Determination of the electric field in filamentary DBDs by laser electric field measurements

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A Coherent anti-Stokes Raman spectroscopy (CARS) like technique has been demonstrated to determine the electric field strength of a pulsed-driven filamentary dielectric barrier discharge (DBD) of 1 mm gap. Hydrogen was used as a tracer in nitrogen at atmospheric pressure for the investigation. The alteration of the electric field was observed during the internal polarity reversal and the breakdown process.

1. Introduction

The characteristic of dielectric barrier discharges (DBDs) is mainly determined by the electric field strength before and during breakdown. There are few methods to measure the electric field strength based on optical emission spectroscopy e.g. Stark polarization spectroscopy [1]. But when there is no discharge and hence no emission other methods have to be applied. To evaluate the electric field strength in the gap during the whole discharge development (including the pre-phase and the afterglow where the emission is weak) a Coherent anti-Stokes Raman spectroscopy (CARS) like technique was applied to a pulsed-driven single filament DBD in a hydrogen-nitrogen gas mixture at atmospheric pressure.

2. Experimental setup

2.1. DBD arrangement

A symmetric single filament DBD arrangement was used for the experiments, implemented in a vacuum cell made of stainless steel with a gas inlet on top and an outlet to a vacuum pumping system at the bottom. The DBDs in the gap were observed through two lateral quartz glass windows also used for the laser beams. To ensure that subsequent DBDs were located in the same position, half sphere alumina-covered metal electrodes were used. Each dielectric barrier was about 0.5 mm thick and the gap between the electrodes was 1 mm (see figure 1). The gas mixture was varied from 5 to 10 % H_2 in N_2 at 1 atm with a constant total flow of 1000 sccm.

The DBD was driven by positive square wave pulses with 10 kV amplitude at a repetition rate of 10 kHz synchronized with the laser system. Two different pulse widths were chosen: 10 µs and 50 µs. The slope of the pulse voltage was approx. 250 V/ns, specified by a pulse generator supplied by a high voltage power supply and controlled by a digital delay generator (see [2] for more details). Electrical and optical measurements were performed with fast probes and detectors and recorded with a digital sampling oscilloscope. The DBDs were observed by a fast ICCD camera.

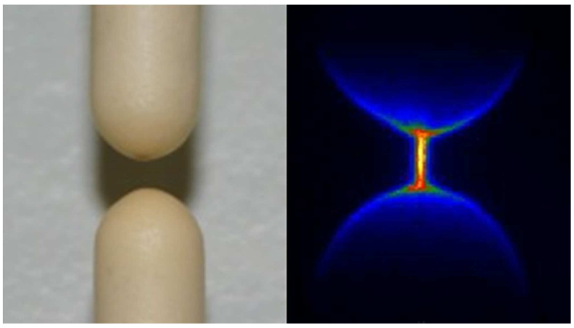

Fig. 1: Alumina covered electrodes without and with DBD filament in the 1 mm gap.

2.2. CARS setup

The CARS setup consists of a frequency doubled Nd:YAG laser operated at 20 Hz and a dye laser pumped with 90 % of the Nd:YAG energy at 532 nm (ω_{pump}, Fig. 2). The dye laser generates tuneable laser radiation at 683 nm (ω_{Stokes}, Fig. 2) necessary for the Raman transitions in hydrogen.

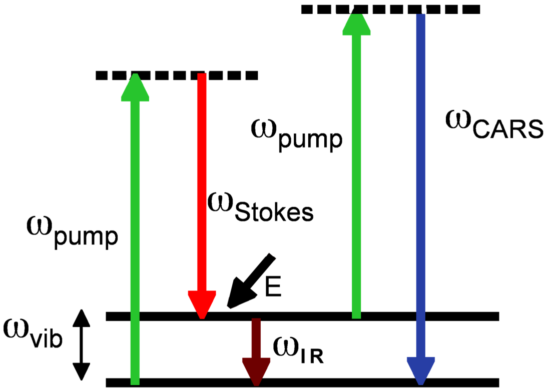

Fig. 2: Energy diagram of the technique.

Both laser beams are superimposed and focused into the discharge cell. They are polarized parallel to each other. The generated anti-Stokes radiation in the infrared (IR, 2.4 µm) spectral range depends on the electric field and is focused on an IR detector (setup shown in Fig. 3). Details of the laser setup and the diagnostics are described in [3].

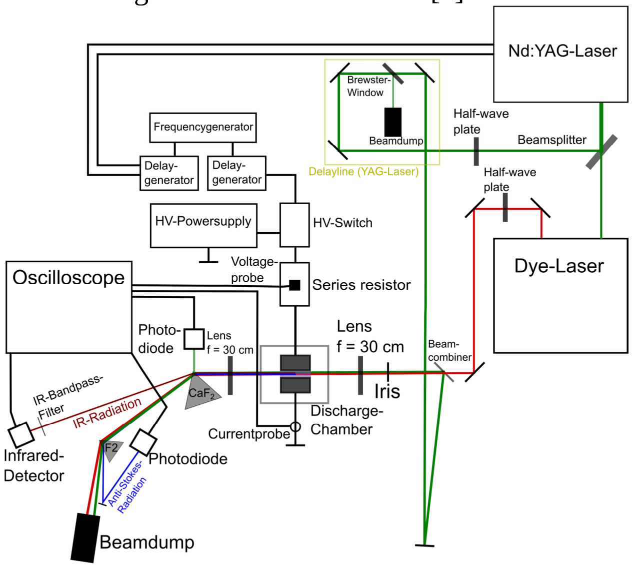

Fig. 3: Experimental setup.

3. Results and discussion

Hydrogen was used as a tracer in nitrogen at atmospheric pressure. Most experiments were performed with 10 % H_2 but also 5 % H_2 admixture delivers sufficient IR signal. The measured relative field strength was calibrated by the applied voltage. An influence of the laser beams on the discharge is not detectable. Current shape and ignition inception are identical. A change of the position of the laser beams in vertical or horizontal direction between the electrodes has no significant influence on the IR signal. Due to the lateral extension of the beam overlap the absolute value of the electric field strength is integrated along the line of sight of the laser beam.

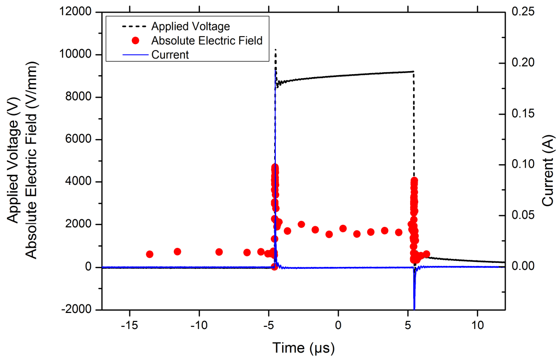

Fig. 4: Overview of the voltage pulse, the corresponding current and the electric field strength for 10 % H_2 in N_2 at 10 kV.

Figure 4 shows an overview of the voltage pulse, the corresponding current and the electric field strength for 10 % H_2 in N_2 at 10 kV pulse amplitude. The pulse width was 10 µs and the off-time was 90 µs. The discharge occurs only in the rising and falling voltage slopes and lasts for about 10 ns. The remaining field differs between the pulse free periods most likely due to changes in the remaining surface charges.

Alteration of the electric field was observed during the internal polarity reversal and the breakdown process. Figure 5 shows the development of the electric field strength during the breakdown process with a better temporal resolution. The pulse width of the laser system of about 7 ns does not allow resolution of the streamer phase in detail but the field dip at current maximum can be related to this instance.

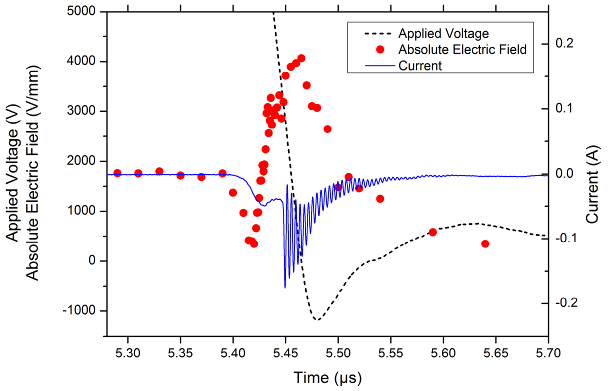

Fig. 5: Development of the electric field strength at the breakdown process. High frequency oscillations are artefacts of the current measurement.

In summary, four wave mixing has been demonstrated as a method to determine the electric field strength of a pulsed-operated filamentary DBD.

4. Acknowledgement

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5. References

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