$K = K_0$. We recall that this field intensity is smaller by approximately one order of magnitude than the intensity at which ionization of noble gases was observed.

Discussion of results. Let us examine the scheme of the atomic levels of Na. As seen from Fig. 2, only after absorbing four neodymium-laser emission quanta does the electron fall in the region of the closely-lying levels in the atom. In this case the distance to the nearest level 7S in the spectrum of the atom, to which the transition is allowed, is ≈ 250 cm^{-1}. The distance between the levels in this region is ≈ 500 cm^{-1}. The Stark shift of the 7S level was determined from the dipole moments calculated by the Bates and Damgaard method, and amounted to ≈ 10 cm^{-1} in a field of 5×10^6 V/cm. The broadening of the 7S level in such a field was determined by using the Burgess-Seaton method to calculate the ionization probability, and amounted to ≈ 10 cm^{-1}. Comparing all the foregoing quantities, we see that in a field $(2 - 5) \times 10^6$ V/cm the levels of the atom are perturbed relatively weakly, and the difference between the energy of an electron absorbing four quanta and the energy of the 7S level is sufficiently large. Thus, neither the effect of level overlap nor the resonant effects play any role in this case. Comparison of the experimental data and these calculations leads to the conclusion that if the differences between the energy of the integer number of quanta and the energy of the discrete levels in the atom are large and are relatively little changed by the radiation field, then the functional dependence of the ionization probability on the intensity is determined by the quantity K_0.

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DEVELOPMENT OF SELF-FOCUSING FILAMENTS IN SOLID DIELECTRICS

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When powerful laser emission is focused inside a transparent dielectric such as glass, sapphire, and ruby, it is possible to observe damage in the form of thin filaments several

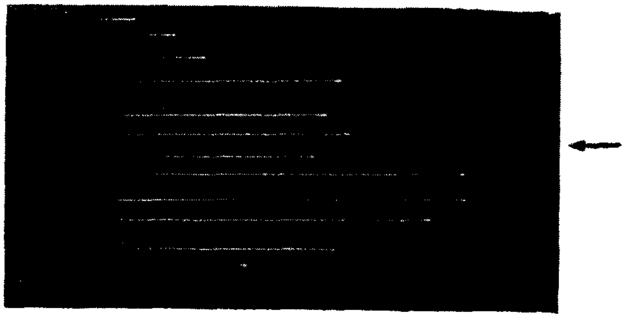

Fig. 1. The arrow shows the direction of propagation of the laser beam. Magnification 4×.

microns in diameter and more than 1 cm long [1,2].

Filamentary damage in glass, observed in [1], was attributed in [3] to waveguide propagation of the light as a result of self-focusing of the laser beam [4]. However, a theoretical analysis of the question of existence of a stable waveguide channel in a nonlinear medium encounters considerable difficulties [5]. At the same time, a numerical solution of the problem of self-focusing of a laser beam in a nonlinear medium, obtained in [6], leads to the appearance of individual bright spots on the beam axis, and not to a waveguide channel.

We have established that the filamentary damage observed in glass and sapphire is not connected with the formation of an extended waveguide. This damage results from the motion of a zone in which the light beam collapses as a result of an increase of the linearity and of a decrease of the self-focusing length during the time of the laser pulse; this zone moves in the medium in a direction opposite to that of the incident radiation.

In the experiment, the second harmonic of a neodymium laser ($\lambda = 0.53\ \mu$) was focused by a lens ($f = 10$ cm) into the volume of extended objects ($\sim$10 cm) of optical glass and leucosaphhire. The laser operated in one transverse mode with axially-symmetrical Gaussian field distribution; the Q-switching was with a phototropic shutter. The energy of the harmonic reached 0.02 J at a pulse duration $\sim$10 nsec, and could be attenuated with neutral filters. The beam diameter in the plane of the lens was 1.5 mm.

The use of a single-mode laser makes it possible to obtain repeatedly one filamentary damage per flash. We note that for radiation with $\lambda = 0.53\ \mu$, the filaments are longer than for $\lambda = 1.06\ \mu$, and they are not accompanied by a strong cracking of the material.

At a power corresponding to the damage threshold (0.5 MW for leucosapphire, 0.3 MW for K-8 glass, 0.1 MW for ZhS-11, diameter of focal spot $\sim 5 \times 10^{-3}$ cm) a short filamentary fissure 0.2 - 0.5 mm long appears in the focus of the lens.

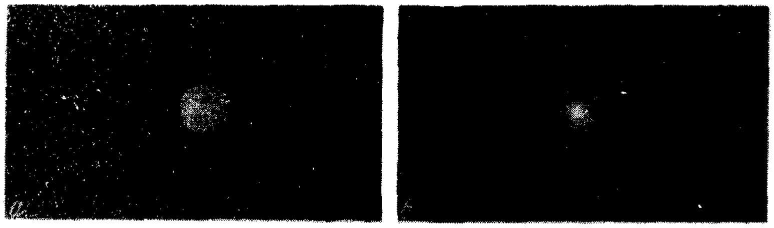

Fig. 2. Propagation of field in the focus of a lens of $f = 40$ cm in a sample of ZhS-11 glass: a - radiation power $P = 0.5\ P_{thr}$, b - $P = 0.9\ P_{thr}$. Magnification 65×.

With increasing power, the length of the filament increases, and its development proceeds in only one direction - opposite to the incident radiation. The maximum length of the filament in the case of total radiation power reaches 20 mm and exceeds the length of the focal region of the lens (~3 mm).

The photograph (see Fig. 1) shows a series of filamentary fissures in sapphire, obtained at different power levels. After each flash, the sample was moved perpendicular to the axis of the laser beam. The ends of the filaments on the far side of the input surface of the sample lie practically on the same line. At the same time, the positions of the opposite ends of the filaments are determined by the power level of the laser radiation. At that end, the filament thickness increases from 5 to 10 - 12 μ and terminates with a crack at ~0.1 mm.

The appearance of filamentary damage, with length greatly exceeding the focal region of the lens, and whose diameter depends weakly on the incident power, is connected with the self-focusing phenomenon. The presence of self-focusing is confirmed by the observed bright central spot in the distribution of the field passing through the sample, at a power somewhat lower than the damage threshold (Fig. 2). At threshold power, the light beam collapses in the focal region of the lens, and the material is damaged in the collapse zone. The field intensity in this zone is $E = [16P/cnd^2]^{1/2}$, where P - power, d - filament diameter, c - velocity of light, n - refractive index, and can reach 3×10^7 V/cm, which is close to the threshold of optical breakdown [7].

If the power of the laser pulse exceeds threshold, then at the first instant the collapse again occurs in the focal region of the lens; with further increase of the field amplitude during the pulse, Δn (nonlinear increment of n) increases, the self-focusing length decreases, and the collapse zone shifts in a direction opposite to that of the laser beam. The displacement of this zone produces the filamentary damage in the material. On the trailing end of the laser pulse, the growth of Δn stops, and the remaining energy of the pulse is absorbed in the plasma of the breakdown, causing the characteristic cracking.

The foregoing analysis is valid for both the instantaneous response of the nonlinear system and for the inertial mechanisms of nonlinearity (thermal heating, electrostriction) which are characteristic of solids. The rate of development of the filament (~10^8 cm/sec) depends on the time of establishement of the nonlinearity.

Thus, the results show that the filamentary damage in a solid is not connected with the existence of an optical waveguide, for otherwise the filamentary damage would develop from the focal region in the direction of the laser beam.

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