# Hybrid States of Surface and Tamm Plasmon-Polaritons in Photonic Crystals

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**Abstract:** Experimental observation of Tamm plasmon-polariton (TPP) and surface plasmon-polariton (SPP) hybrid mode in metal/photonic crystal system is reported. Interaction between TPP and SPP leads to repulsion of their dispersion curves.

## 1. Introduction

Tamm plasmon-polaritons (TPP) in photonic crystals (PC) are optical analogues of electronic density localization at the boundary of periodic atomic potential [1] and appear as electromagnetic field localization at the boundary of photonic crystal and metal [2]. Unlike surface electromagnetic waves and surface plasmon-polaritons (SPP) TPPs do not have phase-matching conditions for in-plane wave vector, thus TPP can be excited for any angle of incidence [3]. However boundary conditions for out-of-plane wave vector are critical for TPP. Experimentally these states manifest themselves as narrow absorption gaps in reflectance spectra of Me/PC systems [4].

The TPP combined with other excitations such as excitons or microcavity modes have been intensively studied last years [5,6] due to prospectives of the TPP application in new compact lasers and sensors [7]. Such states are called "hybrid" ones and can be detected as a series of several non-overlapping resonances in reflectance spectra.

In a Me/PC system, surface plasmon can be excited under conditions of a total internal reflection. Conditions for TPP excitation then would be satisfied automatically because TPP could be excited for any angle of incidence of light. Thereby one can expect hybrid state of SPP and TPP excitation.

## 2. Samples and setup

The studied samples consisted of 6 pairs of $ZrO_2/SiO_2$ (average thicknesses 110 nm and 145 nm, respectively) quarter-wavelength layers with $SiO_2$ layer on top, deposited on quartz substrate using thermal evaporation. According to the calculations optimal thickness of the top most layer was estimated as 225 nm, therefore additional 80 nm layer of $SiO_2$ was deposited on the sample using thermal evaporation. The resultant structure was covered by a 30-nm-thick gold film allowing both good field localization in the TPP mode and possibility of the SPP excitation.

Reflection spectra were measured with the 1-nm resolution using polarized collimated beams. For measurement of angular dependences the θ-2θ goniometer was used providing 0.005° accuracy.

## 3. Experimental results

Figure 1 shows image plots of reflection coefficient spectra depending on the angle of incidence for the TM polarization of incoming light, measured (Fig.1a) and calculated (Fig.1b). TPP dip is observed for incident angles less than angle of a total internal reflection (about 41° for used prism). Note that while angle of incidence increases both photonic band gap (PBG) and position of TPP shift to the shorter wavelengths as perpendicular component of a wave vector decreases. For the angles that exceed angle of a total internal reflection, phase matching conditions for SPP excitation could be satisfied. One can see the SPP dip, starting from $\theta = 43°$ and $\lambda = 990$ nm and rapidly shifting to the blue edge with increasing angle of incidence. TPP resonance as well appears again at 43° and 620 nm.

Inset in Figure 1b shows reflection coefficient spectrum as a function of angle of incidence for a reference sample — 30-nm-thick gold film. In such structure surface plasmon-polariton is excited solely. Dip corresponding to SPP excitation appears at 42°. Spectral position of SPP in the reference sample at 50° is approximately 520 nm while spectral position of SPP in the Au/PC sample at 50° is about 610 nm due to interaction with TPP which leads to repulsion of TPP and SPP resonances.

A set of numerical calculations was also performed to study how coupling of TPP and SPP depends on the thickness of a gold layer. Interaction between two surface modes decreases with the increase of the gold thickness since interaction between TPP and SPP depends on thickness of gold exponentially. For the films thicker than 60 nm TPP and SPP do not sense each other and repulsion of their dispersion curves is absent.

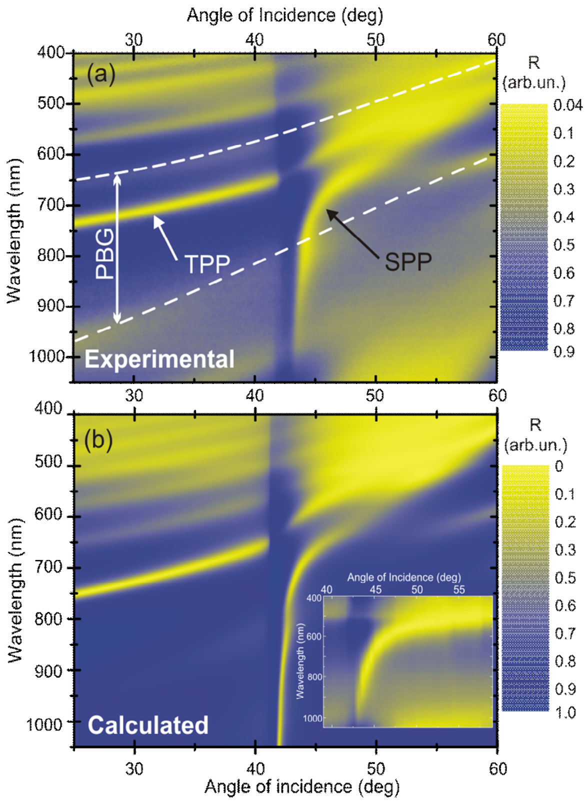


Fig.1. (a) Image plot of experimental reflectivity spectrum of studied Au/PC sample for TM polarization. Arrows show dispersion curves of Tamm plasmon-polariton (TPP) and surface plasmon-polariton (SPP). (b) Image plot of calculated reflectivity spectrum for TM polarization. Inset shows image plot of experimental reflectivity spectrum of a reference gold film for TM polarization, where SPP is excited solely. Yellow stripe corresponds to the SPP dispersion curve.

## 4. Conclusions

In conclusion, we have obtained unambiguous experimental evidence of possibility of Tamm and surface plasmon-polaritons hybrid mode excitation in Au/(1D PC) structure. For TM polarized incoming light these two surface modes exist on the different surfaces of metal and their interaction is evanescently small. Tamm and plasmon components of hybrid mode are revealed as two non-overlapping resonances. However, their interaction leads to repulsion of dispersion curves, which can be used for creating tunable plasmonic filters or sensors. By using numerical calculations was shown that if thickness of gold exceeds 60 nm dispersion curves of TPP and SPP overlap.

## 5. References

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