Threshold characteristics of non-resonator laser generation in dye solutions with ZnO nanoparticles

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Abstract. An experiment was carried out to determine the generation thresholds in solutions of the Rhodamine 6G dye with Au nanoparticles having a plasmon resonance at the pump wavelength and ZnO nanoparticles not having a plasmon resonance. It was shown that solutions with ZnO nanoparticles have lower lasing thresholds in comparison with solutions with Au nanoparticles.

1. Introduction

The development of laser emitters in recent years is associated with their significant miniaturization and the creation of highly efficient active media. One of these lasers is considered to be a stochastic laser, known in the foreign literature as random-laser [1-3]. The active medium of this laser is a composite of laser-active molecules of nanoparticles of various materials.

In a classical laser, generation is usually determined by two factors - optical amplification, which is created by the inversion of the population in the excited active substance, and the formation of feedback by the laser resonator. In this case, the phenomenon of light scattering plays a negative role in this situation and is always minimized. However, in a stochastic laser, a chaotic strongly scattering medium improves the conditions for obtaining a laser effect in it.

In [1], the author H. Cao defines a stochastic laser as a resonatorless laser (due to the absence of external mirrors), in which the positive feedback mechanism is realized due to light scattering in an active medium with optical inhomogeneities.

According to the type of stimulated emission, random lasers can be divided into two classes [1]. The first of which are random lasers based on solutions of laser dyes with embedded nanoparticles of various substances. In such structures, the effect of multiple scattering by small inhomogeneities increases the residence time of stimulated emission photons in an excited active medium. The second class includes stochastic lasers, the principle of generation of which is based on the appearance of stimulated emission in the so-called micro-resonators, the mirrors of which are well-reflecting faces of microcrystals. Closed resonators are formed randomly during the action of the pump pulse.

At present, it is generally accepted that resonance-free laser generation in a scattering amplifying medium is realized either due to an increase in the interaction time of secondary radiation photons with active substance molecules, or due to the plasmon resonance effect. However, from previous experiments in [4], it was shown that the use of plasmon resonance nanoparticles does not lead to a significant decrease in the lasing thresholds.
A stochastic laser has special properties with respect to other types of lasers, namely a simple production technology, a wide angular dependence and the possibility of tuning the wavelength in a wide spectral range. The angular distribution of the output signal of a random laser is very wide and distributed at a total solid angle of \(4\pi\). Such wide angular radiation is, in principle, ideal for use in creating displays. A particular advantage of the active media of random lasers is that they can be prepared in the form of suspensions, which can be used as coatings on surfaces of arbitrary shape.

This communication demonstrates a comparison of the generation thresholds in Rhodamine 6G solutions with Au nanoparticles with plasmon resonance at the pump wavelength (\(\lambda = 532\) nm) and ZnO nanoparticles that do not have this effect.

2. Experimental setup
The experiment was conducted on the setup shown in Figure 1.

![Figure 1. Scheme of the experimental setup. 1 - laser, 2 - light filter, 3 - focusing lens, 4 - prism of total internal reflection, 5 - cuvette, 6 - input window of the receiving system, 7 - spectrometer, 8 - PC.](image)

During the experiments, the studied solution with a thickness of 1 mm was placed in a cuvette onto which the radiation from an aluminum–sodium garnet laser was incident with a pulse duration of 6 ns and a wavelength of 532 nm. Then, radiation passing through a light filter collecting a lens and a prism of total internal reflection fell on a cell with a working solution. The luminescence spectra of the solution were recorded using an Avaspec spectrometer. The obtained spectra were displayed on a PC.

3. Results
Typical spectra of spontaneous luminescence and stochastic generation are presented in Figure 2.

![Figure 2. Typical spectra of spontaneous luminescence (1) and stochastic generation (2).](image)

From the spectra, we plotted the dependences of the half-width of the spectrum and the luminous intensity on the laser pump energy. Dependencies are presented in figure 3.
Figure 3. The dependence of the half-width of the spectrum and the intensity of the luminescence on the pump energy for solutions with Au nanoparticles (a) and ZnO (b) with a concentration of nanoparticles in solution - 1.459×10^{-6} volume fractions.

Using the emission spectra and dependences presented in Figure 3, we determined the generation thresholds in solutions with Au and ZnO nanoparticles at various nanoparticle concentrations. The dependences of the threshold values on the nanoparticle concentrations are presented in Figure 4.

Figure 4. Dependence of threshold energy on the concentration of nanoparticles.

As can be seen from the dependences, solutions with ZnO nanoparticles at all used concentrations have lower lasing thresholds in comparison with solutions with Au nanoparticles.

4. Summary
As a result of the experiment, generation thresholds in solutions with Au and ZnO nanoparticles were obtained. The results indicate that the plasmon resonance possessed by Au nanoparticles at the used pump wavelength does not in any way affect the lowering of the generation thresholds. Such conclusions can be made based on the fact that the zinc oxide nanoparticles used in the experiment cannot possess plasmon resonance, since they are dielectric. Moreover, the generation thresholds in solutions with ZnO are equal to or less than the thresholds in solutions with Au nanoparticles.

References
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