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# Propagation of surface plasmon-polaritons in metal-dielectric structures based on opals

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**Abstract.** Calculations based on the analysis of experimental data allow us to estimate a period of a two-dimensional diffraction grating made of opal globules and to make assumptions about possible directions of surface plasmon-polaritons propagation in metal-dielectric hybrid plasmon-photonic crystals.

**Keywords:** surface plasmon-polaritons, opal globules, metal-dielectric structure, hybrid plasmon-photonic crystal

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# Распространение поверхностных плазмон-поляритонов в металлодиэлектрических структурах на основе опалов

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**Аннотация.** Расчеты, проведенные на основе анализа экспериментальных данных, позволяют оценить период двумерной дифракционной решетки из опаловых глобул и высказать предположения о возможных направлениях распространения поверхностных плазмон-поляритонов в металлодиэлектрических плазмонно-фотонных гетерокристаллах.

**Ключевые слова:** поверхностные плазмон-поляритоны, опаловые глобулы, металлодиэлектрические структуры, плазмонно-фотонные гетерокристаллы.

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## Introduction

Surface plasmon-polaritons are electromagnetic (EM) waves propagating along the metal-dielectric interface [1]. In the last decades, surface plasmon-polaritons (SPPs) were successfully used in photonic crystal devices [2–4] significantly expanding their functionality in EM radiation flow control [5–8]. In this paper, the peculiarities of SPP propagation in hybrid plasmon-photonic crystals obtained by successive deposition of metal (Ag) and dielectric ($SiO_2$) films on a monolayer of opal globules [9] are analyzed.

The law of SPP dispersion and the condition of phase synchronism when the SPP is excited by light with a wavelength $\lambda$ incident on an opal lattice with a period $a$ (Fig. 1) have the form [1]:

$$\beta = \frac{\omega}{c}\left(\frac{\varepsilon_1\varepsilon_2}{\varepsilon_1+\varepsilon_2}\right)^{1/2} = k_x + 2\pi\frac{l}{a}, \tag{1}$$

where $\beta$ and $k_x = k\sin\theta = (\omega/c)\sin\theta$ are tangential projections of wave vectors of SPP and photon of visible light with a frequency $\omega$, respectively, $\theta$ is the angle of light incidence, $\varepsilon_1 = 1 - (\omega_p/\omega)^2$ and $\varepsilon_2$ are the dielectric permittivities of metal and dielectric, respectively, $a$ is the period of grating, $l$ being an integer. Note that silver plasma frequency $\omega_p >> \omega$ ($\lambda_p = 2\pi(c/\omega_p) \approx 136$ nm). Thus, equation (1) makes it possible to estimate period of opal grating and consequently — possible directions of SPP propagation.

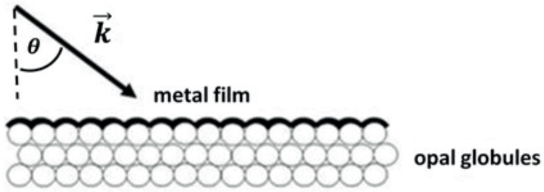

Fig. 1. Phase-matching of light to SPPs using the metal-dielectric opal based grating

## Results and Discussion

Formerly [6–8], we attributed some transmission maxima in optical spectra of hybrid plasmon-photonic crystals $Ag/SiO_2/Ag/ML/Ag$ (Fig. 2 [8]) to an extraordinary transmission (EOT) and minima correlating with resonator $Ag/SiO_2/Ag$ peak positions — to an extraordinary absorption (EOA) associated with the excitation of 'bright' and 'dark' surface plasmon-polaritons, respectively.

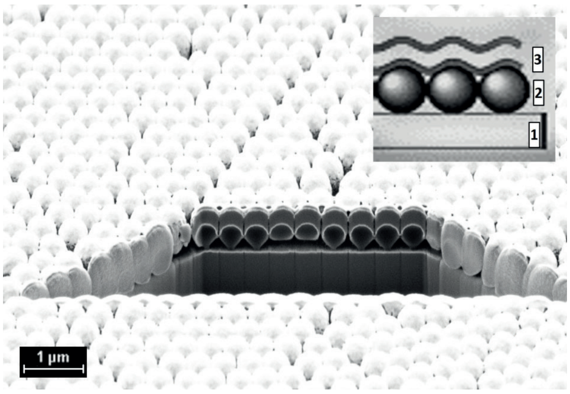

Fig. 2. SEM image of a sample of a hybrid plasmon-photonic crystal $Ag/SiO_2/Ag/ML/Ag$. Insert: 1 – glass substrate, 2 – monolayer (ML) of opal globules, 3 – resonator $Ag/SiO_2/Ag$ [8].

Fig. 3 demonstrates angular dependence of transmission coefficients of a resonator Ag/$SiO_2$/Ag (with its maxima correlating with EOA peak positions) for different wavelengths.

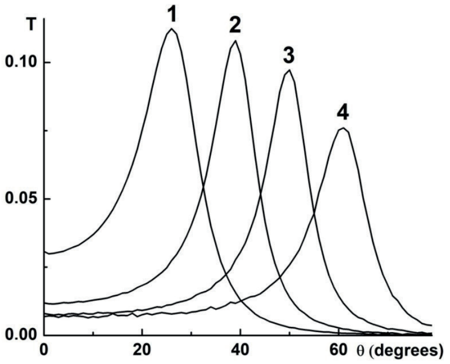

Fig. 3. Angular dependences of transmission coefficients of a resonator Ag/$SiO_2$/Ag (with maxima correlating with EOA peak positions) for wavelengths of 525 nm (1), 500 nm (2), 475 nm (3), and 450 nm (4)

We can use these experimental data to confirm that in our case equation (1) holds. Assuming $l = 1$ this equation could be rearranged as follows:

$$\left[\varepsilon_2 \frac{(\lambda/\lambda_p)^2 - 1}{(\lambda/\lambda_p)^2 - (1+\varepsilon_2)}\right]^{1/2} - \frac{\lambda}{a} = \sin\theta.$$

Thus, the theory predicts a direct proportionality between two values: $X = \sin\theta$ and

$$Y = \left[\varepsilon_2 \frac{(\lambda/\lambda_p)^2 - 1}{(\lambda/\lambda_p)^2 - (1+\varepsilon_2)}\right]^{1/2} - \frac{\lambda}{a}.$$

Experimental results (Fig. 4) confirms this prediction (and, consequently, the excitation of SPPs in this hybrid plasmon-photonic crystals in the conditions under consideration) for small angle of incidence, the best fit parameter $a$ being $a = 363$ nm.

On the other hand, it should be mentioned that the inclination angles of the straight lines in Fig. 4 are too small. The explanation of this fact requires the use of a more complex model that takes into account the peculiarities of the hybrid plasmon-photonic structures under study.

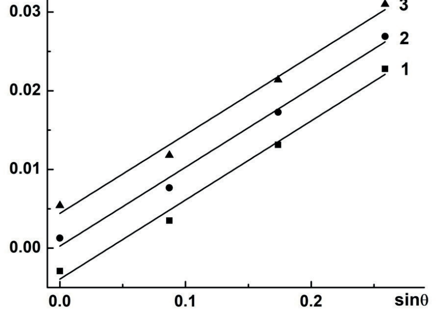

Fig. 4. Angular dependence of the Y value (see text) for different period a values: 362 nm (1), 363 nm (2), and 364 nm (3). Pierson correlation coefficient: $r = 0.995$

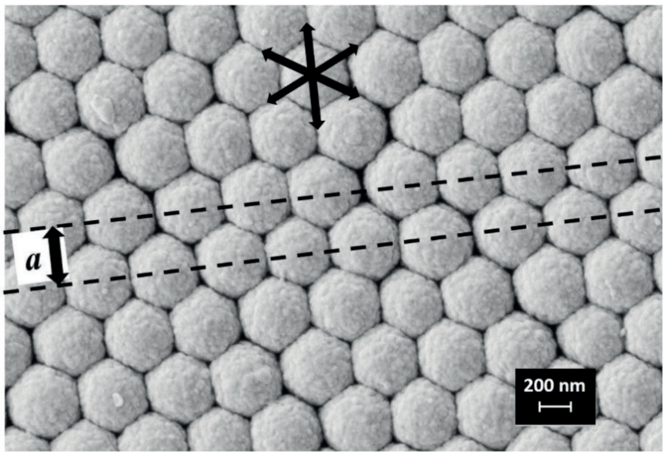

Fig. 5. SEM image of opal globules monolayer. Arrows indicate the corresponding lattice period and probable directions of SPP propagation

Our estimation of the grating period ($a$ = 363 nm) is in reasonable agreement with one of the parameters of a two-dimensional diffraction grating $a = D\sqrt{3}/2 \approx 358$ nm [10], where, in accordance with data of electron microscopy, the diameter of opal globules is $D \approx 413$ nm. This result within the limits of experimental errors is also consistent with the value $a \approx 385$ nm obtained earlier [7] by another method. Fig. 5 illustrates corresponding lattice period and probable directions of SPP propagation.

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