REFLECTION OF PICOSECOND LIGHT PULSES FROM A SCATTERING MEDIUM

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The experimental results for the dependence of the broadening of the reflected signal, the change in the intensity of the reflected signal relative to the maximum intensity of the sounding pulse, and the delay time in the arrival of the peak intensity on the extinction coefficient of the scattering medium when the medium is sounded with a narrow beam of ultrashort light pulses with width $t_0 = 10$ ps *are discussed.*

A method of measurement and the results of experimental investigations of the spatial and temporal structure of a narrow beam of picosecond light pulses, passing through a layer of a scatterring medium, were studied in Ref. 1. To solve the problems connected with the remote sensing of dense hydrometeorological formations the characteristics of the radiation reflected from the medium are especially interesting. Thus in Ref. 2 the results of experimental investigations are presented and a theoretical description of the transformation of the shape of 10 ps light pulses reflected from model scattering media with particle sizes 0.481 and 2.02 μm is given.

In this paper the experimental results obtained for the dependence of the temporal broadening of the reflected signal, the changes in the intensity of the reflected signal relative to the maximum intensity of the sounding pulse, and the delay time in the arrival of the maximum (peak) intensity on the extinction coefficient of the scattering medium are discussed on the basis of the method developed in Ref. 1.

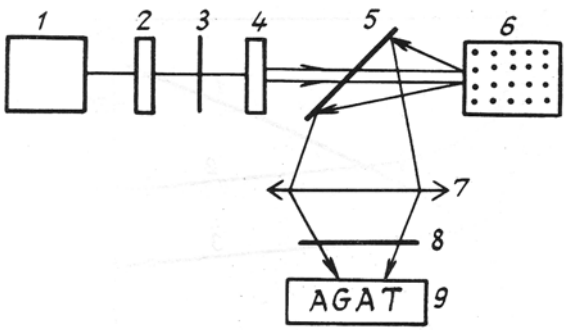

FIG. 1. The structural layout of the experimental apparatus.

The structural layout of the experimental apparatus is shown in Fig. 1. A neodymium-doped lanthanum beryllate ($BeLaO_5$:Nd) laser 1 generated a train of seven to ten pulses with a wavelength of $\lambda = 1.07$ μm. The frequency of the radiation was doubled in a KDP nonlinear crystal in a second-harmonic generator 2 ($\lambda = 0.535$ μm, the average width of a single pulse $t_0 = 10$ ps, and the energy of a single pulse ~ 100–150 mJ). A filter 3 of the SZS–21 type was used to separate radiation with $\lambda = 1.07$ μm. The collimated light beam, having a diameter of 2 mm, was directed normally, through a beam splitting plate 5 with a transmittance of 0.5 and making an angle of 45° with the axis of the sounding beam, on the plane surface of the input window of the cell 6 containing the scattering medium. The radiation reflected from the scattering medium struck the plate 5, was reflected from it, and was projected through a Yupiter–9 objective onto a 0.2 mm wide input slit of an Agat-SFZ electron-optic camera 9. The diameter of the input aperture of the objective is equal to 42 mm and the aperture angle is equal to 42°. In order to operate in the linear blackening regime of the film a neutral light filter 8 was placed in front of the slit.

The scattering medium consisted of a water- suspension of polystyrole latex microspheres with particle size $d = 0.14$ μm and relative index of refraction $m = 1.2$. The transmittance of the medium was measured on an SF-46 spectrophotometer for the lowest concentration. Solutions of different density were placed in a cylindrical cell 80 mm long and 32 mm in diameter. The sell, was long enough so that the condition for. reflection of radiation from a semi-infinite medium was satisfied.

Figure 2 show the densitometer tracings of the shape of the pulses and intensity of the reflected signal for two densities of the scattering medium with, different extinction coefficients. The time in picoseconds is plotted along the abscissa axis and logarithm of intensity is plotted along the ordinate axis in arbitrary units. For curve 2 the scale is indicated in parentheses. The densitometer tracings were obtained by microphotometric measurements with an angular resolution of ~ 3.5°. This was determined by the chosen size of the diaphragm, which was equal to 1 mm. The characteristic feature of the densitometer tracings is the

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presence of overshoots in the temporal structure, which reached 30% of the amplitude of the main maximum of the reflected radiation.

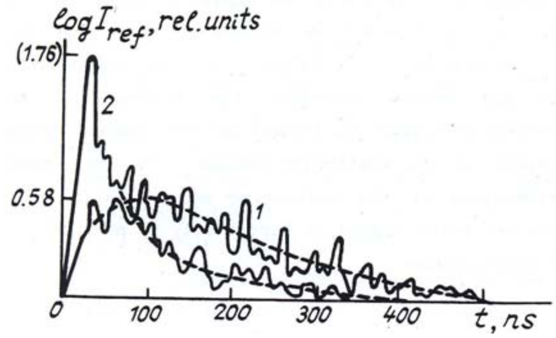

FIG. 2. Densitometer traces of the shape an: intensity of the reflected signal with different extinction factors of the scattering medium: ε_{min} = 56.6 m^{-1} *(1), and* ε_{max} = 3600 m^{-1} *(2). The dashed lines show the average value of the densitometer tracings.*

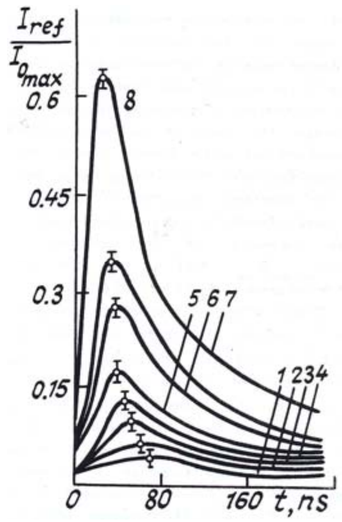

FIG. 3. Densitometer traces of the shape and intensity of the reflected signal scaled to the maximum intensity of the sounding pulse (on a linear scale) for different ε: 56.6 m^{-1} *(1),* 73 m^{-1} *(2),* 115 m^{-1} *(3),* 186 m^{-1} *(4),* 257 m^{-1} *(5),* 506 m^{-1} *(6),* 1200 m^{-1} *(7),* and 3600 m^{-1} *(8).*

Figure 3 shows the averaged densitometer tracings of the shape of the pulses reflected from the medium and the intensity, both scaled to the maximum intensity of the sounding pulses on a linear scale. The lower limit of the sensitivity of the recorded intensity is limited by the light filters placed in front of the input slit of the electron-optic camera. The peak intensity of the sounding pulse was determined based on the reflection of radiation from a mirror surface, placed on the end face of the cell. The start of reflected pulse was measured from the maximum value of the intensity of the "reference" pulse, formed owing to reflection from the input window of the cell. For low densities of the scattering medium ($\varepsilon \le 256.6$ m^{-1}) the maximum of the reflected signal is diffuse and is "smeared" in time. This is connected with the fact that a narrow light beam penetrates deep into the medium and the intensity of the singly scattered light, which is mainly responsible for the formation of the maximum of the reflected signal, is insignificant. As the concentration of scattering particles increases the penetrability of the beam decreases and the intensity of the singly scattered radiation, reflected backwards along the axis of the sounding beam, increases even though the multiplicity of scattering increases. As ε increases the shape of the reflected signal approaches that of the starting signal. For the maximum density of the scattering medium, employed in the experiment, ε_{max} = 3600 m^{-1}, the ratio of the peak intensity of the reflected signal to the peak intensity of the sounding pulse $R_0 = I_{ref \cdot max}/I_{0max} \sim 0.61$. The FWHM of the reflected pulse is equal to ~ 40 ps.

Figure 4 (curve 1) shows the dependence of the R_0 (ordinate axis on the left side) on the extinction coefficient of the medium ε. On the initial section of the curve 1 ($\varepsilon \lesssim 350$ m^{-1}) R_0 increases in proportion to the squared extinction coefficient of the medium: $R_0 \sim \varepsilon^2$. The singly scattered radiation is primarily responsible for the formation of the reflected signal. As ε is further increased R_0 increases more slowly owing to the increased imporatnce of multiple scattering the formation of the reflected signal, and the dependence of R_0 on ε satisfies well the condition $R_0 \sim \sqrt{\varepsilon}$.

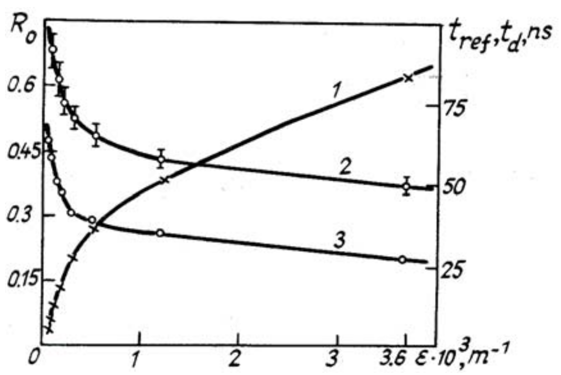

FIG. 4. R_0, t_{ref}, *and* t_d *versus the extinction coefficient of the scattering medium (curves 1, 2, and 3, respectively).*

The figure also shows the FWHM of the reflected pulse t_{ref} and the delay in the arrival of the peak intensity of the reflected signal t_d (ordinate axis on the right side) versus the extinction coefficient of the medium c (the curves 2 and 3, respectively). The delay time was determined from the time interval between the maximum values of the intensity of the "reference" pulse and the pulse reflected from the medium. Using the relation $L = c(t_d = t'_d) / 2n$, where t'_d is the delay time of the signal for double passage through the input window (quartz glass 1 mm thick) of the cell, c is the velocity of light in free space, and n is the index of refraction of water, it is possible to estimate the depth of the layer L of scattering medium in which the maximum intensity of the reflected signal is formed. Thus for $\varepsilon_{min} = 56.6\ m^{-1}$ we obtain $L \approx 7$ mm and for $\varepsilon_{max} = 3600\ m^{-11}$ $L \approx 0.88$ mm, i.e., as the density of the medium increases the maximum of the reflected signal is formed by the nearest-lying layers of the scattering medium. If the linear dimensions of the scattering medium $l < L$, then the reflected signal is formed only by part of the sounding pulse.

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