Modeling the generation and propagation of plasma jets

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We use our previously developed two-dimensional fluid model [1] to study the generation and propagation of plasma jets generated in a dielectric barrier discharge configuration consisting of a cylindrical dielectric tube surrounded by a concentric grounded electrode. A positive voltage pulse is applied to a ring electrode inside the dielectric tube. Experimentally, a plasma jet consisting of a rapidly propagating plasma front (or "bullet") is observed under similar conditions [2] and with a gas flow (mainly helium with a flow velocity of some 10 m/s).
The variables in our discharge model are the electron and ion densities, electron average energy, and electric potential. These variables are functions of space and time. The charged particles are described by their respective continuity equations in the drift-diffusion approximation. Plasma chemistry has not yet been included in these preliminary calculations of the plasma jets and hence electron impact ionization of ground state atoms is the only ionization process taken into account at this point. Secondary electron emission due to ion bombardment is included with a constant secondary electron emission coefficient. Dielectric boundary conditions are applied on the tube walls, and electrons and ions are assumed to stick on the surface and to recombine instantaneously when a charged particle of opposite sign arrives at the same surface element. The computational volume extends a finite distance past the exit plane of the dielectric tube and the computational boundaries are supposed to be at ground potential. The distribution of electric potential is governed by the geometry, the boundary conditions, the applied voltage, the volumetric space charge distribution and the surface charges, and this distribution is calculated by solving Poisson's equation. We do not calculate the hydrodynamics but rather we assume that the gas outside the tube is segregated into a on-axis column of atmospheric pressure helium with a diameter equal to the dielectric tube diameter, surrounded by air or nitrogen at atmospheric pressure.

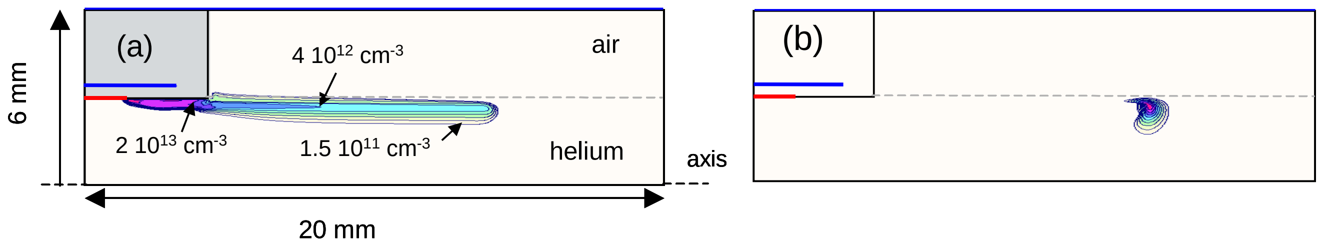

Figure 1: (a) Electron density distribution, and (b) ionisation rate (log scale, max 10^{21} $cm^{-3}s^{-1}$) at time t = 130 ns

The conditions chosen for these preliminary calculations are shown on Fig. 1. A voltage pulse of 5 kV is applied between the electrodes, with a rise time of 50 ns. The pressure of helium in the column (and of air outside) is 1 bar. The boundary conditions on the electric potential (i.e. surrounding potential lower than the anode potential) are essential to obtain ejection of the plasma bullet. The plasma does not move radially toward the lower potential region outside the dielectric tube because the field is not large enough to ionise air and helium (in the central column) is much easier to ionise. As seen on Fig. 1b, ionisation (and excitation) takes place at the front of the plasma column expanding outside the tube because of the presence of an ion sheath in that region. Electron multiplication takes place in this sheath leading to the formation of an ionisation wave, and the calculations show that a very small background charged particle density is sufficient to allow propagation of the bullet. Although the model is a considerably simplified representation of the experimental situation, we believe it captures the essential physics. These preliminary results are consistent with trends observed experimentally : a propagating plasma front, with a propagation speed on the order of 100 km/s and restricted to the volume of the helium gas column, occurs on the rising and falling edges of the voltage pulse. A discussion of the mechanisms of propagation will be presented along with some suggestions for what experiments are needed to validate these ideas.

References

[1] JP Boeuf and LC Pitchford, Phys. Rev. E51, 1376 (1995)

[2] X Lu and M Laroussi, J Appl Phys 100 063302 (2006)