Cavity-Resonator-Integrated Grating Input/Output Coupler with Au Reflection Layer

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***Abstract*—A cavity-resonator-integrated grating input/output coupler (CRIGIC), which consisted of a grating coupler and two distributed Bragg reflectors, was designed and fabricated in a thin-film SiO_2-based waveguide with an Au reflection layer for the first time. Output coupling efficiency of 58% was obtained by 20-μm-aperture CRIGIC.**

Keywords-integrated optics; grating couplers; distributed Bragg reflectors; cavity resonators; waveguides; optical interconnects

I. INTRODUCTION

Grating couplers (GCs) have attracted much attention as one of key components in inter-/intra-chip optical interconnects for future ultra-high-speed signal processing units. We have proposed and investigated an intra-board chip-to-chip optical interconnect device using focusing grating couplers (FGCs) integrated in a thin-film waveguide for two-dimensional parallel signal transmission [1-3]. The channel width of the device was a few hundreds micrometer, which was determined by the aperture size of FGCs. In order to increase the wiring density, the radiation decay factor of GC has to be increased so that the coupling length as well as the aperture size can be reduced. The radiation decay factor depends on and is limited by the modulation depth of refractive index and the groove depth of the grating structure. Short GCs have been recently reported in semiconductor waveguides with large refractive index difference [4–6]. Such large index difference, however, is not obtained in dielectric waveguides, resulting in small radiation decay factors. In order to achieve high-efficiency vertical coupling with smaller aperture size in dielectric waveguides, we have proposed and investigated a new-type GC, namely a cavity-resonator integrated grating input/output coupler (CRIGIC) [8, 9]. CRIGIC consists of one GC and two distributed Bragg reflectors (DBRs). In previous works, we have theoretically investigated [7] and have fabricated [8] the CRIGIC in a thin-film SiO_2-based waveguide on a Si substrate. In this work, we design and fabricated CRIGIC integrated in a thin-film SiO_2-based waveguide with an Au reflection layer on a substrate for the first time. The Au reflection film was introduced to suppress a substrate radiation and to enhance an output air radiation from GC. Output coupling of a guided wave to a free-space wave was demonstrated experimentally.

II. DEVICE CONFIGURATION AND DESIGN

The cross-sectional structure of the waveguide device for TE mode is illustrated in Fig. 1. The waveguide consists of a Ge-SiO_2 core layer (refractive index of 1.54), a SiO_2 buffer layer (refractive index of 1.464), and an Au reflection layer with a Cr adhesion layer on a glass substrate. An electron-beam (EB) resist layer (refractive index of 1.55) is coated on the core for CRIGIC. In CRIGIC, a GC is integrated between a front and a rear DBRs with phase-shifting spaces (PSs).

The incident guided wave is partially reflected by the front DBR, partially coupled out to a radiation wave by GC, and reflected by the rear DBR with reflection efficiency of almost unity. The reflected guided wave from the rear DBR is partially coupled out to another radiation wave by GC, partially reflected by the front DBR, and transmitted the front DBR to eliminate the reflection by CRIGIC. The rear PS between GC and the rear DBR is determined so that the radiation wave from backward guided wave is phase-matched with that from forward guided wave. The coupling efficiency of the front

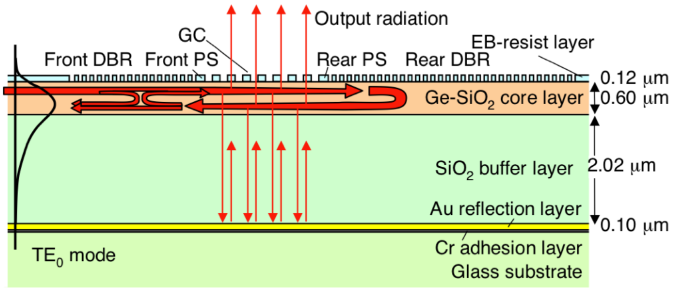

Figure 1. Cross-sectional structure of the designed CRIGIC.

DBR and the front PS between the front DBR and GC are determined so that the reflected wave by the front DBR is canceled by the transmitted backward wave through the front DBR. The thickness of the buffer layer is chosen so that the indirect air radiation wave reflected from the reflection layer is phase-matched with the direct air radiation wave. Therefore, CRIGIC generates only output air radiation.

The device characteristics were predicted by using a coupled mode analysis. The effective index of TE_0 mode was 1.4896, and the grating period of GC and DBRs were 565.7 nm and 282.8 nm, respectively, for operating wavelength of 842.6 nm. The radiation decay factor of GC and the coupling coefficient of DBR were calculated to be 4.46 mm^{-1} and 17.9 mm^{-1}, respectively. The lengths of the front and rear PSs and the front and rear DBRs were calculated to be 212.1 nm, 212.1 nm, 46.9 μm, and 141.4 μm, respectively, for the GC length of 20 μm. Fig. 2 shows the theoretically calculated wavelength dependence of output, transmission, and reflection efficiencies. The maximum output efficiency was calculated to be 96%, which was 6 times as high as that of a conventional GC with the same aperture size. Full width at half maximum (FWHM) of wavelength selectivity was 1.2 nm.

III. FABRICATION AND EXPERIMENTAL RESULTS

A Cr adhesion layer and an Au reflection layer were sequentially deposited by thermal evaporation on a SiO_2 substrate. A SiO_2 buffer layer and a Ge-SiO_2 core layer were sequentially deposited by plasma-enhanced chemical vapor deposition (PECVD). After an EB resist layer was spin-coated, CRIGIC pattern was formed by EB direct writing and developing. GCs of 1.3 μm and 0.6 μm periods with 0.5 mm aperture were also fabricated for exciting TE_0 mode and for reference, respectively.

Cr atoms diffused through the Au layer, and were oxidized on the Au layer to form Cr_2O_3 during the following PECVD [3]. The Cr_2O_3 was needed for the adhesion between the Au and buffer layers, but also increased the optical path length between the CRIGIC and Au layers. The output efficiency seriously depends on the optical path length due to interference between the direct radiation and the indirect radiation reflected from the reflection layer. Therefore, the optical path length of the fabricated waveguide was measured from a reflection spectrum, and the thickness of the buffer layer was estimated to be 2.24 μm. The maximum output efficiency of the fabricated device was predicted to be 74%.

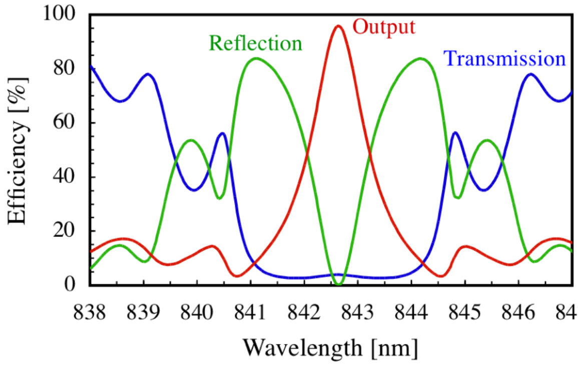

Figure 2. Theoretically calculated wavelength dependence of output, transmission, and reflection efficiencies of CRIGIC.

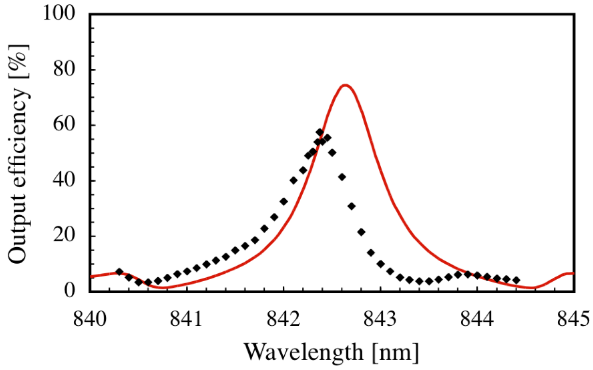

Figure 3. Measured and theoretical wavelength dependence of output efficiency.

A tunable laser diode was used as a light source, and TE_0 mode was excited by the GC. Effective index of TE_0 mode was measured to be 1.486 from the incident angle. The radiation decay factor of the reference GC was measured to be 0.8 mm^{-1} from near-field intensity profile of the diffracted wave. Fig. 3 shows measured wavelength dependence of the output efficiency. A theoretical dependence calculated by using the measured effective thickness of the buffer layer is also shown by the red curve in Fig. 3. The maximum efficiency of 58% was obtained at 842.4 nm with FWHM of 0.8 nm.

IV. CONCLUSIONS

We have designed and fabricated a CRIGIC with an Au reflection layer on a substrate for high-efficiency coupling with small aperture. The maximum output efficiency of 58% was obtained for 20-μm-aperture CRIGIC, which was 78% of the predicted value. Improvement of device characteristics is now under study by precise control of the effective thickness of the buffer layer. Application of the CRIGIC to optical interconnect devices is also being investigated.

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