Structural design of graphene-loaded silicon SW-MS BG modulator for higher ER

○(D3) S. Heinsalu, Y. Isogai, Y. Matsushima, H. Ishikawa, and K. Utaka
Waseda Univ.
Email: siim.heinsalu@fuji.waseda.jp

1. Introduction

Graphene has received extensive research attention for its optical, electrical and physical properties and adaptability with silicon photonic devices. Using it in a modulator useful effects are electro-, thermo- or magneto-optic effects [1-3]. Among these effects electro-optic effect is the more desirable due to its low-voltage and high-speed operation [4]. For TE mode a slot waveguide (WG) was reported to be more effective by about twice than a rib waveguide from viewpoints of refractive index and absorption changes [5]. Especially for efficient absorption modulation with a larger extinction ratio (ER), a Bragg grating (BG) waveguide is effective by using wavelength shift of a steep side-lobe peak. For higher modulation and better fabrication tolerance larger slot counts seem important. In this work structural design of a silicon sub-wavelength multi-slot Bragg grating (SW-MS BG) with graphene on top is studied in terms of various parameters such as, silicon WG widths, duty ratios and period counts of the BG for higher ERs.

2. Device structure and operation principle

A schematic structure of the proposed device is shown in Fig. 1. It consists of 3 areas: input WG, modulation area and output WG. Input and output WGs are in a rib WG configuration with a thickness of 220 nm etched by 200 nm, and they are covered by an Al_2O_3 isolation layer of 10 nm thick. The central part is in a MS-SW BG WG configuration covered with a monolayer graphene to which a voltage is applied. Where, a slot size is 60 nm, a slot count 3, a pitch of the BG 385 to 445 nm dependent on the duty ratio and a period count 20 to 50.

In transmission spectra the side lobe peak wavelength at the longer-wavelength side of the SW-MS BG stop-band was set near 1550 nm as a sensing peak. Application of a voltage to graphene changes its chemical potential μ_c. By changing the chemical potential μ_c its surface conductivity σ is also changed, and resultantly its refractive index n_g is given by the following simplified equation [6]:

$$n_g(\mathrm{f},\Gamma,\mu_c(V),\mathrm{T}) = \sqrt{\left(\varepsilon_{med} + i\,\frac{\sigma(\mathrm{f},\Gamma,\mu_c(V),\mathrm{T})}{\varepsilon_0 2\pi f \Delta}\right)}$$

3. Simulation results

Using Lumerical 3D FDTD simulator, an optimal total WG width for modulation was obtained to be 1300 nm. Fig. 2 shows the transmission spectra dependent on the chemical potential for duty ratios of 50 % and 80 %. A lager ER was obtained for a duty ration of 50 %, though a smaller shift (Δλ). By optimizing the strucure an ER of 7.6 dB can be expected for a period count of 20 with chemical potentials μ_c from 0.39 eV to 2eV. To obtain higher ERs larger period counts was found to be effective to realize ER of 32.1 dB for period count of 50.

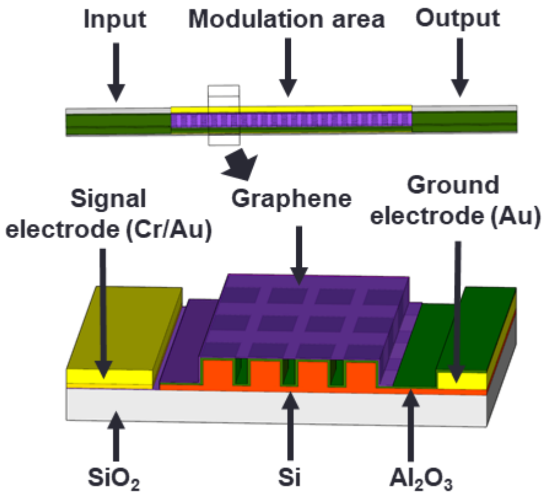

Fig. 1. Schematic structure of the graphen loaded silicon SW-MS BG.

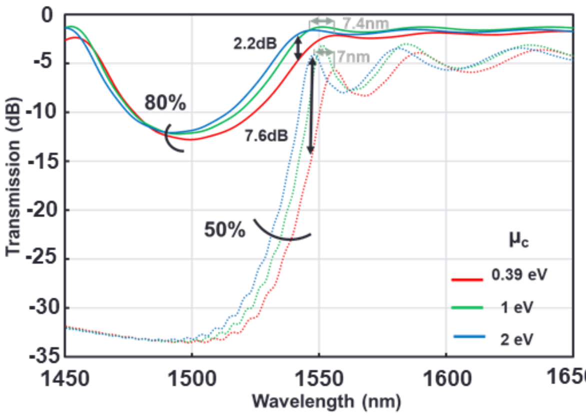

Fig. 2. Transmission spectra of the device with for various μ_c at period count 20.

References

[1] S. Gan et. al, Nanoscale, Vol. 7, pp. 20249-20255, 2015.
[2] Y. Ding et. al, Nano Lett., Vol. 15, Issue 7, pp. 4393–4400, 2015.
[3] X. Hu and J. Wang, Nanophotonics, Vol. 7, Issue 3, pp. 651-658, 2018.
[4] I. Chakraborty, et al., OSA Continuum, Vol. 2, Issue 4, pp. 1273-1284, 2019.
[5] A. Phatak, et al., Optics Lett, Vol. 41, Issue 11, pp. 2501-2504, 2016.
[6] F. Jabbarzadeh, et al., Mater. Res. Express, Vol. 8, No. 6, 086206, 2019.