SUPERBROADENING OF THE SPECTRUM OF ULTRASHORT PULSES IN LIQUIDS AND GLASSES

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In investigations of the self-focusing of nanosecond light pulses in liquids, many workers observed spectral broadening of the radiation, extended over hundreds of cm^{-1} [1, 2]. The use of picosecond pulses generated by lasers with mode locking has made it possible to observe broadenings larger by one order of magnitude [3, 4]. Such a spectrum broadening was observed so far in investigations of the self-focusing of neodymium-laser radiation predominantly in glasses and crystals [4] and was not observed at the same intensities in liquids. We have performed experiments showing that superbroadening of the spectrum of picosecond pulses at sufficiently high radiation powers can be observed in practically any transparent dielectric.

We used in the experiments a neogymium laser with mode locking and two amplifier stages (active element length $\sim$300 mm), delivering a total energy 0.1 - 0.2 J in a train of 10 - 15 ultrashort pulses. To increase the intensity entering the investigated medium, we used an inverted telescopic system, at the output of which the laser-beam diameter was $\sim$1 mm[1]. To observe the spectrum broadening, we used spectrographs of the ISP-51 and STE-1 type. The registration was integral over the entire giant pulse in the visible region of the spectrum. We used liquids with variuos types of molecules and various optical properties: carbon disulfide, nitrobenzene, benzene, toluol, isopropyl alcohol, carbon tetrachloride, water, and liquid nitrogen. Since the threshold of occurrence of the superbroadening of the spectrum in glasses is relatively low, this phenomenon was constantly observed also in the amplifier laser stages, and sometimes in the driving laser itself. We therefore placed an IKS-2 filter ahead of the cell, to separate the radiation due to the superbroadening in the laser amplifiers from the radiation produced in the liquids. At the cell output we used a set of SZS-14 filters to attenuate the laser radiation passing through the liquid.

Superbroadening of the spectrum of the ultrashort light pulses was observed in all the indicated substances with the exception of CS_2 and nitrobenzene. In the latter, a strong breakdown occurred, similar to that observed for nanosecond pulses [5]. An increase of power only brought the sparks closer to the cell entrance window.

The maximum effect, from the point of view of intensity and spectrum broadening, was observed in water, isopropyl alcohol, and CCl_4. For these liquids, the spectrum extended into the short-wave region to $\lambda \approx 3800$ Å. Observation of radiation with shorter wavelengths was made impossible by the absorption in the SZS-14 filters.

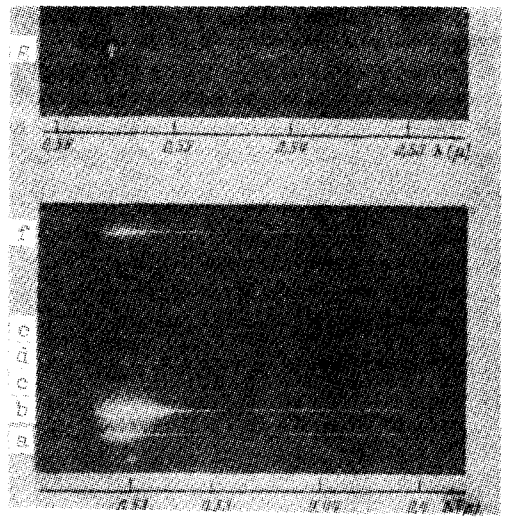

Fig. 1. Spectrograms of superbroadened radiation in liquids: a, b - toluol, c, d, e - benzene, f - water, g - part of spectrogram of superbroadened radiation in water.

[1])We observed superbroadening of the spectrum also in converging beams (when the laser radiation was focused with lenses of focal length $\sim$50 cm).

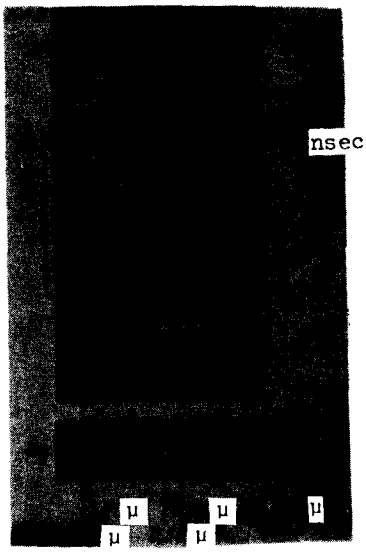

Fig. 2. Spectrally-broadened radiation for different spikes of a train of ultrashort pulses. K-8 class. (The lower part of the figure shows the spectrum of a mercury lamp.)

The broadened spectrum in liquid nitrogen and benzene was much less intense. The observed spectrum was mainly continuous, although in some cases almost periodic modulation was observed in limited spectral regions. The polarization in the visible region turned out to be close to linear and coincided with the polarization of the exciting radiation. Typical spectrograms are shown in Fig. 1.

The effect of superbroadening was observed by us also in a number of glasses and crystals (glasses type K-8, F-1, L-26, and K2SS-7, fused quartz, and potassium tungstate). Much lower intensities were needed for these substances (the energy per self-locking spike was $\sim(1 - 2) \times 10^{-4}$ J) than for liquids.

We investigated the temporal parameters of the spectrally-broadened radiation in glasses. The experiments were performed with an electron-optical image converter and have shown that, within the accuracy of the temporal resolution ($\sim 10^{-11}$ sec), the spike duration in the visible region coincides with the duration of the exciting radiation. It was observed that for each self-locking spike in the giant-pulse train, the broadening of the spectrum in glasses is different both in magnitude and in intensity (Fig. 2).

Observation of the distribution of the radiation over the exit planes of the investigated media (in liquids and glasses) has revealed a one-to-one correlation [3, 4] between the self-focusing and the superbroadening. The characteristic "whiskers" of [3, 4] were not observed in the angular distribution of the spectrally broadened radiation. This is apparently due to the limited apertures of the spectral instruments used by us and to the fact that the observation was carried out far from the wavelength of the exciting radiation. The divergence of the spectrally broadened radiation registered by us amounted to $\sim 1°$.

We observed no singularities in the intensity distribution and in the divergence of the broadened spectrum near the wavelength corresponding to the second harmonic of the neodymium-laser radiation. Nor did we observe a decrease in the spectrum intensity in the regions corresponding to the absorption bands of the substances in the infrared region. Such a decrease of the density was observed, for example, in water [6] in conjunction with spontaneous four-photon interaction. It can therefore be assumed that the observed superbroadening is not due to four-photon interaction [7], but is due to strong phase modulation of the radiation.

The reason for the absence of superbroadening of the spectrum in strongly nonlinear liquids (nitrobenzene in CS_2) is not yet fully clear, although it is possible that it is due to their exceedingly low breakdown threshold.

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SURFACE WAVES IN InSb

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In an investigation of the passage of electromagnetic waves through single-crystal n-InSb samples at T = 300°K in a constant magnetic field, we observed a small surface electromagnetic wave with circular polarization and with nearly-linear dispersion. The wave propagated parallel to the magnetic field and was observed at $\omega \ll \omega_{ci} < \nu_i$ simultaneously with the well-known helical waves (helicons) at $\omega \ll \nu_e \ll \omega_{ce}$ (ν_e and ν_i are the characteristic electron and hole collision frequencies and ω_{ce} and ω_{ci} are their respective cyclotron frequencies). The experimental setup is shown in Fig. 1.

The n-InSb plates were placed between two coupling coils producing and sensing electromagnetic HF fields directed along their axes. The HF signal passing through the plates, with frequencies 15 - 1000 MHz, was recorded as a function of the constant magnetic field $H_z < 30$ kOe normal to their planes. When the coupling coils were placed at the center of the sample, an intense helicon size-effect resonance was observed (curve 1 of Fig. 2), the frequency of which satisfied the relation $\omega = k_z^2 H_z c/4\pi n_e \ell$, where $k_z = \pi/d$ is the longitudinal wave number, d the plate thickness, c the speed of light, e the electron charge, and $n_e = 1.35 \times 10^{16}$ cm^{-3} the electron concentration in our samples. Whenever the coupling coils were near the edges of the plates, a surface-wave resonance was produced simultaneously with the helicon resonance in somewhat weaker fields (curve 2 of Fig. 2), and we could observe these resonances, depending on the setting of the system, either together or separately, and either of them could be separated. When the magnetic field made a certain angle with the normal to the plate, a shift of the surface-wave resonance towards stronger magnetic fields was observed; this shift was proportional to the cosine of this angle, in analogy with the situation with helicons. None of the resonances were observed in a transverse magnetic field.

The observed wave was identified as a surface wave on the basis of measurements of its intensity distribution as a function of the depth (curve 3 of Fig. 2); these measurements were performed by suitably shifting the receiving coupling coil. The wave intensity was maximal at the surface of the side face of the plate and decreased with depth (y axis) like $I = I_0 \exp(-2\tau y)$, where $\tau = 6$ cm^{-1}. This means that the wave is localized in a layer much

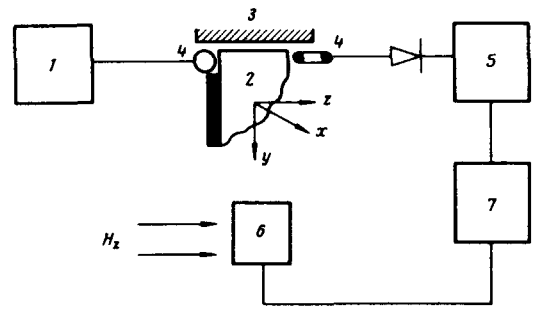

Fig. 1. Experimental setup: 1 - HF generator, 2 - sample, 3 - screens, 4 - coupling coils, 5 - amplifier, 6 - Hall pickup, 7 - x-y recorder.