Self-mode-locking produced when a mirror which undergoes a metal-semiconductor phase transition is used as the modulator

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A self-mode-locking regime obtained as a result of metal-semiconductor phase transition in a vanadium oxide film is reported. The initiation and relaxation times are given for the phase transition in the oxide film produced as a result of excitation by a short laser flash.

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Rapidly clearing media are used as the time modulator to obtain the self-mode-locking regime in lasers.[1] These media are primarily liquid solutions of saturable dyes. In addition, there have been experiments to achieve forced-mode-locking by solid-state means.[2]

This report describes the self-mode-locking regime of a pulsed neodymium laser, which we obtained by using as the modulator a mirror that is a solid-state film consisting of vanadium oxides which undergo a metal-semiconductor phase transition (MSPT) when they are irradiated by a light pulse.

We recall that the MSPT is an effect inherent to a broad class of compounds of rare-earth and transition metals, which appears as an abrupt and reversible change of the nature and magnitude of the electrical conductivity of a substance at the phase-transition (PT) temperature.[3] In addition to the change in electrical conductivity, the optical constants of the substance are also altered in the PT; this makes it possible to use compounds with a pronounced MSPT for the spatial and temporal modulation of radiation.[3] At present, thin-film vanadium-dioxide structures are the primary object for such an application; there are two such structures: a film of stoichiometric vanadium dioxide[4] and a multiphase vanadium-oxide film, placed on a specular reflecting coating.[5] The reflection coefficient of the oxide film for a laser-flash-stimulated PT varies within the limits of 20% to 80% (for $\lambda = 1.06$ μm). Therefore, at radiation-intensity densities exceeding the threshold value ($\sim 10^4$ W/cm^2 in the adiabatic regime) the interaction of the radiation with the oxide film is nonlinear.

In our experiment a vanadium-oxide film,[3,5] which was deposited on a specularly reflecting surface, fulfilled the role of one mirror of the cavity of a pulsed neodymium laser. The reflection coefficient of such a mirror varied from 35% to 75% due to the action of the radiation. The reflection coefficient of the second mirror of the cavity was 40%. The cavity length was $d = 250$ cm. The active element was made from GLS-1 glass. Transverse-mode selection was done with a diaphragm that had a 2-mm-diam

hole. Upon attaining the threshold pump energies (~300 J), lasing was obtained; its time dependence was recorded with an FEK-15KM and S7-15 oscilloscope. Figure 1 shows an oscillogram of the radiation pulse. As seen in this figure, the laser radiation is a regular sequence of pulses. The duration of each pulse is $\sim 3 \times 10^{-9}$ sec, and the interval between the pulses is $\sim 1.5 \times 10^{-8}$ sec. The total duration of the pulse train is $\sim 3 \times 10^{-7}$ sec, and the energy of the train is ~10 mJ.

The interference nature of the lasing process and an agreement between the interpulse period and the axial interval $2d/c$ proves that the observed lasing regime is a self-mode-locking regime.[1] The long pulse duration (3×10^{-9} sec) is explained by the small number of locked modes, which is caused by the strong mode competition in this cavity. This fact may account for the appearance of the intermediate structure in the periodic sequence of pulses.

We have achieved self-mode-locking of a laser by using as one cavity mirror a mirror with nonlinear reflection, which is caused by the PT in a vanadium oxide film. The experimental results make it possible to draw some preliminary conclusions about the PT initiation time τ_{init} by the laser radiation and the PT relaxation time τ_{rel} in the multiphase vanadium oxide film that we have used. The τ_{init} and τ_{rel} values can be obtained from an analysis of the time dependence of the lasing (see Fig. 1). It can be seen that during $\sim 3 \times 10^{-7}$ sec the PT proceeds with a frequency of 10^8 Hz. Using the concepts of Ref. 6, in which the self-mode-locking process was treated as a process of isolating the strongest fluctuations from the total quasiperiodic field distribution in the cavity by means of a nonlinear interaction, we must assume on the basis of the $\sim 10^{-9}$-sec duration of the phased pulse that $\tau_{init} \sim 10^{-10}$ sec and $\tau_{rel} < 10^{-9}$ sec.

We should point out that until now the PT kinetics in vanadium oxides have been studied very little for PT excitation by laser radiation. An initiation time of $\tau_{init} < 10^{-9}$ sec was obtained in Ref. 7 for vanadium dioxide, while the relaxation times in Refs. 3, 7, and 8 were $\tau_{rel} \sim 10^{-6}$ sec. The PT switching frequency in this case did not exceed 10^4 Hz.

In our experiment we have obtained shorter times, which apparently indicate that the kinetics of the MSPT, when it is initiated by a short laser pulse, are caused not solely by the kinetics of the temperature variation of the vanadium oxide film. We also note that the maximum rate of lattice rearrangement during the PT is determined by the velocity of sound in the oxide film, whose thickness is normally $\leqslant 0.1$ μm. Consequently, τ_{init} and τ_{rel} are quantities of the order of 10^{-10} sec; this lies withing the range of values obtained in the experiment described above.

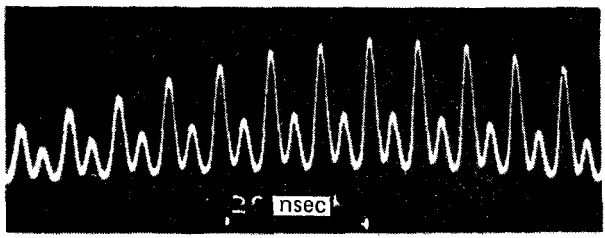

FIG. 1. Time dependence of lasing when a mirror with nonlinear reflection is used.

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