Discharge development in the initial operation phase of a metal-based micro plasma array discharge

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Abstract: Micro cavity plasma arrays (MCPA) are discussed in plasma catalysis as well for the in-plasma reformation as for the recovering of the catalyst. The interaction between plasma, gas and (catalytic) surface are in the focus of the presented project. The control and tuning of the spatial and temporal plasma properties determine the efficiency of these processes. Here, we investigate the initial phase before the quasi-stationary operation of the devices by electrical and optical methods.

Keywords: Micro cavity plasma arrays, atmospheric pressure, initial phase

1. Motivation

Reformation of waste gases containing e.g. volatile organic compounds (VOCs) or transformation of simpler gases into more valuable products is of increasing interest. For reasons of efficiency, the processes have to be operated at atmospheric pressure. Another technical requirement is great throughput and operation at low temperatures. Thus, due to their non-equilibrium properties, plasmas operated at atmospheric pressure can play an important role in these processes. Most of the reformation processes are controlled by the electron energy distribution function (eedf) and can support other catalytic processes. The tendency to contract and form streamer discharges establishes a significant drawback of operation at ambient pressure. Stable operation can then be achieved by reducing the dimension of the plasmas into the sub-mm range [1]. Several different concepts of these microdischarges have been discussed [2]. Very often variations of a dielectric barrier discharge are applied.

Here we investigate as one possibility micro-cavity plasma arrays that combine the advantage of a defined plasma geometry with scalability by grouping many individual micro cavities. In the focus of our research is the coupling of the micro plasma with the gas. To optimize the efficiency of the coupling the eedf has to be tuned to optimally fit the process requirements. After an initial phase the eedf settles to a stationary periodic behavior. We investigate this initial phase of discharge operation by applying controlled bursts of voltage pulses and observing the respective optical and electrical responses of the MCPA.

2. Micro cavity plasma arrays

The investigated MPCAs as shown in Fig. 1 are formed as a stack of a 50 µm Ni foil that contains holes of 50 to 200 µm at separations of about 100 µm in a regular distribution. This powered electrode is separated from the grounded electrode by a 40 µm thick ZrO_2 dielectric. The counter electrode is realized by a plane rectangular CbSm magnet. This magnet is strong enough to keep the complete stack together. This allows to disassemble the stack to modify and analyze the catalytic dielectric surface that forms the bottom of the micro-cavity. At the same time the devices are significantly more stable than silicon based devices that show instabilities that may lead to destruction [3,4].

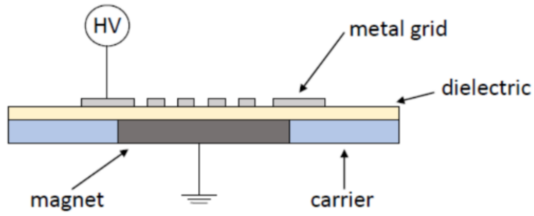

Fig. 1. Schematics of the investigated micro cavity plasma array (MCPA) device

Shape, dimension and separation of the cavities influence the eedf and subsequently the behavior of the discharge [5]. To investigate these effects four MCPAs with varying cavity diameter to distance ratios are incorporated into a plasma reactor that is shown in Fig. 2. Each of the individual arrays covers an area of about 1 cm^2. By this design we assure that the operation conditions are identical for this set of parameter variations [5]. The reactor allows optimized optical access for diagnostics while keeping the gas flow in a small sheath of 1 mm above the integrated MCPAs to optimize the plasma gas interaction.

The quartz glass cover is sealed gas tight to the MCPA assembly in order to operate it under controlled gas conditions. All gas and electrical connections are introduced from the bottom to allow unhindered optical access for active and passive optical diagnostics to the whole device surface.

Including the gas in and outlets the volume of the reactor is about 65x15x1 mm^3. The plasma source can be disassembled to get access to the dielectric for analysis as shown in Fig. 2.

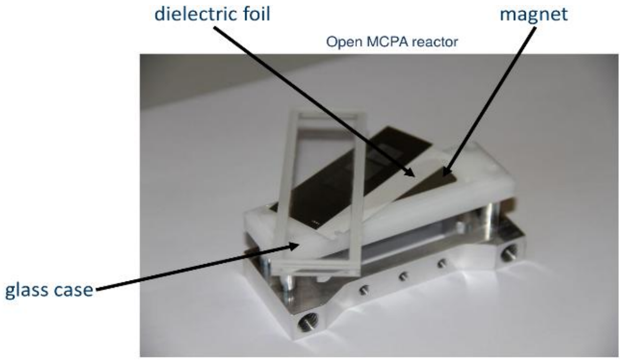

Fig. 2. Photograph of the disassembled MCPA device

3. Experimental configuration

To investigate the establishment of the stationary conditions of the MCPA operation we compare the stationary current/voltage and emission features with their time development over a pulse train (burst) of about 20 bipolar voltage pulses of up to 1.4 kV_{PP}. These pulses are applied at a frequency of 5 to 20 kHz. The pulse trains are generated by a programmable function generator in combination with a voltage amplifier. For some experiments sets of these pulse trains are applied with a repetition frequency of about 100 Hz for signal averaging. The off time is long enough to insure undisturbed conditions before each new excitation sequence.

The plasma response is measured with current and voltage probes as well as the integrated optical emission with photomultipliers. Additionally, phase resolved optical emission spectroscopic investigations are performed.

By all of these diagnostics, we follow the ignition of the discharge within the individual excitation cycles. The position of each ignition (phase) within an excitation cycle can be directly correlated to a specific external voltage.

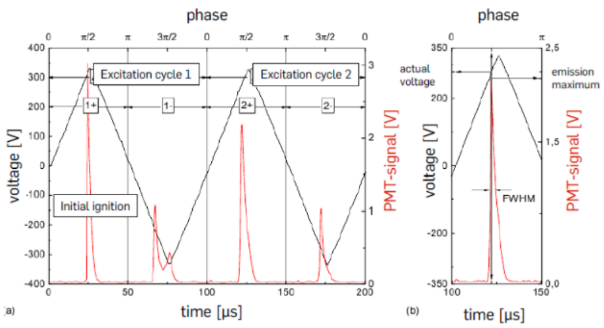

Fig. 3. a) Bipolar voltage ramp waveforms and PMT signals of the first two excitation cycles of a pulse train. Various used phase, voltage and emission definitions are given. In b) additional definitions are indicated.

Fig. 3 a) shows the voltage and emission waveforms of the first two cycles of a pulse train. Here, the first voltage pulse is applied in positive polarity to the Ni grid electrode.

4. Results

As already indicated in Fig. 3 a) the very first positive negative cycle [1-] shows a behavior that separates from the subsequent ones. It is also obvious that the positive half-period yields much higher intensities than the negative one. On the other hand, the ignition of the negative half-periods happens at lower (absolute) voltages.

As shown in Fig. 4 at a repetition frequency of 10 kHz the emission intensity in the negative half-period reaches an equilibrium after about 10 cycles. For this half-period the intensity rises to a maximum value. The equilibrium is achieved for the positive phase already after about 3 cycles but here the signal decays from an intensity similar to that of the opposite half-period to a much smaller value. Similar time dependencies can be observed also for the required ignition voltage to approach stationary values.

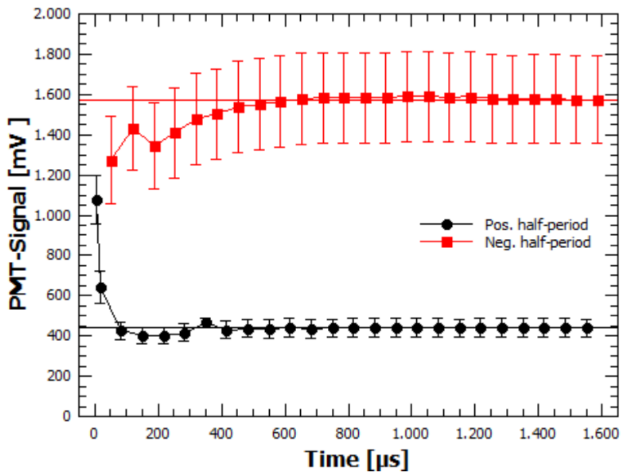

Fig. 4. Evolution of the integrated emission from the MCPA in positive and negative half-period as measured by a photomultiplier

5. Conclusions

The asymmetry of the observed signals can be attributed to the asymmetry of the MCPA device. For the positive half-period the electrons can spread over a much larger area on top of the nickel electrode while in the negative half-period the electrons are confined to the cavity volume as illustrated in Fig. 5. This behavior was described for a silicon based edged device [6].

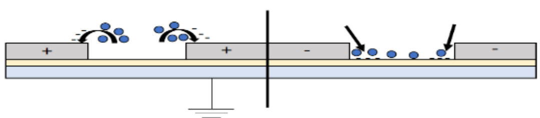

Fig. 5. Illustration of the electron dynamics in positive and negative half-period

In both half-periods the observed parameters show a convergence towards a stationary state. The array device requires about 10 cycles to establish the equilibrium of all processes but the neceassary times differ for positive and negative half-period. This allows to identify the processes that couple positive and negative half-period. This will yield a better insight into the dynamics of the MPCAs. By varying the duty cycle of the excitation voltage waveform it is possible to influence the discharge parameters without changing the applied voltage. A sequence of MCPAs might thus be adjusted to the course of the gas conversion along the reactor axis.

6. Acknowledgements

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7. References

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