Planar focusing lens grating for vertical coupling on 2D photonic crystal slab waveguide

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Abstract: Planar focusing lens gratings are investigated in order to realize an efficient coupling from an optical fiber to a two-dimensional photonic crystal slab waveguide. The optimal gratings exhibit the calculated coupling efficiency of 34%.

1. Introduction

For practical application of two-dimensional photonic crystal (2DPC) slab waveguides (WGs), reduction of the coupling loss between an optical fiber and the 2DPC slab line-defect WG is an important problem. So far, high coupling efficiency up to 90% was reported on the SOI-based nano-wire by attaching a polymer spot-size converter (SSC) on the tapered silicon nano-wire [1]. However, the SSC is not easy in design and fabrication for the current 2DPC slab WGs and strongly depends on polarization states. As an alternative way, a grating coupler for vertical coupling including two-dimensional grating as a polarization splitter is promising for the current purpose [2].

This paper reports design of two kinds of one-dimensional planar focusing lens gratings (P-FLGs). One is a shallow grating, where the structure is simple but fabrication needs two-step vertical etching for the 2DPC WG and grating region. Another is a perforated grating, where fabrication is easier but high efficiency needs detailed numerical study. Coupling efficiencies of these gratings are calculated with a three-dimensional finite-differential time-domain (FDTD) method.

2. Design of a shallow planar focusing lens grating

Figures 1 (a) and (b) show a plan-view and cross-sectional view of the P-FLG with a shallow groove on a GaAs core layer (a thickness of 240 nm). A TE polarized Gaussian beam (diameter of 6 μm and wavelength of 1,3μm) is vertically incident on the structure. Due to the concentric circle groove grating, the incident light is focused on the center of the circle, as shown by the dashed line. Therefore, the maximum coupling efficiency to the 2DPC WG is achieved when the input edge of the 2DPC WG with 620 nm in width is located at the focal point. An angle of incidence, θ, and radius of the most inner circle, r_0, were decided to be 10 º and 3.6 μm, respectively, by optimization.

Geometry of the grating is shown in Fig. 1 (c), while a spatial spectrum of permittivity (ε) distribution with a duty cycle (DC) of 0.5 is shown in Fig. 1 (d). First of all, a horizontal reflection in the WG is given by the second-harmonic spectrum (2/Λ) and is diminished when the DC is 0.5. Therefore, calculation hereafter is performed for the DC of 0.5. At this time, a magnitude of the base spectrum (1/Λ) for the given groove depth decides a relative coupling strength and the base spectrum is 5 for the optimized depth of 100nm. For these conditions, grating period was optimized as 520nm from the well-known grating equation [3]. Resultantly, the values of the optimized geometry, as shown in Fig. 1 (c) give the optimized coupling efficiency (C=30%). Also the out-of-plane reflectance (R=8%), out-of-plane transmittance (T=25%) and in-plane backward efficiency (B=0.4%) are indicated in Fig. 1 (b).

3. Design of a perforated planar focusing lens grating

Here, the perforated P-FLG is studied in detail. Figure 2 shows an enlarged view of the structure. An optimization parameter for this structure is only the DC. The geometry in Fig. 2 (a) gives the DC of 0.8 and the base spectrum of 4.1, as shown in Fig. 2 (b), almost the same as 5.0 in Fig.1. However, since the second harmonic spectrum is as large as 2.7, the calculated coupling efficiency is reduced down to 12% from 30% in Fig.1. The reduced coupling efficiency can be improved by a doubly-grooved grating (DGG), as shown in Fig.2 (c), where the second harmonic spectrum can be reduced to 1.0, as shown in Fig.2 (d). If the DGG has a 1:1 ratio of line and space width, the second harmonic component dominates the spatial spectrum improperly. An unbalanced ratio of line and space width from 1:1 ratio, as shown in

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Fig. 2 (c), reduces the second harmonic component and enhances the base component. As a result, the efficiency can be improved up to 20% from 12%.

Calculation mentioned above has been performed only in the GaAs core layer. Here, an effect of the beam which is crossed through the core layer, reflected by the substrate top-surface (missing in the figure) and incident into the core is considered. This effect is controlled by the sacrificial layer thickness between the core and substrate. Figure 3 shows the calculated coupling efficiency as a function of the sacrificial layer thickness for the perforated P-FLG with the DGG in Fig. 2 (c). The thick solid line corresponds to the coupling efficiency without such a consideration. The maximum coupling efficiency of 34% is achieved for the sacrificial layer thickness of 1900 nm.

4. Conclusion

Two kinds of the P-FLGs were investigated in order to realize the efficient vertical coupling from the optical fiber to the GaAs-based 2DPC slab WG. The coupling efficiency of 34% was achieved by the perforated P-FLG with the DGG in case with the sacrificial layer thickness of 1900 nm.

Acknowledgements
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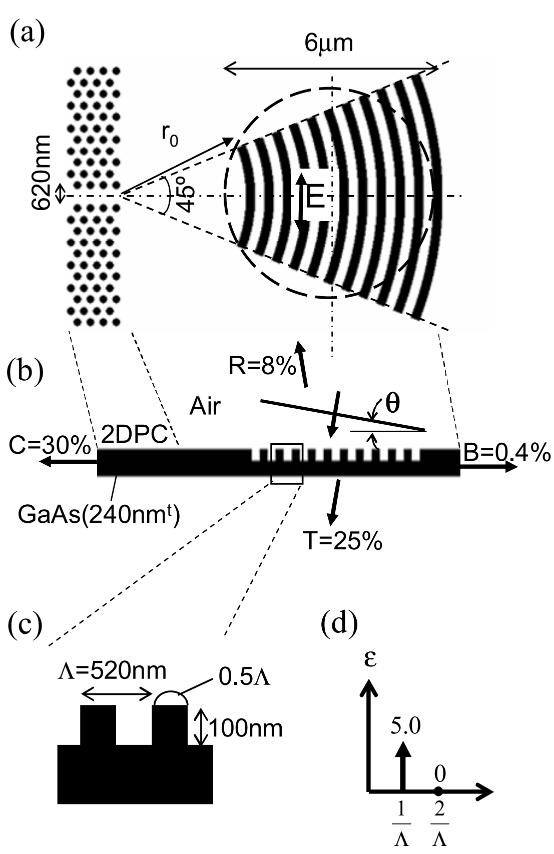

Figure 1: Schematic of shallow P-FLG. (a) Plan-view. (b) Cross-sectional view. (c) Enlarged cross-sectional view of the grating. (d) The spatial spectrum of permittivity distribution with the DC of 0.5.

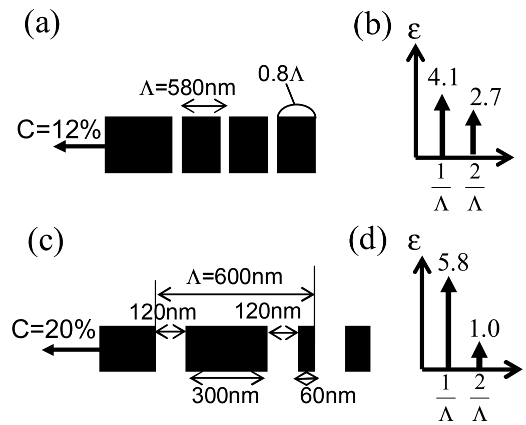

Figure 2: Schematic of perforated P-FLG. (a) Enlarged view with the DC of 0.8. (b) The spatial spectrum with the DC of 0.8. (c) Enlarged view for the DGG. (d) The spatial spectrum for the DGG.

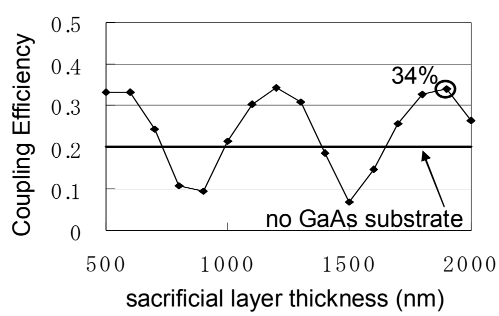

Figure 3: Calculated coupling efficiency as a function of the sacrificial layer thickness for the perforated P-FLG with the DGG.

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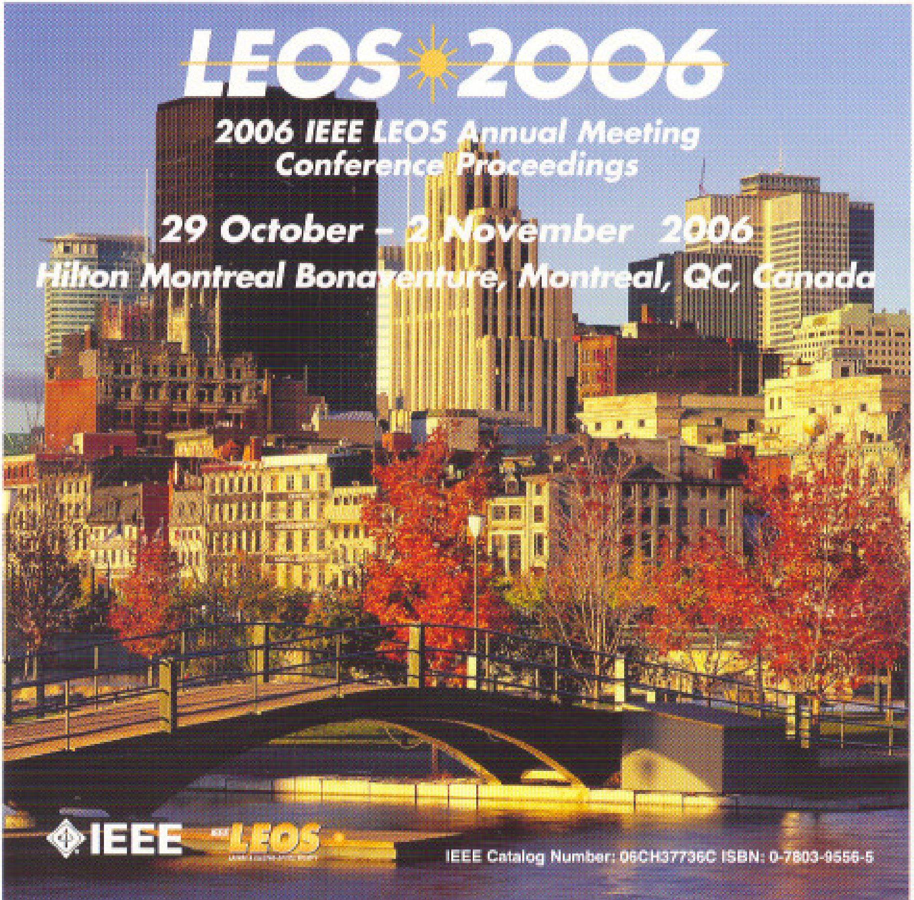
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