Single-frequency traveling-wave neodymium-glass laser with active Q switching

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A method is proposed for narrowing down the emission spectrum of solid-state traveling-wave lasers with active Q switching. The use of this method in a neodymium glass laser has made it possible to obtain a stable single-frequency regime. The prospects of the method for stabilization of the frequency of single-frequency lasers of high power is discussed.

To decrease the number of generating modes in a solid-state laser with active Q switching it is customary to slow down the Q-switching rate,[1] to introduce a "priming" radiation with a narrow spectrum at the instant of Q switching,[2] or to turn on the maximum Q at the instant when the first spike of free generation develops in the laser.[3] A single-frequency regime is obtained with the aid of the indicated methods at the expense of a reduced laser efficiency,[1] a more complicated scheme for the synchronization of the instant when the Q-switch is turned on,[2,3] and the need for using different mode-selection schemes in the resonator.

We consider in this paper a method of decreasing the number of generating modes in solid-state laser with active Q switching, based on the use of a nonselective traveling-wave ring laser. At the instant preceding the Q-switching, conditions are produced in the resonator for the excitation of free generation, the spectrum of which, at a slight excess above the generation threshold, becomes rapidly narrower from spike to spike, down to the width of one axial mode.[4] After the required narrowing of spectrum is reached, the Q is switched on rapidly. The spectrum of the emitted giant pulse is determined in this case by the free-generation spectrum at the instant of the switching. The proposed

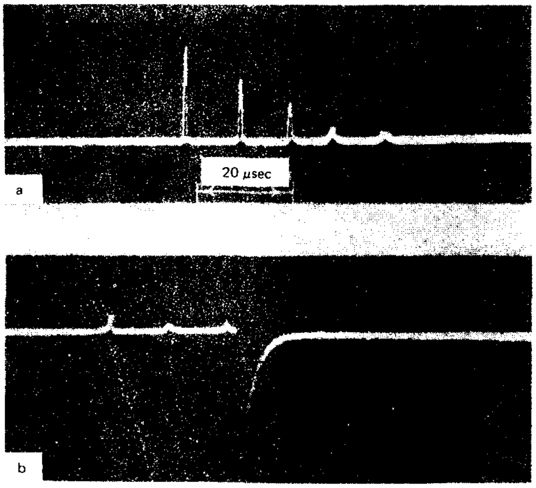

FIG. 1. Oscillograms of free laser emission (a) and in the case of Q switching at the instant when free generation exists in the resonator (b). In oscillogram (b), owing to the strong difference between free-generation spike intensity and the giant pulse, the latter has produced a negative dip.

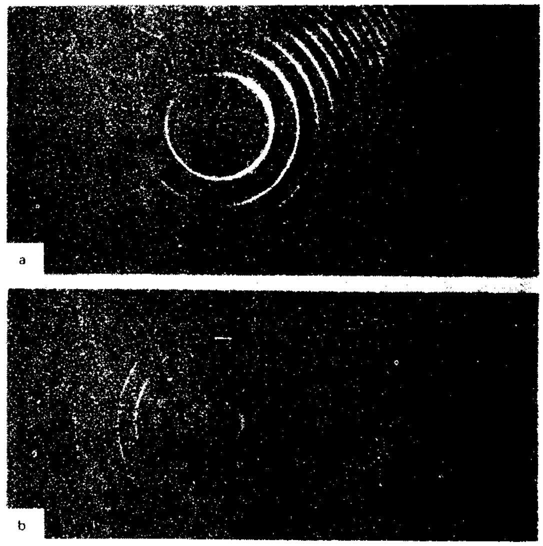

FIG. 2. Interference pattern of the laser emission in the free-generation regime (a) and when the Q is switched on at the instant of existence free generation in the resonator (b). The interferometer base is 2.5 cm.

method does not require, in principle, introduction of selection schemes into the resonator, nor is rigid time synchronization of the switching instant necessary.

For an experimental check on the effectiveness of the method, we chose a neodymium-glass laser, in which single-regime operation is hindered by the large gain-line width of the active medium (~250 cm^{-1}). The ring resonator was of the three-mirror type with rotating total-internal-reflection prisms as mirrors. An active element of 10 mm diameter and 240 mm length, with Brewster end faces, was placed in one arm of the resonator, a Faraday gate was placed in the other, and an electron-optical half-wave shutter based on a KDP crystal was placed in the third. The transmission coefficient of the output mirror was 20%. The optical length of the resonator was $L = 240$ cm. To exclude effects connected with excitation of transverse modes, a diaphragm of 2.5 mm diameter was placed inside the resonator. All the plane-parallel elements of the resonator (with the exception of the KDP crystal) either had faces cut at the Brewster angle to the resonator axis, or were mounted in a way that excluded the possibility of mode selection with them. The emission spectrum was investigated with the aid of the Fabry-Perot interferometer. The time dependences were investigated with a type FÉK photocell with an S1-17 oscilloscope.

The initial transmission of the Q-switch was chosen such that at the maximum possible pump level the threshold of the free generation was exceeded somewhat (~10%). Several spikes of free generation were excited thereby (Fig. 1a), and the total energy and the number of the spikes depended on the excess above threshold. The free-generation emission spectrum turned out to be monochromatic, starting from the very first spike. The shift of the radiation frequency from spike to spike did not exceed the width of the observed integral emission line in the interferometer (Fig. 2a), i.e., it did not exceed 5×10^{-3} cm^{-1}. The reason for the establishment of a single-frequency regime in the first free-generation spike was the presence of only one selective element in the resonator, a 27-mm long KDP crystal with plane-parallel faces. The frequency stability from spike to spike also turned out to be the consequence of the presence of the selective element.

When the optical shutter was turned at the instant of existence of free generation in the resonator, a giant pulse was emitted (Fig. 1b), the spectrum of which was also monochromatic (Fig. 2b), and the output energy of which was several times larger than the free-generation energy. For reliable identification of the obtained integral interference pattern with the spectrum of the giant pulse, the laser radiation was passed through a cell with a saturable solution, which attenuated the free-generation intensity by a factor of 30 and hardly changed the intensity of the giant pulse.

If the Q-switch was turned on at an instant preceding the free generation, then the giant-pulse spectrum had no structure and had a total width of about 20 cm^{-1}.

The output giant-pulse energy was practically independent of whether preliminary free generation was present or absent at the instant of Q-switching; this is due to the small excess above the free-generation threshold. Thus, the described method made it possible to increase the spectral density of the laser emission in the active Q-switching regime, by almost four orders of magnitude.

The strong influence of the plane-parallel element on the free-generation spectrum at a slight excess above threshold, which leads to establishment of a single-frequency regime in the first spike and stabilization of the frequency in subsequent spikes, gives grounds for hoping that when the parameters of such a selector are optimized the described method can be useful for the production of single-frequency solid-state high-power lasers with stabilized emission frequency.

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