Mode locking in magnetic modulation of laser gain

S. K. Isaev, L. S. Kornienko, and E. G. Lariontsev

Nuclear Physics Institute, Moscow State University

(Submitted September 19, 1974)
ZhETF Pis. Red. **20**, No. 9, 600–603 (November 5, 1974)

We have demonstrated experimentally the possibility of obtaining mode locking of a dysprosium laser by modulating the gain of the active medium via the Zeeman splitting of the luminescence line in an alternating magnetic field.

One of the methods of obtaining ultrashort laser pulses is mode locking in stimulated modulation of the laser parameters at the frequency of the intermode beats. It is customary to introduce for this purpose into the resonator a device that modulates the losses or the phase of the transmitted wave. In this paper we report observation of mode locking of a $CaF_2:Dy^{2+}$ laser in which the gain of the active medium is modulated via Zeeman splitting of the luminescence line in an alternating magnetic field. This method may turn out to be particularly convenient for mode locking in the infrared band, since the efficiency of the customarily employed modulators decreases with increasing wavelength. In particular, the known high-frequency modulators operating at 2.36 μ are not efficient enough and as a result no mode locking of a dysprosium laser was obtained to date.

When the amplifying medium is placed in a magnetic field H, the luminescence line is split and this leads to a decrease of the gain at the line center. When the distance Δ between the outermost Zeeman components is small in comparison with the width γ of the Lorentz luminescence line, the gain k can be represented in the form $k = k_0[1 - \alpha(\Delta/\gamma)^2]$. Here k_0 is the gain in the absence of a magnetic field, and α is a numerical factor depending on the energy-level scheme and on the ratio of the intensities of the Zeeman components. For $CaF_2:Dy^{2+}$ the factor α, depending on the orientation of the crystal in the magnetic field, lies in the range $0.33 \leq \alpha \leq 1$; $\Delta = g\beta H$; $g\beta = 4.5\times10^{-4}$ cm^{-1}/Oe [1,2]; $\gamma = 0.25$ cm^{-1} at liquid-nitrogen temperature.

Magnetic modulation of the intensity of laser emission, at frequencies much lower than the frequency of the intermode beats, was investigated in[3-5]. In the present study we investigate resonant modulation of the gain k with the intermode-beat frequency.

If the magnetic field varies like $H = H_0 + H_1 \sin\omega t$, then resonant modulation is possible at $\omega = \Omega/2$ and $\omega = \Omega$. In the former case the depth of gain modulation at frequency Ω is $m_1 = \alpha g^2\beta^2 H_1^2/2\gamma^2$, and in the latter $m_2 = 2\alpha g^2\beta^2 H_0 H_1/\gamma^2$.

The experiments were performed with a $CaF_2:Dy^{2+}$ crystal 50 mm long, having oblique end faces to eliminate mode selection. A coil was wound around the crystal and produced a sinusoidal magnetic field ($H_1 = 80$ Oe, $H_0 = 0$). At these parameters the depth of modulation lies in the range $0.0035 \leq m_1 \leq 0.01$. The crystal

Copyright © 1975 American Institute of Physics

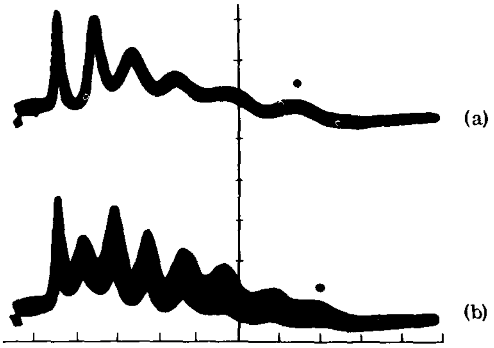

FIG. 1. Sweep rate 20 μsec/div. The radiation modulation is manifest as a "smearing" of the beam. The sections marked by the points are represented in Fig. 2.

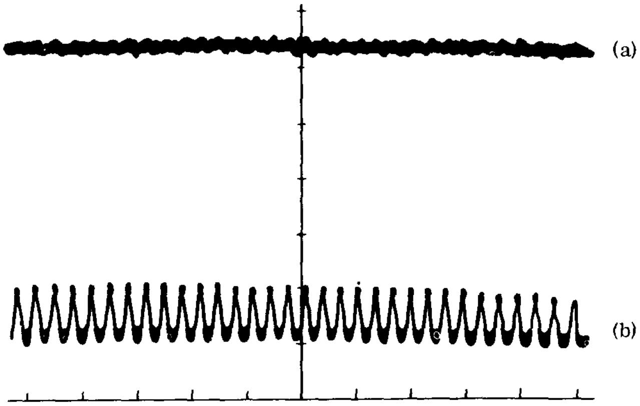

FIG. 2. Sweep rate 0.5 μsec/div.

was placed in an elliptic illuminator, was cooled with liquid nitrogen, and was pumped by a flash lamp. The pump pulse duration was ~200 μsec. The laser resonator was made up of a mirror evaporated on the end face of the crystal and of a removable flat mirror. To decrease the intermode-beat frequency, an optical delay was introduced into the interior of the resonator,[6] so that the effective length of the resonator was 26.6 m and $\Omega = 3.54 \times 10^7$ sec^{-1}.

In the absence of magnetic modulation, and also in the case of nonresonant modulation, the laser emission at three times the threshold pump energy took the form shown in Fig. 1a. Observation of the rapid oscilloscope sweeps shows that the radiation has a complicated noise structure due to beats of the nonlocked modes. When the radiation was recorded by a receiving system having a bandwidth 30 MHz, the observed noise-modulation depth was 10–20% (Fig. 2a).

At resonant magnetic modulation, a gradual transformation of the noise structure takes place, and at the end of the generation pulse the radiation is modulated by a quasiperiodic sequence of pulses that repeat at the intermode-beat frequency (Fig. 2b). It is seen from Fig. 1b that the modulation of the radiation increases with time and reaches 70–80% at the end of the generation pulse. Pictures with this modulation of the radiation are obtained if the frequency ω lies in the range $\Omega/2 \pm 3 \times 10^4$ sec^{-1}.

The results can be interpreted as the onset of mode locking in the case of resonant magnetic modulation of the gain. The absence of 100% modulation of the radiation indicates that a complete mode-locking regime does not have time to become established under these conditions. This is obviously due to too low a gain-modulation depth. We note that by applying a sufficiently strong magnetic field H_0 it is possible to increase significantly the gain-modulation depth. Thus, at $H_0 = 200$ Oe and $H_1 = 100$ Oe and at optimal orientation of the crystal, the modulation depth reaches $m_2 = 0.12$. It is also possible to obtain an appreciable gain-modulation depth by placing the laser crystal in a high-frequency magnetic field of a superconducting resonator.

Our investigations indicate that it is feasible in practice to obtain a mode-locking regime on the basis of magnetic modulation of the gain. The authors thank N.V. Kravtsov for stimulating discussions.

[1] Z.J. Kiss, C.H. Anderson, and R. Orbach, Phys. Rev. 137, A1761 (1965).
[2] B.P. Zakharchenya, A.V. Varfolomeev, and I.B. Rusanov. Fiz. Tverd. Tela 7, 1428 (1965) [Sov. Phys.-Solid State 7, 1150 (1965)].
[3] Z.J. Kiss, Appl. Phys. Lett. 3, 145 (1963).
[4] R.J. Pressley and J.P. Wittke, IEEE Journal of Quantum Electr. QE-3, 116 (1967).
[5] V.N. Tsikunov, Dokl. Akad. Nauk SSSR 199, 306 (1971) [Sov. Phys.-Dokl. 16, 563 (1972)].
[6] L.S. Kornienko, N.V. Kravtsov, E.G. Lariontsev, and A.M. Prokhorov, Dokl. Akad. Nauk SSSR 193, 1280 (1970) [Sov. Phys.-Dokl. 15, 764 (1971)].