Ultrafast Dynamics of Tamm Plasmon-Polaritons in Metal/Photonic Crystal System

B.I. Afinogenov, V.O. Bessonov and A.A. Fedyanin
Lomonosov Moscow State University, 1 Leninskie gory, 119991, Moscow, Russia
afinogenov@nanolab.phys.msu.ru

Abstract: Measurements of temporal profiles of femtosecond pulses reflected from metal/photonic crystal system show that the pulses are distorted when spectra of the pump laser radiation and resonance line of Tamm plasmon-polariton overlap. Lifetime of TPP was estimated at 30 fs.
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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) Tamm plasmon-polaritons 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].

Ultrafast dynamics of SPP was intensively studied last years. Significant distortion of femtosecond pulses travelling in plasmonic nanostructures was shown [5-7]. Ultrafast measurements can provide information about lifetime and excitation dynamics of the TPP which is of the great fundamental interest and on the other hand is useful for the creating brand new devices for controlling the light. However to the best of our knowledge there are no papers in which ultrafast dynamics of Tamm plasmon-polaritons is studied.

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 a sample using thermal evaporation. The resultant structure was covered by a 30-nm-thick gold film allowing good field localization in the TPP. 30-nm-thick gold film on quartz substrate was used as a reference sample.

As a source Ti:Sapphire laser with pulse precompressor was used, providing 30 fs pulses with 80 MHz repetition rate. Polarization of incident light was controlled with a wideband half-wavelength plate. Temporal profiles of femtosecond pulses, reflected from the Au/PC sample, were obtained using noncollinear intensity cross-correlation measurements.

3. Experimental results

Experimental cross-correlation function of pulse reflected from 30-nm-thick gold film is shown in Fig. 1a with dots in a semilogarithmic scale. Corresponding spectrum of a pulse is shown in the inset. Profile of a pulse is in an excellent agreement with Gaussian fit, shown with red solid curve. Cross-correlation functions of *p*- and *s*-polarized pulses reflected from the Au/PC sample are shown in Fig. 1b with black squares and red circles respectively. Inset shows corresponding spectra of *p*- (black curve) and *s*- (red curve) polarized incoming light reflected from the Au/PC sample. Dips, related to the TPP exist in both polarizations, but overlapping of TPP resonance and pulse spectrum is better for *p*-polarization. In the presence of TPP temporal profiles of ultrashort pulses distort. One can see tails on the trailing edges in cross-correlation functions. Tail of *p*-polarized pulse was approximated with function $y = y_0 + \exp(-x/\tau)$, where τ corresponds to the lifetime of TPP, which was found to be 30 fs.

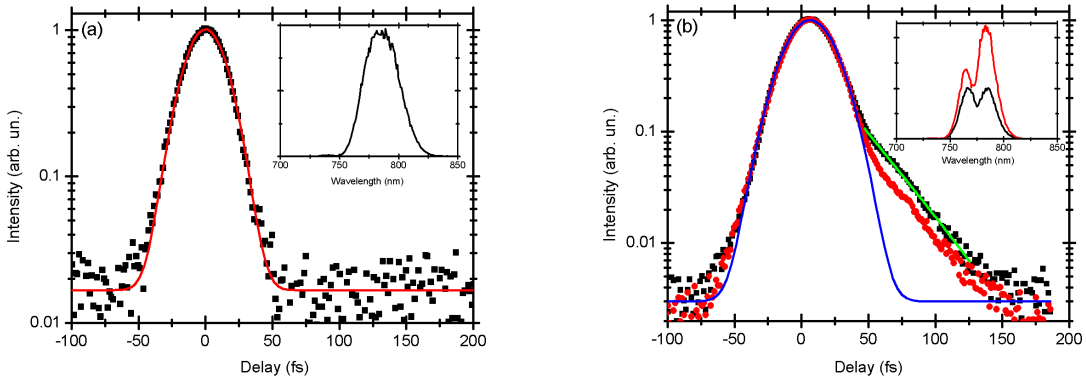

Fig.1. (color online) (a) Dots – cross-correlation function of a pulse reflected from a 30 nm-thick gold film. Red (solid) curve – Gaussian fit. Inset – spectrum of reflected pulse. (b) Cross-correlation function of a pulse reflected from the Au/PC sample for *p*- (black squares) and *s*- (red circles) polarization of incident light. Blue (solid) curve – Gaussian fit. Green solid line – exponential approximation of the tail. Inset – spectra of reflected pulses for *p*- (black curve) and *s*- (red curve) polarization. The plots are semilogarithmic.

4. Conclusions

It is shown that temporal profile of femtosecond laser pulses reflected from Au/PC system modifies in the presence of Tamm plasmon-polariton. Lifetime of TPP was estimated at 30 ± 1 fs from fitting the tail of cross-correlation function of *p*-polarized pulse with exponential function.

5. References

[1] I.E. Tamm, JETP **3**, 34 (1933).
[2] A. V. Kavokin, I. A. Shelykh and G. Malpuech, Phys. Rev. B **72**, 233102 (2005).
[3] A. Kavokin, I. Shelykh and G. Malpuech, App. Phys. Lett. **87**, 261105 (2005).
[4] M. E. Sasin, R.P. Seisyan, M. A. Kaliteevski et al., App. Phys. Lett. **92**, 251112 (2008).
[5] A. S. Vengurlekar, A. V. Gopal, and T. Ishihara, App. Phys. Lett. **89**, 181927 (2006).
[6] P. Vabishchevich, V. Bessonov, F. Sychev et al., JETP lett. **92**, 575 (2011).
[7] C. Ropers, G. Stibenz, G. Steinmeyer et al., App. Phys. B **84**, 183 (2006).