Optik 155 (2018) 74–80

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Full length article

Magneto-plasmonic sensor with one dimensional photonic crystal for methane detection

Jie Li, Tingting Tang*, Yanfen Zhang, Li Luo, Ping Sun

Information Materials and Device Applications Key Laboratory of Sichuan Provincial Universities, Chengdu University of Information Technology, Chengdu 610225, China

ARTICLE INFO

Article history:
Received 29 June 2017
Received in revised form 13 October 2017
Accepted 26 October 2017

Keywords:
Magneto-optical surface plasmon resonance (MOSPR) sensor
Kerr effect
Methane detection

ABSTRACT

In this paper we present a highly sensitive magneto-optical surface plasmon resonance (MOSPR) sensor based on $Ce_1Y_2Fe_5O_{12}$ (Ce:YIG), noble metal (Gold) and one dimensional photonic crystal (1D-PC) for methane detection. We find that due to a combination of strong magneto-optical effect of Ce:YIG and ultralong surface plasmon propagation caused by one dimensional photonic crystal, sensitivity of the sensor to the methane concentration variation achieve a maximum value of 178.2/1%. These results indicate a great potential for application of the structure in methane detection.

© 2017 Elsevier GmbH. All rights reserved.

1. Introduction

Surface plasmon resonance (SPR) is optical excitation of collective charge density oscillation on the surface of a thin metal film interfacing with an adjacent dielectric and propagates along the interface. Another similar phenomenon is long-range surface plasmon resonance (LRSPR) [1,2]. A long-range surface plasmon wave (LRSPW) has a longer propagation distance and a narrower resonance width [3]. The spectral and angular positions of SPR and LRSPR are very sensitive to the optical properties of surrounding medium, like refractive index and gyrotropy. Based on this characteristic, different kinds of biosensors have been presented [4–6].Traditional LRSPW was demonstrated in symmetrical multilayer structures when thin (8–20 nm) metal layer is "sandwiched" between two identical dielectrics, but research suggests that there are several structures can support LRSPW, too. For example, bimetallic structure [7], a thin metal film on a one-dimensional photonic crystal (1-D PC) surface [8,9], and even a lossy metal film [10]. High sensitivity and sharp spectrum sensors have been proposed based on LRSPW in structures with metal film and 1-D PC [11,12]. By careful design and sophisticated signal processing, index resolution of intensity interrogation type SPR sensors can be improved up to 10^{-6}. However, the improvement of the sensor sensitivity remains essential for broadening of the application area [13]. Therefore, improving the index resolution has been a major research topic for this type of SPR sensors.

On the other hand, sensors based on magneto-optical surface plasmon resonance (MOSPR) have been investigated theoretically and experimentally to enhance the resolution of SPR sensors [14,15]. By applying external transverse magnetic field with opposite directions to magnetic material (like Fe, Co and Ni) in sensing structures, two reflection spectrums with slight difference of SPR resonance angle can be obtained. Using the difference between two spectrums (which called MOSPR spectrum), we can detect changes of sensing environment more clearly. Generally speaking, MOSPR spectrum is narrower

* Corresponding author.
E-mail address: skott@163.com (T. Tang).

https://doi.org/10.1016/j.ijleo.2017.10.156
0030-4026/© 2017 Elsevier GmbH. All rights reserved.

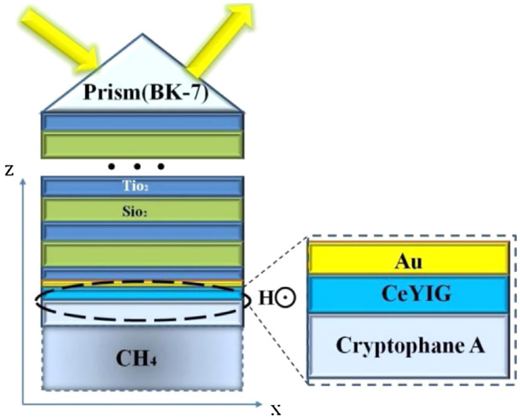

Fig. 1. Schematic of the proposed DMOSPR sensor.

and has a higher signal-to-noise ratio compared to reflectance spectrum of a MOSPR sensor [16]. To find a balance between the increase of the magneto-optical effects and the decrease of the resonance quality factors due to high optical losses, ferromagnetic metals are used in combination with noble ones [17]. However, the high optical losses of the ferromagnetic metals such as Co or Fe are still limiting the performance of MOSPR sensors [18,19]. A good solution for sensitivity improvement is replacing the ferromagnetic metals with dielectrics like Ce-doped $Y_3Fe_5O_{12}$ (Ce:YIG) which offers very low optical losses as well as strong magneto-optical response (it shows a strong Faraday rotation at around 1 μm wavelength due to Ce^{3+}-Fe^{3+} (tetrahedral) charge transfers) [20], which is the so called DMOSPR sensor [21].

Cryptophane A is one kind of Cryptophanes (which are synthetic organic compounds with enforced cavity of suitable size for molecular guest encapsulation) and it is particularly adapted for the recognition of methane [22,23]. The specific absorption of methane by Cryptophane A will lead to an increase of the refractive index. Based on this principle, several types of sensors have been presented [24,25]. A similar Cryptophane molecule named Cryptophane E which has a lager internal volume is also used in methane detection [26,27].

In this work, we report a systematical numerical study of the DMOSPR sensing response in a magneto-optical heterostructure for methane detection based on Ce:YIG layer, Gold layer and a specially designed photonic crystal. We use Crytophane A as sensitive layer, which is a cage-like compound been widely used in recognition of methane [25]. To analyze sensing performance of the DMOSPR sensor we proposed, we have investigated the effects of key parameters of the structure and calculated the magneto-optical responses($\Delta R = R(-H)-R(+H)$, $TMOKE = (R(+H)-R(-H))/((R(+H)+R(-H)))$) and sensitivities. The results show that DMOSPR sensor we proposed is more sensitive than conventional gas sensors such as SPR sensors based on optical fibers [28,29]. In general, coating is easier than machining fiber, and nano-thin film structure has a greater contact area for gas sensing. At the same time, DMOSPR sensors have a higher signal to noise ratio [30].

2. Model and simulation methods

Fig. 1. shows the proposed DMOSPR device schematics. Incident light beam is coupled into the sensing structure by a prism made of BK-7 glass. The Gold layer and one dimensional photonic crystal consisting of alternating Tio_2/Sio_2 layers can support ultralong surface plasmon propagation, evanescent wave of SPP mode penetrates into sensitive layer (Crytophane A). By combining ultranarrow resonance of the structure and strong magneto-optical effect of Ce:YIG, a high sensitivity for methane sensing can be achieved, it will be discussed in simulation part.

A thin metal film on a one-dimensional photonic crystal surface can support ultralong-range surface plasmon polaritons which has a propagation length of several millimeters [9], thus a ultranarrow angular SPR resonance can be obtained [13]. On the other hand, compared with ferromagnetic metals like Fe and Co [13], Ce:YIG offers very low optical losses as well as strong magneto-optical response. So we combine the advantages of both of them to achieve stronger transverse magneto-optical Kerr effect and better sensing performance. For actual fabrication, a periodic structure is more convenient than a metal-insulator-metal structure [32]. Meanwhile, the higher index of the Ce:YIG compared to Crytophane A creates much higher electromagnetic field intensity at the Ce:YIG/Crytophane A interface, so we place Ce:YIG layer at the side of gold film which closed to methane rather than the other side like Ref [31].

The sensing performance is quantified by index sensitivity S, which can be written as

$$S = \left(\frac{\partial |sgn|}{\partial \theta}\right)_{\theta=\theta r} \cdot \left(\frac{\partial \theta}{\partial n}\right) \quad (1)$$

Where *sgn* is intensity of the sensing signal, H is external magnetic field, and H is supposed to saturate the Ce:YIG thin film in-plane and typically around 500 Oe, θ is incident angle, n is the refractive index of sensing medium.

Download English Version:

https://daneshyari.com/en/article/7225155

Download Persian Version:

https://daneshyari.com/article/7225155

Daneshyari.com