High Efficient Vertical Binary Blazed Grating Coupler for Chip Level Optical Interconnections

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Abstract: A high-efficiency vertical binary blazed grating coupler is proposed. An 83% of efficiency and 65nm 3dB bandwidth are demonstrated. The tolerance of incident angle is 11.5°.
OCIS codes: (050.6624) Subwavelength structures; (230.1950) Diffraction gratings

1. Introduction
Silicon photonics is attractive for the communication applications. However the efficient coupling between silicon chips and external elements remains a challenge due to the huge mode mismatch between the optical fiber and the nanowire waveguide. Several attempts were made to overcome this problem. Spot-size converters provide large bandwidth and efficiency, but they can’t be used for wafer scale testing, while grating couplers stand out as an attractive alternative since light can be coupled out of the plane. In recent years, sub-wavelength gratings especially the binary blazed gratings (BBG), have attracted more and more attention and find wide applications in optical circuits [1-4]. Compared with conventional uniform grating, the binary blazed gratings can "blaze" all diffracted light into a single diffraction order, suppress other diffraction orders, and enhance the efficiency and directionality of the gratings. Other types of blazed gratings, such as the triangular shaped grating and parallelogram shaped grating, cannot be fabricated with standard etch processes. The BBG is formed with multiple rectangular pillars having different widths and uniform height, which is a kind of binary version of the triangular tooth shape of the blazed grating and can be easily fabricated by only one etching step. It is COMS compatible and available for mass production.

However, in current grating coupling schemes, most of the incident light is not vertical, which is not always desirable in integrated applications, or additional complexity has to be included in the optical system design. In this work, we propose a novel high-efficiency perfectly vertical binary blazed grating coupler, which enables a simpler optical alignment process and offers an efficiency as high as 83%. This is the highest efficiency obtained through a vertical grating coupling method.

2. Device Structure and Design
To make the design valid and unique, the rigorous coupled-wave analysis for diffraction [5] and the simulated annealing optimization method [6] have been applied for the design process.

The schematic diagram of the structure is shown in Fig.1 (a). The incident power P0 is divided into four parts throughout the grating: P’, P, Pr and Pt. The coupling efficiency η in this work is defined as η = P/P0.

![Fig. 1. (a) Basic structure for simulation. (b) (I) Common blazed grating. (II) Discrete multilevel grating. (III) Binary blazed grating.](image)

The BBG is composed of variable sub-wavelength pillars with uniform height and different widths shown in Fig.1 (b). In our structure, every period is divided into M equal sub-periods with the width of q=T/M. The optimum M is fixed as 4, which is a compromise of considering the coupling efficiency and the fabrication constraint [7]. Each ridge’s width is modulated to obtain the blaze effect [8]. H1 is the height of the common blazed grating, hi (i = 1, 2, 3, 4) is the height of each discrete multilevel grating. The fill factor of each sub-period fi (i = 1, 2, 3, 4) is defined as
the ratio of the pillar width to the sub-period width, which can be derived by discretizing the common blazed grating structure. According to the localized effective refractive indices theory of binary gratings and the discrete processing of signal phase, the fill factors can be computed. In this structure, f4 is set to 1, then the rest fill factors can be optimized, f1 = 0.075, f2=0.293, f3= 0.6. Moreover, considering the most common type of single mode fiber with a core diameter of 8 to 10 μm, the grating length will be fixed at 9.81 μm (18T). The optimized grating etching depth H is 350nm with a 160nm-thick slab waveguide left, grating period T=545nm, waveguide height is 340nm, BOX layer thickness L is 2.43μm, the incident angle is 0°.

3. Simulation results and discussion

The coupling efficiency as a function of incident wavelength is illustrated in Fig. 2(a). The coupling efficiency can reach 83% at the wavelength of 1560nm, with a 3dB bandwidth of 65nm from 1546nm to 1579nm. Fig. 2(b) shows the Poynting vector distribution of the coupling efficiency calculated by Opti-FDTD software. Obviously, the light propagates along the right direction. According to Fig. 2(c), the coupling efficiency is higher than 50% when incident angle θ varies from -4.5° to 7°. While, under the condition of perfectly normal incidence, i.e. θ= 0°, the coupling efficiency can reach 83%. This coupling efficiency is quite high compared with other common vertical grating coupler case. This property is intrinsic to diffractive elements composed of sub-wavelength features and cannot be achieved with common diffractive elements.

4. Conclusion

We designed and demonstrated a novel binary blazed grating coupler with efficient vertical coupling. This coupler has 3dB bandwidth of 65nm and high coupling efficiency of 83% at a wavelength of 1560 nm, the efficiency of which is much better than that of uniform grating couplers with oblique incidence, and vertical grating couplers with bottom mirror. This structure has a tolerance of 11.5° in incident angle, which brings convenience to integration. Experiments are being carried out and results will be presented soon.

Acknowledgments
This work was supported by Natural Science Foundation of China (Grant No. 61177058), the Major International (Regional) Cooperation and Exchange Program of the National Natural Science Foundation of China (Grant No. 61120106012).