INVESTIGATION OF BREAKDOWN IN ARGON AND HELIUM PRODUCED BY A PICOSECOND RUBY LASER LIGHT PULSE

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The threshold flux for breakdown in argon and helium induced by a 50-picosecond ruby laser pulse is investigated. The results show that for both argon and helium, there exist pressure ranges in which breakdown occurs either as a result of the avalanche mechanism or as a result of multiphoton ionization of the gas atoms in the field of a strong light wave. Separation of these mechanisms of breakdown is possible because of the different effect on them of the gas pressure in which the breakdown occurs. The probabilities of multiphoton ionization are estimated for threshold fluxes of breakdown. A comparison is made of the threshold values of breakdown obtained experimentally and the probabilities of ionization with those calculated on the basis of theoretical data available in the literature.

WE showed experimentally in[1] that even in the region of comparatively high pressures, breakdown occurs in nitrogen under the action of a picosecond ruby laser radiation pulse by direct photoionization of the molecules in the field of a strong light wave. This is a consequence of the fact that the shortening of τ, the length of the light pulse that induces the breakdown, leads to an increase in the avalanche mechanism threshold of breakdown that is inversely proportional to τ. The flux densities of the laser radiation reach values for which the probability of direct photoionization of the atoms or molecules in the field of a strong light wave whose frequency is much less than the ionization potential.[2] A weak pressure dependence of the threshold intensities of breakdown allows us to distinguish the observed breakdown mechanism from the avalanche for which this dependence is much stronger.

A similar method has been used by us in the present research for the study of breakdown under the action of a picosecond ruby laser radiation pulse in argon and helium. The interest in these gases is connected with the fact that there are detailed theoretical data in the literature for the threshold breakdown fluxes in the case of multiphoton ionization mechanism.[3]

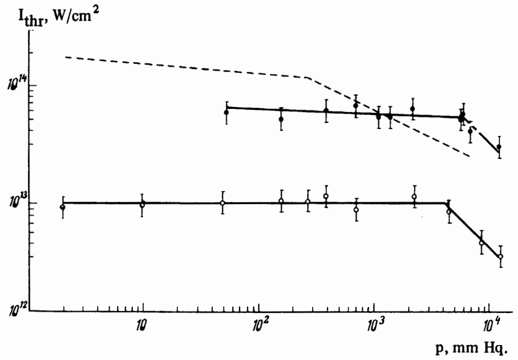
The study has been carried out with the help of an experimental apparatus, the scheme of which is similar to that described in[1]. The pulse of the optical radiation of a ruby laser of length 50 nsec was focused in the investigated gas on an area of 4×10^{-6} cm^2 of a lens of focal length 2 cm. The pressure was changed in the limits from 2 to 10^4 mm Hg. The appearance of breakdown was recorded by an FÉU-15B photomultiplier in conjunction with a C1-29 oscilloscope.

The results of the experiment are shown in the drawing. It is seen from the data of the drawing that both for argon and for helium there is a region of weak dependence of the breakdown threshold on the pressure. This indicates that the breakdown mechanism in the given region of pressures is direct photo-ionization of the atoms of the studied gases in a field of a strong light wave. For the given values of the threshold fluxes of breakdown for both argon and helium, the parameter γ[4], which determines the character of the photoionization is seen to be larger than unity. Consequently, the photoionization takes place by direct multi-quantum absorption in the field of a strong light wave.

It is of interest to carry out a comparison of the resultant experimental values of the thresholds of the "multiquantum" breakdown for the studied gases with the theoretical estimates of Bebb and Gold.[3] Here we shall assume that in our experimental conditions there is complete ionization of the atoms in the focal region for threshold fluxes of the ruby laser radiation. Such an assumption is valid and is confirmed by the absence of a dependence of the value of the breakdown threshold on the pressure.

A comparison of the theory with experiment for helium shows that the experimentally obtained value of the breakdown threshold of 1.9×10^{32} (in units of photons-cm^{-2}-sec^{-1}) and the theoretically calculated 1×10^{32} are close together. For argon, the difference of the thresholds is much greater: 3.6×10^{31} is the experimental value, and 1.8×10^{30} the theoretical. This difference can scarcely be associated with error in the experimental determination of the value of the breakdown threshold in argon and the reason for it is unknown at the present time.

From the experimental data, one can also determine the probability of multiquantum photoionization per unit time on a single atom, $w_0 = \sqrt{N}/\tau$, where τ is the length of a pulse of Gaussian shape at half-height, N is the degree of multiplicity of the quantum character. Thus, for argon, $w_0 = 6 \times 10^{10}$ sec^{-1} and for helium, $w_0 = 7.5 \times 10^{10}$ sec^{-1}. On the other hand, one can estimate these probabilities on the basis of the theoretical results of[3] by using the values of the threshold fluxes of the laser light obtained in the present research. Such an estimate gives $w_0 = 8.3 \times 10^{13}$ sec^{-1} for helium and $w_0 = 5 \times 10^{19}$ sec^{-1} for argon. The difference of the theoretically calculated probability and that determined from experiment for helium can be connected with the error in the determination of the absolute values of the threshold fluxes, inasmuch as the dependence of the multiquantum photoionization on the intensity is very strong. There-



Experimental dependence of the breakdown threshold intensity I_{thr} on the pressure: ○—in argon; ●—in helium. The dashes indicate data for nitrogen from [1].

fore, in order that a comparison of the theoretical values of the probabilities with the experimental give satisfactory results, it is necessary to measure the absolute values of the threshold fluxes with greater accuracy than is done in the present research. For argon, the difference of many orders of magnitude between the theoretical and experimental values of the probabilities is due to the great divergence of the measured and commuted threshold intensities.

For pressures greater than 5×10^3 mm Hg, for both gases studied, the breakdown threshold changes in inverse proportion with the pressure, which is characteristic for the avalanche mechanism of breakdown. We note that for nitrogen, which was studied in[1], the avalanche mechanism of breakdown begins at much lower pressures. This is seen from the drawing, when the dashed lines indicate the corresponding curve.

Comparison of the results obtained in this range of pressures with data on breakdown for nanosecond length pulses[5] shows that the breakdown threshold for helium increases according to the law $1/\tau$, where τ is the pulse length. For argon, the breakdown threshold value obtained is somewhat smaller than one would have expected from the dependence $1/\tau$.

The results obtained in the present research indicate that the transition to picosecond pulse lengths allows us to achieve breakdown in gaseous argon and helium as a result of multiphoton ionization in the field of a strong light wave in the region of comparatively high pressures. Here the avalanche mechanism of breakdown is entirely absent. On the basis of the experimental results, one can estimate the value of the probability of multiquantum photoionization of the atoms of the gases studied. However, as has already been pointed out above, one must approach rather carefully the comparison of the values of the probabilities obtained from experiment and from theoretical calculations.

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[1] I. K. Krasyuk, P. P. Pashinin and A. M. Prokhorov, ZhETF Pis. Red. 9, 581 (1969) [JETP Lett. 9, 354 (1969)].

[2] F. V. Bunkin and A. M. Prokhorov, Zh. Eksp. Teor. Fiz. 52, 1610 (1967) [Soviet Phys.-JETP 25, 1072 (1967)].

[3] H. B. Bebb and A. H. Gold, Phys. Rev. 143, 1 (1966).

[4] L. V. Keldysh, Zh. Eksp. Teor. Fiz. 47, 1945 (1964) [Soviet Phys.-JETP 22, 1307 (1965)].

[5] R. G. Tomlinson, E. K. Damon and H. T. Buscher, Physics of Quantum Electronics, New York, 1966, p. 520.

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193