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Four Channel Splitter on Surface Plasmons-Polaritons

D.V. Nevinskiy[1,*],V.A. Pavlysh[1], L.I. Zakalyk[1], S.Y. Lebid[2]

[1] *National University Lviv Polytechnic, 2, Profesorska Str., 79013 Lviv, Ukraine*
[2] *European University, 5 Kushevycha str., 79019, Lviv, Ukraine*

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Modeling process of surface plasmon polaritons-(SPP) distribution in the 10 mm long four channel-splitter is discussed in current paper. 20 mm long two channel splitter was formed by the projection optical lithography in order to test the model relevancy. Studies have shown that excited SPP propagates along both channels in a dual channel splitter.

Keywords: Surface plasmon polariton, Splitter, Model, Lithography, Channel.

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1. INTRODUCTION

The number of research papers on surface plasmon polaritons-(SPP), which opens up the prospect of a new generation of optical devices [1], increased over the past several years. Various approaches to achieve effective SPP excitation [2-5] and design of geometrically limited channels for its distribution are proposed to date [6,7]. Manufacturing of nanoscale waveguides that provide a simple and cost-effective way of SPP side control and implementation of integrated components are topics of current investigations.

SPPs are coherent oscillations of surface electrons of the metal at the interface metal-insulator [8]. SPP which have lower frequencies than surface plasmon resonance of the metal-insulator are very limited and can spread along the waveguide. SPP excitation on the metal surface opens new opportunities for use of their nonlinear properties, e.g. for sensing and detection of single molecules, wich could find an application in chemistry, biology, medicine, electronics, and information and communication technologies [9].

Lateral limitation in the plane of the metal surface, perpendicular to the direction of the SPP propagation, is required to implement compact plasmon devices and circuits.

The SPP propagation process in the four-channel splitter was simulated in current study using the 632.8 nm wavelength laser as a source of optical signal. Also it was experimentally demonstrated that SPP can propagate in a dual channel splitter, which has larger geometric dimensions.

2. MODELLING OF THE SPP PROPAGATION

Processes arising at the SPP propagation on the surface of nanosized metal film can be described by the model of the physical system based on a dot dipole approximation [10]. This method has some limitations, but enables to bypass the problems associated with the interface energy dissipation on the metal film-dielectric basis interface and takes into account only the energy transfer between the particles.

A surface of nanostructured metal film can be represented as a chain of strongly interacting atoms. The light is directed at the first atom in chain - the rest is irradiated by the energy scattered from the first one. The polarization of the external field can be S or P. Therefore, Maxwell's equations and the Green function can be applied to describe such a physical system. The electric field in such a structure can be determined from the Lippmann-Schwinger equation [11]:

$$\mathrm{E(r)} = \mathrm{E}^0(r) + k_0^2 \sum_{i=1}^{N} \int_{V_i} \hat{G}(r,r')(\varepsilon_3 - 1)E(r')dr'$$

where E_0 – external electric field at the starting point;

k_0 – ballistic wave vector;

N – total number of particles in the chain;

V_i – volume occupied by a particle with i number;

ε_3 – Au dielectric constant.

Given the identity of the spherical particles with the half axis h_x, h_y, h_z and parallel axes, polarization tensor in the long-wavelength approximation has the form [12]:

$$\hat{\alpha} = (\alpha_x \hat{x}\hat{x} + \alpha_y \hat{y}\hat{y} + \alpha_z \hat{z}\hat{z})$$

$$\alpha_\tau = \frac{\varepsilon_0 V(\varepsilon_3 - 1)}{1 + (\varepsilon_3 - 1)m_\tau}, \ \tau = x, y, z.$$

where $V = 4\pi h_x h_y h_z/3$ – volume of a particle;

m_x, m_y, m_z – depolarization ratio.

Because nanoparticles are based on a dielectric substrate, the Green tensor will be $G_0(r, r')$ and $G_s(r, r')$. The component $G_0(r, r')$ defines a value of a constant electric field, and $G_s(r, r')$ represents a field scattered on the metal-insulator interface.

Accordingly, the electric field on the metal surface can be described by the equation:

$$\mathrm{E(r)} = k_0^2 \sum_{i=1}^{N} [\hat{G}^0(r,r_i) + \hat{G}^S(r,r_i)]p_i$$

Tensor $G_0(r, r')$ can be solved analytically [13]. In general, given that the particles in the chain are close to the surface of the interface and have a size much

* nevinskiy90@gmail.com

smaller than the wavelength, then it greatly simplifies the numerical method. In particular, if the distance between the source and the observation point is less than 20λ - Green tensor has an exact value, including all methods of dispersion and only a part of plasmon is approximated.

The dependence of the SPP intensity on distance is obtained as a result of SPP propagation process simulation in the four-channel splitter. SPP propagates along all splitter channels, although the intensity slightly decreases at the distance of 6 mm (Fig. 1).

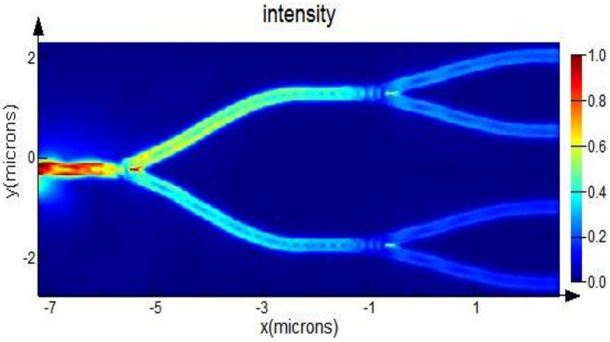

Fig. 1 – The intensity of SPP propagation in the four-channel splitter

Fig. 2a shows the intensity of the input signal of 50 fs duration and Fig. 2B shows the intensity of the output signal.

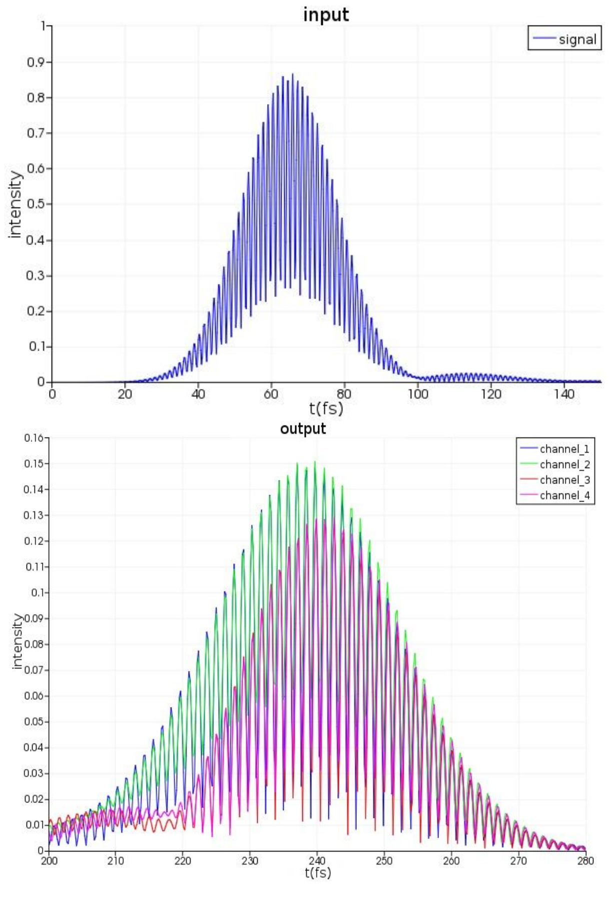

Fig. 2 – Calculated dependance of the signal intensity on time: a) – signal applied to the input of the four-channel splitter; b) - signal applied to the output of the four-channel splitter

Figure 2 shows that the output intensity is small but it is enough for identification.

3. SPP PROPAGATION IN DUAL CHANNEL SPLITTERS

The dual photon polymerization method was chosen to create two-channel splitter [14]. Nanoscale waveguides were formed using optical lithography [15], taking into consideration that the femtosecond laser is quite expensive and sensitive to the environment. The dual channel splitter is 20 mm long, has 5 mm width between the splitter branches and 500 nm thick (Fig. 3). SPP is exited with 632.8 nm laser perpendicularly to the splitter plane. The laser beam is focused in the center of the first splitter channel, as shown in Figure 3a.

Fig.3b shows SPP propagation along the splitter. It is demonstrated that the SPP propagates in two channels along the entire length of 20 mm splitter and the light partially attenuates due to ohmic losses.

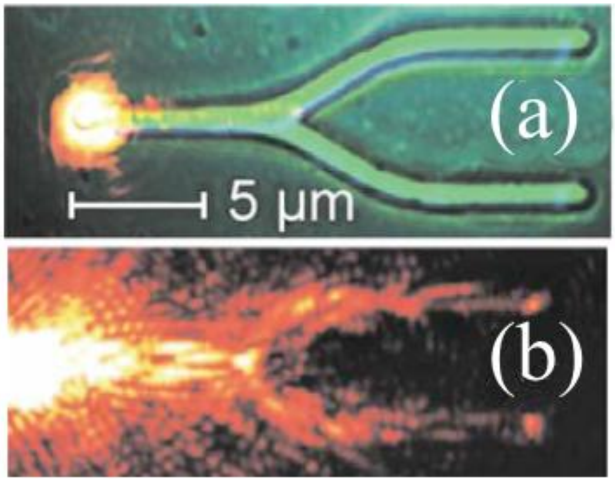

Fig. 3 – SPP propagation in splitter 1:2: a) - the image of the 20 mm long splitter; b) - SPP propagation within the splitter made by LR microscope.

The investigated properties of the splitter suggest that it might be possible to create a larger splitters, including four-channel splitters operating under the light control. Application of these splitters is possible in nanocircuits where large signal losses are present during optical into electrical signal convertion. Studied splitter opens up opportunities for creation of various new devices on SPP, such as multiplexers, adders, and other logic elements.

4. CONCLUSIONS

Propagation process of SPP in four channel splitter is simulated in current work. Two-channle splitter was created by projection optical lithography to test the mathematical model. The manufacturing technology chosen in current studies enables to simplify nanoscale structures fabrication and cheapen the process of obtaining inhomogeneous dielectric nanoscale waveguides for next generation devices.

Samples obtained by optical photolithography have better pattern resolution, steep walls of exposed or polymerized photoresist.

Figure 2 show that SPP fades during propagation, but the intensity is sufficient to identify it on the four-splitter outputs.

Obtained results will be used to create ultra-compact optical information processing elements, and a new class of adders and multiplexers for information and communication devices.

Thus received a new four-channel splitter on SPP for nanooptic circuits for procession and transmittion of the information.

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