Laser-Induced Fluorescence Images of NO Distribution After Needle-Plane Pulsed Negative Corona Discharge

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Abstract—Images showing the spatial distribution of nitric oxide (NO) following propagation of a 30 ns pulsed, negative streamer between needle-plane electrodes, in 25 parts per million (ppm) NO seeded air, are reported. The images were generated using laser-induced fluorescence, and show uniform destruction of 10 ppm NO between the cathode and anode. This evidence shows that processes associated with the propagating streamer are responsible for uniform destruction of NO throughout the electrode gap.

Fig. 1. Shown above are LIF images of NO before (b) and 10 ms after (c) a pulsed negative corona discharge in 25 parts per million (ppm) NO seeded air. (a) is the difference between the two images. The gray regions indicate the electrode location. Gas flows in from the left-hand side, while the laser propagates from the right-hand side. The inset on (a) is a plot of the calculated reduced pre-breakdown electric field as a function of position in the gap for the centerline of the electrodes.

STREAMER-TYPE atmospheric pressure discharges can be used in a variety of chemical processing applications [1], [2]. The discharges have several advantages for chemical processing including large active plasma volume, high throughput, and low background gas temperature. It is particularly of interest to generate energetic electrons without heating the background gas. The energetic electrons can then generate dissociated, ionized and radical species. One application is the destruction of nitric oxide (NO)\textsubscript{x} from combustion effluent through the production of O, O(\textsuperscript{3}D), OH, and N radical species, which can then produce subsequent chemical reactions [3].

Models of the streamer dynamics are under development [4]. To test them, time and spatial measurements of NO destruction in an actual reactor are required [5]. The images presented here...
are a first attempt to directly determine NO destruction in a single streamer. Such measurements are needed to provide data for the development of detailed time and spatially dependent single-streamer simulations.

The experiment is comprised of a needle-plane electrode assembly mounted within a flow chamber. Dry bottled air flows through the system at a low velocity of $\approx 2$ cm/s. A short high voltage Gaussian pulse of either polarity applied to the needle electrode creates the streamer discharge which propagates between the needle and ground electrodes. For the images shown in Fig. 1 negative pulses were used. Negative polarity was chosen because of the tendency for negative streamers to form only a single channel. The switched voltage is 20 kV, pulsewidth 30 ns, corona current 500 mA, and anode-cathode gap 7.3 mm. The laser system consists of a tripled-Nd: YAG-pumped optical parametric oscillator (OPO) that is subsequently doubled, and generates $\approx 3$ mJ of 226.2 nm radiation in a 7 ns pulse. The bandwidth of the radiation is $\approx 4$ cm$^{-1}$, somewhat larger than the pressure broadened bandwidth of the absorption transition, which is $\approx 0.5$ cm$^{-1}$. The beam is focussed to a sheet with a 550 mm cylindrical lens. The NO fluorescence is imaged onto a charge-coupled device camera. A narrow bandpass filter centered at 253 nm is used to pass the Stokes shifted fluorescence and block both the pump wavelength and N$_2$ fluorescence.

The laser and discharge are synchronized and operate at 10 Hz. After each streamer discharge the gas flows $\approx 2$ mm. Thus, every discharge/laser shot processes a “fresh” supply of gas. This permits the use of multiple exposures to increase signal to noise. The images of Fig. 1 are accumulations of 50 discharge/laser shots. The camera shutter is opened for 5 s, time-integrating the light from both the laser and the discharge. Background due to the discharge is eliminated by subtracting images of the discharge alone, taken with the laser tuned off resonance (228 nm). The use of the detuned laser insures similar discharge characteristics for the laser-induced fluorescence (LIF)/no LIF images. Rapid quenching of the NO fluorescence by oxygen in the air causes fluorescence of the LIF signal to follow the temporal profile of the laser pulse. This was verified by with fast photo-multiplier tube measurements.

Fig. 1(b) shows the LIF when fresh gas is between the electrode, approximately 10 ms before the discharge. Note that the downstream NO concentration is significantly depleted due to previous discharges. When the delay between the laser and the discharge is greater than 10 ms, significant smearing of the NO destruction zone occurs in the horizontal direction due to the gas velocity. The image of Fig. 1(c) was taken 10 ms after the discharge, thus the resolution is degraded. The resolution in the horizontal direction is further limited because the streamer discharge location varies with each shot. The accumulation of 50 images thus completely smears the spatial information in the horizontal direction over the region where streamers can occur. Though some spatial information can be reconstructed by statistically surveying the spatial location of the streamers for hundreds of shots and applying the measured profiles to the final images, such a deconvolution has not been done for the images of Fig. 1. In the vertical direction, the streamer profile will be essentially constant with each discharge. Thus, the spatial information from the images in the direction perpendicular to the flow is informative.

The image in Fig. 1(a) suggests that the destruction of NO is nearly uniform across the laser sheet. The measured destruction is $\sim 10$ ppm throughout most of the streamer region. This implies a fairly uniform radical production regime within the destruction zone. Since the radical production is a very strong function of the local electric field, this would imply a fairly uniform field along the gap. The high field is most likely generated in the region near the streamer head which sweeps across the gap.

REFERENCES