The possibility of lasing in Al/Mg devices with photopumping by liner radiation

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The Al/Mg short-wave laser with resonant photopumping by the radiation of a plasma column formed by compression of a liner in a terawatt current generator diode is analyzed on the basis of kinetic and gasdynamic calculations.

One of the possible methods of attaining lasing in the short-wave region in devices with resonant photopumping is the use of strongly radiating plasmas of liners on *Z*-pinches, obtained in terawatt current generator diode. The problem of obtaining lasing in a system of two pinches has been considered in most of the papers,[1–3] where one of the pinches plays the role of an excitation source and the other plays the role of the active medium. In the present paper we analyze an experimental arrangement in which the active medium is formed by vaporization of a solid-state target by a pulse of radiation of a plasma column, formed by compression of a liner. The plasma column is simultaneously a source of excitation lines. The target is a layer of active material deposited on the inner cylindrical surface of a conductor. The pair of ions AlXI/MgIX were considered as the resonantly coupled pair.[4] For this pair the exciting line is the resonant line of the lithium-like ion AlXI $2s^2\,{}^2S_{1/2} - 3p^2P^0_{1/2}$ ($\lambda = 48.338$ Å); the transition $2s^2\,{}^1S_0 - 2s4p\,{}^1P^0_1$ ($\lambda = 48.34$ Å) of the beryllium-like ion MgIX is excited.

First, we consider the spectrum of radiation of the excitation source. This problem was solved on the basis of the stationary multi-level model for a uniform column of aluminum plasma with a given temperature T_e, ion density N_i, radius R, and height h. All of the basic processes in a multiply charged, dense plasma[5] were taken into account in the model, including reabsorption of radiation. The line profiles were assumed to have the Voight form. The rates of the processes and the oscillator strengths were calculated from semi-empirical formulas,[5] and also by using the program "ATOM".[6] The energy levels of the ions were given in the approximation of a truncated *H*-like ion, except for the ion AlXI, where the actual spectrum was used.

The average intensity (in terms of which the rates of the photoprocesses in the active medium are given), created outside the column at a distance L, was determined as a function of the radius of the system, the distance Z from middle of the longitudinal axis and the flux H_ν going out from the surface:

$$J_\nu(L,Z) = \frac{2}{\pi}\arcsin\frac{R}{L}\left[\frac{h/2+Z}{\sqrt{L^2+(h/2+Z)^2}} + \frac{h/2-Z}{\sqrt{L^2+(h/2-Z)^2}}\right]H_\nu, \tag{1}$$

$$H_\nu = \frac{1}{4\pi}\int_0^\pi \sin^2\theta\, d\theta \int_{-\pi/2}^{\pi/2} \cos\varphi\, I_\nu(\theta,\varphi)\, d\varphi.$$

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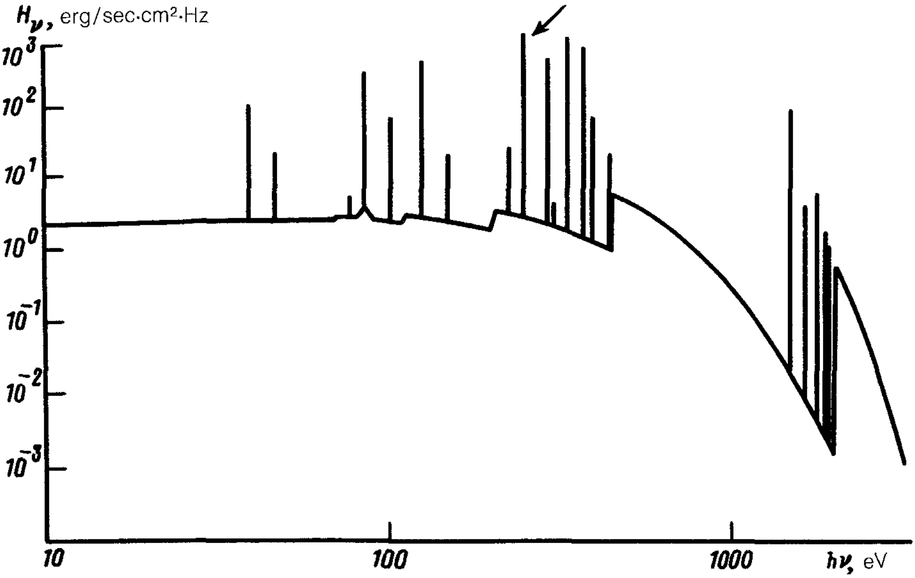

FIG. 1.

Here $I_\nu(\theta,\varphi)$ is the intensity of the outgoing radiation, which is found by solving the transfer equation along the specified direction inside the column.

A typical calculated spectrum of the source is shown in Fig. 1 for the parameters: $T_e = 200$ eV, $N_i = 3\times 10^{19}$ cm^{-3}, $R = 0.2$ cm, and $h = 4$ cm (the arrow shows the excitation line). The integrated flux in this case is 2×10^{11} W/cm. The above parameters and the total flux lie within the experimentally attainable region for terawatt power devices.

Figure 2 shows the frequency dependence of the excitation intensity created at the distance $L = 0.7$ cm ($Z = 0$), at which the required values of the parameters of the active medium can be attained (see below). The intensity is expressed in terms of the equilibrium value at $T_e = 20$ eV. The two peaks correspond to the two lines of the doublet $^2S_{1/2}$–$^2P^0_{1/2,3/2}$. The flux in the excitation line is 3×10^9 W/cm. The arrows on the graph show the frequencies of the center of the excited transition for different dispersion velocities of the target. The calculations show that the temperature interval over which the radiation in the excitation line reaches a maximum is $T_e = 150$–200 eV, depending on the density and the radius of the column ($N_i = 10^{19}$–5×10^{19} cm^{-3}, $R = 0.1$–0.2 cm).

2. As above, the active medium was calculated using the stationary multi-level model, in which photoionization and photoexcitation by the radiation of the source is taken into account together with collisional ionization and excitation. Radiative transfer was disregarded in this problem, since the transverse dimension of the active medium was less than the path length of a photon at the frequency of the excitation line (0.03–0.1 cm).

For the conditions considered here, the controlling ionization mechanism of the

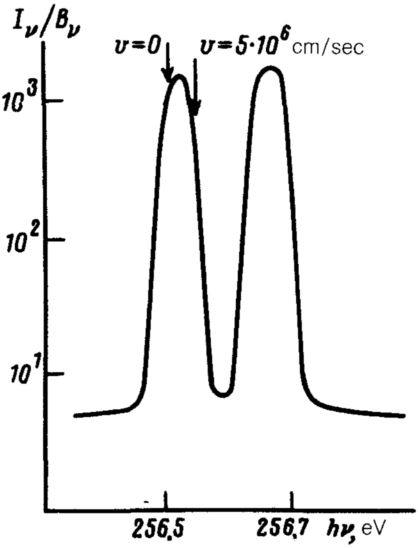

FIG. 2.

medium is photoionization from the ground state. For the MgIX ion, photoexcitation followed by collisional ionization makes a significant contribution to the ionization. Since the rate of the photoprocesses depends only weakly on the multiplicity of the ionization (for $z \gg 1$) and does not depend on the temperature of the medium, the ionization equilibrium is shifted markedly in the direction of larger z, and the ion composition curve becomes quite flat. As a result, lasing is possible at temperatures beginning with 10 eV and extending to 30 eV.

The dependence of the amplification factor g_0 on the density N_i for different temperatures T_e (1—15 eV, 2—20 eV, 3—25 eV, 4—30 eV) for the transition $4f\,^3F$–$3d\,^3D$ ($\lambda = 230$ Å) was calculated for the spectrum in Fig. 1 at the point $Z = 0$,

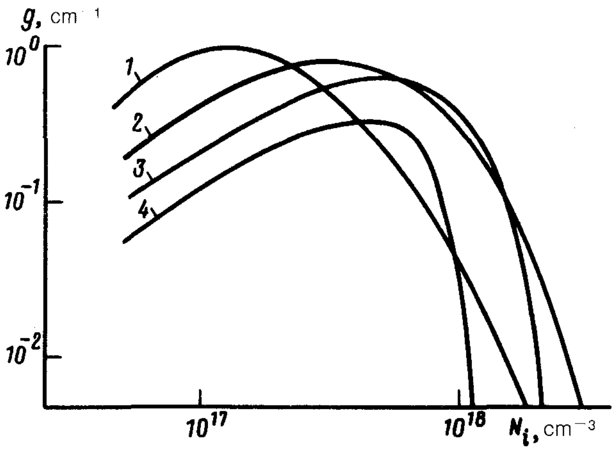

FIG. 3.

$L = 0.7$ cm for a dispersion velocity of $v = 5 \times 10^6$ cm/sec and is shown in Fig. 3. A population inversion of the $4f$ sublevel is formed due to collisional redistribution between the sublevels of the level with principal quantum number $n = 4$. The maximum value of g_0 was close to unity and corresponds to the concentration interval 10^{17}–10^{18} cm^{-3}.

3. The problem of determining the parameters of the dispersing active medium was solved in the one-dimensional gasdynamic formulation, including a description of radiative transfer, electronic heat conduction, diffusion of the azimuthal magnetic field away from the current passing through the pinch, Joule heating by the back current, and realistic thermodynamic properties of the material. We assumed a radiant flux of 2×10^{11} W/cm at the boundary of the target with buildup and decay fronts of 5 nsec and a pulse duration of 60 nsec. For the magnetic field we used the boundary condition $B_\varphi = 2J/cL$ ($J = 1$ mA).

The calculations showed that for an initial position of the boundary $L_0 = 1$ cm, the boundary of the plasma is displaced to the point $L = 0.7$ cm at the time $t = 50$ nsec, which corresponds to a dispersion velocity of $(5–6) \times 10^6$ cm/sec. Except for a thin boundary layer, the temperature is nearly constant and equal to 15–20 eV over the entire thickness, and the concentration falls from 10^{20} to 10^{18} cm^{-3}. Near the boundary, where the skin thickness is 200–300 μm, the temperature increases to 30 eV due to heating by the current flow. The concentration of particles in the layer was 10^{17} cm^{-3}. We note that a boundary layer is already formed at the times $t = 5–7$ nsec, and at later times it merely approaches the axis. It follows from comparison with the results of the kinetic calculations that the parameters of the active medium in the layer correspond to the values of N_i and T_e required for lasing.

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