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Investigations of a novel plasma torch at 915 MHz

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Introduction

Atmospheric plasma devices are an important tool for technological applications and since there is no need for vacuum components, they are mostly easy to integrate in the processline. The microwave plasma torch at 2.45 GHz previously developed at IPF was upscaled and modified to a frequency of 915 MHz [1]. This upscaling, proportional to the wavelegths, yields to an enlargement of the resonator based plasma source and thereby to an increased plasma volume. At a frequency of 915 MHz microwave generators with a power up to 100 kW are available, hence large industrial applicators can be equipped with it. A gas throughput over 30 m^3/h can be handled and atmospheric plasma volumes of above 2 liters are possible. Thus the plasma torch becomes interesting for industrial applications, e.g. the treatment of critical exhaust gases like CF_4 and SF_6 [2]. Another possible application is the deposition process with powder as precursor, the so called plasma spraying. First experiments were performed with silicon powder.

Experimental Setup

The plasma source is based on a cylindrical resonator with an adapted coaxial resonator, as seen in Fig. 1. The resonator is directly mounted on the waveguide, which feeds the resonator with microwave. In the middle of the cylinder a quartz tube with an outer diameter of 80 mm is placed. The gas supply is embedded into the coaxial resonator part and consists of one central and four tangentially orientated gas inlets. The tangential inlets yield to a rotating gas flow which stabilises the plasma and also protects the quartz tube against contact with hot plasma. The central gas inlet is integrated into the ignition tip and allows a seperated gas feeding. The ignition tip is attached to a metric fine thread M42×1.5 to tune the resonator frequency to the

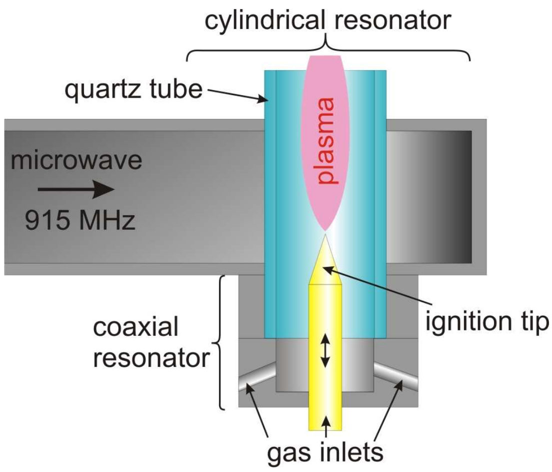

Figure 1: Schematic view of the resonator based plasma source.

magnetron frequency.

Two different modes can be found. The plasma discharge starts in the coaxial mode at the tip and switches immediately into the resonator mode if the appropriate initial parameters are set. In this second mode a voluminous freestanding plasma develops, which extends in axial direction inside the quartz tube.

Fig. 2 shows the schematic view of the experimental setup. The microwave source is a magnetron at a microwave frequency of 915 MHz and has a power of 30 kW. The circulator protects the magnetron from damage due to the reflected power. The 3-stub-tuner enables the impedance adjustment to the resonator. The experiments were carried out with compressed air which was measured by a rotameter.

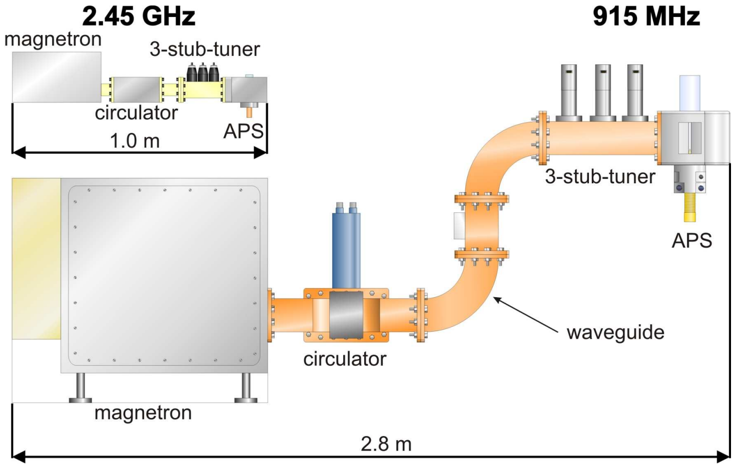

Figure 2: Schematic draw of the experimental set up and comparison between the 2.45 GHz and the 915 MHz atmospheric plasma source (APS).

For temperature measurements a spectrometer was used with a focal length of 0.75 m and a resolution $\lambda/\Delta\lambda = 20000$. The spectra are taken by an 2D ICCD camera with 1300 pixel for the spectral resolution and 1030 pixel for the spatial resolution. To image the plasma to the spectrometer slit we used an optical lense system.

For the experiments with powders we adapted the plasma torch to a vacuum vessel with a diameter of 50 cm and a length of 120 cm. We used a Roots pumping system and the pressure was controlled by a leak valve and two capacitance gauges. Nitrogen, argon and hydrogen were fed by an electronic mass flow controller to the gas inlets. The silicon powder was fed through the central gas inlet into the resonator. The variable parameters are the speed of the conveyor disc and the carrier gas flow.

Experimental results

To determine the rotational temperature profile of the neutrals and plasma ions we add to the compressed air a small amount of water vapor, which results in an emission of the OH radical between 306 and 320 nm. The molecular band system is strongly depending on the rotational temperature [3]. The measured intensity is from emissions integrated along a line of sight through the plasma. For a radially symmetric profile, which we estimated from the plasma source, the Abel inversion is a valid transformation to obtain a radial emission profile. After the transformation we compared the measured OH band system with simulated spectra at different temperatures. The temperature of the best fitting simulation was taken.

Fig. 3 shows the temperature profile determined for a gas flow of 100 slm air at a microwave power of 5.0 kW. The height of the flame is about 350 mm and the radius about 20 mm. In the region between 120 and 175 mm no spectra were obtained because of the upper boundary plate of the resonator. The maximum of the temperature profile T_{max} = 3500 K is in the middle of the resonator. The radial section of the temperature is not symmetric as we assumed above, thus we inverted the left and the right side seperately. There is a slight enhancement of the temperature on the right side of the shown plot. This behaviour can be explained by the fact that the right side faces to waveguide components and the microwave source. One can also identify a modulation of the profile in the axial direction. This is a result of the tangential gas feeding which creates a helical structure.

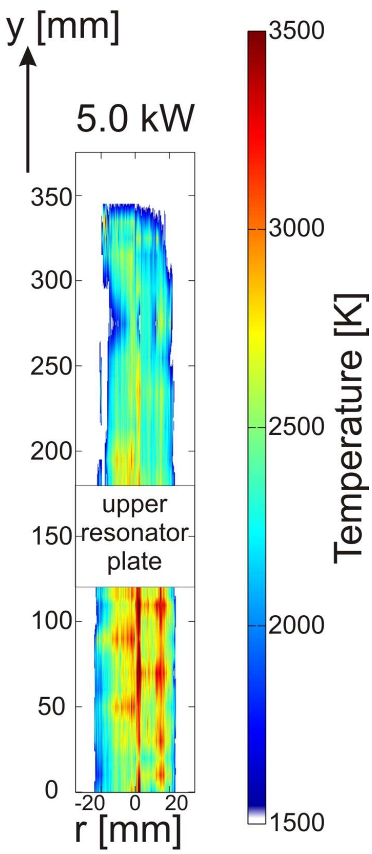

Figure 3: Temperature profile of the plasma at atmospheric pressure.

The high gas temperature found in the spectroscopic results leads to the idea to evaporate powders with the plasma and use the novel plasma torch for plasma spraying. At a pressure close to atmospheric pressure it is possible to melt up and evaporate the silicon powder completely in the plasma. This is shown in Fig. 4. The photograph in the upper right corner is a view into the resonator. It shows melted particles, which were fed from the right side following the rotating gas flow. The overview spectra shows N_2 as well as N_2^+ molecule ion band systems. In the UV region below 300 nm there are also atomic silicon lines which indicate the evaporated powder.

Our first results show, that the deposited coatings are very porous and the adhesion is insufficient. The processes which are important for the formation of the coatings happen in front of the substrate. Below a pressure of about 100 mbar the plasma cannot melt the particals completely. This is due to reduced collision frequency and a lower energy transfer between plasma and particles. The partly melted particles build a hard dense coating. By decreasing the pressure below 10 mbar the atomic silicon lines dissappear, the particles leaves the plasma source unaffected and no coating is formed.

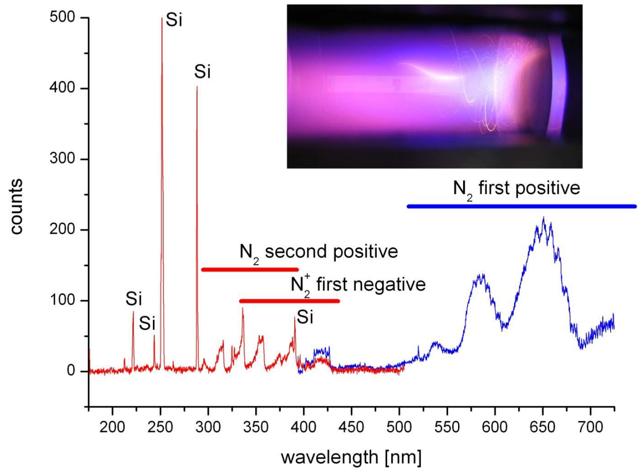

Figure 4: Overview spectra of a N_2 plasma with silicon particals and a photograph into the resonator.

Conclusion

By up-scaling our microwave plasma torch at 2.45 GHz to a frequency of 915 MHz we obtained a plasma source for many industrial applications with high throughput. In simulations we found two different modes of our system, which fit well with our experiments. Moving the ignition tip into the resonator permits an easy tuning of the source to the magnetron frequency. Optical emission spectroscopy was carried out and rotational temperatures of the plasma ions and neutrals in radial as well as axial dimension of up to $T_{max} = 3500\,K$ were measured. In first experiments we evaporated silicon powder in a nitrogen plasma and deposited coatings with different properties depending on the pressure. The next step is to improve the coating process and the coating properties in regard to their electronical and optical properties.

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