Ultrafast Nanosecond Imaging of Non-thermal Plasmas with Multiple emICCD Cameras

Background

Scientists at the Institute for Pulsed Power Science of Kumamoto University in Japan are studying streamer discharge where a voltage difference is applied across an insulating gas or air. Streamers have a filamentous structure (think of the fine discharge arc from a tesla coil that are used for electricity shows and demos) and are a form of non-thermal plasma where the electron temperature is much higher than the ion temperature. Roughly speaking a fast-pulsed high voltage will mainly move atomic electrons whereas the atomic nuclei are unaffected due to their higher mass.

Non thermal plasmas have found use in both ozone production and plasma medicine. Air purification has become an important application for non-thermal plasmas, as they can decompose mold, bacteria, viruses and other hazardous substances and pollutants such as NOx, SOx and volatile organic compounds.

The group from Japan is currently most interested in ultrashort discharges with durations of about 5ns that turn out to be more efficient in air production. There also seems to be differences in efficiency between positive and negative streamers (relating to the change in polarity of the high voltage potential used in their production). The mechanisms for this efficiency increase are not yet well understood though.

Ultrafast nanosecond imaging of plasma discharge

The researchers recently published a conference paper where they describe how they use ultrafast imaging of the generated streamers on the nanosecond timescale to characterize their size as well as propagation distance and velocity. A new experimental system based on intensified CCD cameras (ICCDs) can take snapshots of the plasma discharge. ICCDs use an image intensifier tube that allows to apply a variable electronic shutter, called the gate, with opening times (gatewidth) down to sub nanosecond timescales and amplifies the signal using a variable gain so even low numbers of photons can be observed. The interframe time in ICCDs is much longer (100 times or more) than the lowest gatewidth. However, observing the dynamics of the sub 10ns plasma discharge requires acquisition of more than one snapshot image.

The researchers present a new experimental setup using a framing system based on 4 electron-multiplied ICCD cameras (PI-MAX4:1024EMB emICCDs). The cameras are setup to precisely trigger acquisition with 2.5ns delay between cameras so a sequence of 4 images taken within 10ns can be used to analyze the dynamics of the generated streamers. This corresponds to a burst frame rate of 400MHz. Besides the ultrafast timing, emICCD cameras are designed using a double gain mechanism, combining intensifier gain with on-chip signal gain which allows for stronger amplification of low light signals using ultrashort gatewidths. The double gain of the emICCD solves the problem of non-linear signal response of standard ICCDs. The combined gain of the camera allows for linear response over a wide intensity range, so low and high light intensity regions can be quantitatively analyzed.

This research shows that sensitive detection with multiple emICCD cameras is an effective way to analyze the dynamics of ultrafast phenomena and works well to characterize non-thermal transient plasma discharges on the nanosecond timescale.

References:

- https://ieeexplore.ieee.org/abstract/document/9009760
- https://www.intechopen.com/books/air-pollution-a-comprehensive-perspective/non-thermal-plasma-technic-for-air-pollution-control