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POSSIBLE CHARACTERISTICS OF A BREMSSTRAHLUNG SOURCE FOR PUMPING AN OKG

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The emission spectrum of a gas-discharge plasma, in which the radiation mechanism is only a bremsstrahlung process, proves to be very advantageous from the standpoint of pumping an OKG: such a source can have a high intensity in the range of photon energies that create an inverse population in the working substance of the laser (for example, in the range $1 \div 3$ eV, as in ruby or neodymium glass), and can emit a small amount of radiation (compared with a black body of the same temperature) in the ultraviolet and still shorter-wavelength part of the spectrum. The physical reason for this circumstance lies in the sharp dependence of the bremsstrahlung absorption coefficient on the photon energy ε. In the quasiclassical approximation $\chi = a^{-1} z^3 n^2 [1 - \exp(-\varepsilon/T)] T^{-1/2} \varepsilon^{-3}$ cm^{-1}; n is the ion density (cm^{-3}); T is the plasma temperature; T and ε are measured in electron-volts; $a = 4 \cdot 10^{36}$.

For a plane plasma layer having a constant temperature T, the emission spectrum $S(\varepsilon)$ is determined by the well-known formula

$$S(\varepsilon) = \frac{2\pi k^4}{h^3 c^2} \frac{\varepsilon^3}{\exp(\varepsilon/T) - 1} [1 - 2E_3(\chi\Delta)] \left[\frac{\text{erg}}{\text{cm}^2 \cdot \text{sec} \cdot \text{eV}}\right]; \qquad (1)$$

E_3 is the integral exponential; $k = 1.6 \cdot 10^{-12}$ erg/eV; Δ is the layer thickness.

It follows from the formula that $S(\varepsilon)$ decreases rapidly with increasing ε: $S \sim \exp(-\varepsilon/T)$. Qualitatively, the spectrum $S(\varepsilon)$ is shown in Fig. 1; the smooth maximum is located at photon energies $\varepsilon \simeq (1 \div 1.5)\varepsilon_1$, where $\tau(\varepsilon_1) = \chi(\varepsilon_1)\Delta = 1$.

It is essential that in the "transparency" interval of the plasma ($\varepsilon > \varepsilon_1$) a larger fraction of the energy can be emitted than in radiation from the surface. Under the assumption of equality of volumetric radiation and Joule heating, the usual system of magnetohydrodynamic equations for a stationary discharge has an analytic solution that makes it possible to relate the discharge emission spectrum to the plasma current, the electric field E, and the total number of particles N (per unit length). The initial system is

$$2\pi \int_0^\infty nr\,dr = N, \qquad \frac{1}{r}\frac{d(rB)}{dr} = \frac{4\pi}{c} j, \tag{2}$$

$$\frac{dp}{dr} = -\frac{j}{c}\left(B - \frac{2I_0}{cr}\right), \qquad jE = \frac{8\pi k^4}{h^3 c^2 a} n^2 T^{1/2} \quad \text{or} \quad p = B_0 j, \qquad B_0 = \frac{p_0 (h^3 c^2 a)^{1/2}}{(8\pi k^4 \sigma_0)^{1/2}}.$$

We consider a coaxial discharge in which the current density is j; the plasma in the form of a layer surrounds a conductor carrying current I_0; I_0 and j have opposite directions. The plasma is an ideal gas, $p = p_0 nT$; σ_0 is the constant in Ohm' s law $j = \sigma_0 T^{3/2} E$; the electron thermal conductivity is assumed to be negligible. The system of equations (3) and the additional assumptions stated above are valid for a comparatively dense ($n = 10^{19} \div 10^{20}$ cm^{-3}) and low-temperature plasma ($T \sim 10$ eV) in fields $B \simeq 5 \cdot 10^5$ gauss and $E \simeq 0.5 \div 1$ CGSE.

The solution of system (2) is the function

$$u = \frac{rB}{B_0 c} = \frac{2I_0}{B_0 c^2} + 2 + \alpha \frac{r^\alpha - r_0}{r^\alpha + r_0}, \qquad \alpha = 2 + \frac{2I_0}{B_0 c^2}, \qquad r_0 = R^\alpha \left(1 + \frac{2B_0 c^2}{I_0}\right),$$

$$\left.\frac{dp}{dr}\right|_{r=R} = 0. \tag{3a}$$

The condition at infinity $u(\infty) = 2I/c$ determines the total plasma current

$$I = 2I_0 + 2B_0 c^2; \tag{3b}$$

for $I_0 = 0$ one obtains the formulas for a solid cylindrical cord; the case $I_0 = \infty$ corresponds to a plane discharge.

If the central current I_0 is large in comparison with $B_0 c^2$, then the maximum values of the temperature and plasma density, as well as the radius R at which these values are attained, are simply expressed in terms of E, N, and $\delta = I_0 / B_0 c^2 \gg 1$, namely:

$$T(R) = \frac{2^{2/3} \cdot 2.64\, B_0^2 c^2}{p_0} \frac{\delta}{N} \text{ eV},$$

$$n(R) = \frac{2^{1/3}\sqrt{2.64\, B_0^2 \sigma_0^2 c\, E \delta^{1/2}}}{p_0^{3/2} N^{1/2}}\ \text{cm}^{-3}, \tag{4a}$$

$$R = \left(\frac{p_0^{3/2}}{4\pi \cdot 2.64^{3/2} B_0^2 \sigma_0 c}\right)^{1/2} \frac{N^{3/4}\delta^{1/4}}{E}\ \text{cm}.$$

Fig. 1. Radiation spectrum of the plasma layer. 1—radiation of a "black" body; 2—S.

For the optical thickness

$$\tau = 2\int_0^\infty \varkappa\, dr$$

one obtains the dependence (the luminous layer is assumed to be geometrically thin)

$$\tau = 2\frac{2.64^{3/4} B_0^2 \sigma_0^{3/2} c^{1/2}}{\sqrt{\pi}\, p_0^{1/4} a}\, \frac{1}{\varepsilon^3}\left[1 - \frac{\sqrt{3\pi}\, \exp[-\varepsilon/T(R)]}{2^{2/3} \cdot 2.64\sqrt{1 + 2\varepsilon/T(R)}}\right] \frac{E^{3/2} N^{1/4}}{\delta^{1/4}}. \tag{4b}$$

Formula (1), with account taken of (4a), (4b), makes it possible to estimate the spectrum and energy of the radiation as functions of N, E, and I_0. The spatial distributions following from formula (3a) are shown qualitatively in Fig. 2.

Fig. 2. Spatial distributions (in relative units). 1—density; 2—temperature; 3 —pressure (current density); 4—magnetic field of the central current and of the plasma.

A coaxial discharge for thermonuclear purposes has been studied experimentally ([1]); the equilibrium conditions of a solid cord and the bremsstrahlung radiation of the plasma have been considered in many works, detailed references being given in ([2]); a solid self-compressed discharge as a radiation source was considered in ([3]).

In contrast to a cylindrical discharge, in a coaxial one the plasma current is not limited; therefore, by increasing N and I_0, one can develop the discharge surface at given T and τ, i.e., with an unchanged radiation spectrum. The literature also notes the greater stability of the coaxial discharge.

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Note: Figure translations are in progress. See original paper for figures.