UDC 533.9.01:621.378.1

APPLICATION OF HIGHLY IONIZED PLASMA TO LASER CONSTRUCTION

L. I. Gudzenko, V. N. Kolesnikov, N. N. Sobolev, and L. A. Shelepin

Magnitnaya Gidrodinamika, Vol. 1, No. 3, pp. 54-56, 1965

In recent years there has been considerable discussion of the principles of designing magnetohydrodynamic (MHD) energy converters based on nonequilibrium plasma. The present paper proposes the use of such a system for constructing lasers.

Lasers, unique sources of comparatively powerful coherent highly directional radiation, are no longer merely laboratory devices, but are becoming valuable pieces of technical equipment. Thus, both in the Soviet Union and abroad new principles for obtaining amplifying media are being sought. One line of research is linked with the development of a laser based on a highly ionized low-temperature plasma. In [1] the possibility of preparing from a highly ionized plasma, with rapid cooling of free electrons, a medium that amplifies optical radiation is illustrated using hydrogen as an example. Estimates show that for sufficiently fast cooling of the electrons in a plasma of density $N \sim 10^{14} - 10^{16}$ cm^{-3} from a temperature of about 20 000° to a temperature of about 1000° the amplification in the resulting nonequilibrium plasma is sufficient to produce a laser at a whole range of frequencies in the discrete spectrum of the hydrogen atom. A high degree of ionization at a sufficiently low mean free electron energy leads to the inverse population of a series of discrete levels for a specific interval of time – this is characteristic not only for hydrogen but for any plasma. The immediate basic problem is to seek the most effective practical method of rapidly cooling the free electrons in a highly ionized low-temperature plasma.

Such methods may be divided into two classes:

1) use of the heavy particles (ions and neutral atoms) of the plasma itself for cooling the free electrons;
2) use of the walls of the vessel as a cooler.

Method 1 will be effective enough (it is clear from the estimates that rapid and deep cooling is required here) provided that two conditions are fulfilled:

a) a substantial difference between the electron temperature T_e and the temperature T of the heavy particles ($T_e \gg T$). The temperature T_e should be close to the temperature of almost complete single ionization of the gas, and the temperature T to the final temperature to which the free electrons are to be cooled;

b) comparatively high heat capacity of the heavy particles $c_e \ll c$.

As is well known, condition a) is not difficult to realize when the gas is heated by an electric field. Condition b) is realized only when the electron concentration is small in comparison with the total gas concentration; this will be so for a one-component gas which is far from fully ionized, also for almost total ionization of one easily ionized component of a mixture of gases which makes up only a small percentage of the total concentration. In the latter case the components of the gas mixture which are less easily ionized play the part of a cooler with high thermal capacity. Moreover, in order that nonradiative transitions should not determine the population of the lower discrete levels, the total density should not be too great.

From what has been said we may conclude that the use of various magnetohydrdynamic cooling methods may be of considerable interest in the problem of creating an amplifying medium based on a low-temperature highly ionized plasma.

At present, experiments are being conducted on MHD power converters, using a nonequilibrium plasma stream in which there is a considerable difference between the electron temperature and the temperature of the heavy particles. Papers [2, 3] discuss the results of experiments carried out on mixtures of inert gases with alkali metal vapors (Ar-K and He-Cs); in these experiments the free electrons were heated by the field to such a degree that the alkali metal atoms were fully ionized, while at the same time the ions and neutral atoms remained comparatively cold. The metal vapor densities were taken in precisely the range of values suitable from the point of view of making lasers.

When the electric or magnetic field is modulated, heating in the MHD converter channel will alternate with cooling of the electrons by the cold heavy particles. Changes of mean electron energy ε in the absence of a field have a characteristic time kv, where v is the number of collisions, and k is the efficiency of energy transfer. Estimates show that even for pure hydrogen at pressures of $p \sim 0.1 - 1$ mm Hg cooling times resulting from elastic collisions are close to the times τ sufficient for population inversion; when many-electron atoms and molecules are present in the plasma, inelastic collisions may substantially reduce the cooling time for free electrons. The effectiveness of cooling is also raised by cooling the electrons on the walls of the vessel [4].

Hamberger [5] discusses the experimental deep intensity modulation of the hydrogen Balmer lines resulting from the change of mean free electron energy over the period of a high-frequency field feeding a gas discharge. This period coincided with the period of radiation modulation and was $\sim 10^{-6}$ sec. Hamberger associates the change in ε with the cooling of electrons on ions and atoms; however, in our opinion, cooling on the vessel walls also played a significant part, since the gas discharge in these experiments burned in a capillary tube.

This brief reviews offers some hope that certain special modifications of existing MHD equipment may give an effective method of creating a new type of laser. Moreover, it seems likely that media with negative absorption are realized both in certain pieces of technical equipment designed to solve quite different problems and also in nature (detonation waves, lightning, flare phenomena in solar and stellar atmospheres).

At present, we are making theoretical estimates of the effectiveness of several methods of cooling free electrons, and also carrying out experimental work to determine free electron cooling times in a highly ionized plasma for different mixtures when an electric discharge is terminated abruptly. Two types of apparatus were chosen to conduct these experiments: 1) a dc discharge tube, which can be disconnected from the electric circuit in a very short time by means of a short-circuit, and 2) a flash discharge tube with an electric pulse having a very steep trailing edge. The discharge tubes are filled with $He-H_2$, $Ar-H_2$, $He-H_2-Hg$ mixtures, and others.

The solution of the question discussed here would enable thermal energy to be transformed not only into electrical energy, as in an ordinary MHD converter, but also into coherent light radiation.

REFERENCES

1. L. I. Gudzenko and L. A. Shelepin, ZhETF, vol. 5, p. 1446, 1963.

2. W. F. Westendorp, C. M. Bishop, H. Hurwitz Jr., L. M. Goldman, and D. J. Ben-Doniel, Phys. Fluids, vol. 4, p. 786, 1961.

3. J. L. Kerrebrock, Physics Today, vol. 14, p. 18, 1961.

4. M. A. Biondi, Phys. Rev., vol. 93, p. 1136, 1954.

5. S. M. Hamberger, J. Nuclear Energy, Part C, vol. 5, p. 73, 1963.

10 August 1964