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ラマン増幅器用シリコングレーティング導波路の設計

Design of Silicon Grating Waveguides for Raman Amplifier

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Silicon photonics is regarded as a key technology for low cost production and on-chip integration of nanophotonic devices. To realize efficient silicon-based light sources, recently some works reported stimulated Raman scattering (SRS) in silicon photonic crystal (PhC) waveguide (WG) [1-3]. In our previous report [4], we proposed a design that support two WG modes with symmetric electric field distributions, which can be coupled from outside efficiently. Furthermore, both pump and Stokes wavelengths are designed in ultraslow-light regions. However, considering CMOS-compatible fabrication processes, simple geometry structures are strongly needed. In this report, we design silicon grating WGs (GWGs) for high gain factor (*G.F.*) Raman amplifier. The optimized structures not only keep the advantages that we reported before [4], but also have simple structure for easier fabrication.

The figure of merit is estimated by calculating a $G.F. \equiv S_s S_p / A_R$, where S_s and S_p are slow down factors (S, defined as $n_g/n_{si}=c/n_{si}v_g$, c is light velocity in vacuum, n_g is group index, and n_{si} is refractive index of silicon) of Stokes and pump signal, respectively. A_R is Raman cross section effective area defined in Ref.[3].

The basic structure in our study is a mechanically strong silicon grating WGs with SiO_2 cladding in the vertical and in-plane directions as shown in Fig. 1 (a). The thickness of the slab is 0.48a (a is the period of grating). As Fig. 1 (b), the grating shape could be controlled by changing the parameters x and y of grating fins. We firstly investigate the band structure of TE-like modes with x of 0.2 and y of 0.64 as shown in Fig. 1 (c). There are three modes named A, B, and C in the low order modes region. The mode A (Fig. 1 (d)) and B (Fig. 1 (e)) are symmetric modes, and mode C (Fig. 1 (f)) is anti-symmetric mode. As symmetric modes could be coupled from outside efficiency, the mode A and B could be set as Stokes frequency and pump frequency respectively. In order to match the Raman shift of silicon $\Delta\omega_R=2\pi\times15.6$ THz, the frequencies of mode A and B are calculated by fixing x=0.2 and tuning y as shown in Fig. 1 (g). The frequency difference ω_B-ω_A and the corresponding $\Delta\omega_R$ as we set pump wavelength as 1.55μm are also calculated in Fig. 1 (g). The cross point of two lines mean that the frequency difference at the Brillouin edge matches the Raman shift of silicon as y of 0.64 and a of 0.439 μm.

v_g, A_R, and *G.F.* of is summarized in Table I with the best result in the past works [2] and our previous report [4]. Our new design shows good performance in *G.F.* along crystal direction [110], which is 92 times as large as previous works from other groups. This enhancement is attributed to the smaller A_R and ultra-low v_g for pump and Stokes modes. Furthermore, slow pump mode is accessible from outside because only symmetric modes are used. Importantly, the *G.F.* of GWG is the same order as our previous work [4], and the simple shape structures could easily fabricate by CMOS-compatible processes. Therefore, our designs are directly applicable to Silicon Raman amplifiers and lasers.

Table I Performance comparison in different scheme

Type	$v_{g,p}$	$v_{g,s}$	Along	A_R(μm^2)	*G.F.* (μm^{-2})
Ref[3]	$2.18\times10^{-1}c$	$1.70\times10^{-4}c$	[100]	0.4185	5.37×10^3
			[110]	0.4142	5.43×10^3
Ref[4]	$1.23\times10^{-4}c$	$2.37\times10^{-3}c$	[100]	0.7678	3.72×10^5
			[110]	0.4424	6.46×10^5
GWG	$7.79\times10^{-4}c$	$6.80\times10^{-4}c$	[100]	0.3426	4.59×10^5
			[110]	0.3148	5.00×10^5

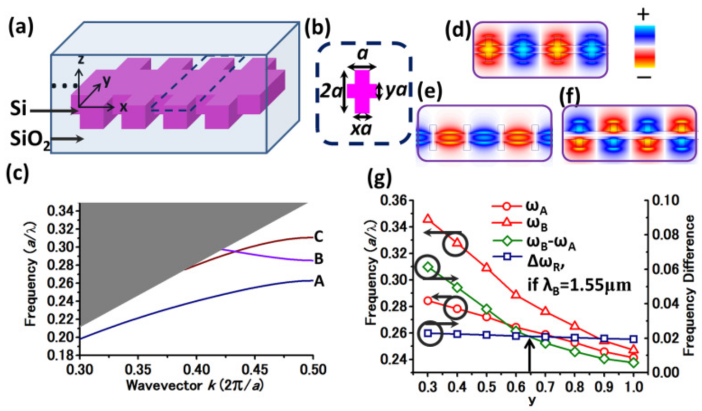

Fig. 1 (a)-(b) Illustration of grating WG, where x and y define the grating shape. (c) Band structures of x=0.2, y=0.64 calculated by plane-wave-expansion method. The E_y mode profile of (d) mode A, (e) mode B, and (f) mode C. (g) The frequencies and the frequency difference of mode A and B by tuning y, and the $\Delta\omega_R$ when we set the wavelength of mode B as 1.55μm.

Acknowledgements

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