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Synergistic control of radical generation in an RF atmospheric-pressure plasma jet via voltage waveform tailoring and structured electrodes — We investigated a modified COST radio frequency, atmospheric pressure microplasma jet operated in He with 0.1% O_2, featuring rectangular trenches in both electrodes and driven by “Peaks” and “Valleys” voltage waveforms synthesized from four consecutive harmonics. Using 2D fluid simulations (nonPDPSIM) together with PROES and TDLAS experiments, we show that waveform-controlled sheath dynamics and trench-induced current focusing act synergistically to localize electron power absorption and, consequently, electron-impact-driven radical production. The tailored voltage waveforms break the symmetry typical of single-frequency excitation: a single pronounced hotspot forms inside a trench at either the powered or grounded electrode (depending on the waveform), while additional maxima may occur at trench edges. Switching between “Peaks” and “Valleys” therefore provides an electrically reversible way to shift the region of strongest excitation and radical generation, enabling spatially selective enhancement of species such as He metastables and atomic oxygen [1].

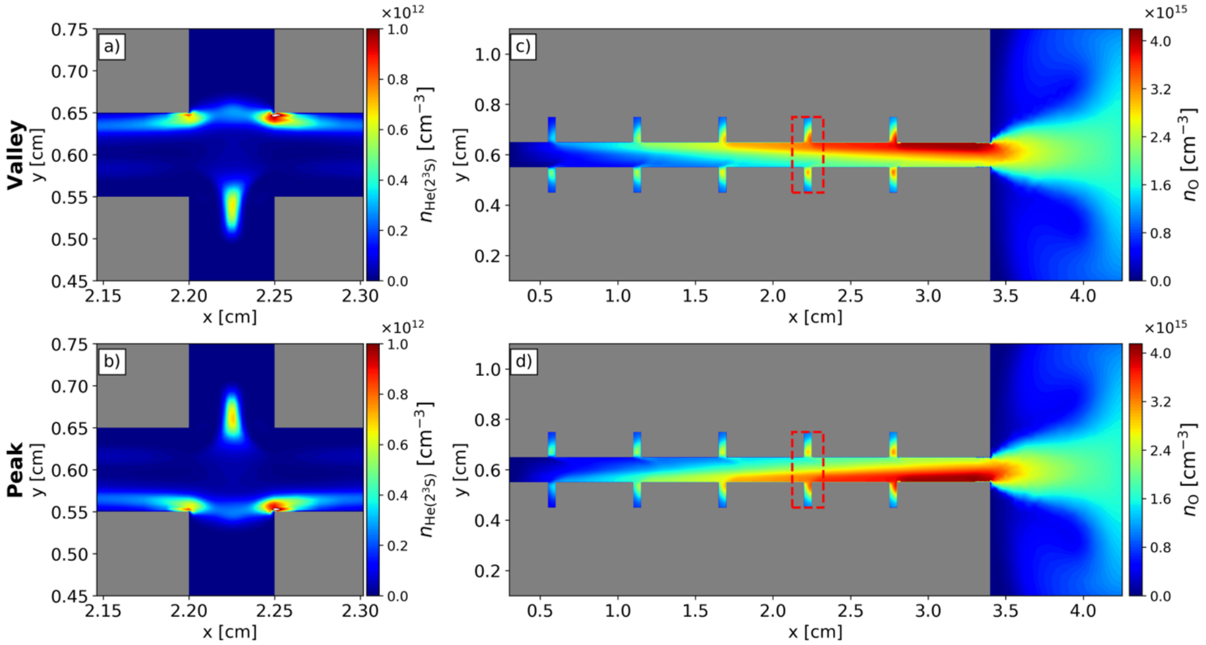

Figure 1. Simulation results for “Valleys” (top) and “Peaks” (bottom) driving waveforms: helium metastable density in (a, b) and atomic oxygen density in (c, d). The red dashed rectangles in (c) and (d) indicate the trench region. Operating conditions: p = 10^5 Pa, V_{pp} = 600 V, f_b = 13.56 MHz.

Electron density measurements and calculations in a helium capacitively-coupled radio-frequency plasma. — Measurements of the electron density in low-pressure radiofrequency (RF) discharges can be accomplished by various types of probes (Langmuir probes, hairpin probes, etc.), by microwave interferometry, and by laser diagnostics methods. We have carried out, in collaboration with Sandia National Laboratory, Laser-Collision Induced Fluorescence (LCIF) measurements and numerical modeling calculations of the electron density and the electron temperature in low-pressure capacitively-coupled radiofrequency discharges in helium gas. The experimental plasma source was a symmetric Capacitively

Coupled Plasma (CCP) cell, with a pair of stainless-steel electrodes of 14.2 cm diameter, placed at a distance of L = 4 cm from each other. The gas pressure was set between 50 mTorr and 1000 mTorr and RF peak-to-peak voltages between V_{PP} = 150 V and 350 V were used at a frequency of f = 13.56 MHz. LCIF is an extension of the Laser Induced Fluorescence (LIF) technique, employing laser excitation of the gas atoms in the plasma from a lower-lying level (L1) to a higher-lying level (L2). In LIF, the radiation emitted from the atoms as these decay spontaneously from the higher-lying level (L2) to a lower-lying level (L3, typically different than the original lower-lying level, L1) is measured to quantify the density of the atoms in level L1. In the case of LCIF, in addition to monitoring the LIF signal from the level L2, the emission is also monitored from additional levels, which are close to L2 but have somewhat higher energy. These excited levels are populated primarily via collisions between the laser excited species (L2 level) and energetic electrons of the plasma. The computational framework was based on a Particle-in-Cell / Monte Carlo Collisions (PIC/MCC) simulation code that included He atoms in several excited levels in addition to the ground-state He atoms, as targets for electron-impact collisions. The results of the measurements and the calculations are compared in Figure 2. for the case of V_{PP} = 350 V peak-to-peak RF excitation voltage and various pressures; panel (a) shows the electron density, n_e, while panel (b) the electron temperature, T_e. There is a generally good agreement between the measured and computed values of the electron density in the central region of the plasma, whereas differences exist in the sheath domains. A general feature of the measured electron density distributions is the relatively high density in the sheath regions, which needs further clarification. The agreement of the bulk electron density values is weaker at the lowest pressure, but still remains within a factor of two, which is acceptable considering the experimental errors as well as the accuracy of the input data of the discharge model. The electron temperature values in the plasma bulk agree well as it can be seen in Figure 2(b). The measurement, however, appears to underestimate this quantity in the sheath regions [2].

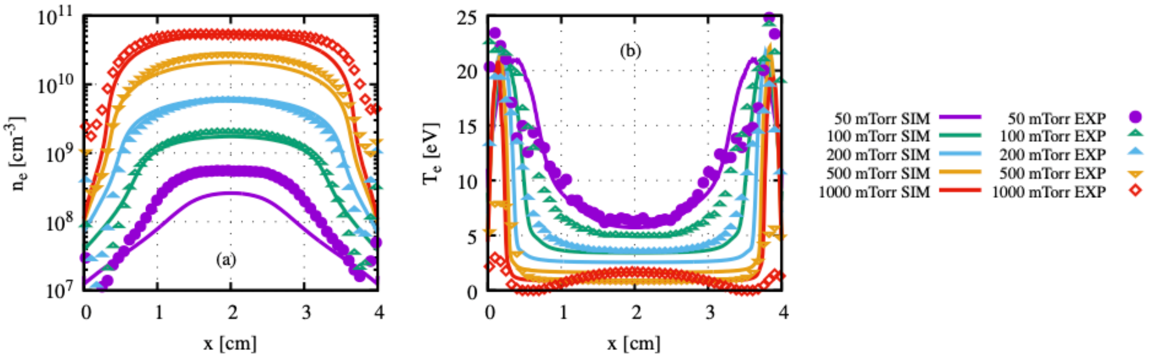

Figure 2. Comparison of the measured ('EXP') and computed ('SIM') electron density, n_e, (a) and electron temperature, T_e, (b), at V_{PP} = 350 V peak-to-peak RF excitation voltage and various He gas pressures.

References:

[1] https://iopscience.iop.org/article/10.1088/1361-6463/ae08c7

[2] https://iopscience.iop.org/article/10.1088/1361-6595/adb178