Controlling the Ambient Air Affected Reactive Species Composition in the Effluent of an Argon Plasma Jet

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The influence of ambient air species is an ever-present problem for atmospheric pressure plasma jet applications. Especially applications where the plasma induced effects are extremely sensitive to ambient species (O_2, N_2, humidity) – as for example in plasma medicine – require concepts to exclude or to control ambient species flux into the jet effluent. In this paper it is shown that the effluent of an atmosperic-pressure plasma jet is effectively shielded from ambient air species by a novel method using a gas curtain. This is confirmed by optical emision spectroscopy as well as VUV absorption measurements.

Cold plasma jets operated at atmospheric pressure generate a variety of active components like radiation, charged particles, radicals and reactive as well as excited species and are therefore valuable tools for surface treatment. Due to the moderate gas temperature cold atmospheric pressure plasma jets can also be used for biomedical applications or in plasma medicine. Although device specific distinctions in different plasma jet setups exist - ranging from the excitation frequency to the inner electrode configuration - basic similarities can be observed. Generally, plasma jets consist of a capillary or a similar type of gas channel. The electrodes, necessary for electrical power input, are situated inside or outside the capillary. A working gas, in most cases a noble gas with some molecular admixtures, is led into the jet's capillary mostly with gas flow rates of below one to up to several standard liters per minute (slm). The working gas flows through the jet's nozzle into ambient air. When a sufficient high electric field is applied on the electrodes a jet-like plasma ignites. The reaction chemistry inside the effluent is not only determined by the choice of working gas but also by the mixing of ambient air species with the effluent species. This effect leads for example to the generation of atomic oxygen and nitrogen, oxygen/nitrogen compounds, ozone as well as to hydroxyl radicals. While e.g. for bacterial inactivation treatment many of the species generated in this way are desired, this does not necessarily apply to sensitive applications in plasma therapy. Furthermore, ambient conditions can change with time and location, leading to different results, when plasma treatments are performed at different ambient conditions. In this work, we present a way to control the effluent species composition by creating a well defined gas curtain around the effluent to shield the effluent from ambient species. The invented setup is presented in Fig. 1. The atmospheric-pressure plasma jet (kinpen, neoplas GmbH, Germany; working gas: argon; flow rate: 5 slm) is enclosed by an additional hull [1]. Into that hull a shielding gas (nitrogen, oxygen or mixtures of both) with a gas flow rate of 5 slm is introduced. The effect of the shielding gas is demonstrated in the photographs of Fig. 2. When

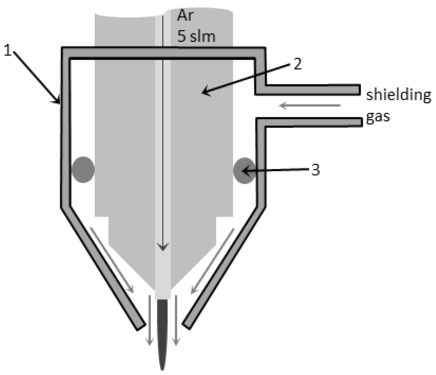

Fig. 1: Schematic setup of the gas curtain generation. 1 glass hull, 2 plasma jet, 3 centering O-ring

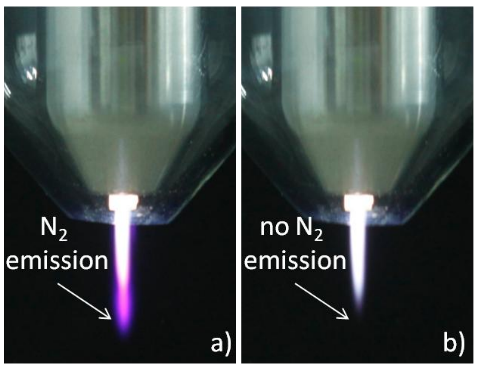

Fig. 2: Photograph of the modified plasma jet with two different shielding gas conditions. a) no shielding gas, b) 5 slm oxygen shielding gas.

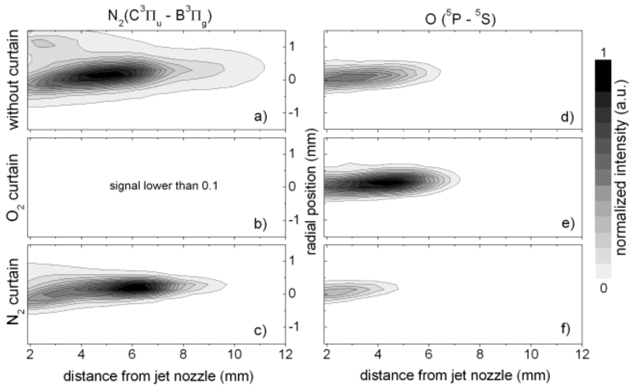

Fig. 3: Optical emission map of the 2nd positive system of nitrogen and of atomic oxygen of the plasma jet effluent for three different shielding gas conditions (100% nitrogen, 100% oxygen, and without shielding gas).

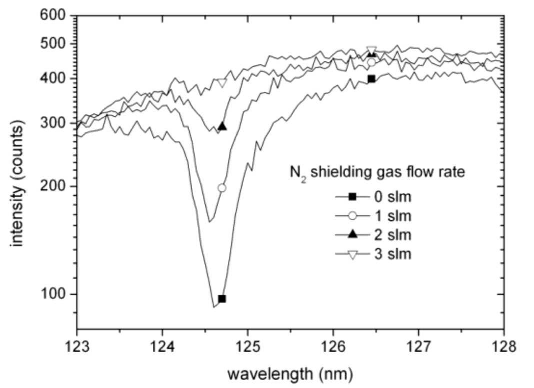

Fig. 4: Absorption dips of molecular oxygen in the VUV spectral range for different shielding gas flow rates of pure nitrogen. The distance from the jet nozzle is 9 mm.

no shielding gas is applied a violet emission is obtained at the jet nozzle. This emission can be assigned to excited nitrogen molecules. Since no nitrogen is admixed to the argon working gas ambient nitrogen must be responsible for this emission. In contrast, when oxygen is used as shielding gas no ambient nitrogen can penetrate the effluent and the violet emission is totally suppressed. This finding is confirmed by space resolved optical emission spectroscopy measurements (Fig. 3). In addition to the emission signal of excited nitrogen bands $N_2(C^3\Pi_u – B^3\Pi_g)$ integrated from 330 nm to 338 nm the integrated emission signal of atomic oxygen $O(^5P$ - $^5S)$ in the range 775 nm – 778 nm is displayed as well. The N_2 and O emission signals are normalized separately to the highest obtained intensity value that was measured for three shielding gas configurations (no shielding gas, oxygen, nitrogen). In Fig. 4a-c emission signal of N_2 displayed for no shielding gas (a), 5 slm oxygen shielding gas (b) and 5 slm nitrogen shielding gas (c). When no shielding gas is applied the highest N_2 emission is detected at about 5 mm from the jet nozzle in the center of the effluent. A comparable intensity distribution is obtained when a nitrogen shielding gas is applied. With oxygen as shielding gas, no nitrogen emission can be detected, which shows the efficiency with which the gas curtain shields from ambient nitrogen influx. The results for the O emission signal are displayed in Fig. 4d-f for the same shielding gas variations as for the presented N_2 emission signals. The highest emission intensity of the evaluated atomic oxygen line is found in the oxygen shielding condition (Fig. 4e). The profile shape is similar to the shape in the case of no shielding gas (Fig. 4d). Since no ambient oxygen is expected in the effluent when applying a nitrogen shielding gas no emission signal should be detected (compare situation in Fig. 4b). However, Fig. 4f still shows a small emission signal located near the glass nozzle. Since excited OH molecules are found in the OES this remaining signal is assumed to be not due to the ambient oxygen influx but due to the production of atomic oxygen from feed gas humidity.

In order to investigate the efficiency of the gas curtain an absorption technique in the VUV spectral range is applied [2]. Here, the radiation produced in the inside of the jet capillary is used as background light source. The intensity of this light source is detected by a VUV monochromator and a photomultiplier tube. Since oxygen diffuses into the effluent when no shielding gas is applied a molecular oxygen-specific absorption dip at 124.6 nm occurs in the spectrum (Fig. 4). By increasing the flow rate of pure nitrogen shielding gas from 0 slm to 3 slm the absorption dip vanishes.

The experimental data and fluid dynamics simulation (not shown in this abstract) confirm that a gas curtain effectively shields the effluent of a cold atmospheric pressure plasma jet from ambient air species and that plasma species are controllable by the gas curtain composition. These findings will open up a new and necessary quality level of plasma jet treatment and will help to make therapeutic applications as well as fundamental research in plasma medicine safe and more reproducible.

References

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