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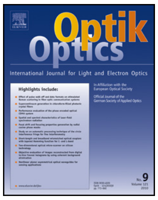

Period fold structure of graphene SPP waveguide

Jun Zhu[a,c,*], Xu Wenju[a], Liuli Qin[b], Shuxiang Song[a]

[a] College of Electronic Engineering, Guangxi Normal University, Guilin 541004, China
[b] College of Mathematics and Statistics, Guangxi Normal University, Guilin 541004, China
[c] Guangxi Key Laboratory of Automatic Detecting Technology and Instruments, Guilin University of Electronic Technology, Guilin 541004, China

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ABSTRACT

The field of plasmonics has experience a renaissance in recent years by providing a large variety of new physical effects and applications. Surface plasmon polaritons (SPPs), i.e. the collective electron oscillations at the interface of a metal/dielectric, may bridge the gap between electronic and photonic devices, provided a fast switching mechanism is identified. Here, we design folds graphene waveguide excited SPPs and full compensation structures with periodic array by graphene material. Theoretically, we analyzed the loss of the way by periodic array gain full compensation is analyzed. By the results of theoretically analysis, we discover period fold structure not only excites SPPs, which also we can control device parameters using SPPs wave relations. In addition, periodic array compensation can significantly increase the propagation distance of SPPs. Simulation results we further find by simulation results: structure of our design has the advantage of strong localized and subwavelength waveguide size; periodic array compensation can significantly improve the electric field strength of nanocavity; structure of graphene waveguide expresses high levels of population inversion and low spontaneous emission noise disturbance. The graphene waveguide devices which we design can be the key device for the micro-nano optics, photonic sensing and measurement.

1. Introduction

Optical interconnects possess an unimaginable data carrying capacity, which may allow photonic components to mitigate the present bottlenecking in increasing the computational speed2. However, their implementation is hindered by the physical size or dimensional mismatch between electronic and dielectric photonic components [1,2]. Moreover it is expected that CMOS foundries will further decrease the feature sizes on silicon chips [3], ultimately down to 10 nm. Such reduction in size would further increase the dimensional mismatch between the electronic and optical elements, as the size of the dielectric photonic devices is restricted by the diffraction limit [4,5]. Moreover, miniaturization introduces several problems including dielectric break down, hot carriers and short channel effects, that degrade device reliability [6]. The Surface Plasmon Polaritons (SPPs), spatially confined transverse magnetic (TM) electromagnetic modes propagating at the metal-dielectric interfaces, offer the bandwidths of photonic devices and physical dimensions shared with nanoscale electronics. The potential of plasmonics to bridge the gap between electronics and photonics is now well recognized by the scientific community with a large number of investigators working in the field of plasmonics [7,8]. Nikolajsen team of Denmark used thermo-optic effect on the strip of metal embedded in polymer materials to achieve light modulator and optical switches, and the transmission loss of 20 nm thick gold-plate waveguide is as low as 6 dB/cm in optical communication wavelength window. However, this model of the waveguide size has gone up to 12 μm [9]. The cooperation project of Zhejiang University and Sweden's Royal Institute of Alfven Laboratory group put forward the SPPs waveguide of metal slot. They undertook an in-depth theoretical of optical modes. Also the team get that waveguide of subwavelength scale can be achieved limits of optical field, which is loss up to 4 dB/μm. At the same time, Bozhevolnyi team from Aalborg University, Denmark, they used focused-ion beam etching process and near-field scanning optical microscopy to study v-groove SPPs waveguide devices [10]. They used conformation to wavelength division multiplexers, which is Bragg grating filters based on MIM structure. They simultaneously achieved the filtering of applications for SPPs wave [11]. In 2007, the cooperated research team by State Key Laboratory of superconducting physics and optical physics studied the periodic hole arrays in metallic films. They get higher order surface plasmon resonance peaks at the first time [12], and enhanced of electric field was the

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[*] Corresponding author at: Guangxi Normal University, College of Electronic Engineering, Guilin 541004, China. Tel.: +86 018907736251.
E-mail address: zhujun1985@gxnu.edu.cn (J. Zhu).

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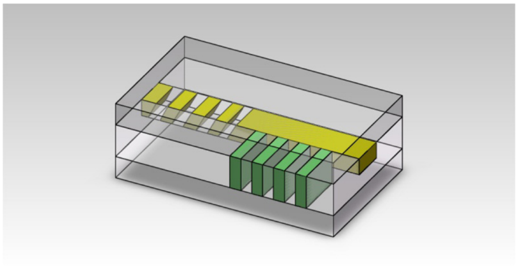

Fig. 1. Design of the structure.

diffraction of SPPs based on theoretical analysis of Maxwell equations. The team by CAs semiconductor Nano-Photonics Laboratory and Hebei Polytechnic University get vertical-cavity surface-emitting lasers in normal 850 nm, which achieved diameter of small holes by 100 nm and 400 nm, respectively, and the output power is up to 0.5 Nw [13]. With the deepening of the study, researchers have found that they were difficulty to control the permittivity of medium and the loss of metal, which was especially in the visible band [14,15]. Meanwhile, graphene materials became the current focus of research directions [16], which is very suitable for optical device application. Particularly graphene is applied to SPPs propagation that the loss is obviously less than precious metals, such as gold, silver, etc. [17,18].In particular, in 2012 the scientists from the United States University of California at San Diego, they published the surface of graphene excites the electron wave by infra-red light beam by Nature. And they can through a simple circuit to control the wave length and height of surface plasmon oscillation [19]. Based on above development background, we design graphene waveguide of SPPs. And we design folds structure to achieved SPPs excited. The array column structure of graphene waveguide can compensation SPPs loss. Theory analysis and simulation results showed that the structure can keep subwavelength confined while the distance of SPPs was enhanced. This device is great potential in the new photon devices.

2. Design of structure

In this paper, the particular design of the structure is shown in Fig. 1.The incident light source go into folded structure of graphene waveguide, which is excited SPPs. Then SPPs propagate through the array dye of the gain medium that can compensate the loss. The length of structure is 4200 nm, the width is 2700 nm, and the 900 nm thick Si substrate grow on the SiO_2 800 nm thick in an oxygen environment. After that, we use the method of electron beam reticle to get a depth of 600 nm graphene waveguides. In the graphene waveguides, we use the plasma dry method to etch fold structure which is the length of 1200 nm and the period of 200 nm. At the SiO_2 layer, we use the plasma dry method to etch the growth cycle of 2200 nm and the period of 400 nm gain medium tank. We use spinning method to fill an array of gain compensation medium. The gain medium is the hybrid of rhodamine dye indole pentamethine saturated absorber dyes, and the premixed ratio of the number of molecules is 2:1. Finally we use ultraviolet lights to dry, which can control the gain medium. Due to the structure by the graphene low loss and good conductor characteristics, it can overcome the noise generated by spontaneous emission channel. The method is the whole array dye gain loss organic dyes which is good adaptability gain medium wavelength, high quantum efficiency. The use of array full compensation can significantly increase the SPPs propagation distance.

3. The excited SPPs mode of found structure

For the TM mode of subwavelength, the characteristic impedance can be defined that:

$$Z=\frac{E_1 d}{H_2 w}=\frac{kd}{\varepsilon_1 w\omega} \tag{1}$$

where ω is incident light frequency, k is the propagation constant of TM mode. w, d is the width of x_2, x_3 direction of waveguide, respectively. Characteristic impedance is reduced by reducing the waveguide width of the insulating layer, we also can fill higher refractive index into the insulating layer. Dispersion of characteristic impedance Z is small, especially in the larger wavelength region. When two waveguides having different characteristic impedance are connected, there is reflection at its joints. Reflection can be reduced by match their impedance. When the width of the waveguide is much smaller than the wavelength, the transmission waveguide problem may be approximated to the transmission line model. The electromagnetic field of the junction of the waveguide transmission problems may correspond to the equivalent current and the equivalent voltage problems between the transmission lines. The voltage transmission line connections should be equal,

$$V_1^+ + V_1^- = V_2^+ + V_2^- \tag{2}$$

The equivalent current of the incident wave and the exit wave is equal to the sum of the equivalent current

$$I_1^+ + I_2^+ = I_1^- + I_2^- \tag{3}$$

Relation matrix of input equivalent voltage and out equivalent voltage is:

$$\begin{bmatrix} V_1^- \\ V_2^- \end{bmatrix}=\begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}\begin{bmatrix} V_1^+ \\ V_2^+ \end{bmatrix} \tag{4}$$

where:

$$\begin{aligned} S_{11}&=\frac{Z_2-Z_1}{Z_1+Z_2} & S_{12}&=\frac{2Z_1}{Z_1+Z_2} \\ S_{21}&=\frac{2Z_2}{Z_1+Z_2} & S_{22}&=\frac{Z_1-Z_2}{Z_1+Z_2} \end{aligned} \tag{5}$$

There is only one reflection at the signal interface between the two waveguide, and if the two different waveguides alternately laminated to form a periodic structure, the plurality of waveguide reflection at the interface is possible to greatly improve the superposition total energy reflectivity. We consider that a periodic waveguide structure with different width of the waveguides A and B connected. Respectively, its width are d_A and d_B, respectively, and its length are l_A and l_B, respectively. Equivalent voltage of the nth cycle units may be written as A B

$$V_n^A = V_n^{A+}e^{-ik_A x_1} + V_n^{A-}e^{ik_A x_1} \tag{8}$$

$$V_n^B = V_n^{B+}e^{-ik_B x_1} + V_n^{B-}e^{ik_B x_1} \tag{9}$$

here +, − represent positive and negative direction x_1 axis.

Written in the form of the transfer matrix,

$$\begin{bmatrix} V_n^+ \\ V_n^- \end{bmatrix}=D_{AB}P_B D_{BA}P_A\begin{bmatrix} V_{n+1}^- \\ V_{n+1}^+ \end{bmatrix} \tag{10}$$

$$D_{AB}=\begin{bmatrix} \frac{1}{2}\left(1+\frac{Z_A}{Z_B}\right) & \frac{1}{2}\left(1-\frac{Z_A}{Z_B}\right) \\ \frac{1}{2}\left(1-\frac{Z_A}{Z_B}\right) & \frac{1}{2}\left(1+\frac{Z_A}{Z_B}\right) \end{bmatrix} \tag{11}$$