Investigation of Laser Induced Breakdown Threshold

Violeta M. Petrović[1], Sanja D. Tošić[2], Hristina Delibašić Marković[1] and Ivan D. Petrović[3]

[1]Faculty of Science, University of Kragujevac, Radoja Domanovića 12, 34000 Kragujevac, Serbia
[2]Institute of Physics Belgrade, University of Belgrade, Serbia
E-mail: seka@ipb.ac.rs
[3]Technical Collage of Professional Studies Šumadia, Department in Kragujevac, Serbia

The phenomenon of laser-induced breakdown (LIB) in the air attracted great interest after the invention of the Ruby laser (see Damon et al. 1963). It occurs due to the interaction of the laser with a considered target when the laser pulse energy is greater than that of the binding electrons, involving different ways to create plasma. The initial step is photoionization (PI), which is followed by induced avalanche ionization (AI). As a result, a vast increase in the free electron density, $\rho(t)$, occurs. Usual way to describe their evolution is by the rate equation (see Vogel et al. 2005):

$$\frac{\partial\rho(t)}{\partial t} = \left(\frac{\partial\rho(t)}{\partial t}\right)_{PI} + \eta\rho(t) - g\rho(t) - \alpha\rho(t)^2.$$

The first two terms on the right side of the equation describe PI and AI rates, respectively, while the losses terms (due to diffusion $-g\rho(t)$ and recombination$-\alpha\rho(t)^2$) enter with a minus sign.

Even though LIB is a threshold-like process in terms of peak laser pulse strength (Polynkin et al. 2011, Shneider et al. 2012), defining the LIB threshold (LIBT) has long been recognized as an important challenge for developing methods that can produce trustworthy results.

Depending on the general-purpose, there are several types of evaluations that can be conducted to calculate the value of LIBT. For instance, according to Breischenk (2013), the portion of the laser pulse which initiates the plasma formation becomes equal to the LIBT.

The theoretical estimation of LIBT can be done by using the standard rate equation (see Keldysh 1964, Vogel 2005). According to Bekefi (1976) the LIBT in air, I_{th}, is given as:

$$I_{th} = \left(\frac{8\times10^2}{Pt_p\lambda^2}\right)(1 + 4.5\times10^{-6}P^2\lambda^2)(1 + 2\times10^8 Pt_p),$$

where P is pressure, while t_p and λ denote pulse duration and wavelength of the applied laser, respectively.

The validity of our calculations was tested by comparing the results of comprehensive propagation simulations with data from available experiments (Gao et al. 2019). Experimental results were satisfactory and gave good agreement to the presented model.

References

Bekefi, G. Principles of Laser Plasmas (John Wiley, New York, 1976)
Brieschenk, S., Kleine, H. and O'Byrn S., 2013, J. Appl. Phys. 114: 093101
Damon E. K. and Tomlinson R. G., 1963, Appl. Opt. 2, 546- 547
Gao, Z., Han, L. and Li, J., 2019, Pacific Rim Laser Damage 2019: Optical Materials for High-Power Lasers 11063, 1106305.
Keldysh, L.V., 1965. Zh. É ksp. Teor. Fiz. 47, 1945 1964 Sov. Phys. Jetp, 20, 1307
Polynkin, P. and Moloney, 2011, Appl. Phys. Lett., 99, 151103
Shneider, M.N. and Miles, R.B. 2012, Phys. Plasmas, 19, 083508
Vogel, A., Noack, J., Hüttman, G. and Paltauf, G.J.A.P.B., 2005, Applied physics B, 81(8), 1015-1047