SURFACE METALLIC NANOSTRUCTURES FOR PHOTOACOUSTIC FIBER-OPTIC TRANSDUCERS SYNTHESIZED BY LASER PLASMA CONDENSATION

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Wideband ultrasonic signals are widely investigated as powerful diagnostic tool for advanced applications, for example, biomedical high-resolution high-contrast imaging and nondestructive analysis /1/. Number of studies of ultrasonic transducers have been conducted because ultrasonics offers very high-resolution diagnostics due to the relatively small speed of sound within the most part of liquids and solids (ultrasound waves are typically characterized by the optical-scale wavelengths even in the sub-gigahertz frequency range). But there are some limitations for effective ultrasonic transducers design. Conventional transducers based on piezoelectric effect typically allows bandwidths only up to tens of megahertz. Moreover, such transducers are quite bulky. Furthermore, the attenuation of ultrasonic wave is higher than 100 dB/mm in the frequency range exceeding gigahertz /1,2/. Thus, the thickness of absorption layer on the surface of an optical fiber should be minimized. Additionally, a tiny transducer is only suitable variant because it should be place directly on the object under test. Fiber-optic transducers based on the photoacoustic effect are comparatively small (optical fiber core diameter is less than 10 μm), flexible and movable. Moreover, they are characterized by high electromagnetic immunity, dielectric design and chemical durability. Metallic nanostructures, which are formatted on the surface of an optical fiber edge by laser plasma condensation, can potentially provide very high absorption (up to 90%) within the thickness of nanoparticles (NPs) monolayer. Photoacoustic transformation of the modulated optical signal in the acoustic waves takes place due to periodical thermal expansion/contraction.

In this paper, we present theoretical investigation of absorption of laser radiation within metallic NPs monolayer on the surface of the optical fiber edge.

Optical characteristics of surface metallic nanostructures. In general, surface nanostructures can be synthesized by means of chemical deposition /3/, optical assisted deposition in liquid media /4/, and laser plasma condensation /5,6/. The procedure of NPs formation within the ablation flare allows the expulsion of the atmospheric gases, which in turn provides the direct synthesis of chemically pure NPs of noble metals without an oxide/hydroxide shell /7/.

A frequency domain simulation by means of the CST Microwave Studio Student Edition is performed for the modelling of optical characteristics of a metal NPs monolayer on the surface of an optical fiber edge. The unit cell of the NPs monolayer is simulated as follows. The unit cell contains two infinite osculating parallelepipeds, one of them is the solid substrate and another is the surrounding medium. NPs is placed on the surface of the solid substrate (fiber edge), so the whole NP volume is located within the surrounding medium. The representation of the structure and scattering parameters is shown in the Fig. 1.

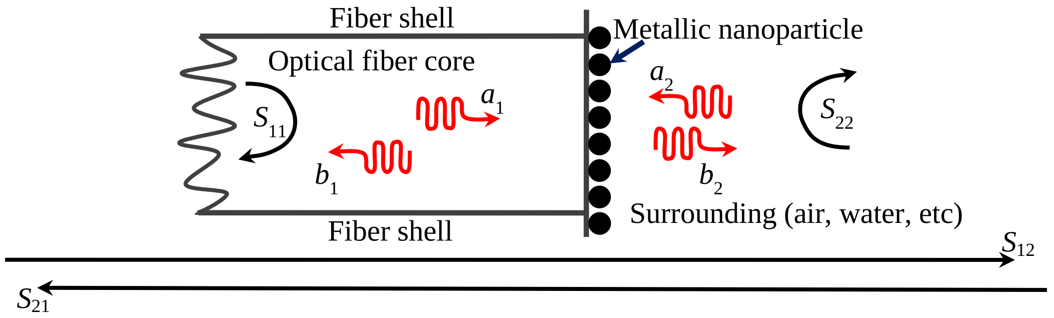

Fig. 1 – Simulation layout of the nanostructure based on the metal NPs monolayer on the fiber edge

For effectiveness of the photoacoustic transformation of the modulated optical signal in the acoustic waves due to periodical thermal expansion/contraction, it is necessary to fulfil the following conditions: 1. Commercially available cheap laser with up to GHz-range frequency response (405, 445, 450, 510–530 nm semiconductor lasers are studied theoretically); 2. Wide peak in the absorption spectrum (full width at the 90% maximum exceeding 25 nm is studied); 3. High absorption value at the spectral peak (more than 50% is studied).

Semiconductor lasers allow easy and effective coupling with optical fiber. In this work, optical loss coefficient is calculated from optical scattering parameters. Optical loss in the nanostructure are calculated as loss associated with energy dissipation. It is shown earlier that Au NPs monolayer on the optical fiber edge allows the most effective transformation of the modulated optical signal in the acoustic waves within wide ranges of sizes (from 10 to 30 nm) and surface occupation densities (from 35 to 70%) /8/. In particular, it is possible achieve optical power up to 60 mW at the wavelength of 520 nm in the optical fiber. Absorption peak for nanostructures based on Ag NPs monolayer on the optical fiber edge is observed near the wavelength of 445 nm. Absorbtion coefficients are less than to 30%. But it is possible achieve optical power up to 1800 mW at the wavelength of 445 nm in the short optical fiber pigtails /8/.

Fig. 2 shows regions of nanostructure parameters, which provide the most effective absorption of the laser radiation (1 denotes region for Ag NPs within the air surrounding, 2 denotes region for Ag NPs within the water surrounding). It is necessary to note, that thin protective coatings can be deposited on the NPs monolayer.

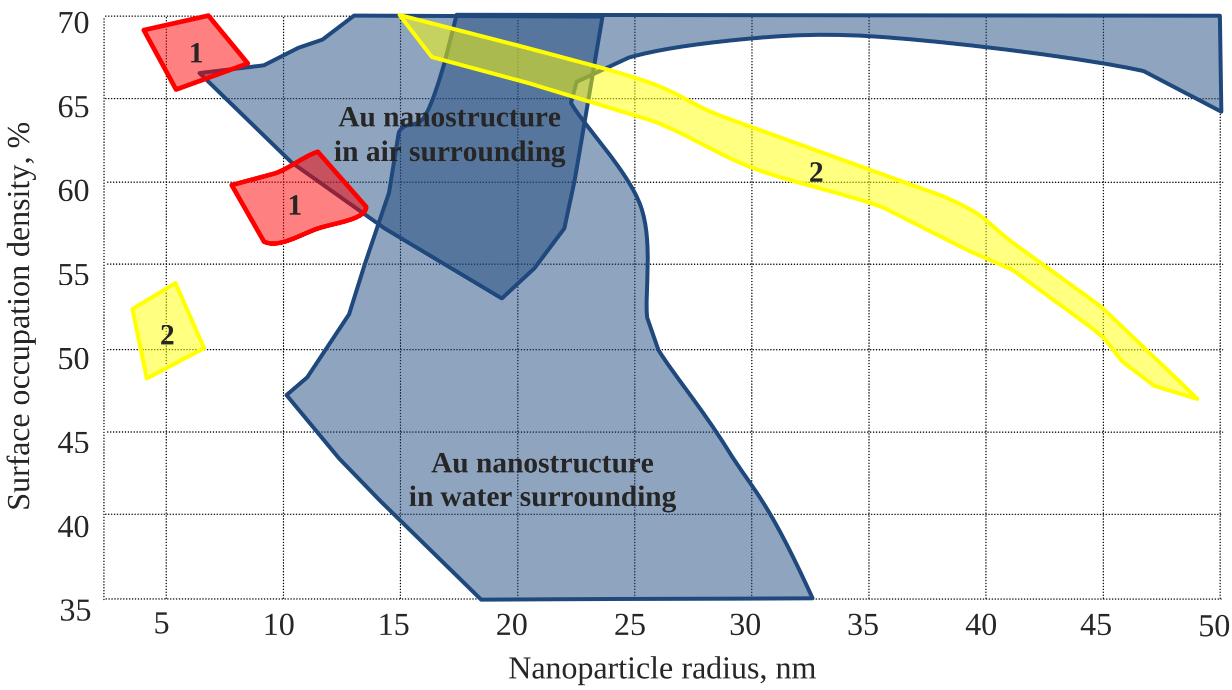

Fig. 2 – Regions of parameters, which provide the most effective absorption of the laser radiation by surface nanostructures (1 for Ag NPs in the air surrounding, 2 for Ag NPs in the water surrounding)

It is shown that Au NPs monolayer on the optical fiber edge allows the most effective transformation of the modulated optical signal in the acoustic waves within wide ranges of sizes (from 10 to 30 nm) and surface occupation densities (from 35 to 70%).

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