Selective relaxation of long-lived states of metal atoms in a gas-discharge plasma. Stationary generation on $^1P_1^0-^0D_2$ transitions of calcium and strontium

V. M. Klimkin, S. S. Monastyrev, and V. E. Prokop'ev

Institute of Atmospheric Optics, Siberian Division, USSR Academy of Sciences
(Submitted July 2, 1974)
ZhETF Pis. Red. **20**, 251–253 (August 20, 1974)

Selective relaxation of metastable states of alkali-earth metals has been effected in a hot-discharge plasma. This has made it possible to realize for the first time stationary lasing on transitions from resonant to metastable levels.

Transitions from resonant to metastable levels of metallic atoms promise to make stationary gas lasers in the visible and near infrared, with high energy parameters feasible.[1] The problem encountered when it comes to realization of such lasers is how to ensure a high relaxation rate of the metastable states in a hot-discharge plasma. Several methods of increasing the relaxation rates were recently proposed and based on introducing impurities, but none were realized in practice.[1,2] We report here significant progress in this direction.

Experiments with cyclic gas lasers show that to ensure stationary inversion the relaxation rate of the metastable levels must be increased by not less than 1–2 orders of magnitude.[1,3] In stationary discharges, without gas flow, the thermal processes limit the active-medium working pressures to values on the order of $P < 50$ Torr. The probability of spontaneous transitions from resonant to metastable levels is $A \geqslant 10^6$ sec^{-1}.[4] In most metal atoms, the metastable levels are singlet, and the defect of the binding energy between them and the ground states is 1–2 eV. It is therefore clear that the required relaxation rates can be realized by deexcitation of the metastables with the aid of selective and resonant processes that have cross sections not less than 10^{-15} cm^2.

Such cross sections are possessed by energy-transfer processes in collisions between atoms and molecules.[5] Among the large number of processes participating in the quenching of excited states of atoms by molecular impurities, for example resonant transfer of electron energy of the atoms to vibrational-rotational levels of molecules, dissociation, etc., the most selective and effective are processes accompanied by chemical reaction.[6,7] For metal-vapor lasers, greatest interest attaches to reactions of the type

$$M' + H_2 \rightleftarrows (MH)_{rot} + H \qquad (1)$$

between atoms in the metastable state (M') and hydrogen molecules. The rate constants of such reactions exceed 2×10^{15} cm^3/mole-sec,[7] the cross sections exceed 10^{-15} cm^2,[6] selectivity is guaranteed by the requirement that the energy be exactly balanced, and the thermal dissociation of the reaction products ensures recirculation of the initial components.

Calculation of the energy defects of reaction (1) for a number of metals in which lasing on transitions from resonant to metastable levels is possible, has shown that the energy resonance condition is satisfied for Ca, Sr, Mn, and Cu.

Stationary lasing was achieved in $Ca + H_2$ and $Sr + H_2$ mixtures on transitions from the resonant $^1P_1^0$ to the metastable $^1D_2$ levels of calcium and strontium atoms at wavelengths $\lambda = 5.54$ μ and $\lambda = 6.45$ μ, respectively. The discharge was excited in the indicated mixtures in tubes of 0.7 cm diameter and $l = 30$ cm, equipped with Brewster windows of BaF_2. The resonator consisted of a gold mirror ($R = 2$ m) and a flat germanium mirror. The latter was used for extraction of the radiation. Lasing was observed at $P_{Ca,Sr} \cong 10^{-2}$ Torr and $P_{H_2} = 0.1$–5 Torr at a tube-wall temperature ~600 °C.

The $Ca + H_2$ mixture laser had a power 0.1 W and an efficiency 0.07%. At the present time this is the most powerful stationary gas laser operating on atomic transitions, in spite of the fact that the energy parameters obtained in our experiments appear to be far from optimal.

The authors consider it their pleasant duty to thank P. A. Bokhan for stimulating interest in the work and for systematic discussions.

[1] G. G. Petrash, Usp. Fiz. Nauk 105, 645 (1971) [Sov. Phys.-Usp. 14, 747 (1972)].
[2] G. Gould, Appl. Optics Suppl., Chemical Lasers, 1965, p. 59.
[3] P. A. Bokhan and V. I. Solomonov, Kvantovaya ėlektronika No. 6, 53 (1973) [Sov. J. Quant. Electron. 3, 481 (1974)].
[4] C. Corliss and W. Boseman, Transition Probabilities and Oscillator Strengths of 70 Elements (Russ. Transl.), Mir, 1968.
[5] H. Beutler and E. Rabinowitsch, Z. Phys. Chem. B8, 231, 403 (1930).
[6] A. Mitchell and M. Zemansky, Resonance Radiation and Excited Atoms, McMillan, 1934.
[7] V. N. Kondrat'ev and E. E. Nikitin, Kinetika i mekhanizmy gazofaznykh reaktsiĭ (Kinetics and Mechanisms of Gaseous Phase Reactions), Nauka, 1974.