A Study of Collective Plasma Properties by Means of Induced Light Emission

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It is demonstrated that coherent light emission can be used to investigate collective processes in a beam-plasma discharge. The spectrum of oscillations excited in the interaction between an electron beam and a plasma is investigated by Fourier analysis of the intensity fluctuations of coherent radiation in the discharge. An expression is obtained for the frequencies that bound the range of applicability of the method. Frequencies generated by the photodetector are taken into account in the treatment of the spectrograms.

IT has been shown in[1,2] that collective processes in a plasma can be investigated effectively through a Fourier analysis of the directly observed intensity fluctuations of spontaneous spectral lines. This procedure can be used to study the frequency spectrum and the hf field strengths of stochastic and regular oscillations excited in a plasma. However, the utilization of spontaneous radiation for plasma diagnostics is handicapped by the low intensity of this radiation and by the lack of sufficiently sensitive photodetectors for high enough frequencies. These difficulties are unimportant when coherent induced radiation in the optical region is used for the diagnostics. It has been shown in[3] that coherent radiation can be generated in a high-temperature plasma.

The inversion of the level populations, and therefore the generation, is caused by the development of instabilities. Therefore the parameters of induced light emission depend on the parameters of the collective processes developed in a high-temperature plasma. By investigating the modulation of induced light intensity we can obtain a picture of the frequency spectrum excited in a plasma and learn some characteristics of the frequencies. The high intensity of this radiation makes it unnecessary to have highly sensitive photodectors. Detectors of coherent radiation have been developed for high frequencies up to about 40 GHz. The investigation of light generation can yield additional information about both collective and elementary plasma processes. In the present work we have investigated the possibility of studying the spectrum of hf oscillations excited in a beam-plasma discharge by analyzing the induced light emitted from the discharge.

Figure 1 is a schematic diagram of the apparatus. The beam-plasma discharge was generated by a pulsed electron beam inside an optical resonator formed by spherical mirrors with a dielectric coating. The beam current reached 30 A at 40 keV; the pulse length was 90 μsec. The discharge was generated in an argon atmosphere. The maximum electron density of the plasma was 2×10^{13} cm^{-3}. The induced light in the discharge represented transitions of singly ionized argon in the blue-green region of the spectrum.

Detailed investigations of the generating mechanism have shown[3] that the generating level is pumped by plasma electrons accelerated through their interaction with hf fields excited in the plasma by the development

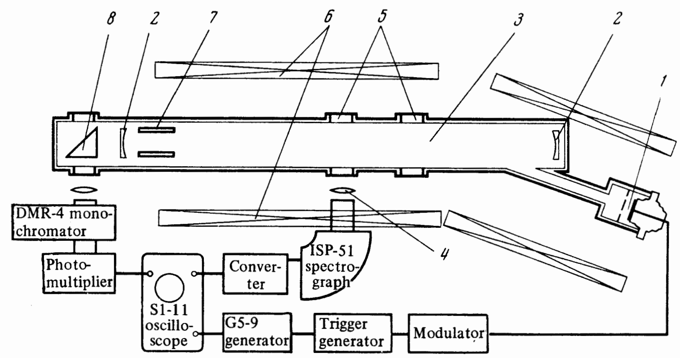

FIG. 1. Diagram of apparatus and experiment. 1—electron gun, 2—mirrors of optical resonator, 3—discharge chamber, 4—lens system, 5—window for discharge diagnostics, 6—solenoid, 7—collector, 8—prism.

of beam instability. Thus the fluctuations of the generated intensity bear information about the frequency spectrum of the oscillations excited in the plasma, the plasma temperature, and the density distribution in the cross section of the discharge.

The oscillation spectrum was studied by investigating the fluctuations of coherent radiation intensity in the Ar II transitions $4p^2D^0_{5/2} \rightarrow 4s^2P_{3/2}$ (wavelength 4880 Å) and $4p^4D^0_{5/2} \rightarrow 4s^2P_{3/2}$ (5145 Å). The radiation passed through a DMR-4 monochromator to an FÉU-36 photomultiplier operated for maximum time resolution. Signals from the photomultiplier were fed to the input of the high-speed oscillograph, whose sweep was triggered at the required time relative to the start of the current pulse. The oscillograms were recorded on film to permit a Fourier analysis that yielded the oscillation spectrum. The form of this spectrum determined the observed form of the intensity fluctuations.

The spectrum can be determined through Fourier analysis of a single oscillogram only in the case of ergodic systems. The justification for using this procedure in our case is given in[1,4].

Figure 2a shows an oscillogram of the intensity fluctuations of 4880 Å coherent radiation and the spectrum (obtained by Fourier analysis) of oscillations excited in the plasma. At the same time we studied the oscillation spectrum by means of the spontaneous radiation representing the same transition. Figure 2b shows an oscillogram of the intensity fluctuations of spontaneous radiation and the corresponding spectrum obtained by Fourier analysis.

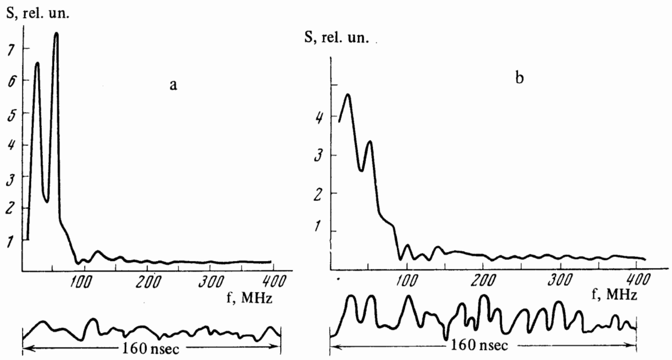

FIG. 2. Oscillogram and derived spectrum from (a) modulation of the coherent radiation intensity, and (b) modulation of the spontaneous radiation intensity.

The maximum frequency ω_{max} of oscillations excited in the plasma, which determines the modulation of the radiation intensity, is obtained from the relation

$$\omega_{max}\tau \lesssim 1,$$

where τ is the upper-level lifetime in the observed transition. In our case $\omega_{max} \approx 100$–120 MHz. The study of the oscillation spectrum through analysis of the spontaneous emission is not limited in the direction of low frequencies. For the case of coherent radiation the studied oscillation spectrum has a low frequency limit given by

$$\omega_{min} \approx \frac{2\varepsilon_0 E^2 c(1-R)}{(N_1-N_2)\hbar\omega_{12} d},$$

where ϵ_0 is the dielectric constant of the active medium, E is the field strength of the light wave in the resonator, c is the velocity of light, R is the reflection coefficient of the resonator mirrors, d is the distance between the mirrors, $\hbar$ is Planck's constant, ω_{12} is the frequency of the observed transition, N_1 and N_2 are the respective population densities of the upper and lower laser levels. We obtained this expression in the small perturbation approximation from balance equations written for a three-level generating system.

In the treatment of the data it must be taken into account that the photomultipliers themselves can generate intense hf oscillations in a broad frequency range. We therefore investigated the spectrum of intrinsic photomultiplier frequencies that were generated when the photocathode was exposed to coherent and to white light in the working regime of the photomultiplier. The regime used for the study of oscillations excited in the plasma according to the intensity modulation of the spectral lines was designed to permit us to neglect the intrinsic noise of the photomultiplier.

The use of coherent radiation for plasma diagnostics enables us to obtain additional data regarding the plasma parameters, to construct wide-range correlometers, and to extend the range of the investigated oscillations considerably into the high-frequency region.

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[1]E. V. Lifshitz and E. A. Kornilov, Diagnostika plazmy (Plasma Diagnostics), No. 11, Atomizdat, 1968.

[2]G. J. Morris, Phys. Rev. Lett. **18,** 734 (1968).

[3]Yu. V. Tkach, Ya. B. Faĭnberg, L. I. Bolotin, Ya. Ya. Bessarab, N. P. Galetskiĭ, I. I. Magda, A. V. Bogdanovich, and Yu. K. Chernen'kiĭ, Ukr. Fiz. Zh **14,** 1470 (1969).

[4]E. B. Lifshitz and E. A. Kornilov, Zh. Tekh. Fiz. **40,** 996 (1970) [Sov. Phys. Tech. Phys. **15,** 767 (1970)].

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