

Femtosecond Laser-guided Electric Discharge in Air

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Abstract: We study a new type of electric discharges triggered in air by intense femtosecond IR laser pulses. The discharge initiation is attributed to Joule heating of the laser-generated plasma column of uniform density.

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We have studied a new type of electric discharge triggered in air by intense femtosecond IR laser pulses. When propagating in atmosphere, such pulses self-organize in the form of filaments, leaving in their wake a thin plasma column with uniform density along the axis. This plasma column can act as a trigger for electric discharges. The discharge occurs under reduced applied voltage and follows the path of the self-guided laser pulse (see figure). Its onset is reproducible, but occurs with a measurable delay. This is to be contrasted with the typical discharge initiated by a non-uniform laser-produced plasma, for which the onset of the discharge fluctuates considerably from shot to shot.

We explain the discharge initiation as follows. During the relaxation of the electron density in the uniform plasma column, Joule heating is locally efficient around the column axis. The temperature and thus the pressure in the column is higher than in the ambient gas, causing a lateral expansion, which eventually leaves a diminished gas density around the axis. The reduced gas density gives rise to a lower discharge threshold.

Simulations in cylindrical geometry with the hydrodynamic code MULTI show that the formation of a density depression of down to 50% around the column axis is established within a time interval of 30-50 ns, assuming a homogeneous gas density and an enhanced temperature around the axis due to the applied DC field.

Time-resolved diffraction measurement of the plasma column confirms this model. In the absence of applied DC electric field, the far field diffraction pattern vanishes within a few ns, translating the recombination lifetime of the plasma carriers. In the presence of the DC field however, a second diffraction pattern appears after 40 ns, in good agreement with the predicted time scale for the density depression seen in the simulations. We also deduce from diffraction analysis that the gas density is about 50% lower than in the ambient gas.



Left: spontaneous discharge in air between two electrodes with 30 kV/cm applied voltage. Right: discharge triggered by a self-guided femtosecond IR laser pulse. Applied voltage is 15 kV/cm.
The distance between the electrodes is 2 cm.