Gas laser with solar excitation

B. F. Gordiets, L. I. Gudzenko, and V. Ya. Panchenko

P. N. Lebedev Physics Institute, USSR Academy of Sciences
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The possibility of effectively converting solar energy into laser radiation is analyzed. A solar-excited gas laser based on a mixture of the gases CO_2, Br_2, and He is considered by way of example.

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The use of single crystals as active media of lasers pumped by sunlight (see, e.g., [1–3] has so far involved complicated installation and low laser-emission intensity. The use of gases for amplification offers advantages due to the possible utilization of large volumes of the active medium with lower values of the pump threshold. It is natural to hope to obtain cw lasing of appreciable power under relatively simple conditions.

The difficulties in the choice of the active medium of a solar laser are brought about by the low density of the solar-radiation flux incident on the earth ($J_{\odot} \sim 1$ kW/m^2) and by the fact that the major fraction of this radiation lies in the long-wave (visible) region of the spectrum, which is not convenient for pumping. We shall illustrate the possibility of triggering a solar laser with a gaseous active medium by analyzing the amplification of light in a particular mixture, Br_2—CO_2—He. The choice of the gas composition was governed by the following considerations: the solar radiation should be absorbed by the bromine in the course of the dissociation $Br_2 + h\nu_{\odot}\sigma \rightarrow Br^* + Br$. The metastable atoms $Br^* \equiv Br(4^2P_{1/2})$ produced thereby excite an asymmetric oscillation mode of the carbon dioxide molecules

$$CO_2 + Br^* \xrightarrow{K_1} CO_2(001) + Br + \Delta E_1. \qquad (1)$$

The helium improves the cooling of the gas by heat conduction to the walls of the vessel. The population inversion and lasing are obtained on the 001→100 transition of the CO_2 molecule. Besides (1), important channels for deactivation of the Br atoms are the collisions

$$Br^* + CO_2 \xrightarrow{K_2} Br + CO_2' + \Delta E_2, \qquad (2)$$

$$Br^* + Br_2 \xrightarrow{K_3} Br + Br_2 + \Delta E_2; \qquad (3)$$

we assume for the sake of argument that (2) does not include the acts (1), i.e., $CO_2' \neq CO_2(001)$. Harmful effects impeding the population inversion are also the heating of the gas and the deactivation of the upper working level in the collisions ($M = CO_2$, Br_2, Br, He)

$$CO_2(001) + M \xrightarrow{K_4^{(M)}} CO_2(\theta_1, \theta_2, 0) + M. \qquad (4)$$

It is important to note here that a laser with the mixture Br_2—CO_2—He has already been realized, albeit in a pulsed regime and pumped by a high-power flash lamp.[4] This, of course, is insufficient for the task discussed in the article. We shall show that the chosen medium makes it possible to realize continuous lasing with solar pumping, at realistic values of the solar-radiation concentration. The stationary values of the concentration of the excited Br^* atoms and CO_2 (001) molecules on the upper working level of the laser will be described by the equations

$$\frac{dN_{Br^*}}{dt} = 0 = K_{ph}N_{Br_2} - N_{Br^*}[(K_1 + K_2)N_{CO_2} + K_3 N_{Br_2}], \qquad (5)$$

$$\frac{dN_{100}}{dt} = 0 = K_1 N_{Br^*} N_{CO_2} - N_{001}\sum_M K_4^{(M)} N_M.$$

Here $K_{ph} = \sigma\Phi\Delta\lambda$ is the frequency of the photodissociation act of the bromine molecule by the solar photons, Φ is the flux intensity of the solar-radiation quanta in the active medium, referred to one angstrom of the spectrum, $\Delta\lambda \approx 1500$ Å is the bandwidth of the spectra absorption that leads to the formation of the Br^*, and $\sigma \approx 3 \times 10^{-19}$ cm^2 is the average photo-absorption cross section in this band. Recognizing that as a result of the collisions the population N_{100} of the lower working level of the laser is close to equilibrium, we obtain

$$\Delta N \equiv N_{001} - N_{100} = A\Phi - N_{CO_2}\exp(-E_{100}/T). \qquad (6)$$

We have used here the notation

$$A \equiv K_1\sigma\Delta\lambda\{[a(K_1+K_2)+K_3](K_4^{CO_2}+(b/a)K_4^{He})\}^{-1};\ N_{Br_2}:N_{CO_2}:N_{He} = 1:a:b;\ E_{100}$$

is the energy of the CO_2 (100) level; T is the temperature of the medium. At $T = 300$ K we have

$$K_1 \approx 6\times10^{-12}\,\text{cm}^3/\text{sec},^{[4]}\ K_2 \approx 10^{-11}\,\text{cm}^3/\text{sec},^{[5]}\ \mathring{K}_3 \approx 2\times10^{-11}\,\text{cm}^3/\text{sec},^{[5]}\ K_4^{CO_2} \approx K_4^{He} \approx 10^{-14}\,\text{cm}^3/\text{sec}.^{[6]}$$

The gas temperature, meaning also the value of A, depends on the intensity Φ of the solar-photon flux in the medium, as well as on the pressure and composition of the mixture. Therefore ΔN is not a monotonic function of the parameters written out above. Analysis shows that inversion takes place when the following conditions are satisfied

$$\Phi/N_{Br_2} > \frac{a}{A}\exp(-E_{100}/T_o),\quad \Phi N_{Br_2} \ll \kappa[h\bar{\nu}\sigma\Delta\lambda l^2(E_{100}/T_o)]^{-1}, \tag{7}$$

where κ is the coefficient of thermal conductivity of the mixture (convection only facilitates the cooling of the gas); $h\bar{\nu}$ is the average energy of the solar-radiation photons absorbed in the course of dissociations; T_0 is the temperature of the vessel walls; l is the vessel dimension and determines the thermal conductivity to the walls.

Proceeding to numerical estimates, assume that the vessel with the active medium has a square cross section with side lengths H, consisting of a set $n = H/l$ cells. For a mixture with a component-density ratio $N_{Br_2}:N_{CO_2}:N_{He} = 1:2:8$ at $T_0 = 230$ K, $l = 2$ cm, $n = 10$, and a total gas pressure ~ 10 Torr, the conditions (7) are satisfied at a solar-radiation flux density ~ 100. The laser gain in the medium is then $\sim 4\times10^{-5}$ cm^{-1}, and the specific lasing power is ~ 10 W per meter of length of the active medium. The length required for reliable lasing is therefore $L \gtrsim 10$ m. The chemical composition above is most likely far from optimal. The energy conversion coefficient cannot exceed here $\sim 1\%$ (bromine absorbs ~ 0.3 of the incident solar radiation, and the quantum yield of the medium is $\sim 1/20$). The real efficiency will be lower, since to satisfy condition (7) and thus ensure a low population N_{100}, it is necessary to have a rather low gas pressure; the absorption of the sunlight by the medium is thereby decreased. By calling attention to the feasibility of high-power solar lasers, we wanted this article to stimulate a search for the corresponding active media.

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[1]A. A. Kaminskiĭ, L. S. Kornienko, and A. M. Prokhorov, Dokl. Akad. Nauk SSSR **161**, 1063 (1965) [Sov. Phys. Dokl. **10**, 334 (1965)].
[2]N. A. Kozlov, A. A. Mak, and V. M. Sedov, Opt. Mekh. Prom. No. **11**, 25 (1966).
[3]C. G. Young, Appl. Opt. **5**, 993 (1966).
[4]A. B. Petersen and C. Witting, Appl. Phys. Lett. **27**, 305 (1975).
[5]R. J. Donovan and D. Husain, Chem. Rev. **70**, 489 (1970).
[6]B. F. Gordiets, A. I. Osipov, E. V. Stupochenko, and L. A. Shelepin, Usp. Fiz. Nauk **108**, 655 (1972) [Sov. Phys. Usp. **15**, 759 (1973)].