill factors of the different dielectrics in cavity spacing[3,9-12]. It needs to pattern the cavity layer and fill other material. A filter array with different refractive indices and narrow band pass is beneficial to the integration of filters with an image sensor or the complementary metal-oxide-semiconductor (CMOS) chip, due to the same processing and production[3,10].

We present the filter array which consists of an FP resonator formed by two Bragg mirrors separated by a cavity layer and a grating array with variable periods. The transmission peak wavelength is mainly determined by the period of the grating. The adjustment of the light beam direction by the grating is equivalent to the regulation of the effective cavity length. The transfer matrix method (TMM) is used to obtain the relationship between light beam direction and peak wavelength, by which the grating period is calculated. The finite-difference time-domain (FDTD) method is employed to simulate and study the multi-pass band filtering effect of the filter array. It shows that this configuration is suitable for the state-of-the-art fabrication techniques and the integration of the micro-filter array with the detectors.

The configuration shown in Fig.1 consists of a grating array with different periods and an FP resonator which has the structure of $(LH)_2(L)_{2.39}(HL)_2$ to form two similar Bragg mirrors separated by a cavity layer. Bragg mirror coatings are composed of alternative quarter-wave layers with low (L) and high (H) refractive indices, where the quarter-wave layer represents that it has the quarter-wave optical thickness at the designed wavelength of 850 nm. Si and SiO_2 are high and low refractive index materials with refractive indices of 3.64 and 1.48, respectively.

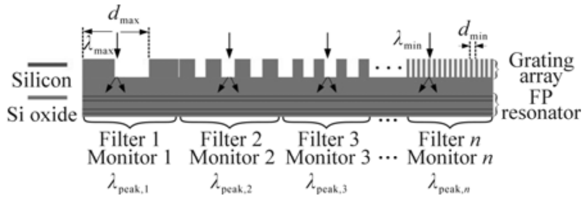

Fig.1 Schematic diagram of the vertical cross section of the filter array

When a light beam is incident on the grating vertically, the ±1st-order diffraction light beams distribute symmetrically on two sides of the normal, and accomplish simultaneously the constructive and destructive interferences. So both ±1st-order diffraction light beams are de-

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tected by the monitors. Set a little space between monitors, because there are some optical cross-talks between adjacent filters. For the rectangular grating, the 0-order and ±1st-order diffraction efficiencies can be calculated by[13]

$$\eta_0 = (1+\cos\Delta\phi)/2 , \tag{1}$$

$$\eta_{\pm 1} = 2\cdot(1-\cos\Delta\phi)/\pi^2 , \tag{2}$$

where $\Delta\phi = 2\pi h(n-1)/\lambda$.

The groove depth (h) calculated by Eq.(2) is 0.997 μm, the ±1st-order diffraction efficiency is about 40% for the wavelengths ranging from 850 nm to 950 nm, and the 0-order diffraction efficiency is less than 5% in the same wavelength range, as shown in Fig.2.

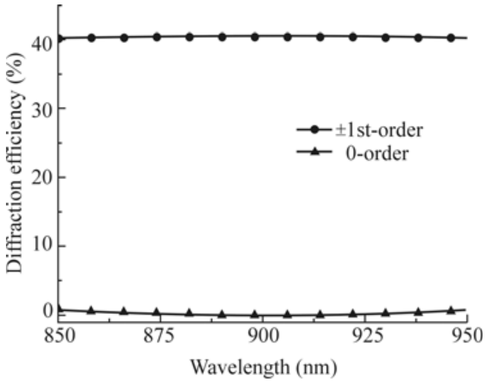

Fig.2 Diffraction efficiencies of wavelengths from 850 nm to 950 nm with the groove depth of 0.997 μm

For our design considerations, we assume the grating period to be a spatially varying parameter, while the grating thickness remains constant. In order to form the different filtering conditions of the FP resonator, the light beams transmitted through the grating array with different periods have different diffraction angles. A transmission peak is generated when precise phase-matching conditions are met. As a result, the transmission peaks depend on the period of the grating.

The grating equation is

$$d(\sin\beta_0 - \sin\alpha) = m\lambda_0,\ m=\pm1,\ \alpha=0 , \tag{3}$$

where α and β_0 represent the incident angle and diffraction angle, and d is the grating period.

The transmission peak wavelength of the FP resonator can be described as[14]

$$\lambda_0 = \frac{2nL\cos\beta_0}{m+(\varphi_1+\varphi_2)/2\pi},\ m=0,\pm1,\pm2\cdots , \tag{4}$$

where n represents refractive index of the cavity layer, L is the thickness of the cavity layer, and φ_1 and φ_2 are reflection-phase shifts of two Bragg mirrors. In order to achieve the constructive interference of wavelength λ_0, Eqs.(3) and (4) should be fulfilled simultaneously.

Theoretically, as the diffraction angle increases, the effective cavity length of the FP resonator also increases. It results in a blue-shift of the transmission peak. Fig.3 shows the calculation results of the transmission peak wavelengths at different diffraction angles obtained by using TMM and the relationship between diffraction angle and wavelength at the grating period d_0 from Eq.(2). The intersection of the two curves is the position of constructive interference.

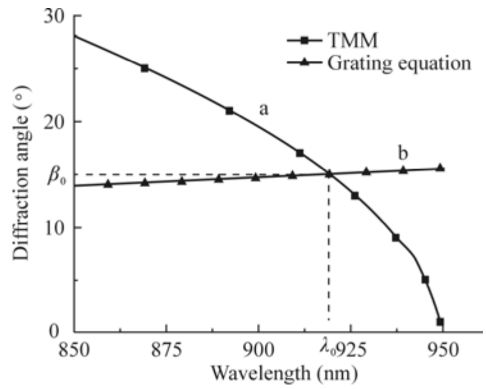

Fig.3 Calculation results of the transmission peak wavelengths at different diffraction angles obtained by using TMM and relationship between the diffraction angle and wavelength at the grating period d_0 by grating equation

We analyze the filtering behavior of the combinational structure of the FP resonator with grating array by means of FDTD method. As shown in Fig.4, with different grating periods ranging from 1.188 μm to 5.39 μm, the different peak wavelengths are from 850 nm to 950 nm with full-width at half-maximum (FWHM) of 11−28 nm. Moreover, the 0-order diffraction light of the grating with different periods cannot be reduced to zero and is injected into the FP resonator vertically. Therefore, there is the same 0-order peak wavelength for all gratings as shown in Fig.4.

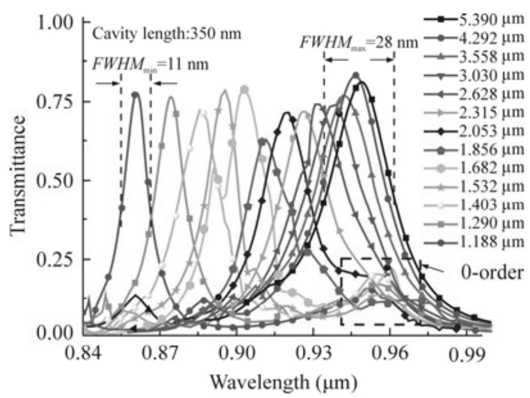

Fig.4 Simulated spectral responses of the filter array with grating periods ranging from 1.188 μm to 5.390 μm

When the narrow-band thin-film filter is used in tilted incidence, the bandwidths of s-polarization and p-polarization can be separated[15]. In this paper, the filter array is designed for p-polarization. Fig.5 shows the polarization-dependence of the FP resonator. The peak wavelengths of s-polarization and p-polarization beams do not coincide with each other for the incidence angles of 10°, 20° and 30°, and the passband width of p-polarization is greater than that of s-polarization.

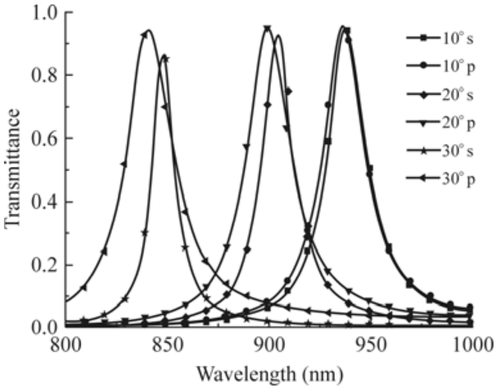

Fig.5 Transmittance spectra of the FP resonator for different incident angles and polarization states

In conclusion, we present an optical filter array based on the grating array with variable periods and FP resonator formed by two Bragg mirrors separated by a cavity layer. The filtering response can be tuned by changing the grating period instead of the effective cavity length. The filter array can cover the wavelengths ranging from 850 nm to 950 nm with the FWHM of 11−28 nm. The configuration is suitable for state-of-the-art fabrication techniques and the integration of micro-filter with detector array.

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