ELIMINATION OF SELF COLLAPSE OF A POWERFUL BEAM IN A NONLINEAR MEDIUM WITH THE AID OF A RASTER - MULTIPLE WAVEGUIDE ENERGY PROPAGATION. DIFFRACTION GRATING IN A NONLINEAR MEDIUM

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It was found in a study of self-focusing [1 - 4] that self-collapse [5] and breakup [3, 6, 7] of a high-power beam in a nonlinear medium can hinder the propagation of radiation having a power much higher than the threshold value. It is shown in the present paper that the collapse of such a beam can be prevented by superimposing on it a small-scale raster (grid) and effecting a multiple waveguide regime of energy propagation[1]). We have observed an effective possibility of controlling the self-focusing by varying the distance from the raster or from a diaphragm to the entrance to the nonlinear medium. We have in fact formulated and investigated the problem of propagation of a diffraction image of a grating in a nonlinear medium.

The experiment was performed with a Q-switched axial-mode neodymium laser with a power rating up to 10 MW (a selector and a diaphragm in the resonator ensured a smooth radiation distribution and a smooth pulse waveform even when a prism Q-switch was used). The laser beam passed through a cell with nitrobenzene. The beam power exceeded by hundreds of times the threshold power $P_{thr} \simeq 100$ kW. The minimum position of the self-focusing focus was determined from the sparks [8, 9] produced in the liquid at the instants of maximum concentration of the heat release - when the beam power P(t) reached the maximum and the focus stopped, i.e., while $\dot{P}(t) \simeq 0$. We recorded simultaneously the maximum power of the pulse on an oscilloscope screen. The beam diameter was 2 mm and we used grids with openings of $(1.5 - 3) \times 10^{-2}$ cm and transparency 50 to 60%, or else diaphragms with the same hole diameters. When the grid was placed over the beam, the sparks were distributed over almost the entire cross section of the beam. It was observed that the distance Z_f from the end face of the cell to the spark depends strongly on the distance ℓ from the grid or diaphragm to the end of the cell. Figure 1 shows a plot of $Z_f(\ell)$ at a constant incident beam power. When the cell with the nonlinear liquid was moved away, the points where the beam collapses moved away from the entrance face of the cell to the interior of the medium and could be led to the outside of the medium. The points were moved through a large distance at $\ell_{cr\ nl} \simeq 4.5$ cm for a grid with openings having $d = 2 \times 10^{-2}$ cm. Such a distance is commensurate with the so-called Fresnel length $L \simeq d^2/\lambda$ at which the beams begin to broaden noticeably or neighboring beams begin to overlap. Near this distance λ_{cr}, the greatest spreading occurs in the shadow of the grid on the input face of the cell. It is interesting to note that the picture becomes sharp not only at smaller distances $\ell < \ell_{cr}$ (which is natural), but also at large distances. Figure 2 shows photographs of the shadow of a grid with $d = 2 \times 10^{-2}$ cm, photographed from a ground-glass screen placed at the following distances to the grid: a) $\ell = 6$ cm, b) $\ell = \ell_{cr} = 5$ cm ($\ell_{cr\ nl} \simeq 4.5$ cm differs little from ℓ_{cr}, owing to the influence of the longitudinal contrast gradient on the self-focusing). We see a strong

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[1]We note that the scattering of a beam by a grid in order to prevent collapse offers advantages over an increase of the beam divergence by a diverging lens, which cannot eliminate the collapse at beam powers much above threshold ($P >> P_{thr}$, i.e., $\Delta r << r$), owing to the small gradient of the angular separation of the sub-beams (through an angle $\Delta\theta \sim r/F$, where F is the focal length and Δr the dimension of the beam region prone to collapse).

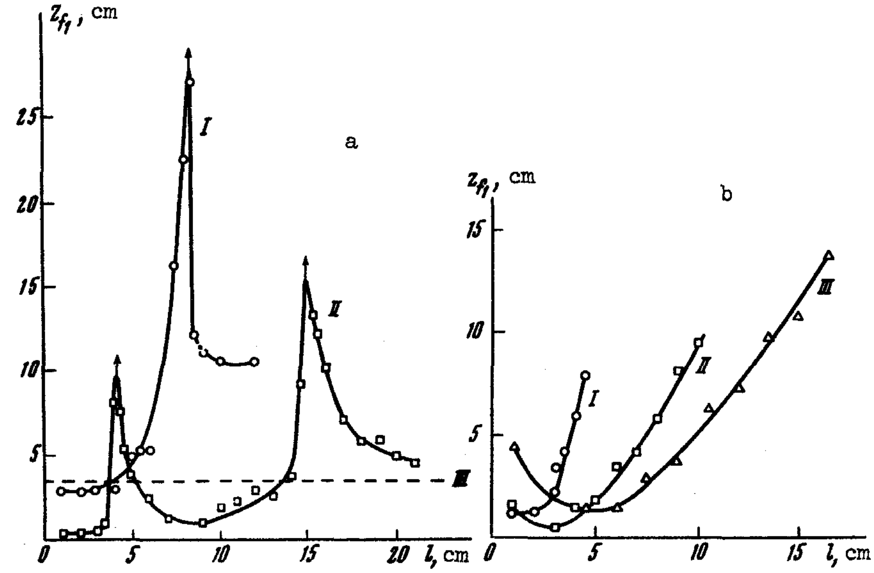

Fig. 1. Shift of the position of the beam-collapse point to the interior of a linear medium at different distances from the grid (a) or the diaphragm (b) to the end face of the cell. Z_f is the distance from the end face to the point of beam collapse inside the liquid, ℓ is the distance from the grid or from the diaphragm to the end face of the cell. a) The $Z_f(\ell)$ dependence is given, for grids with cell dimensions 3×10^{-2} cm (I), 2×10^{-2} cm (II), III - position of collapse point without the raster. b) The $Z_f(\ell)$ dependence is given for diaphragms with diameters 3×10^{-2} cm (I), 4×10^{-2} cm (II), and 5×10^{-2} cm (III). All at flux densities 2.5 × 10 W/cm.

smearing of the image near ℓ_{cr} and a restoration of the contrast at $\ell = \ell_{cr} \pm 1$ cm. The removal of the collapse point to the interior of the nonlinear medium was traced up to $Z_f \simeq 26$ cm, whereas without a grid the collapse point was located at $Z_f \simeq 3$ cm behind the entrance end face[2].

The removal of the collapse point at $\ell \lessapprox \ell_{cr}$ can be attributed to the increase of the divergence angle and the radius of the elementary beams at the entrance to the nonlinear medium. Indeed, according to an aberration-free estimate we have for each sub-beam

$$Z_f \approx a_s\{-\theta_{os} + \sqrt{n_2 E_{os}^2 - K^2/a_s^2}\}^{-1} \approx a_s^2\left\{-\theta_{os} a_s + \sqrt{\frac{n_2}{c}}\sqrt{P_1 - P_{thr}}\right\}^{-1},$$

where the radii a and the angles θ of the sub-beams on the surface of the medium are marked with the subscript s, i.e., at $P_1 \simeq$ const (prior to the touching of the sub-beams) we have

[2]We note that it was very difficult to observe a large shift of the sparks by adjusting the laser power, whereas control of the focus by selecting ℓ turned out to be much simpler and more convenient.

$$Z_f \sim a_s^2/(-\theta_{os}a_s + \kappa),$$

where $a_s(\ell)$ and $\theta_{0s}(\ell)$ are determined by the diffraction broadening, with $a_s(\ell_{cr})\theta_{s0}(\ell_{cr}) \simeq \kappa$.

At $\ell = \ell_{cr}$ there is formed a diffraction image that decreases a_s, increases the radiation density, and decreases θ_s owing to the presence of many cells of the grid (in the Fraunhofer limit $\theta_s \simeq \theta_{s1}/N_1$, where N_1 is the number of cells per unit length of the grid, and the limiting power at the maximum is $P \sim P_1 N$, where $N \sim N_1^3$ is the total number of cells in the grid). We note that an important role in self-focusing is played not only by the initial image contrast (which gives the transverse intensity gradients), but also by the longitudinal rate of change of contrast (which gives the divergence angles).

The change of flux density in the investigated Fresnel zone of the diffraction grating at $I \gtrsim I_{cr}$ is determined by the contrast of the intensity function. This contrast is determined in turn by the factor $\cos(\pi\ell\lambda/d^2)$, where d is the period of the grating. For example, for a sinusoidal grating we have

$$I = \left|\int e^{ik\sqrt{\ell^2+(Y-y)^2}}\left(1+\cos\left(\frac{2\pi y}{d}\right)\right)dy\right|^2 \sim 1 + 2\cos\left(\frac{2\pi Y}{d}\right)\cos\left(\frac{\pi\ell\lambda}{d^2}\right) + \cos^2\left(\frac{2\pi Y}{d}\right)$$

For example, at $\cos(\pi\ell\lambda/d^2) = 0$ we have $I \sim 1 + \cos^2(2\pi Y/d)$ and ranges from 1 to 2 and at $\cos(\pi\ell\lambda/d^2) = 1$ we have $I \sim [1 + \cos(2\pi Y/d)]^2$ and ranges from 0 to 4. Here ℓ is the distance to the diffraction grating, Y is the transverse observation coordinate, and y is the coordinate along the grating. We see that the contrast decreases sharply at $\ell_{cr} \simeq (2m + 1)d^2/2\lambda$, i.e., $\ell_{cr}(m = 0) \simeq d^2/2\lambda$

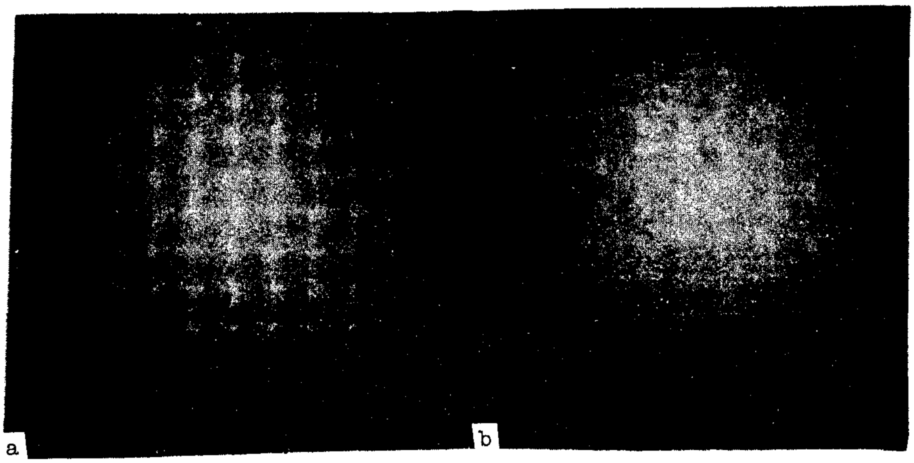

Fig. 2. Distribution of intensity on the screen at the following values of the distance ℓ from a diffraction grating with $d = 2 \times 10^{-2}$ cm in air (without a nonlinear medium): a) $\ell = 6$ cm, b) $\ell = 5$ cm. It is seen that near ℓ_{cr} the image contrast weakens sharply, and at $\ell = \ell_{cr} \pm 1$ cm the contrast is restored (this repeats at $\ell = 16$ cm).

and $\lambda_{cr}(m = 1) = 3d^2/2\lambda \approx 2\lambda_{cr}(m = 0)$, as was indeed observed in experiments both with a neodymium laser ($\lambda_{cr_1} \approx 5$ cm, $\lambda_{cr_2} \approx 16$ cm) and with a helium-neon gas laser ($\lambda_{cr_1} \approx 8.5$ cm, $\lambda_{cr_2} \approx 25.5$ cm) for a grid with $d \sim 2 \times 10^{-2}$ cm.

The beam easiest to cut up with a raster is one with a near-rectangular radial distribution of the intensity. However, even for any radial distribution of the radiation intensity density I(r) one can choose a raster with radially-dependent cell areas s(r) such that the power passing through each cell is close to the threshold value, $s(r) \sim I(r)/P_{thr}$. The transverse gradient of the sub-beam is then significantly weakened by diffraction, so that its bending and its scattering are decreased. The results of this investigation extend considerably the possible use and manifestation of waveguide self-focusing.

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[1] G.A. Askar'yan, Zh. Eksp. Teor. Fiz. 42, 1567 (1962) [Sov. Phys.-JETP 15, 1088 (1962)].
[2] V.I. Talanov, Izv. Vuzov Radiofizika 7, 546 (1964).
[3] R.Y. Chiao, E. Garmire and C.H. Townes, Phys. Rev. Lett. 13, 479 (1964).
[4] S.A. Akhmanov, A.P. Sukhorukov, and R.V. Khokhlov, Usp. Fiz. Nauk 93, 19 (1967) [Sov. Phys.-Usp. 10, 609 (1968)] (a review).
[5] P.L. Kelley, Phys. Rev. Lett. 15, 1005 (1965).
[6] V.M. Bespalov and V.I. Talanov, ZhETF Pis. Red. 3, 471 (1966) [JETP Lett. 3, 307 (1966)].
[7] A.L. Dyshko, V.N. Lugovoi, and A.M. Prokhorov, ibid. 6, 655 (1967) [6, 146 (1967)].
[8] T. Bergqwist, B. Kleman, and P. Wahren, Arkiv for Fysik, B34, 81 (1967).
[9] V.V. Korobkin and R.V. Serov, ZhETF Pis. Red. 6, 642 (1967) [JETP Lett. 6, 135 (1967)].

LOW-FREQUENCY MAXIMA OF THE DENSITY OF STATE OF PHONONS. HARMONICS AND SUBHARMONICS OF THE ENERGY GAP OF Nb_3Sn

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1. Detailed tunnel investigations of the energy gap of Nb_3Sn were reported in [1], and four values (4.70, 2.24, 1.50, and 0.36 meV) were obtained for the gap 2Δ. The principal maximum of the tunnel density of states (the region of the second and third gaps) corresponds to an energy $2\Delta_{eff} = 1.9$ meV, where Δ_{eff} is the effective value of the gap in Nb_3Sn.

It was shown earlier [3, 4] that the use of low-resistance contacts with microscopic short circuits makes it possible to observe clearly all the singularities of the tunnel characteristics.

In the present paper we report an investigation of the differential conductivity (dI/dV) and of its derivative (d^2I/dV^2) both in the voltage region $V < 2\Delta$ and in the region $V > 2\Delta$, for Nb_3Sn-Pb, Nb_3Sn-Sn, and Nb_3Sn-Al tunnel junctions with micro-short-circuits. We used junctions with resistances 10^{-2} - 1 ohm/mm^2.

2. At low voltages, maxima of the differential conductivity (gap subharmonics) are observed at voltages $V_n = (\Delta_{eff} + \Delta_m)/n$, where n is an integer and Δ_m is the energy gap of the second metal. As a rule, the amplitude of the even