Generation of the $\omega/2$ harmonic in a laser plasma

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The generation of the $\omega/2$ harmonic of the heating radiation was detected and measured for the first time during the formation of a laser plasma by radiation with a wavelength of 530 nm. The ratio of the intensity at the $\omega/2$ frequency to the radiation of the $3\omega/2$ harmonic was estimated. The threshold intensity of heating radiation for excitation of the $\omega/2$ harmonic was determined.

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A great deal of attention is now directed toward studying the spectrum of the radiation scattered by a laser-beam-produced plasma. There is particular interest in studying the generation of harmonics of the heating-radiation frequency, since this makes it possible to evaluate the parameters of the produced plasma, to follow the

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processes occurring in the plasma corona, etc.

The 2ω harmonic[1] and the $3\omega/2$ harmonic[2] for a heating-radiation wavelength of 1060 nm, i.e., when neodymium laser radiation is used to produce the plasma, have been studied most thoroughly both theoretically and experimentally. In addition to these harmonics the radiation corresponding to one-half the frequency of heating radiation ($\omega/2$) has also been observed.[3] When the plasma is produced by means of a neodymium-glass laser, this harmonic lies in a wavelength region (near 2 μm) that is "inconvenient" for experiments, and its study involves serious difficulties because of a lack of sensitive recording instrumentation. Therefore, the authors[3] obtained information only about the $\omega/2$ harmonic that has been averaged over many pulses.

We also note that there is considerable interest in experiments with short-wave heating radiation.[4] Using short-wave radiation, on the one hand, increases the plasma absorption and , on the other hand, the fraction of fast electrons, which prevent compression of fusion targets, decreases. The most realistic prospect, at least in the very near future, is to use the second harmonic of neodymium-laser radiation (530 nm) as the heating radiation, although a report[5] recently appeared concerning a high conversion coefficient into the third harmonic (353 nm). The high harmonics (2ω and $3\omega/2$) for such heating frequencies are in the ultraviolet region of the spectrum, which makes it difficult to use them for plasma-parameter diagnostics. On the other hand, the $\omega/2$ harmonic, which moves to the near-infrared region, can be an effective method of investigation.

This paper presents first results of an observation of the $\omega/2$ harmonic and of the $3\omega/2$ harmonic produced as a result of formation of a plasma by radiation at a wavelength of 530 nm. The "Kamerton" laser system[6] was used in the experiments. The duration of the heating pulse was 200–300 psec, and the radiation energy varied up to 4 J. A cell containing a $CuSO_4$ solution was used to block radiation at the fundamental wavelength (1060 nm), whose energy amounted to 20 J. The transmission of the cell at 1060 nm was $\leqslant 10^{-17}$ and at the 530-nm wavelength it was ~ 0.5.

The radiation was focused on the target by a lens with a 300-nm focal length and a 1:6 relative aperture. The size of the focal spot at the target varied from 30 to 60 μm.

The targets were polyethlene $(CH_2)_n$ disks. The heating radiation was incident on the target at an angle of 45° to the normal, the $\omega/2$ harmonic was observed along the normal to the target, and the $3\omega/2$ harmonic was observed in the specular direction relative to the heating radiation (Fig. 1a).

An autocollimation prism spectrograph on a UF-90 camera base and an electron-optical converter, (EOC) which operated in the gating regime, were used to record the $\omega/2$ radiation . The total magnification was 9.6 when the plasma was imaged on the spectrograph slit and then through the EOC on a film. The sensitivity in the $\omega/2$ channel was sufficient to record the continuum in the plasma spectrum in the wavelength region 1000–1100-nm. The dispersion was 20.8 nm/mm.

To record the $3\omega/2$ radiation, the plasma was imaged on the slit of an MDR-4 monochromator that was converted to operate as a spectrograph. The dispersion in this channel was 4.2 nm/mm. The sensitivity was sufficient to record the continuum.

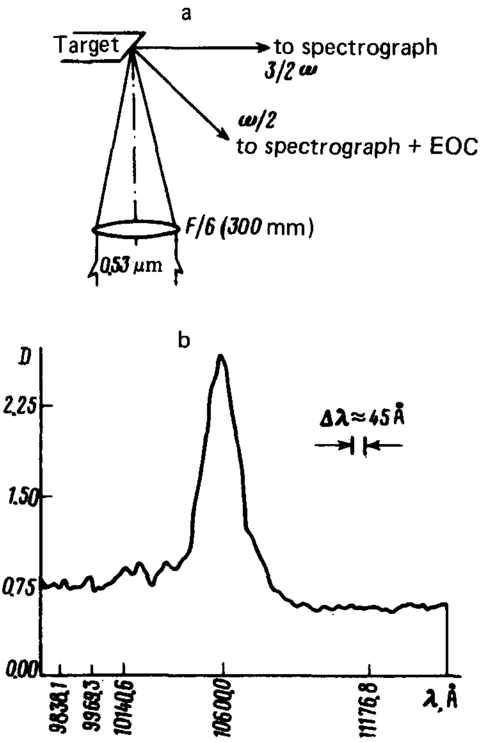

FIG. 1. (a) Experimental setup: (b) densitometer trace of the spectrum of the $\omega/2$ harmonic.

The principal results of the experiments reduce to the following. The threshold for the appearance of the harmonic lies at heating-radiation intensities of $(1–4)\times 10^{14}$ W/cm^2. The $\omega/2$ generation strongly depends on the focusing conditions. The $\omega/2$ spectral line is greatly broadened (Fig. 1b). We observed in many flashes a broadening of 30–40 nm on both the blue and the red side.

This broadening was not observed in the entire focusing spot, but in rather small portions of it

A simultaneous observation of the $3\omega/2$ radiation showed that this harmonic depends to a much smaller extent on the degree of focusing at the target, and it is observed in almost all the flashes with an intensity of more than 5×10^{13} W/cm^2.

The ratio of the intensities of the $\omega/2$ and $3\omega/2$ harmonics can be estimated from their continuum ratio in the corresponding spectral regions. Although an EOC was used in one channel, the dynamic range and characteristic curve (the intensity dependence of the film density) are determined primarily by the film. Since the same film was used in both channels and the maximum film densities were of the same order of magnitude, such relative estimates are quite justifiable. Hence, if it is assumed that the continuum intensity is $I_{cont} \sim \lambda^{-2}$, it follows that $I_{\omega/2}/I_{3\omega/2} \lesssim 10^{-1}$.

There are some differences in the shape of the $3\omega/2$ line when 530 nm is used as the heating radiation, as compared with the results of Ref. 7, where the radiation at

1060 nm was used. The $3\omega/2$ harmonic in our case does not have a two-component structure. This may be due to the geometry of the experiment, which was chosen to be close to optimum for observing the $\omega/2$ harmonic.

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