OBSERVATION OF DYNAMIC SPECTRUM OF RADIATION FROM A HIGHLY IONIZED DENSE PLASMA

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It is shown in [1 - 5] that short and ultrashort laser pulses can be used for the investigation of rapid relaxation processes in a number of substances. In [1 - 3], investigations were made of processes in the plasma of a laser spark. The spectral composition of the laser-spark radiation was analyzed in [6]. In the present work, we observed the dynamic spectrum of the radiation from a plasma produced by a laser pulse in sodium vapor. As is well known, a non-equilibrium highly-ionized plasma of sufficiently high density can serve as a source of intense radiation in a wide range of characteristic frequencies of atoms and ions. A theoretical analysis of the kinetics of a dense plasma is presently hindered by the lack of reliable data on the nonradiative-transition probabilities. Experimental investigations of non-equilibrium processes in such a plasma are therefore all the more important. An appreciable deviation from equilibrium in the populations of the discrete levels calls for the introduction of sufficient energy into the medium at a rapid rate. Inasmuch as the essential relaxation times in a plasma with free-electron density 10^{16} cm^{-3} are of the order of 10^{-9} sec, the duration of the light pulse must not exceed 10^{-10} sec.

In the case of rapid and strong plasma heating, it is natural to expect population inversion of several pairs of levels. In the case of a dense plasma of sufficient thickness, the inversion should be accompanied by a sharp increase in the intensity of the corresponding lines, primarily because at these frequencies the entire plasma contributes to the radiation, rather than a relatively thin surface layer determined by the photon mean free path. From calculations performed in [7] it follows that a non-equilibrium highly-ionized alkali-metal plasma can be used as an active medium for laser with a large running gain. At the same time, the probabilities used in [7] for the collision transitions of alkali metals, which determine the course of relaxation in a dense plasma, are not yet known with sufficient accuracy. We have therefore observed directly the rapid changes of the spectral-line intensities of highly-ionized sodium vapor with density 10^{16} cm^{-3}. The dynamic spectrum of the sodium emission was recorded with a high-speed moving-image camera with an electron-optical converter.

The schematic of the experimental setup is shown in Fig. 1. The radiation of laser 1, which generated either giant pulses or series of ultrashort pulses, entered into cylindrical working chamber 2, which was connected to the vacuum system;

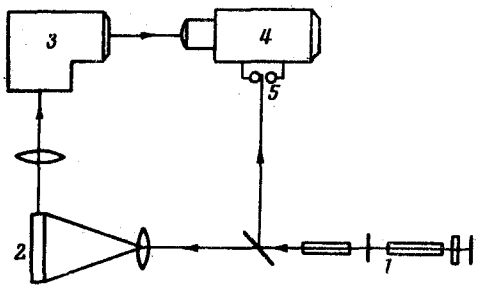

Fig. 1. Experimental setul: 1 - laser, 2 - working chamber, 3 - spectrograph, 4 - moving-image camera, 5 - spark discharge gap.

the required sodium-vapor pressure was regulated by heating. A glow discharge was maintained in the chamber to produce the initial ionization that ensured the initial absorption of the laser beam by the sodium vapor. The radiation of the sodium plasma was directed to spectrograph 3, from which the image of the spectrum was projected on the time slit of the type FEP-24 image camera. The screen of the latter displayed the time sweep of the spectrum, which was recorded with a time resolution of 5×10^{-11} sec. The image-camera sweep and the laser emission were synchronized by diverting 10% of the laser emission to a spark discharge gap 5, which was connected in the image-camera sweep circuit and was ignited directly by the laser beam [3].

Observations made in the visible part of the spectrum have shown that irradiation of a sodium plasma of density $10^{15} - 10^{17}$ cm^{-3} by a laser operating in the giant-pulse regime ($\sim$30 - 40 nsec) does not lead to a noticeable change of the spectral composition of the plasma radiation compared with the glow-discharge spectrum in sodium vapor. This indicates that the giant pulse does not porduce in the dense plasma a sufficient degree of non-equilibrium.

On the other hand, irradiation by a series of ultrashort pulses ($10^{-12} - 10^{-10}$ sec) changes the character of the plasma radiation radically. A typical dynamic spectrogram is shown in Fig. 2. The photographs were taken at a high image-camera sweep rate, at which the 3p - 3s resonant transition of sodium ("yellow doublet") is represented on the film by a weak line that practically disappears after the second or third laser pulse of the series. The spectral lines of the remaining transitions, which are brighter in the case of quasistatic glow of a dense sodium plasma, do not appear on the film at all in this case. At the same time, bright segments of several nanosecond duration reveal spectral lines corresponding to transitions not observed in the case of quasistatic plasma glow. This intense radiation, which is connected with rapid relaxation of the dense plasma, appears on the spectrogram each time, with a separate delay for each transition, following each ultrashort pulse in the series.

The reduction of the image-camera photographs has shown that the pulses in the visible part of the spectrum correspond to the transitions 4d - 3p, 5d - 3p, and 6d - 3p. The pulse brightnesses exceed by no less than 50 times the brightness of the yellow doublet. The kinetics of the emission due to the foregoing transitions (and particularly the extremely short emission time) point to the possibility of population inversion

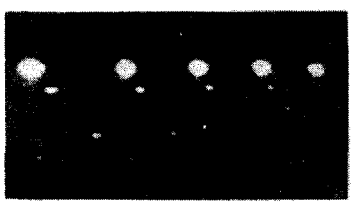

Fig. 2. Moving image photograph of emission spectrum of a sodium plasma. Upper row - time markers spaced 13 nsec apart. The plasma lines correspond to the less intense markers on the photograph (the line wavelength decreases in the downward direction).

The FER-2 camera used for our high-speed measurements, was constructed by a group of inventors [8]; we are grateful to A. M. Tolmachev, one of the developers of this equipment, for help and consultations. We are also sincerely trateful to Academician A. M. Prokhorov for interest in the work and valuable discussions.

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FOUR-PHOTON RESONANT PARAMETRIC INTERACTION IN LASERS USING DYE SOLUTIONS

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We report in this paper observation of four-photon parametric interaction in dye solutions; this interaction leads to the appearance of a narrow intense line with controllable frequency in the spectral region of the dye emission.

The frequency-variation effect was obtained by using the experimental setup shown in Fig. 1. The dye solution was contained in a cylindrical cell, one face of which was coated with a dielectric coating having a reflectance 85% in the region of $\lambda \sim 1\ \mu$. The cell was placed in the field ofa neodymium laser with pulsed Q-switching, having a radiation power $\sim$50 MW/cm^2. The optical axis of the resonator with the dye was inclined at an angle α to the direction of the neodymium-laser radiation. The dye radiation was registered with an STE-1 spectrograph. The working media were solutions of an analog of pentacarbocyanine, the lasing of which was reported earlier [1]. The solvents were nitrobenzene and ethyl alcohol. The molecule concentration in the solution was of th the order of 10^{18} mol/cm^3.

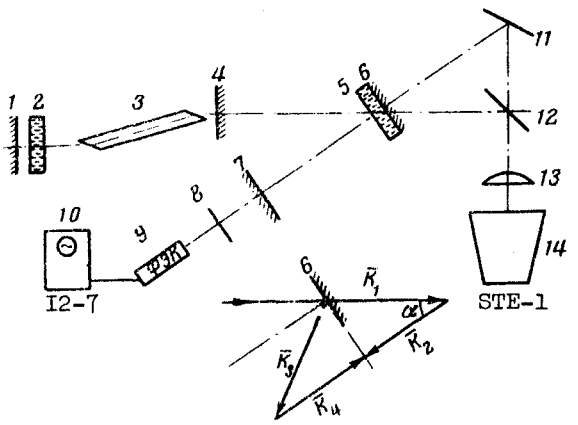

Fig. 1. Experimental setup: 1, 4, 6, 7 - mirrors; 2 - cell with passive shutter, 3 - neodymium-glass rod, 5 - cell with investigated dye solution, 8 - light filter, 9 - coaxial photocell, 10 - oscilloscope, 11, 12 - tilting plates, 13 - cylindrical lens, 14 - spectrograph.

We investigated the generation spectra of the dye at different angles α. The results are shown in Fig. 2. At $\alpha < 9°$, the spectrum represented the broad band (10850 - 11050 Å) customarily observed in the generation of the dye (Fig 2a). At $\alpha = 9°10'$ (Fig. 2b) we observed, besides the aforementioned band, also an intense spectral line shifted towards the shorter wavelengths relative to the generation spectrum of the dye (λ = 10790 Å). An increase of the angle α led to a shift of this line towards the long-wave side (Figs. 2c - g). In many cases, when the line fell in the spectral region of the