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Field Dependence of Optical Breakdown Probability in Liquids by Q-switched Lasers

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Introduction

Probabilistic behavior of optical breakdown in water is investigated as a function of the laser intensity using Q-switched 1.06μm and 0.532μm lasers with 5~6 nsec duration and is compared with the breakdown probability of air in which a avalanche mechanism is believed to govern the breakdown process. These results suggest us a mechanism of optical breakdown is the following. Initial electrons are supplied from liquid itself or impurities in liquids by multiphoton absorption process. These seed electrons absorb laser radiation thorough collision with liquid molecules(microwave breakdown process) and acquires sufficient energy to induce avalanche ionization of liquid molecules.

Experimental Results and Discussions [1], [2],[3],[4]

Typical behavior of the breakdown probability in distilled water, on a logarithmic scale, versus the reciprocal laser field is shown in Fig.1. The curve is divided into two regions, the low laser field region and the high laser field region. In the low laser field region the breakdown probability P depends on the laser field E, through the next simple relation

$$P \propto \exp(-K/\lambda E) \qquad (1)$$

for values of P ranging from a few percent to more than 60 ～ 70%.This dependence has been considered suggestive for an avalanche-breakdown mechanism because the dc ionization coefficient that governs avalanche breakdown in gases and semiconductors depends on the electric field in the same manner. In the high laser field region, the breakdown probability becomes low deviating from the $\ln P \propto 1/E$ curve.

The share of these two regions depends on the experimental conditions. For instance, in the high doped NaCl solutions the breakdown field decreased and the linear region of the $\ln P \propto 1/E$ becomes narrow. Doping NaCl into distilled water gives rise to optical absorption near the band edge. This means the initial electron supply is likely to occur in the high laser field by multiphoton absorption which reduce the breakdown field. We consider that in the linear region of the $\ln P \propto 1/E$ curve the electron avalanche is an important process in the breakdown and in the deviated region ,in the high laser field, the initial electron

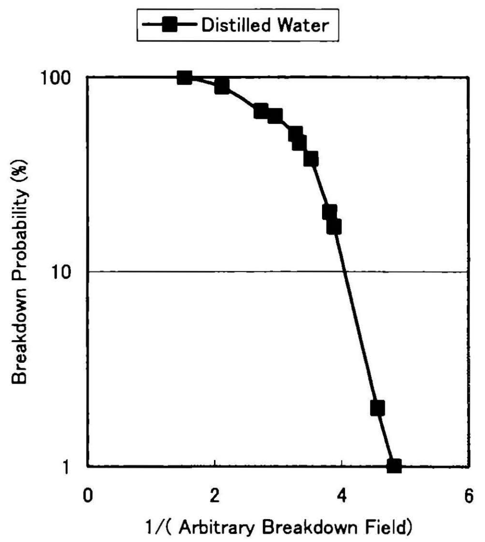

Fig.1 Logarithm of breakdown probability vs. the inverse of the laser field (at 0.532μm)

supply process by multiphoton absorption become important addition to avalanche ionization.

So far, the Eq.(1) was used to analyze the breakdown probability under laser irradiation. The denominator λE of the exponential term in Eq.(1) shows the gain of the electron energy which an electron moves the length of mean free path, which will be explained in the following.

The rate of energy gain of an electron under the influence of laser field of frequency ω will be given by

$$dW/dt \propto \nu_m / (\omega^2 + \nu_m 2) \qquad (2)$$

where e, m and ν_m are the electric charge, the electron mass and the collision frequency of electrons with liquid molecules, respectively.

In the DC limit ($\omega = 0$),

$$dW/dt \propto 1/\nu_m \propto \lambda \qquad (3)$$

The energy gain of the electron is in proportion to λ.

In the optical field ($\omega > \nu_m$),

$$dW/dt \propto \nu_m/\lambda \propto 1/(\lambda \omega^2) \qquad (4)$$

The energy gain of the electron is in inverse proportion to $\omega^2 \lambda$. Then we assume the breakdown probability P is expressed by the next equation.

$$P \propto \exp(-\lambda \omega^2 K/E) \qquad (5)$$

This equation can explain the experimental results summarized above.

Conclusion

(1) The breakdown probability P of distilled water depends on the laser field E through the simple relation $P \propto \exp(-K/E)$. This suggests that the mechanism of laser-induced breakdown in distilled water is governed by the electron avalanche process. We propose a following new relation,

$$P \propto \exp(-\lambda \omega^2 K/E),$$

which can explain the laser frequency and λ dependence of the breakdown probability.

(2) In distilled water multiphoton ionization from impurities plays an important role in breakdown in addition to the avalanche ionization process. At 0.532 μm multiphoton ionization is more important than at 1.06 μm.

References

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