FABRICATION OF SILICON-BASED GUIDED-MODE RESONANCE FILTER WITH SPECTRUM-MODIFYING LAYER DESIGN

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Abstract: In this paper, the guided-mode resonance filter was fabricated with Si-based materials in a suspended membrane. With the membrane-type structure, the spectral response can be modified with a post deposition of spectrum-modifying layer. With optimized design, the Si-based resonant filter can be adopted as an optical bandstop filter of high rejection ratio within a wide spectral range. © 2005 JSAP

1. Introduction
Recently, guide-mode resonance (GMR) filters have raised considerable interests for their excellent spectral properties and versatile possible applications.[1-4] GMR filters possess fine spectral properties as well as the most conventional optical filter constructed of stacked multilayer thin-film but with much simpler structure and less fabrication complexity. Several GMR devices have been demonstrated with different materials, however, most of these devices used non-Si-based materials and that will limit their potential applications to integrated system.[1,4-5] In this paper, we propose a GMR filter fabricated with Si-based materials, therefore, it may be a candidate for the rapid growing demand of Si photonics.

GMR devices basically consist of a grating layer and a waveguide layer on various substrates. These devices were fabricated sequentially from the lower substrate to the upper layers. The device performance was unmodifiable after the fabrication process was completed. Unusually, we proposed a spectrum-modifying layer that can improve the spectral characteristics. Under optimized design, the Si-based GMR device can be used as an optical bandstop filter of high rejection ratio within a wide spectral range.

2. Device Description
The proposed Si-based GMR filter is as shown in fig.1. It was fabricated in a suspended SiN_x membrane on a Si substrate by using Si bulk micromachining technology. The etched grooves upon the membrane are used as the coupling layer to couple the incident light to excite the resonance. The membrane under the groove region is served as the waveguide layer to support the guided-mode. A subsequent SiO_2 membrane is added to the bottom of the membrane structure as the spectrum-modifying layer to modify the spectral response.

The rigorous coupled-wave analysis (RCWA) and the effective-medium theory (EMT) are used to predict the resonance locations and the sideband performance. By using the EMT, the region of etched grooves can be considered as a uniform layer with effective index n_{eff}[6]. Thus the GMR structure can be considered as stacked multilayer thin-film, as shown in fig.2, to estimate the sideband performance. By using RCWA, several resonance dips were found as shown in fig.3. The resonance dips nearby 1550nm were in our concerned. It is worth to note that the results of sideband calculated by RCWA agree well with the results obtained by using EMT. As shown in fig.3(a), the sideband transmittance of the filter without spectrum-modifying layer was around 0.7 and the maximum transmittance is around 0.82 as a results of Fresnel reflection. Moreover, the asymmetrical line shape resulting from the asymmetric waveguide structure is in evitable. Therefore, the introduction of additional membrane into the GMR filter is essential to overcome the above problems.

Fig.2. (a) Structural parameters of the silicon-based GMR filter; (b) Illustration of structure when considered as stacked multilayer thin-film.

The influence of SiO_2 spectrum-modifying layer were shown in figs.3(b) and 3(c). It is worth to note that the sideband can be modified by altering the SiO_2 thickness. Thus, its symmetrical characteristic declines again. Moreover, the variation of its transmittance at sideband is also observed.
Fig.3. Simulated spectrum of the proposed GMR filter without and with lower SiO₂ cladding layer by using RCWA and EMT theory. The incident waves are with TM polarizations.

3. Experimental Results

Fig.4 shows the measured spectrum of fabricated GMR filters. As shown in figure, the transmission spectrum of GMR filter without SiO₂ layer can be improved by incorporating the additional SiO₂ layer. The symmetrical line shape at sideband can be obtained for the case of the SiO₂ thickness of 250 nm. The corresponding simulated spectrum revealed in figs.3(a) and 3(b) verify that the introduction of SiO₂ layer of 250 nm thickness can tailor its spectrum as shown in measured results.

As the thickness of SiO₂ layer increases to 500 nm, the measured results show that the symmetrical characteristic at sideband declines as mentioned above. According to the simulated spectra in figs.3(a) and 3(c), both line shapes are similar, but the sideband variation is more abrupt than that of the original filter. The drastic variation at sideband would enhance its transmission response. This improvement from 0.82 to 0.93 at sideband off resonance is also exhibited in fig.4 as well.

4. Optimized Designation

According to the proposed structure, when the structural parameters are optimized, the transmission bandstop GMR filter of high rejection ratio within wide spectral range can be achieved. As shown in fig.5, when the filter is designed as grating-waveguide-cladding layer of λ/4−λ/2−λ/4 thickness, the filter has a resonance dip of higher than -50dB and high sideband transmittance over 0.96 in 700nm spectral range.

Fig.5. Spectral response of the proposed Si-based GMR filter simulated by RCWA method.

5. Conclusions

In this paper, the Si-based GMR filter with suspended membranes was experimentally demonstrated. With the membrane structures, the spectral response can be modified significantly by adding a spectrum-modifying layer. Since the grating layer is designed at the zero-order diffraction, its spectral response at sideband can be precisely predicted by regarding the GMR structure as a stack of effective homogeneous thin films. Moreover, it can be used as a bandstop filter with high rejection ratio higher than -50dB within 700nm spectral range under optimized design. Since the filter was based on Si-technologies, it may be integrated with other optoelectronic elements for more potential applications.

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7. References