Numerical Modelling of the Plasma Discharge During Electron Beam Welding (EBW)

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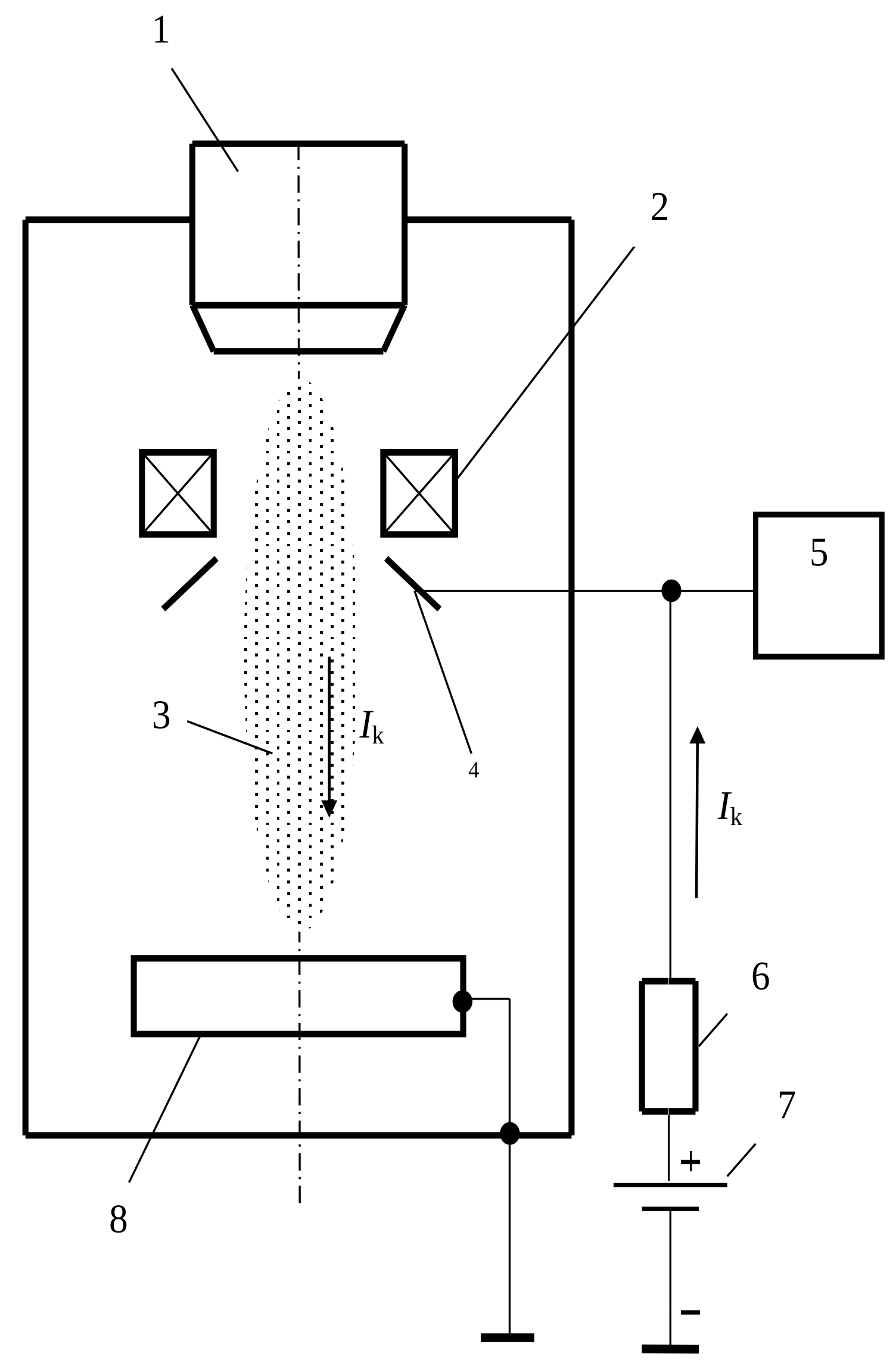
Introduction: This work describes a model for plasma formation in the keyhole and above the EBW zone. The parameters of the plasma are closely connected to the characteristics of the thermal action of the electron beam on the welded metal, which allows operational control and study of EBW (Fig. 1).



1 – electron gun;
2 – focusing lens;
3 – plasma generated above the welding zone; 4 – collector;
5 – registration of data;
6 – load resistor;
7 – voltage source;
8 – welded sample

Figure 1. Registration of a non-independent discharge current in a plasma during EBW

Computational Methods: The work used DC Discharge extension of the Plasma Module [1]. The model is based on solution of two drift-diffusion equations for the density of electrons and the mean electron energy. The mass transfer of heavy plasma particles (neutral atoms, excited atoms and ions) is taken into account in the analysis by the diffusion equation for a multicomponent mixture. The electrostatic field is calculated using the Poisson equation. Thermionic electron emission is calculated for the keyhole wall. In the keyhole plasma is collisional. On leaving the keyhole output, the plasma becomes collisionless.

Results: The ionization intensity of the vapour due to beam electrons and high-energy secondary and backscattered electrons is calibrated using the plasma parameters when there is no polarized collector electrode above the welding zone (Fig.2). It is shown that there is a need to consider the effect of a strong electric field in the crater near the crater wall on electron emission (the Schottky effect) when calculating the current of a non-independent discharge (Fig 4,5).

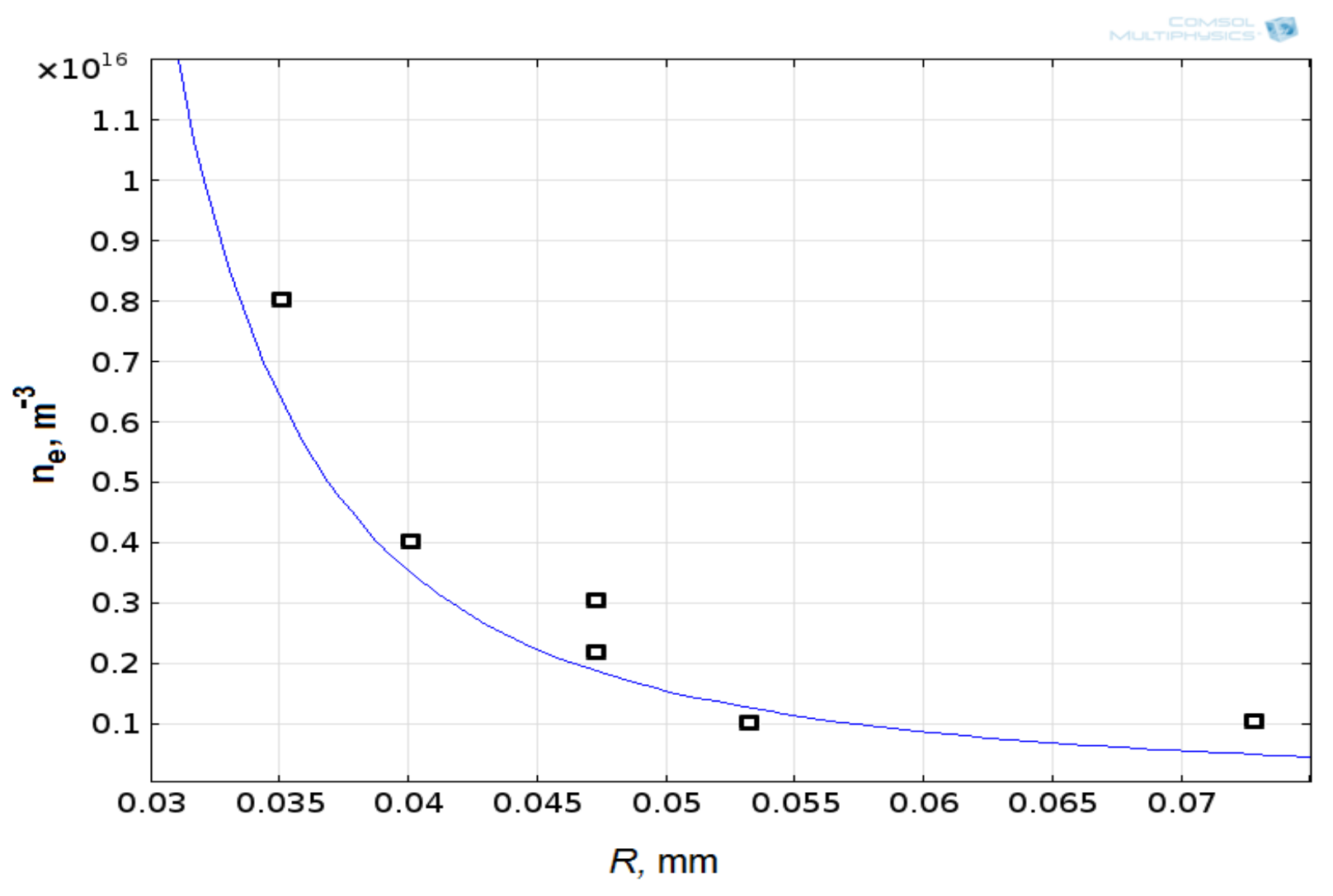


Figure 2. Plasma concentration against distance from the welding zone

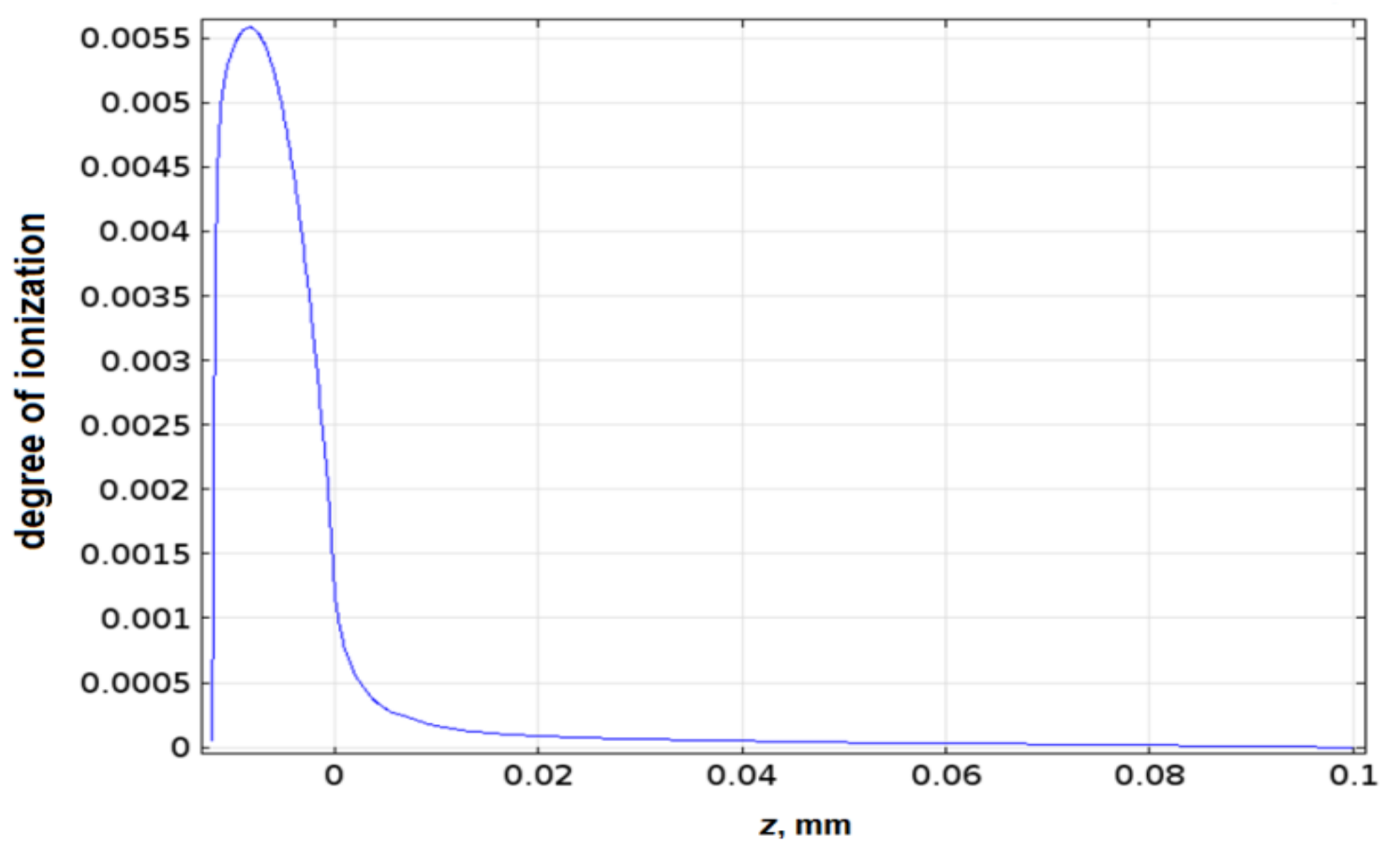


Figure 3. Ionization degree against beam axis z for the keyhole and above the sample surface

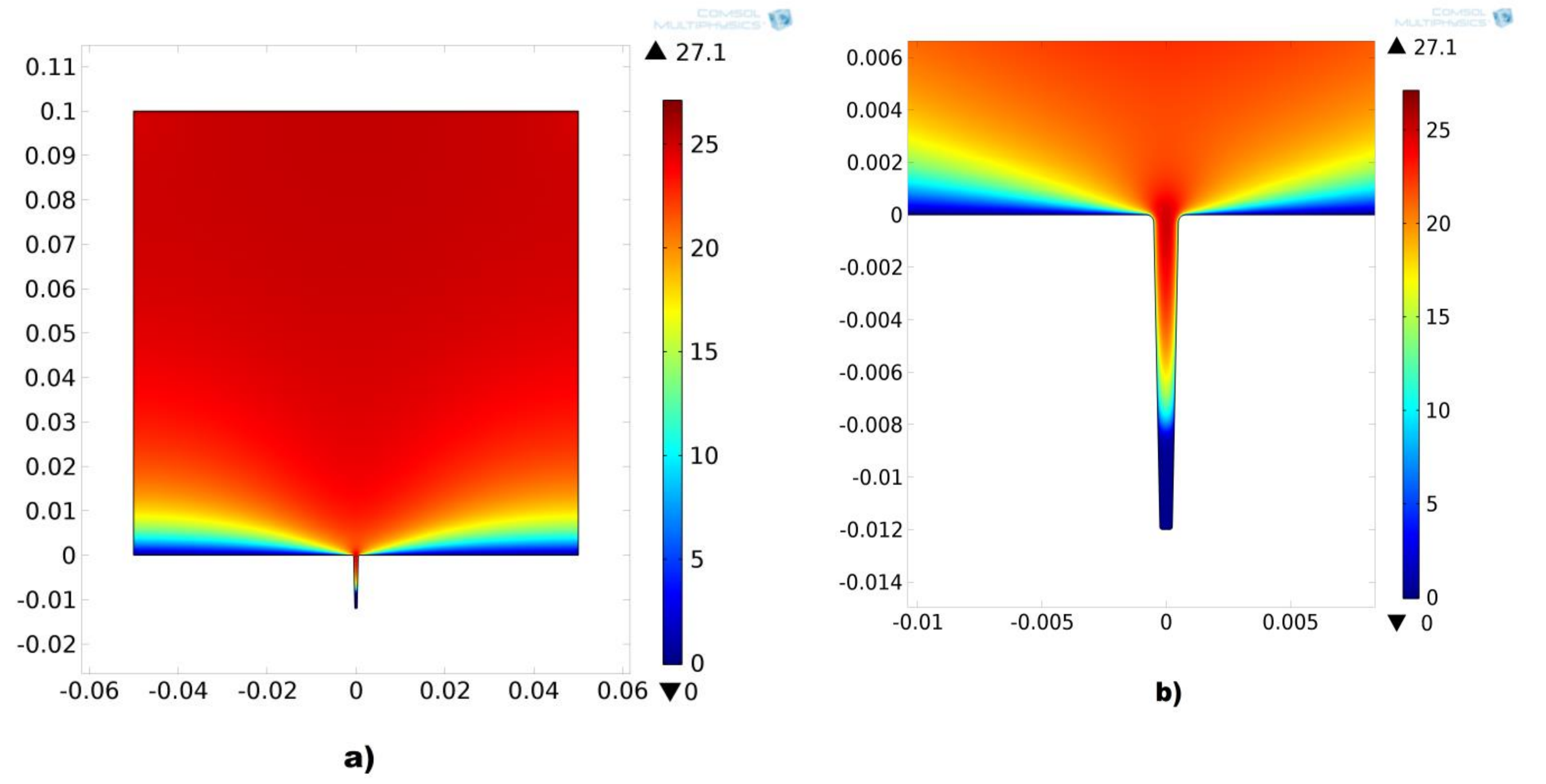


Figure 4. Potential distribution at excitation of a non-independent discharge: (a) in the vacuum chamber space; (b) magnified section

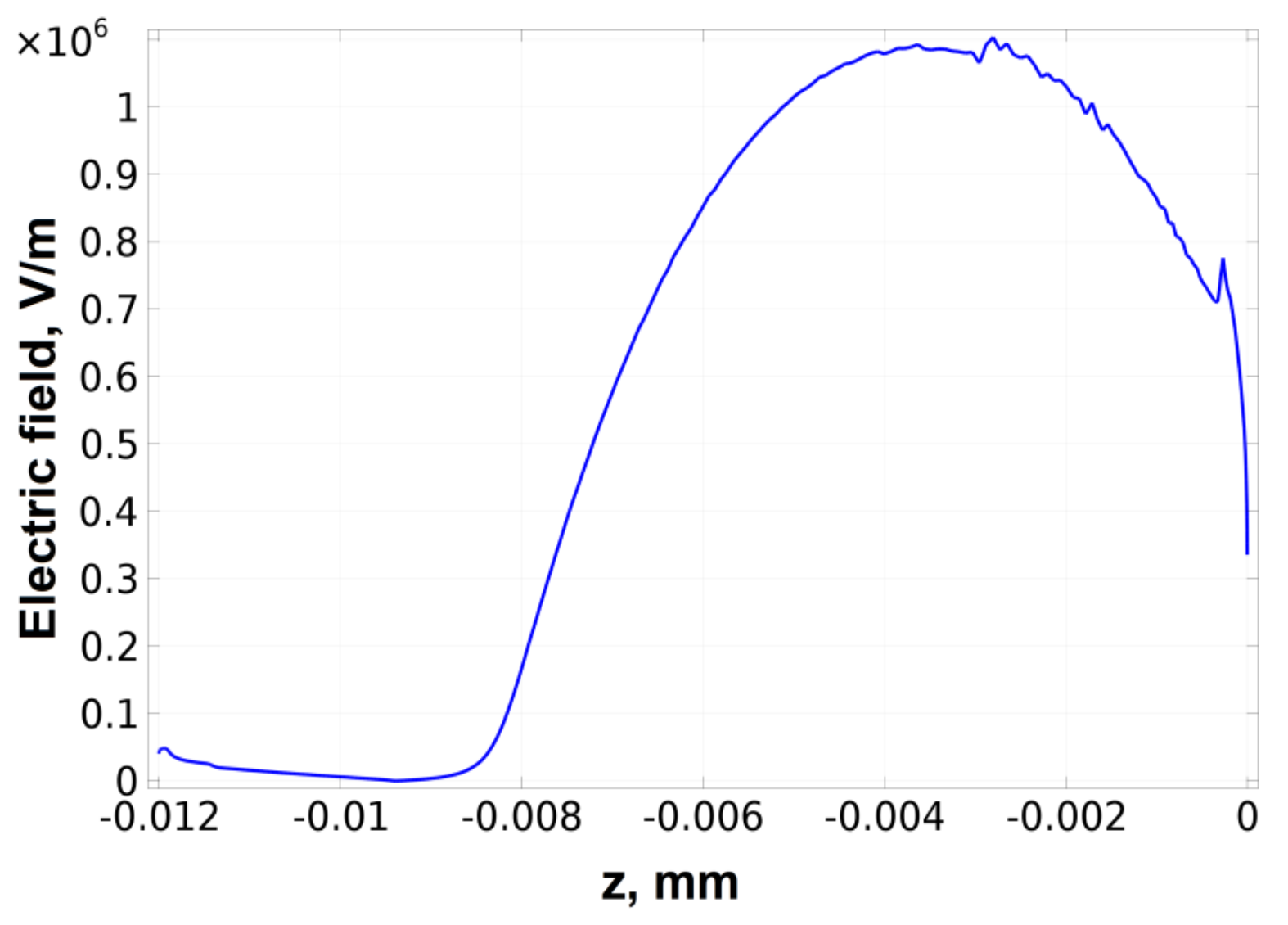


Figure 5. Electric field distribution against z on the wall of the keyhole

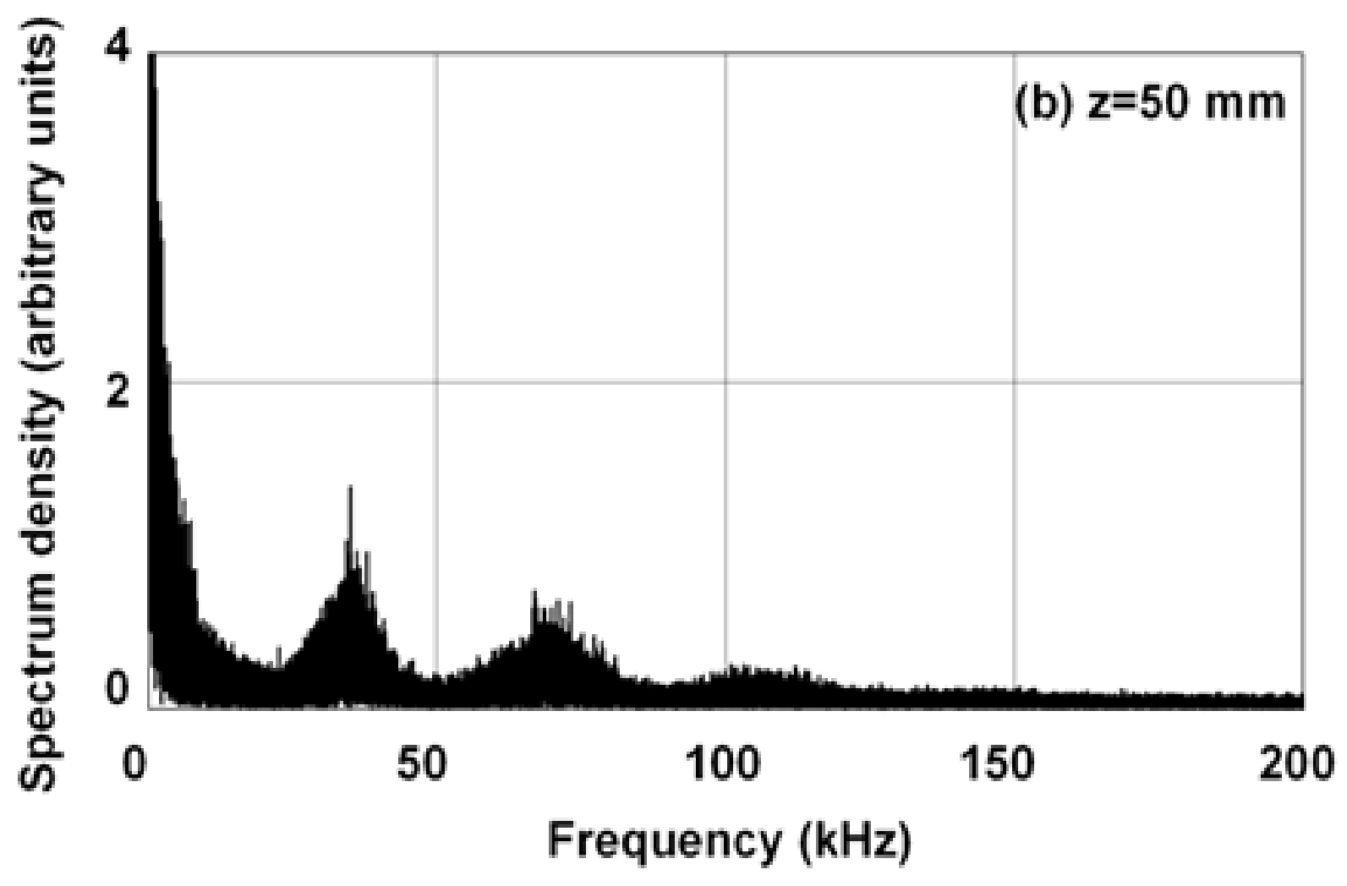


Figure 6. Spectra collected electron current in plasma at EBW [2]

The calculated electron drift velocities are much higher than the velocity at which the current instabilities arise (Fig.6). This confirms the assumption for the beginning of ion-acoustic instabilities, which was also observed experimentally [2].

References:

1. Vladimir Gorokhovsky. Modeling of DC Discharges in Argon at Low Pressures. Proceedings of the 2012 COMSOL
2. Trushnikov, D. N., et al. Current-driven ion-acoustic and potential-relaxation instabilities excited in plasma plume during electron beam welding. AIP Advances 4.4 (2014): 7105.