Photon-phonon interaction in submicron particles systems – new method of Q-switching

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Background – Intracavity excitation of different kinds of stimulated scattering is very useful method for spectroscopy investigations and for numerous applications. In this method both exciting and scattered radiation propagate in the same cavity, which gives possibility to decrease scattering threshold and to increase its efficiency. Different kinds of stimulated scattering were registered and studied in the intracavity configuration: stimulated Rayleigh scattering, stimulated Brillouin scattering, stimulated Raman scattering [1,2]. We studied experimentally intracavity stimulated low-frequency Raman scattering [3].

Low-frequency Raman scattering (LFRS) is a result of light interaction with acoustic vibrations of nanosized or submicron particles systems. Its frequency shifts are defined by eigenfrequencies of particles vibrations lying in giga- or terahertz range and depend on the particles size and morphology. Stimulated low-frequency Raman scattering (SLFRS) is stimulated analogy of LFRS. It is very useful tool for nanoparticles study, identification and for impact on them. We studied SLFRS in many nanoparticles systems, including biological nanoobjects.

Samples and methods – In this work we show that with the help of intracavity SLFRS it is possible to obtain Q-switching and mode-locking. Suspensions of monodisperse polystyrene particles with similar particle sizes (0.05–1.0 μm) in water were used as samples. The concentration of suspensions was in the range 10^{10}–10^{12} cm^{-3}. We also studied suspensions of diamond, quartz and gold nanoparticles. Size distribution of nanoparticles was obtained with the help of dynamic light scattering.

Intracavity SLFRS was excited by single pulses of ruby laser ($\lambda = 694.3$ nm, $\tau = 20$ ns, $E_{max} = 0.3$ J, $\Delta\nu = 0.015$ cm^{-1}, divergence $3.5 \cdot 10^{-4}$ rad). Cell with particles suspension was placed inside laser cavity between back (100 %) mirror and ruby rod. SLFRS spectra were registered with the help of Fabry-Perot interferometer with changeable base. Temporal characteristics were obtained with the help of high-speed photodiode connected with oscilloscope.

Results – In the intracavity SLFRS spectra we registered lines corresponding to the radial and quadrupole spheroidal modes. Frequency shift dependence on the reciprocal diameter was shown to be almost linear and different for different modes.

With concentration of nanoparticles in suspension a little larger than that necessary for excitation of SLFRS we could obtain Q-switching. Fig. 1 demonstrates free laser oscillation and Q-switched pulse.

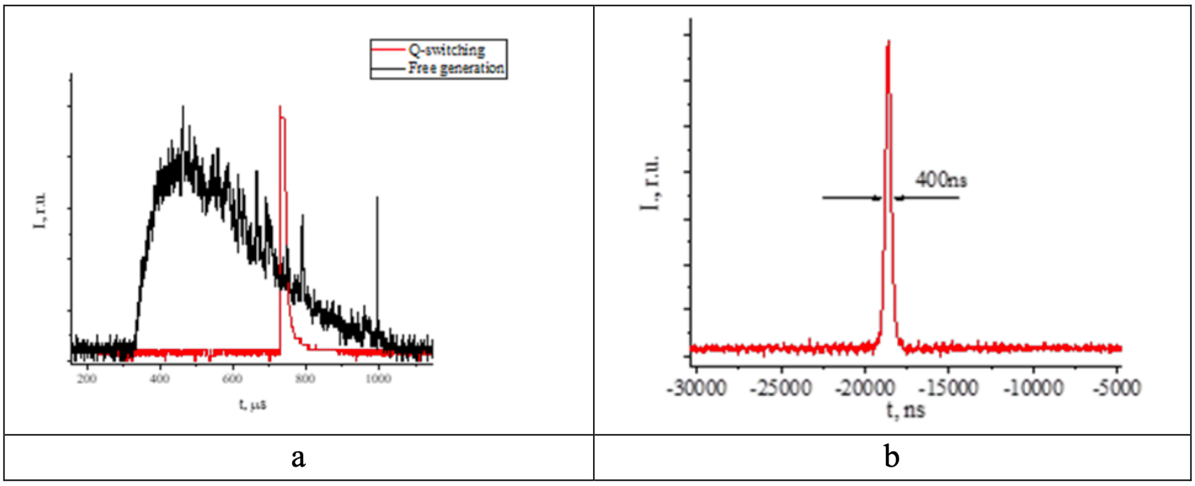

Fig. 1. a - free oscillation of a ruby laser, b - temporal profile of pulse in Q-switching regime.

We also could obtain mode locking in the same experimental setup. The resulting pulse is presented in Fig. 2.

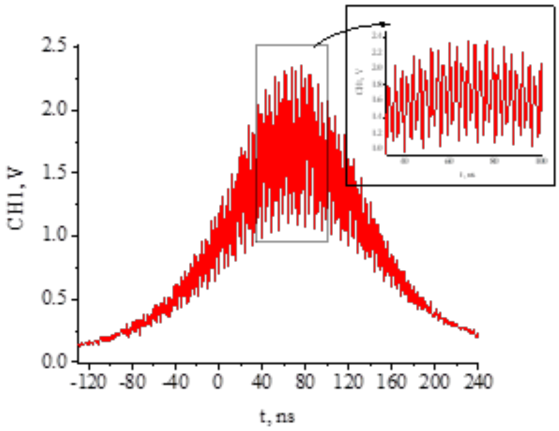

Fig. 2. Mode locking in intracavity SRLFS in a suspension of polystyrene nanoparticles with a size of 300 nm in water.

Conclusions – We for the first time obtained Q-switching and mode locking with the help of stimulated low-frequency Raman scattering, which is caused by photon-phonon interaction in nanosized or submicron particles systems. Conditions (particles size, suspension concentration, threshold) were defined for achieving these effects. Results can be used in nonlinear spectroscopy and for numerous applications, for instance, in remote sensing, laser processing, and optical communications.

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References

[1] D. Pohl, A New Laser Q-Switch-Technique Using Stimulated Brillouin Scattering, Phys. Lett. 24A (1967) 239-240.

[2] A.Z. Grasyuk, V.V. Rogul'skii, F.S. Faizulov, Formation of Powerful Nanosecond Pulses with the Aid of Mandel'shtam-Brillouin Scattering and Stimulated Raman Scattering, JETP Lett. 9 (1969) 6-9.

[3] M.A. Shevchenko, V.I. Grebenkin, M.V. Tareeva, et al, Intracavity Stimulated Low-Frequency Raman Scattering, Bull. of the Lebedev Phys. Inst. 45 (2018) 397-398.