Investigation of emission spectra of atmospheric CO_2 plasmas sustained with microwave pulsation in a high Q resonator

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With rapidly growing renewable energy capacity from seasonal fluctuating resources like wind and solar energy, the demand for technologies to store the surplus of renewable energy is increasing [1]. Power to liquid technologies can be used to convert surplus renewable energy into liquid fuels. The extended storage time and the high energy density per volume surpasses alternative storage solutions like flywheels, batteries or comppressed air storage [2]. Liquid fuels can be produced from syngas by use of the Fischer-Tropsch process. The use of green hydrogen and CO that was produced by reduction of CO_2 (eq. 1), captured from industrial processes or from air will finaly result in a carbon neutral liquid fuel production process [3].

$$CO_2(g) \rightarrow CO(g) + 1/2\ O_2 + 283\ kJ/mol, \tag{1}$$

For this reduction process microwave plasmas have shown the highest conversion efficiency (over 80 %) at low pressure conditions [4]. Atmospheric pressure plasma systems are much more suitable for industrial applications, however, the efficiency of the process decreases with increasing presure beacause of excessive heating of the reaction gas. At atmospheric pressure, the mean gas temperature can be lowered by modulating the supplied microwave power with times shorter than the residence time of the gas in the reactor. This was demonstrated in experiments with a coacial plasma torch [5]. Moreover, it was experimentally proven that after plasma ignition in the coaxial torch within the first two microseconds a transient non-equilibrium regime with $T_{vib}/T_{rot} \sim 2$ can be reached. This was desmonstrated to be beneficial for the CO_2 conversion and efficiency. Because of the limited power handling capabilities (< 300 W @ 2.45 GHz) of the plasma torch, the approach of microwave power modulation was also investigated in a surface wave reactor called Surfaguide, which can be operated with a power of several kilowatts [6]. Yet as compared with continuous wave operation, for the investigated pulse regimes only limited improvement in conversion and efficiency of the CO_2 splitting process was measured. For a given maximum peak power of 4 kW at 2.45 GHz the plasma inside the reactor destinguished for power off times above a certain threshold time. Therefore the electric field strength was too low to re-ignite the plasma in the Surfaguide with the next pulse. Thus to sustain the plasma with microwave modulation in the Surfaguide, the intervals between the microwave pulses had to kept below 11 µs at 4 kW microwave power. Through the concentration of electromagnetic energy in a high Q microwave resonator a surface-wave plasma re-igntion regime can be enabled. To investigate that, a reactor based on a TM_{01} cylindrical resonator with a high quality factor (Q = 2500) was designed and built to operate with microwave power modulations in a broad parameter range from 200 ns to 400 ms. The microwave cavity (see Fig. 1) is designed to ignite a CO_2 plasma at atmospheric pressure with a microwave power of 4 kW. With high resolution optical emission spectroscopy the emission spectra of pulsed CO_2 plasmas in the cavity were recorded. The latest results will be presented a the conference and carfully compared with the results reported for the pulsed CO_2 plasma sustained in the coaxial plasma torch.

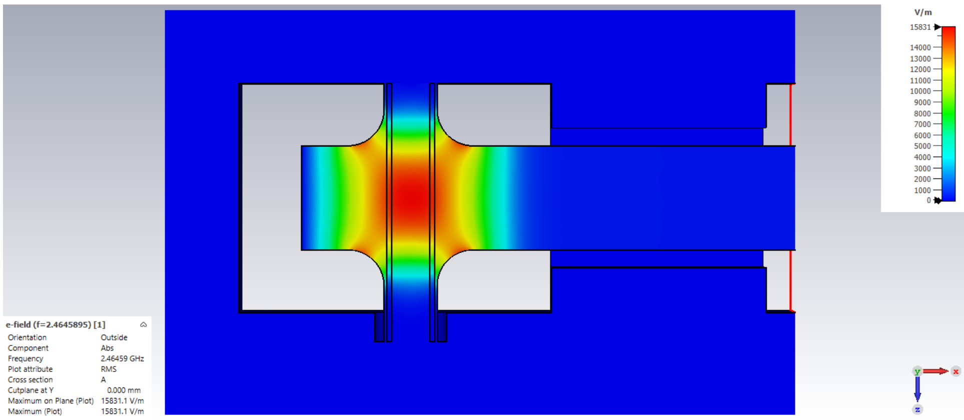

Fig. 1: Simulated electric field (RMS) in the cross-section of the self-igniting microwave cavity. CST Studio Suite was used for the simulation. The microwave input port is on the right edge and the reaction gas travels through the center of the resonator guided by a quarz tube in the maximum electric field zone.

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