Optics Communications 427 (2018) 85–89

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

Highly sensitive biochemical sensor based on nanostructured plasmonic interferometer

Z. Khajemiri [a], S.M. Hamidi [b,*], Om. K. Suwal [c]

[a] Department of Physics, Shahid Beheshti University, G.C., Evin, Tehran 19839, Iran
[b] Magnetoplsamonic Lab, Laser and Plasma Research Institute, Shahid Beheshti University, Tehran, Iran
[c] Department of Physics and Astronomy, Seoul National University, Seoul 151-747, Republic of Korea

ARTICLE INFO

Keywords:
Plasmonic interferometer
Finite-difference time-domain
Figure of merit
Sensitivity

ABSTRACT

We propose a novel plasmonic interferometric sensor with a slit and surrounding rectangular grooves array on an optically thick gold film for biochemical sensing. We did finite-difference time-domain (FDTD) simulation for design optimization and analytical calculation for characterization of sensitivity in the proposed sensor. Our interferometer is functional for visible to near infrared region with maximum sensitivity of 500 nm/RIU and figure of merit 1933 at 741 nm wavelength. The peak intensity and wavelength change in different refractive indices. In conclusion, the results obtained in the present study indicate the potential of the proposed plasmonic interferometer as a low cost, compact, and label-free high-throughput device.

1. Introduction

Optical interferometry has a long history and wide range of applications. In interferometers, interference of two or more waves from the same light source with the same frequency are superimposed to travel along separate paths to combine and produce bright and dark fringes. The detected bright and dark fringes as interference pattern are related to the path difference equals to even and odd times of the half wavelength, respectively [1].

The unique applications of nanoplasmonic either in surface plasmon polaritons (SPPs) propagation or localized surface plasmon resonance (LSPR) fields have stimulated great interests in light–matter interaction at a sub wavelength scale [2,3]. There are several routs to excite SPPs including prism-based Kretschmann configuration [4], gratings [5], and nanoplasmonic structures [6,7]. The highly sensitive plasmonic sensors are applicable for real-time and label-free biochemical sensing because of its reproducibility and reliability [8–13].

In recent years, there have been extensive interests in plasmonic interferometers for refractive index sensing [13,14], medical imaging [15], and light–matter interactions because of their compactness and reliability [16–19]. Schouten et al. [20] had proposed a double-nanoslit structure on an opaque gold film for plasmonic interferometer with the advantage of propagating surface plasmons in the transmission of perforated metal screens. Thereafter, symmetric grooves near to the slit was found with higher contrast interference patterns due to surface plasmonic wave resonances [21]. Further, a recent study introduced a plasmonic interferometer device with semi-circular grooves on a gold film containing a nanoaperture surrounded by two nanopatterned semicircular grooves with different radiuses [22]. The efforts of the mentioned studies have generated considerable improvements thanks to their compact size and narrow linewidth while they suffer from the relatively low FOM. Therefore, there is still a room to optimize plasmonic interferometers with higher FOM. We here proposed a plasmonic interferometer with rectangular grooves array around a slit for better sensitivity and enhanced interference contrast. When the structure is normally illuminated with a broadband light source (400–800 nm), plasmons are oscillated on the surface generating plasmonic wave propagating to the rectangular central slit, where interference occurs between the SPPs and the direct light and it modulates the far-field transmission. In addition, we used the finite-difference time-domain (FDTD) method for simulation and analytical calculation of our interferometer. Thus, the main motivation of this work is to introduce a plasmonic interferometer device with high spectral contrast, narrow spectral linewidth, and high FOM.

2. Design and simulation

The proposed interferometer consists of a nanoslit surrounded by symmetric grooves on a gold film (Fig. 1a). Gold film as a plasmonic material has unique advantages such as a long range of SPPs propagating at λ >550 nm, and a stable metal in chemical environment. This

---

[*] Corresponding author.
E-mail address: m_hamidi@sbu.ac.ir (S.M. Hamidi).

https://doi.org/10.1016/j.optcom.2018.06.032
Received 22 May 2018; Received in revised form 31 May 2018; Accepted 12 June 2018
0030-4018/

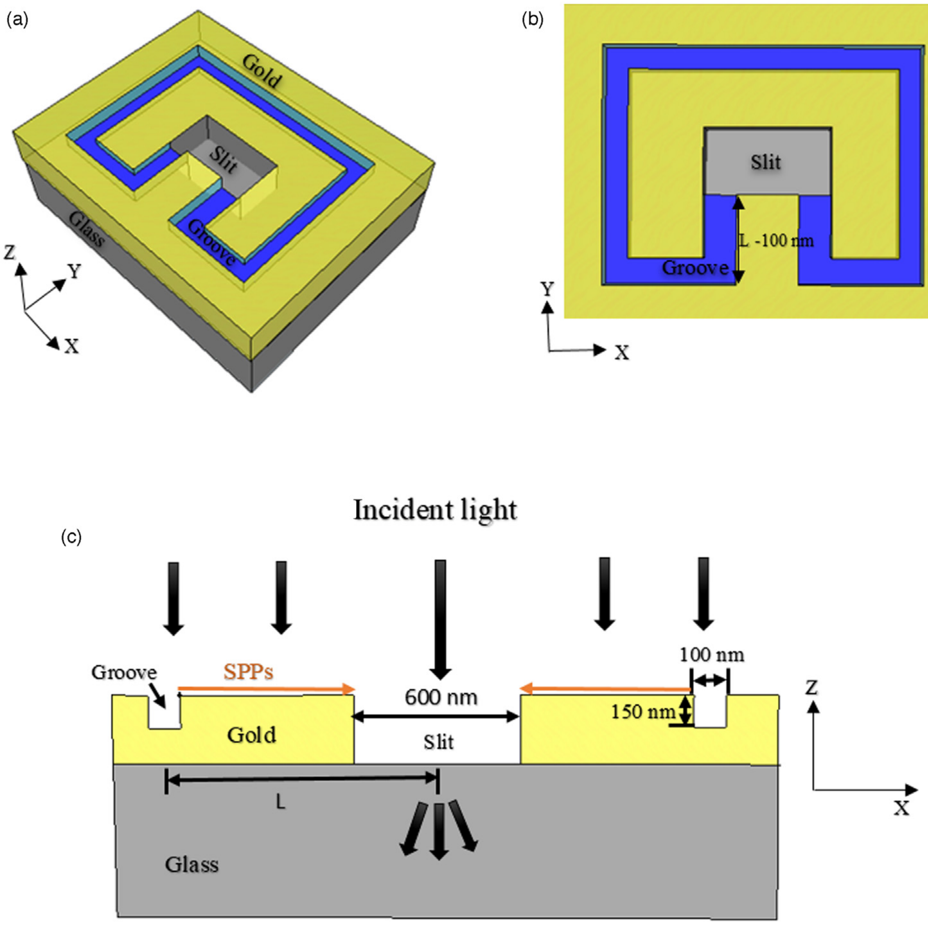

Fig. 1. Schematic of the proposed plasmonic interferometer, (b) Profile xy (top view), (c) cross section view with wave propagation schematic.

interferometer includes a slit of dimensions 600/300/300 nm in length, width, and depth located at the center of symmetric rectangular grooves of 100-nm-width and 150-nm-depth at the L distance. A gold film of 300 nm thickness will be deposited by e-beam evaporation onto glass slide at a deposition rate of 0.5 Å/s. Prior to the evaporation, the glass slides should be cleaned thoroughly with acetone and isopropyl alcohol in an ultrasonic cleaner for 10 min, followed by extensive deionize water rinsing, and subsequently blow-dried with nitrogen. Focused ion beam milling will be used to fabricate semi-rectangular plasmonic interferometer. In our design, two grooves are connected to one slit at a side, forming the semi-rectangular plasmonic interferometer (Fig. 1b). The broadband light source was normally illuminated on the sample surface and transmission interference spectrum was observed in this design. This design is investigated for the functional effects of the distances between slit and grooves, incident wavelength, and groove numbers in a semi-rectangular plasmonic interferometer.

As shown in Fig. 1c, when light was illuminated on the interferometer, the generated SPP at grooves travels through the surface and propagates through the slit, interfering with the incident light, resulting the frequency dependent interference transmission. At the slit location, the SPP (E_{SPP}) will interfere with the coherent incident beam (E_{Light}).

Three-dimensional finite difference time domain (FDTD) commercial software package (Lumerical Solution Inc.) is used to characterize and optimize the device. In the FDTD three-dimensional (3D) calculations, the plane wave is normally incident from the top and polarized along x-axis, as indicated in Fig. 1c, and the boundary conditions for x axis and y axis are periodic, and boundary conditions for z axis is perfectly matched layer (PML).

The simulation is set by automatic non uniform conformal mesh technology with minimum mesh size of a 10 nm at the slit region, which is sub $\lambda/10$ of the minimum wavelength of incidence. The multi-coefficient models are applied to test the accuracy of the extracted experimental data from optical response of gold [23]. A detector is placed at proper position to monitor the transmission spectra and electric field profile. The refractive index sensitivity, relative intensity change, and FOM* of the designed plasmonic interferometer are calculated when refractive index change from 1.3302 to 1.3342 in different L. The simulation time for every L at different refractive indices in an 8-core processor (2.8 GHz) with 32 GB RAM is around 3 h.

3. Results and discussions

3.1. Detection principle

The current study focuses on the benefits of spectral interference peaks which is quite sensitive to the dielectric properties of the material in contact with the interferometer. The theoretical interference patterns are given as [12]:

$$I = E_{Light}^2 + E_{spp}^2 + 2E_{Light}E_{spp}\cos({}^{4\pi L}/{}_{\lambda}\, n_{spp} + \varphi_0) \tag{1}$$

Here E_{Light} and E_{spp} represent the incident electrical fields at the free-space and SPP field due to light–matter interaction in the regime of interferometer. Phase difference [24] is a function of wave vector, $k = 2\pi/\lambda$, distance between groove and slit, L, and an effective refractive index of SPP as given by $n_{\mathrm{spp}}(\lambda) = \mathrm{Re}((\varepsilon_{\mathrm{m}} n^2/(\varepsilon_{\mathrm{m}} + n^2))^{1/2})$, [25] where ε_{m} represents the metal permittivity and n is absolute refractive index of dielectric media for free space wavelength, λ and φ_0 is an initial phase shift [26]. According to the equation, at a specific wavelength the phase difference between free-space light and SPPs modulate the intensity of