

# Gas laser with solar excitation

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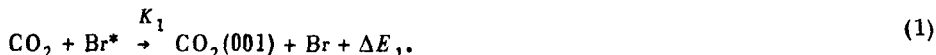
The possibility of effectively converting solar energy into laser radiation is analyzed. A solar-excited gas laser based on a mixture of the gases  $\text{CO}_2$ ,  $\text{Br}_2$ , and He is considered by way of example.

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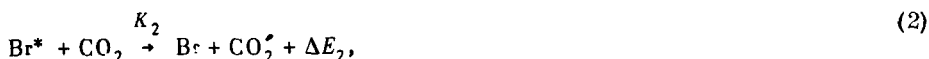
The use of single crystals as active media of lasers pumped by sunlight (see, e.g., <sup>[1-3]</sup> has so far involved complicated installation and low laser-emission intensity. The use of gases for amplification offers advantages due to the possible utilization of large volumes of the active medium 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 ( $J_{\odot} \sim 1 \text{ kW/m}^2$ ) 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,  $\text{Br}_2\text{--CO}_2\text{--He}$ . 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  $\text{Br}_2 + h\nu_{\odot} \sigma \rightarrow \text{Br}^* + \text{Br}$ . The metastable atoms  $\text{Br}^* \equiv \text{Br}(4^2P_{1/2})$  produced thereby excite an asymmetric oscillation mode of the carbon dioxide molecules



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  $001 \rightarrow 100$  transition of the  $\text{CO}_2$  molecule. Besides (1), important channels for deactivation of the Br atoms are the collisions



we assume for the sake of argument that (2) does not include the acts (1), i. e.,  $\text{CO}_2' \neq \text{CO}_2(001)$ . Harmful effects impeding the population inversion are also the heating of the gas and the deactivation of the upper working level in the collisions ( $M = \text{CO}_2, \text{Br}_2, \text{Br}, \text{He}$ )



It is important to note here that a laser with the mixture  $\text{Br}_2\text{--CO}_2\text{--He}$  has already been realized, albeit in a pulsed regime and pumped by a high-power flash lamp.<sup>[4]</sup> 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  $\text{Br}^*$  atoms and  $\text{CO}_2(001)$  molecules on the upper working level of the laser will be described by the equations

$$\begin{aligned} \frac{dN_{\text{Br}^*}}{dt} &= 0 = K_{\text{ph}} N_{\text{Br}_2} - N_{\text{Br}^*} [(K_1 + K_2) N_{\text{CO}_2} + K_3 N_{\text{Br}_2}], \\ \frac{dN_{100}}{dt} &= 0 = K_1 N_{\text{Br}^*} N_{\text{CO}_2} - N_{001} \sum_M K_4^{(M)} N_M. \end{aligned} \quad (5)$$

Here  $K_{\text{ph}} = \sigma \Phi \Delta \lambda$  is the frequency of the photodissociation act of the bromine molecule by the solar photons,  $\Phi$  is the flux intensity of the solar-radiation quanta in the active medium, referred to one angstrom of the spectrum,  $\Delta \lambda \approx 1500 \text{ \AA}$  is the bandwidth of the spectra absorption that leads to the formation of the  $\text{Br}^*$ , and  $\sigma \approx 3 \times 10^{-19} \text{ cm}^2$  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

$$\Delta N \equiv N_{001} - N_{100} = A \Phi - N_{\text{CO}_2} \exp(-E_{100}/T). \quad (6)$$

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

$$K_1 \approx 6 \times 10^{-12} \text{ cm}^3/\text{sec},^{[4]} K_2 \approx 10^{-11} \text{ cm}^3/\text{sec},^{[5]} K_3 \approx 2 \times 10^{-11} \text{ cm}^3/\text{sec},^{[5]} K_4^{CO_2} \approx K_4^{He} \approx 10^{-14} \text{ cm}^3/\text{sec}.^{[6]}$$

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

$$\Phi/N_{Br_2} > \frac{a}{A} \exp(-E_{100}/T_0), \quad \Phi N_{Br_2} \ll \kappa [h\bar{\nu} \sigma \Delta \lambda l^2 (E_{100}/T_0)]^{-1}, \quad (7)$$

where  $\kappa$  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  $\sim 10$  Torr, the conditions (7) are satisfied at a solar-radiation flux density  $\sim 100$ . The laser gain in the medium is then  $\sim 4 \times 10^{-5} \text{ cm}^{-1}$ , and the specific lasing power is  $\sim 10$  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  $\sim 0.3$  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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