GENERATION OF GIANT PULSES IN $CaF_2:Dy^{2+}$ *CRYSTALS USING AN* $LiNbO_3$ *ELECTRO-OPTICAL SHUTTER*

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The first electro-optical shutter (EOS) based on single-domain $LiNbO_3$ crystals is described. Generation of giant pulses in $CaF_2:Dy^{2+}$ crystals (emission wavelength of 2.36 μ) has been achieved using the EOS as a Q-switch.

THE generation of giant pulses in $CaF_2:Dy^{2+}$ with a Q-switch consisting of a rotating total internal reflection (TIR) prism has been described in[1,2]. The disadvantage of such a Q-switch is the slow Q-switching rate causing the appearance of two or more giant pulses at high inversion levels in the active medium and hampering any attempts to increase power. As we know, the EOS (electro-optical shutter) has a short switching time and furthermore can prove indispensable in cases when a precise synchronization of the laser pulse with any other process is necessary. A synchronization precision not worse than 10 nsec could be obtained in our case.

The primary criteria in the selection of a crystal for the active shutter element are a good transmission in the required spectral region and adequate electro-optical coefficients to allow for low driving voltages at the necessary phase shift between the ordinary and extraordinary rays in the crystal. The currently used shutter materials such as ADP and KDP have a long-wavelength transmission edge at ~ 1.4 μ and are not suitable for $CaF_2:Dy^{2+}$ lasers whose emission wavelength is $\lambda = 2.36$ μ.

We considered also other available materials. For example, crystalline quartz has a sufficient transmission at this wavelength but it cannot be used because of the high driving voltages. Computation shows that for a ruby laser in a half-wave regime the driving voltage $V \sim 30$ kv at $d_\parallel/d_\perp \sim 10$, where $d_\parallel$—is the crystal diameter in the direction of light propagation and $d_\perp$—is the crystal size in the direction of the applied electric field. The $CaF_2:Dy^{2+}$ laser requires a 3.5 times higher driving voltage precluding such a shutter altogether because of breakdown in the crystal. Electro-optical coefficient data are available for the materials ZnS and $Na_8(AlSiC_4)_6 \cdot (OH, Cl)_2$ (sodalite)[3,4]. To obtain path differences of $\lambda/2$ at the wavelength of 0.579 μ the driving voltage is 10 kV in the ZnS crystal and is twice as high in sodalite.

In view of the shortcomings of these materials, the $LiNbO_3$ crystal was selected as the active substance for the shutter to operate at the wavelength of 2.36 μ. Its transmission spectrum fully meets the given requirements and a computation of the linear electro-optical effect in $LiNbO_3$ shows its superiority over the above materials. The properties of $LiNbO_3$ are described in detail in[5-8]. Having analyzed the linear electro-optical effect in $LiNbO_3$, we selected the zero-degree orientation as the optimum; as a result the emission was directed parallel and the applied field perpendicular to the optical axis of the crystal. In this case the electro-optical properties are described by the coefficient r_{22} and the driving voltage in the half-wave regime is determined by the expression

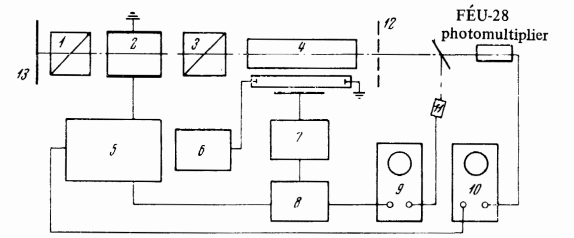

FIG. 1. Diagram of experimental setup: 1, 3 – Glan prisms; 2 – $LiNbO_3$ crystal; 4 – $CaF_2:Dy^{2+}$ crystal; 5 – high-voltage pulse generator; 6 – charging circuit; 7 – starting circuit; 8 – G5-15 generator with delay line; 9 – SI-16 oscilloscope; 10 – S1-11 oscilloscope; 11 – PbS photoresistor; 12 – quartz substrates; 13 – mirror with R = 100%

$$V_{\lambda/2} = \lambda d_\perp / 2 n_0^3 r_{22} d_\parallel, \quad (1)$$

where n_0 is the index of refraction. Since we were not able to find published values of r_{22} for the wavelength of 2.36 μ, we measured it within the spectral interval from 0.7 to 2.5 μ. The coefficient r_{22} remains approximately constant within the investigated interval and equals[1)] $(5.5 \pm 0.2) \times 10^{-10}$ cm/stat.V.

The experiments with giant pulses were carried out with the setup shown in Fig. 1. The resonator was of the Fabry-Perot type in which a substrate with multiple dielectric layers served as the mirror with R = 100% and a stack of three plane parallel quartz plates served as the output mirror. The resonator base was 150 cm long. Glan prisms cut from Iceland spar served as polarizers. As a shutter we used a $LiNbO_3$ crystal in the form of a rod with square cross section 8 × 8 mm and 19 mm long. According to (1), the driving voltage is 8.7 V for this crystal in a static half-wave regime at $\lambda = 2.36$ μ. We note that the driving voltage should be higher in a dynamic regime since the electro-optical effect in static fields equals the sum of the intrinsic and induced electro-optical effects, the latter being due to the piezoelectric effect. When the driving voltage is rapidly switched on the piezo-optical effect is absent since crystal deformation cannot follow the field changes and it is necessary to apply a higher driving voltage to the Pockels cell.

1)The measurements of r_{22} were performed together with Yu. N. Solov'eva.

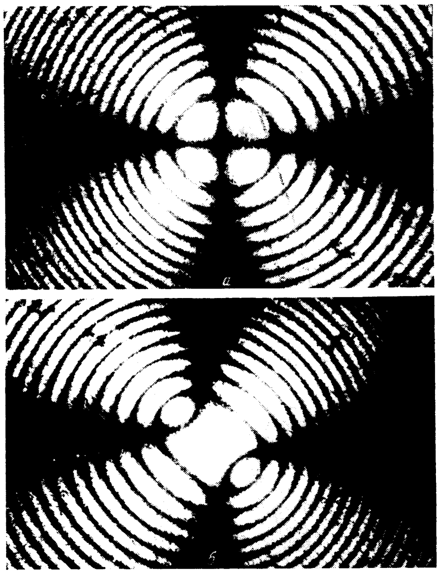

FIG. 2. Conoscopic pictures of the $LiNbO_3$ crystal in crossed polaroids: a – corresponds to minimum transmission with zero field on crystal; b – corresponds to the first transmission maximum at $V = V_{\lambda/2}$.

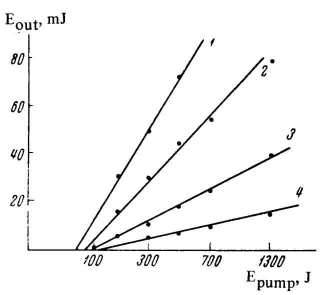

FIG. 3. Output emission energy as a function of pump energy in free-running mode: 1 – no shutter elements in resonator; 2 – a single Glan prism in resonator; 3 – two Glan prisms with parallel oscillation planes; 4 – $LiNbO_3$ crystal in crossed Glan prisms.

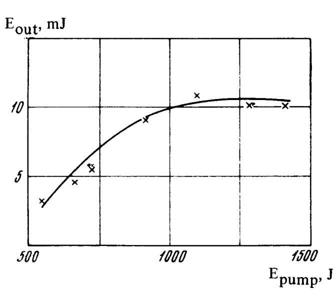

FIG. 4. Output emission energy as a function of pump energy in giant pulse mode.

In the experiment we plotted the output energy as a function of voltage across the $LiNbO_3$ crystal in static and pulse regimes. The maximum output energy corresponds to the voltage of 8.5 kV in the static regime and to 10.5 kV in the dynamic regime. The quality of the $LiNbO_3$ crystals used for the measurements can be judged from the conoscopic pictures taken in the light of a helium-neon laser at $\lambda = 6328$ Å (Fig. 2). The degree of modulation of a shutter with this crystal was 80%.

One of the significant problems concerns the losses introduced by the elements of the electro-optical shutter. In order to determine these losses we measured the output energy in the free-running mode as a function of the pump energy (Fig. 3). In the measurements we used various passive shutter elements in the resonator. The losses were determined from the threshold pump energy based on the self-excitation condition and their total value was 0.015 cm^{-1}. Generation was achieved in $CaF_2:Dy^{2+}$ crystals 120 mm long and 10 mm in diameter that yielded an output energy of 0.2 J in the free-running mode. In the experiment we obtained giant pulses 20 nsec long which is in good agreement with computations. The energy per pulse from a 1000 J pump was 10^{-2} J so that peak power was 0.5 MW. Figure 4 shows the output energy in a giant pulse as a function of pump energy.

For comparison we used the same $CaF_2:Dy^{2+}$ crystals to generate giant pulses with a rotating prism Q-switch. The output energy was also 10^{-2} J but the pulse length was 30 nsec so that the power was 1.5 times lower. Furthermore two giant pulses were generated when the pump energy was as low as 800 J, a phenomenon observed earlier[2], while the EOS laser generated a single pulse only at any pump level.

In conclusion the authors thank A. S. Bebchuk for supplying the $LiNbO_3$ crystals.

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