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# Laser Effect on Spherical Nanoparticles with Thin Surface Layer

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***Abstract.*** **It is shown that metal nanoparticles with thin atomic surface layer can be used as laser active medium. Significant narrowing of the emission band in the spectrum of the particle with a surface layer was found.**

***Keywords:*** **nanoparticles, lasers, radiation.**

## I INTRODUCTION

The relevance of the study is conditioned by the need to create materials for lasers on nanoparticles. The possibility of laser design based on nanoparticles coated with dielectric shells was demonstrated, for example, in [1], [2]. The purpose of this work is to suggest a way of fabrication of nanolaser active medium including nanoparticles with thin atomic surface layers.

## II THEORETICAL APPROACH

We consider surface excitations of a spherical metal particle with inverse population of atoms in a thin surface layer (one or two layers of atoms on the particle surface) as an active medium. The possibility of significant deformation of the surface collective excitations' spectrum of spherical particles with a thin surface layers was shown in our work [3]. The atoms of the surface layer directly interact with the radiation and the particle (see details in [3]). Dielectric layer is not formed in a thin surface layer of atoms. If one examines surface dielectric layer, the spectrum of surface excitations of the particle is weakly deformed.

In the presence of a thin surface layer (one or two atomic layers) polarizability $R^3 A(\omega)$ of a spherical particle can be represented in the following form [3]:

$$A(\omega)=\frac{tg(K(\omega))}{\sqrt{2}}+\frac{1}{\cos^2(K(\omega))}\cdot\frac{\alpha(\omega)}{1-\sqrt{2}\cdot\alpha(\omega)tg(K(\omega))},$$

where the particle radius $R$ is much smaller than the characteristic absorption wavelength in the particle's material and in the atoms of the surface layer,

$$\alpha(\omega)=\frac{\varepsilon(\omega)-1}{\varepsilon(\omega)-2}.$$

Here $R^3\alpha(\omega)$ represents polarizability of a spherical particle in vacuum, $\varepsilon(\omega)$ is the dielectric constant of the particle substance. The surface layer is described by the function

$$K(\omega)=\sum_a\frac{\sqrt{2}\cdot\alpha_a(\omega)N_a}{R^3},$$

where $N_a$ is the population of the state number $a$ in the atoms of the surface layer, $\alpha_a(\omega)$ represents polarizability of an atom in $a$ - state with regard to its short-wavelength interaction with the particle surface. If the atoms of the surface layer are described in three-level approximation, the function $K(\omega)$ can be represented in the form

$$K(\omega)=\frac{a_0\omega_0^2}{\omega_0^2-\omega^2-i\gamma\omega}+\frac{a_1\omega_1^2}{\omega_1^2-\omega^2-i\gamma\omega},$$

where $\omega_0$, $\omega_1$ are the transition frequencies in the atoms of the surface layer; these values can be shifted as compared with the transition frequencies of the free atom due to the short-wavelength interaction (e.g., chemisorption) with the particle; $\gamma$ represents the attenuation frequency of the transition, $a_0, a_1$ are parameters, which are proportional to the difference between the populations of the transition levels in the atoms of the surface layer.

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## III RESULTS AND DISCUSSION

An example of the absorption (or radiation) spectrum (imaginary part of $A(\omega)$) of the particle with a thin surface layer is shown in Fig. 1.

The emission spectrum of atoms in the surface layer of the particle (imaginary part of the first term in the expression for $A(\omega)$) is shown in Fig. 2. The parameters of the surface layer are $\frac{\omega_0}{\omega_p} = 0.54$, $\frac{\omega_1}{\omega_p} = 1$, $\frac{\gamma}{\omega_p} = 0.05$, $a_0 = -0.0125$ (population inversion), $a_1 = 0.025$. The choice of parameters is made for the sake of the clarity of the demonstration effect. The dielectric constant of the substance of the particle is described in the hydrodynamic approximation:

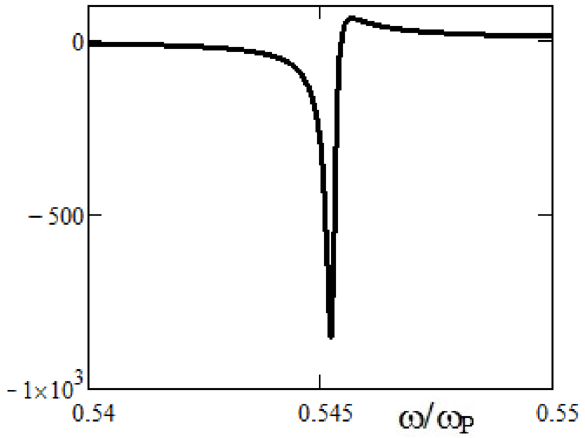


Fig. 1. Absorption (or radiation) spectrum of the particle with a thin surface layer.

$$\varepsilon(\omega) = 1 - \frac{\omega_P}{\omega(\omega + ig\omega_P)},$$

where $\omega_P$ is the plasma oscillation frequency, $g\omega_P$ represents the damping frequency of the plasma oscillations in the substance of the particle ($g = 0.1$).

From the spectra in Figs. 1 and 2 one can observe significant narrowing of the emission band in the spectrum of the particle with a surface layer by many orders of magnitude as compared with the width of the emission band of the atoms in the surface layer as well as with a typical absorption bandwidth of the particle without the surface layer. The lifetime of collective surface excitations in the particle with the surface layer also significantly increases. Narrow radiation band (long lifetime) of surface excitations in the particle demonstrates the possibility of lasing by nanoparticles possessing thin surface layers of atoms with inverse population.

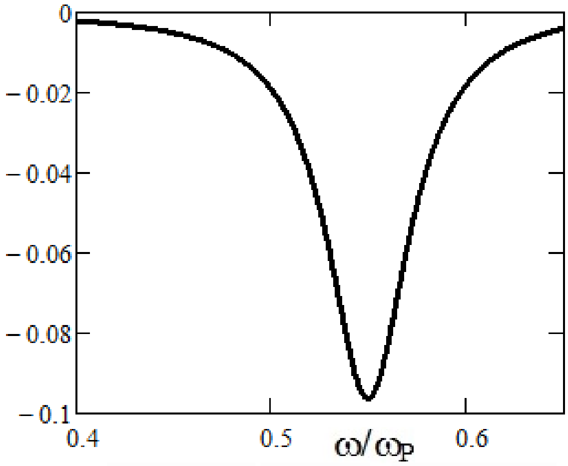


Fig. 2. The surface layer contribution to emission spectrum.

## IV CONCLUSIONS

The possibility of radiation generation and amplification by metal particles with thin surface layers has been theoretically demonstrated.

## V REFERENCES


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