A comparative study on the physical processes responsible for the breakdown of He and Kr gases by excimer laser pulses

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Summary

Although there have been a great deal of researches reported on the breakdown of gases by lasers operated at different wavelengths , the results obtained for shorter wavelengths, however, showed a healthy contradiction concerning the threshold intensity for breakdown in the nanosecond time scale under laser wavelengths in the VUV regime (Davis et al ,1991 and Thareja and Tambay, 1996). Moreover, in their measurements (Turcu et al ,1997) on the breakdown threshold intensity as a function of gas pressure for a number of rare gases (He, Ne, Ar and Kr) by a KrF laser operating at 248 nm wavelength and 18ns pulse duration 18 ns over a wide pressure range (4.5-3000 torr), it was found that threshold intensity varies between, 4.0 X 10^{11} and 2.0 X 10^{13} W/cm^2. The highest measured threshold intensities was corresponing to He (at pressures of 180- 3000 torr), while the lowest ones refer to Kr (over a pressure range varies between 4.5-300 torr). Generally the physical models that have been emerged from theory and experiment include processes acting as sources for seed electrons (multi-photon ionization,

tunneling ionization and inverse Bremsstrahlung) as well as mechanisms responsible for the rapid buildup of electrons density (cascade ionization by collision).

Accordingly, in this work a numerical analysis is under taken to investigate the physical processes responsible for the breakdown of these two gases to find out the origin of this threshold intensity difference. The investigations are based on a modified realistic electron cascade model which is previously developed by Evans and Gamal (1980). The model solves numerically the time dependent Boltzmann equation for the electron energy distribution function (EEDF) and a set of rate equations describing the rate of change of the formed excited states population . The model considers the electron energy gain through inverse Bremsstrahlung absorption and electron generation by both multi-photon ionization and collisional ionization of the ground state as well as these formed excited states. In this work the He and Kr atoms are treated as four state atoms namely; a ground state an ionized state and two exited states. For more reasonable results, the rate coefficients and cross sections of the physical processes involved into the model are taken to vary with the electron energy. A computer program (in Fortran 77) is developed to calculate the threshold intensity as a function of gas pressure at each pressure value for both gases. This enabled us to obtain a comparison between the calculated threshold intensity as a function of gas pressure and the measured ones for both gases. Reasonable agreement is shown for both of them over the whole range of gas pressure examined experimentally. This validates the applicability of the model to investigate the experimental measurement given by Turcu et al (1997). It is noticed here that over the common pressure range tested experimentally for the two gases the obtained thresholds for He lie about

two order of magnitude above those obtained for Kr. Consequently, ,the study is performed to analyze the EEDF in order to find out the exact relationship between the physical processes, gas pressure and nature of gas viz, atomic number Z and ionization energy E_i. In addition the study of the time evolution of the electron density, excited states density as well as the excitation and ionization rates showed that for Kr (at the low pressure regime) electrons are mainly generated through Multi photon ionization process form ground and excited states. These electrons are found to have high probability to diffuse out of the focal region causing a pronounced loss of the electron density in particular at the lowest pressure region. This result explains the steep decrease of the threshold intensities with pressure associated with the Kr gas at this considerably low pressure regime. For He however, the analysis revealed that only multi-photon ionization of the formed excited atoms is the main process which contributes to the breakdown phenomenon over the whole pressure range considered in this study. Electron impact ionization processes are found to convert only the ground state atoms into the excited states. No evidence for electron diffusion or recombination losses is observed for He over this pressure range (180 -3000 torr) . The noticeable slop shown in the I_{th} versus p relation is attributed to the effect of inelastic collision processes ,which lead to high rate of atomic excitation followed by an immediate ionization through multi-photon absorption processes.

Analyzing the temporal variation of the EEDF enabled the determination of the time and energy region at which plasma (breakdown) is formed as a function of gas pressure for both He and Kr gases. It was found that for He gas at low pressure (180 torr) the plasma develops before the end of the laser pulse with energy ranging from 1.0-2.0 eV. With the increase of gas pressure (p= 3000 torr) the plasma is produced at the end of the laser pulse and confines in a very small energy region near zero eV.