

Abstract

The Improvement of Tamm Interface State Detection by Using a Porous Layer between a Metal Nanostructured Grating and a DBR[†]

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Abstract: In this work, we propose a sensor based on Tamm plasmonic resonance; the structure is composed of gold nanoribbons deposited on a Distributed Bragg Reflector (DBR) (SiO₂/Si₃N₄)₆. We have enhanced the sensitivity of our sensor from 40 nm/RIU to 200 nm/RIU for a refractive index change of 1% by replacing the last layer of Si₃N₄ in contact with gold with porous Si₃N₄ with a porosity of $p = 40\%$.

Keywords: Tamm plasmon; distributed Bragg reflectors; photonic bandgap; sensor; sensitivity



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1. Introduction

Tamm plasmons are confined modes that propagate between the metal and the DBR, characterized by a fine peak that appears in the photonic band gap [1]. But Tamm sensors have low sensitivity compared to delocalized plasmons due to the energy confinement between the metal and the DBR. Ferrier et al. [2] theoretically and experimentally studied a structure that generates Tamm plasmons, constituted of gold nanoribbons deposited on a DBR (SiO₂/Si)₄. The advantage of our structure over the metal layer is that the spacing between the nanoribbons will allow us to introduce the analyte into the pores of a porous layer between the metal and the DBR.

2. Materials and Methods

In this work, we used the numerical calculation by COMSOL Multiphysics software Version 5.6 which is based on the finite element method. Perfectly matched layers (PML) are used at the top and bottom of the structure proposed in Figure 1a to ensure accurate modeling of wave propagation and avoid electromagnetic wave reflections outside the calculation domains.

The refractive index of the porous nitride is calculated from the Burgmann relation as follows:

$$-2\varepsilon_{P1}^2 + \varepsilon_{P1}[2\varepsilon_1 - \varepsilon_{P2} + 3P(\varepsilon_{P2} - \varepsilon_1)] + \varepsilon_1\varepsilon_{P2} = 0 \quad (1)$$

where ε_{P1} is the permittivity of the porous nitride, P is the porosity, ε_1 is the permittivity of the nitride and ε_{P2} is the permittivity of the material filling the pores.

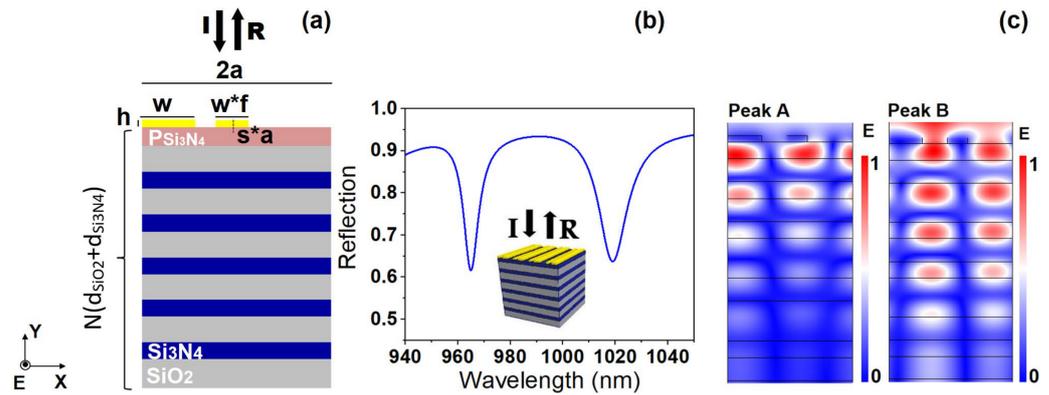


Figure 1. (a) Schematic representation of the Tamm plasmon structure constituted of double period Tamm structure, with $p = 0\%$. (b) Reflection spectrum of Tamm structure. (c) Norm of the electric field of peaks A and B.

3. Results and Discussion

The structure is composed of a nanostructured grating constituted of two different nanoribbons per period 2^*a deposited on a DBR of $(SiO_2/Si_3N_4)_6$, as shown in Figure 1a.

Indeed, the porous nitride allows us to reach a porosity of $p = 40\%$ without losing the quality of the Tamm modes. The parameters of the structure are $d_{SiO_2} = 182$ nm, $d_{Si_3N_4} = 133$ nm, $a = 480$ nm, $w = 260$ nm, $s = 0.16$, $f = 0.6$, $h = 50$ nm.

The excitation of the Tamm structure without the porous layer allows us to observe two modes that are located in the band gap of the DBR; the field intensity maps of peaks A and B Figure 1c show that mode A is a metal mode and mode B is an air mode. We are interested in the air mode because it is more sensitive than the metal mode to the change in the refractive index of the detection medium.

From the reflection spectra of the Tamm structure without a porous layer (Figure 2a), we calculate the sensitivity to detect an index change of 1%, $S = 40$ nm/RIU. The use of a porous nitride layer allows us to increase the sensitivity of the structure 5 times, $S = 200$ nm/RIU.

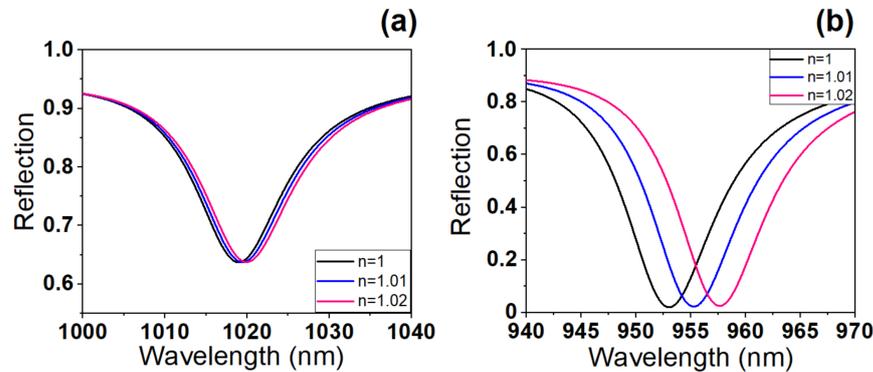


Figure 2. Reflection spectra as a function of wavelength for different refractive indices of the double period Tamm structure (a) without a porous layer and (b) with a porous Si_3N_4 layer of porosity $p = 40\%$.

4. Conclusions

In this work, we have proposed an efficient Tamm sensor to be fabricated and used. Indeed, it is not necessary to use porous DBR structures to improve the sensitivity of Tamm sensors [3]. A single porous layer at the location where the electric field is high and is largely sufficient.

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