DISTINCTIVE Features of electron capturing and acceleration during the interaction between self-focusing laser pulse and plasma jet

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In our time, there is a great interest in obtaining high-energy electron beams on compact accelerators for use in various applications such as medicine, isotope production, substance diagnostics, and more. The construction of such accelerators is possible with the use of laser-plasma method of electron acceleration. This method differs from vacuum acceleration by much larger accelerating fields, which can significantly reduce the size of the accelerator. The creation of high-energy electron sources for injection into a laser-plasma accelerator was considered in [1], [2]. In the previous work [3] the influence of the self-focusing effect of the laser pulse on the processes of plasma wakefield generation was investigated. This work is devoted to the study of the features of electron injection and acceleration in the plasma layer in the interaction of a laser pulse with a gas jet, considering the process of self-focusing of the laser pulse. Numerical modelling was carried out using a three-dimensional PIC-code (”particle-in-cell”) [3]. The parameters of the laser pulse incident on the plasma in the calculations correspond to the experiment [2]. The calculation parameters are following: the laser spot size and pulse duration are equal to 9.7 µm and τ = 50 fs, the central laser wavelength equals 1 µm, the laser pulse intensity is 7 × 1017 W/cm2 which corresponds to the dimensionless amplitude a0 = 0.715. The energy of the laser pulse is W = 40 mJ, and the power of the laser pulse is P = W/τ = 0.8 TW. The distribution of the hydrogen plasma density along the laser pulse propagation direction is Gaussian with a characteristic width of 200 µm. The maximum density is equal nmax = 2 × 1020 cm–3 (nmax/ncr = 0.1882), where ncr is the crtitical density of the plasma (m is the electron mass, ω is the laser frequency, e is the absolute value of the electron charge).

As a result of the analysis of the laser pulse propagation and the dynamics of the plasma wave generated behind the laser pulse, the following results were obtained: when the laser pulse in the process of its propagation in plasma reaches the region where the pulse power exceeds a critical value for self-focusing, the laser pulse is self-focused and a steepening of the leading edge of the pulse increases. Further, compression of the laser pulse in the transverse direction and increasing of the laser field amplitude leads to self-modulation of the pulse. As the self-modulation depth increases, the phase velocity of the plasma wave decreases in comparison with the group velocity of the laser pulse, according to [5]. This leads to the injection of plasma background electrons, and the subsequent acceleration of trapped electrons in the plasma wave to an energy of about 10 MeV. The energy distribution of accelerated electrons agrees with data obtained in the experiment [2].

References

1. Malkov Y.A., Stepanov A.N., Yashunin D.A., Pugachev L.P., Levashov P.R., Andreev N.E. and Andreev A. A. // Quantum Electronics. 2013. V. 43. P. 226–31.
2. Goers A. J., Feder G.A., Miao B., Salehi F., Wahlstrand J.K., and Milchberg H.M. // Physical Review Letters. 2015. PRL. 115. 194802.
3. Popov V. S., Pugachev L. P. and N. E. Andreev. // Journal of Physics: Conference Series. 2018, in press.
4. Pukhov A.J. // Plasma Physics. 1999. V. 61. P. 425–433.
5. Andreev N. E., Kirsanov V. I., and Gorbunov L. M. // Physics of Plasmas. 1995. V. 2. 2573.