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Change in the spectrum of optical whispering-gallery modes in a quasi-cylindrical microresonator caused by an acoustic pressure pulse

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***Abstract*. A change in the spectrum of optical whispering-gallery modes in a quasi-cylindrical microresonator caused by an acoustic pressure pulse produced by a laser pulse, which was predicted earlier, was observed experimentally for the first time.**

Keywords: *microresonator, whispering-gallery modes, resonator Q-factor, spectrum of optical modes.*

Optical glass microresonators attract attention due to the ease of fabrication and a very high Q-factor exceeding 10^9 [1 – 3]. High-Q modes can be obtained in a cylindrical microresonator, if the microresonator has a barrel-shaped region characterised by a slight change in the diameter d ($\Delta d/d \approx 0.05\,\%$). Optical whispering-gallery modes [4] excited in such resonators have a number of interesting properties. For example, an acoustic pressure pulse of a sufficient amplitude can shift the radiation, which is stored in the resonator, to its narrowing region [5, 6]. In this case, the radiation wavelength decreases proportionally to Δd.

This paper presents the results of experiments on the observation of changes in the spectrum of optical radiation from a spindle-shaped resonator subjected to an acoustic pressure pulse.

Figure 1 shows a schematic of the experiments. An optical resonator (*1*) was made of fused silica. The resonator diameter in the thickened region was 1.87 mm, and the angle at the vertex of the resonator conical part was $2\gamma = 0.8\ \times 10^{-2}$. Whispering-gallery modes were excited in the resonator by a second-harmonic pulse (*6*) from a single-mode 1.064-μm Nd : YAG laser coupled through a prism (*3*). The size of the illuminated region (*12*) depended on the strength of prism pressing against the resonator side surface. Under our experimental conditions, the longitudinal size of the illuminated region was 100 μm. A prism (*4*) for radiation extraction from the resonator was located on its conical part, and its front edge was at a distance of 150 μm from the centre of the illuminated region.

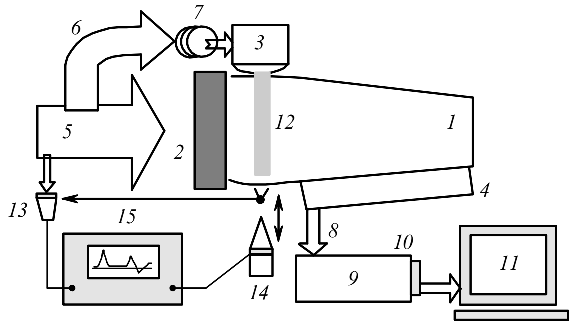

Figure 1. Schematic of the experimental setup: (*1*) spindle-shaped optical resonator; (*2*) aluminium foil; (*3*) prism for radiation coupling; (*4*) prism for radiation outcoupling; (*5*) radiation pulse at 1.064 μm; (*6*) second-harmonic pulse; (*7*) optical delay line; (*8*) optical fiber; (*9*) spectrograph; (*10*) CCD camera; (*11*) personal computer; (*12*) region of coupling of second-harmonic radiation; (*13*) LFD-2A photodetector; (*14*) pressure gauge; and (*15*) oscilloscope.

The oscillograms of an exciting laser pulse and a radiation pulse emerging from the resonator shown in Fig. 2a were recorded with an LFD-2A photodetector (*13*) and a Tektronix TDS-740 oscilloscope (*15*). The comparison of these oscillograms shows that the radiation inside the resonator exists for a much longer time than the duration of the exciting laser pulse. Beginning with the moment $t = 40$ ns, the radiation intensity in the resonator decays exponentially [$I = I_0 \exp(-t/\tau)$] with a time constant $\tau = 110$ ns. In this case, the resonator quality factor is $Q = \omega\tau = 4 \times 10^8$.

An acoustic pressure pulse was produced upon the interaction of a laser pulse (*5*) with a FWHM duration of 12 ns with an aluminium foil (*2*) 250-μm thick located at the front end of the resonator. The maximum energy of the laser pulse was 250 mJ, the diameter of the focal spot was 2 mm, and the radiation intensity on the target was no higher than 10^{10} W cm^{-2}.

Figure 3 shows the spatial distributions of the pressure pulse with respect to the center of the illuminated region at various time instants. In order to record the acoustic pressure pulse, a glass prism playing the role of an acoustic line with a pressure gauge (*14*) attached to it was brought in contact with a resonator side surface in the illuminated region. The contact region was 10 μm wide, thus ensuring a measurement accuracy of 1.5 ns. The acoustic-pulse propagation time in the prism was 118 ns. The pressure jump at a distance of 75 μm was $\Delta p = 3$ kbar. The corresponding absolute and relative changes in the refractive index [7]

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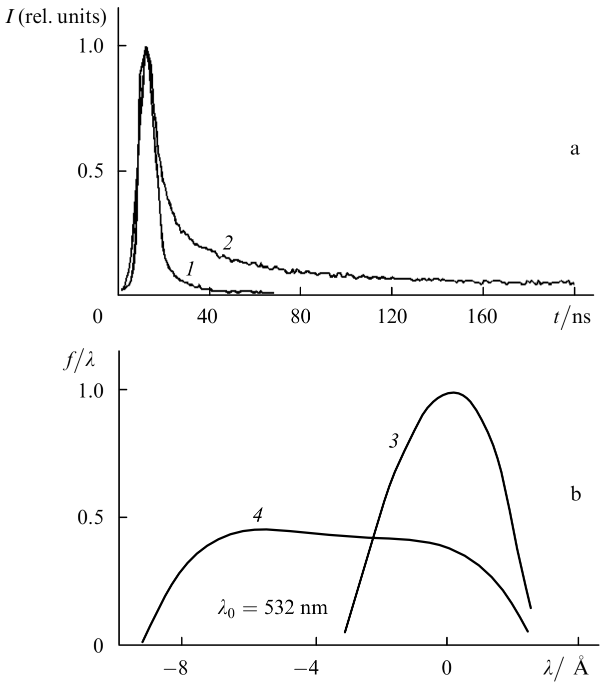

Figure 2. Oscillograms of (*1*) a resonator-exciting laser pulse and (*2*) the radiation emerging from the resonator (a); spectra of radiation emerging from the resonator measured (*3*) in the absence of an acoustic pressure pulse and (*4*) under its action on the resonator (b).

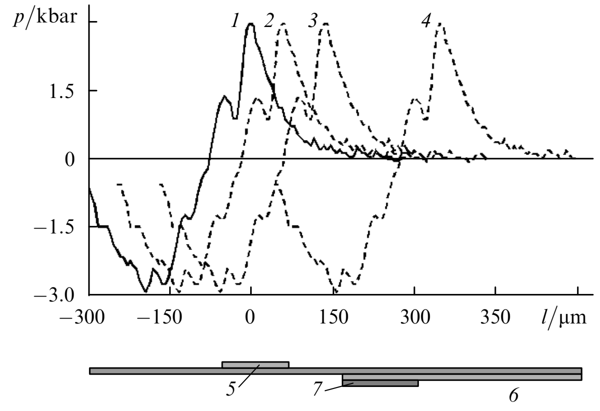

Figure 3. Spatial positions of the acoustic pressure pulse at time instants $t = 0$ (*1*), 12 (*2*), 21 (*3*), and 110 ns (*4*). The bottom diagram shows the positions of the region of radiation coupling into the resonator (*5*), zone of contact between the radiation outcoupling prism and the resonator conical part (*6*), and the region of collection of the radiation emerging from the resonator (*7*).

were $\Delta n = 0.94 \times 10^{-3} \Delta p = 2.8 \times 10^{-3}$ and $\Delta n / n = 2 \times 10^{-3}$, respectively.

Using an optical delay line (*7*) made of an optical fibre with a core 50 μm in diameter, the resonator was excited at the instant when the positive part of the pressure pulse was positioned symmetrically with respect to the illuminated region (*12*). At the instant of time $t = 110$ ns, when the pressure pulse minimum reached the outcoupling region, the radiation energy in the resonator decreased to 20 % of the initial energy level.

The spectrum of radiation emitted from the cavity was recorded with a spectrograph (*9*) with a reflection diffraction grating with a reciprocal dispersion of 5 nm mm^{-1} in the exit plane. The spectrum was stored in a PC (*11*) using a CCD camera (*10*) with a resolution of 499 × 582 pixels, which determined a limiting spectral resolution of ~ 0.1 nm. The radiation emerging from the resonator was transmitted to the spectrograph entrance slit via an optical fibre (*8*) whose diameter (100 μm) determined the size of the collection region of the radiation leaving the resonator. The width of the entrance slit (24 μm) determined the width of the instrumental function (curve *3* in Fig. 2b). A further decrease in the slit width resulted in a reduction of the signal below the detection threshold.

The result of the action of an acoustic pressure pulse on the optical microresonator, when whispering-gallery modes are excited in it, is shown in Fig. 2b. One can see that, under our experimental conditions, the spectrum broadens by $\Delta\lambda \approx 0.6$ nm in the direction of shorter wavelengths. The relative spectrum broadening $\Delta\lambda/\lambda$ achieves $\sim 10^{-3}$, which agrees with the theoretical estimates of Ref. [6]: $\Delta\lambda/\lambda = \Delta d/d = 2\gamma\Delta l/d \approx 10^{-3}$, where $\Delta d = 2\gamma\Delta l$; $2\gamma = 0.8 \times 10^{-2}$, and $\Delta l = 250$ μm is the maximum length on which the light conversion occurs inside the resonator.

Thus, the experimental data obtained show the possibility of affecting efficiently the spectral characteristics of the optical whispering-gallery modes in a quasi-cylindrical microresonator using an acoustic pressure pulse.

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