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Original research article

High-speed optical FSK demodulator using plasmonic nano bi-dome

Majid Akhlaghi

Young Researchers and Elite Club, Omidiyeh Branch, Islamic Azad University, Omidiyeh, Iran

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ABSTRACT

An optical frequency-shift-keying demodulator with ultra-small plasmonic nano bi-domes that can filter the coherent optical frequency is developed. Since filtering efficiency depends strongly on the position and number of the plasmonic nano bi-domes in the array, binary Teaching-Learning-Based Optimization (BTLBO) algorithm is proposed to design an array of plasmonic nano bi-domes in order to achieve maximum absorption coefficient spectrum. In BTLBO, a group of learner consists a matrix with binary entries; control the presence ('1') or the absence ('0') of nano particles in the array.

1. Introduction

Advanced data modulation formats have become quite important within the optical communications community. Micro-ring based devices have attracted a great deal of attention in recent years. Silicon based microring demodulators, modulators, switches and filters, fabricated in silicon-on-insulator (SOI) platform, have been demonstrated [1–7]. In addition to the microring demodulators, FSK signal is demodulated by utilize of a fiber Bragg grating [8]. But, to our knowledge, there is no report to use the plasmonic nanostructure −based devices to demodulate the FSK signals. In this paper, we propose an ultra-small demodulator for optical FSK signal detector, using plasmonic-based nano particles. As compared to conventional fiber Bragg grating and micro-ring demodulators, require a relatively small chip area and have higher speed operation. The plasmonic nano particles are widely used to design nano antennas with improved capabilities. Efficiency of these materiels strongly depends on the localized positions of nano-particles [9]. The characteristics of near and far- field of nano-particles can be calculated using discrete dipole approximation (DDA). Optimization problems in the plasmonic nano structure area can be divided into two categories. In the first type continuous optimization algorithm can be done to engineering the geometrical metal nano structures [10,11] whereas in the second type, binary optimization algorithm can be used to control the presence ('1') or the absence ('0') of metal nano particles in the array. In this paper BTLBO is proposed to generate the binary gold nano bi-domes for getting higher absorption coefficient spectrum in order to increase the efficiency of plasmonic demodulator.

2. Theory

The proposed plasmonic demodulator is shown schematically in Fig. 1. In this figure plasmonic demodulator consists of an array of metallic nano bi-domes in which periodically arranged in the x y −plane of a silicon substrate. The object is excited by a monochromatic incident plan wave $\vec{E}_{inc}(r,t)=\vec{E}_0 e^{jk(r-\omega\, t)}$ where r, t, ω, k = ω/c = 2π/λ, c, and λ are the position

E-mail address: m.akhlaghi@sutech.ac.ir

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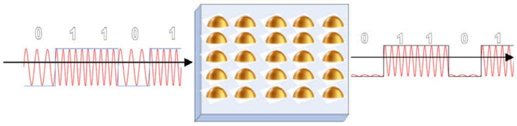

Fig. 1. Concept of plasmonic FSK demodulator by plasmonic nano domes on top of silicon waveguides.

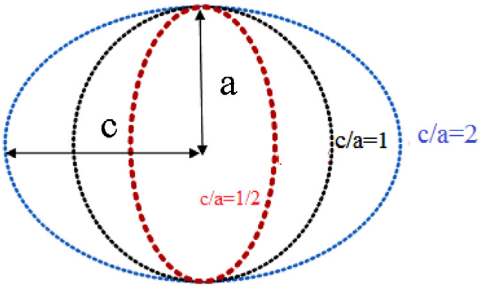

Fig. 2. nano particle with different c/a; bi-pyramid (c/a = 1/2), sphere (c/a = 1), and bi-dome (c/a = 2).

vector, the time, the angular frequency, the wave vector, the speed of light, and the wavelength of incident light, respectively. To calculate the E-field of each dipole time harmonic component −iωt of the E-field is left out.

Local field arises from incident light with polar (θ) and azimuth (ϕ) angle at each particle is:

$$\vec{E_{inc}}(\vec{r_s}) = \vec{E_0} e^{j\vec{k}.\vec{r_s}} \tag{1}$$

Where:

$$\bar{k} = \frac{2\pi}{\lambda}\hat{k} = \frac{2\pi}{\lambda}[\sin(\theta).\cos(\phi),\ \sin(\theta).\sin(\phi),\ \cos(\theta)] \tag{2}$$

For incident field with P-polarize, the following can be written:

$$E_0 = [\sin(\theta - \frac{\pi}{2}).\cos(\phi),\ \sin(\theta - \frac{\pi}{2}).\sin(\phi),\ \cos(\theta - \frac{\pi}{2})] \tag{3}$$

and, for incident field with S-polarize:

$$E_0 = [\cos(\phi + \frac{\pi}{2}),\ \sin(\phi + \frac{\pi}{2}),\ 0] \tag{4}$$

When the applied field is parallel to one of the principle axes, polarizability, α, is [12]

$$\alpha = V\varepsilon_0 \frac{\varepsilon_r - 1}{1 + L_1(\varepsilon_r - 1)} \tag{5}$$

where $\varepsilon_r = \varepsilon_{particle}/\varepsilon_{medium}$ is the relative dielectric function of the particle with respect to the medium, V is particle volume, and L_1 is shape factor. For prolate spheroids (b = c<a), the following analytical expression can be given for L1 as a function of eccentricity e [25]:

$$L_1 = \frac{1 - e^2}{e^2}(-1 + \frac{1}{2e}\ln\frac{1 + e}{1 - e}) \tag{6}$$

and for oblate spheroids (b = c>a):

$$L_1 = \frac{1 + f^2}{f^2}[1 - \frac{1}{f}\tan^{-1}(f)] \quad , \ f^2 = \frac{b^2}{a^2} - 1 \tag{7}$$

As shown in Fig. 2 bi-dome is an oblate spheroid.

The dipole moment induced in a single particle by a local electric field is given by:

$$\vec{P_s} = \varepsilon_0 \alpha_s \vec{E}Loc(\vec{r_s}) \tag{7}$$

Here, $\vec{P_s}$ is the induced dipole moment,α_s is Polarizability of the particle centered at $\vec{r_s}$, $\vec{E_{loc}}$is local electric field, and ε_0 is permittivity of free space. The local field arises from two sources, appearing as two terms. The first term is incident light,