A METHOD OF CONSTRUCTING A UNIDIRECTIONAL RING LASER

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A new method of obtaining unidirectional emission in a ring ruby laser involving a Faraday rotator with a small angle of rotation of the polarization plane (~5°) is considered. Some features of mode excitation in a generator of this type with an electro-optical shutter are investigated. The generator is characterized by enhanced laser-radiation stability of the electro-optical crystal and other elements within the resonator.

THE traveling wave regime in lasers can be obtained by means of a ring resonator with a return mirror[1,2] or with a Faraday filter in which the wave polarization plane is rotated through 45°[3]. The first method limits the selection of a suitable output mirror to obtain the optimal generation conditions, while the second introduces appreciable additional losses into the resonator reducing the efficiency of the laser. The present paper reports on a new principle of a unidirectional ring laser that has a number of advantages especially with respect to Q-switching.

The system is based on a Faraday rotator with a small angle of rotation ψ of the polarization plane (a few degrees), as shown in Fig. 1. A quartz plate next to the rotator provides for a reciprocal rotation of the polarization plane through the same angle ψ. A wave propagating in the forward direction through such a system does not experience any rotation of the polarization plane. The plane of polarization of the backward wave however rotates through the angle 2ψ reducing its gain somewhat since the ruby crystal amplifies only the component whose electric field vector is perpendicular to the C axis.

Consequently the forward wave having more favorable excitation conditions is first to reach the intensity necessary for a rapid relaxation of the active atoms and consequently is capable of capturing practically the entire energy stored in the active medium.

The ratio of intensities of the forward and backward waves can be estimated by considering the linear development of generation where the change of population inversion due to radiation is negligible. This ratio does not change significantly in the course of generation of the main emission spike. For example in the case of a generator with instantaneous Q-switching we easily find

$$\frac{I_{\text{fd}}}{I_{\text{bd}}}=\frac{I_{\text{fd}}^0}{I_{\text{bd}}^0}\left(\frac{K_{\text{fd}}}{K_{\text{bd}}}\right)^n=\frac{I_{\text{fd}}^0}{I_{\text{bd}}^0}\left[\frac{1}{\cos 2\psi}\right]^n, \quad (1)$$

where I_{fd}^0 and I_{bd}^0 are the intensities of the forward and backward waves at the Q-switching instant, K_{fd} and K_{bd} are the gains per pass of the resonator, and n is the number of traversals of the resonator during the time interval between Q-switch actuation and the beginning of intense emission of the active atoms. Analogous formulas can be obtained for the free-running regime and for the case of a non-instantaneous Q-switching.

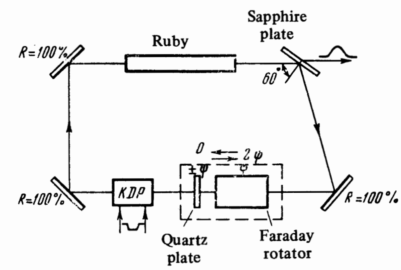

FIG. 1

According to the above formula an angle of magnetic rotation of the order of 10°, for example, and n ~ 100, the emission power of the forward wave is approximately e^6 times that of the backward wave even if the difference between the initial intensities of the forward and backward waves is not taken into account. The experiment shows that these intensities can be appreciably different at the beginning of generation due to the presence of an anisotropic element that results in a weaker gain of the backward wave even in the noise signal. In the experiments described below we found that a Faraday rotator with a 5° rotation angle of the polarization plane was sufficient. Here the ratio of radiation intensities in the two directions was approximately 20 : 1.

The generator was based on ruby crystals 12 cm long with the optical axis oriented close to 90°. The Q-switch was represented by a KDP crystal operating near a half-wave regime. The driving pulse amplitude was 9–10 kV at half-wave voltage of 12 kV. The shutter switching time was 25 nsec. The polarizer was a sapphire plate 0.3 mm thick used as the output mirror of the resonator. The plate was placed at an angle of 60° to the resonator axis corresponding to the Brewster angle for a wave whose electric vector is parallel to the C axis of the ruby crystal (closed shutter). The generated pulse was about 50 nsec long at an emission energy of 0.4 J[1)].

Figure 2 a shows a typical pulse shape (a photograph was taken of the screen of an I2-7 oscilloscope with a time resolution of 0.5 nsec). The presence of pulse modulation indicates the generation of many axial modes (the modulation frequency of 250 MHz corresponds to the frequency interval between the neighbor-

[1)]In the free-running regime (i.e., in the absence of the KDP crystal) the radiation energy was approximately 0.5 J and the suppression of the backward wave was more pronounced (the ratio of intensities was 30:1).

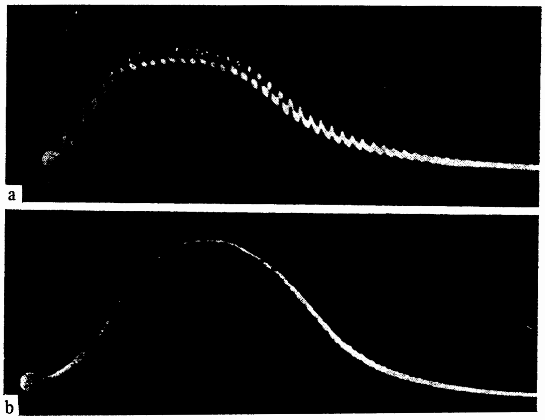

FIG. 2

ing axial modes since the optical length of the resonator was 120 cm).

Consequently the case of a generator with an electro-optical shutter is not covered by the well-known results of Tang and others[3,4] in which the simultaneous generation of many axial modes was attributed to the presence of standing waves in the ruby crystal, noting that a single axial mode is excited in a unidirectional resonator. A unidirectional regime in a generator with an electro-optical shutter does not result in the selection of axial modes; this is in agreement with the theoretical results of[5] which show that under normal conditions the emission spectrum in such a resonator does not differ significantly from the spectrum of the initial signal, i.e., of the spontaneous noise that contains components corresponding to a series of natural frequencies of the resonator[2)]. The experimental verification of this is the fact that the pulse shape shown in Fig. 2a remains unchanged in the absence of the anisotropic element.

[2)]This has no bearing on the special case of a slow actuation of the Q-switch that permits mode selection.

Mode selection is a laser with an electro-optical shutter is best obtained when the generator is close to the excitation threshold with the shutter closed. The spontaneous noise spectrum is sharpened here due to regeneration that favors the selection of modes with the highest Q. In this case we can obtain a practically smooth pulse corresponding to the emission of a single axial mode (Fig. 2b).

The attractive feature of the above unidirectional laser consists in the fact that the electro-optical shutter (and the totally reflecting mirrors) is not exposed to the main flux of laser radiation. The shutter transmits only radiation that has been reflected from the output mirror and whose intensity has been reduced several times. This makes it possible to increase the energy of the generated emission and in principle provides an opportunity to use crystals with a high electro-optical activity but with a low radiation stability. We note that such a generator also improves the working conditions of all the elements internal to the resonator because of the absence of nodes and concentrations of the field.

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