Atomic nitrogen measurements in an atmospheric-pressure plasma jet

Erik Wagenaars(*) [1], Timo Gans[1], Deborah O'Connell[1], Kari Niemi[1]

[1] *York Plasma Institute, Department of Physics, University of York, York, YO10 5DD, United Kingdom*
(*) erik.wagenaars@york.ac.uk

A two-photon absorption laser-induced fluorescence (TALIF) diagnostic to measure atomic nitrogen concentrations in an atmospheric-pressure plasma jet is presented. This technique uses 206.65 nm photons for the excitation of ground-state N atoms and observes fluorescence around 745 nm. With this system we achieved a good signal-to-noise ratio for the TALIF fluorescence signal with a spatial resolution of about 80 μm. Preliminary investigations show a dependence of the observed TALIF signal, and hence the atomic nitrogen concentration, on the concentration of the nitrogen admixture in the feed gas.

Atmospheric-pressure plasma jets (APPJs) in a noble gas, driven with radio-frequency (RF) voltages can operate into open air, remain at room temperature, and still have the selective reactivity characteristics known from plasma processing applications such as thin-coating technologies, production of computer chips, lighting and solar cells. The unique combination of characteristics of these new atmospheric-pressure plasmas makes them ideal tools for healthcare. Emerging applications in plasma medicine include new sterilisation techniques for medical instruments, surgical tools for clean cutting and development of techniques to directly treat living human tissue.

It is vital that a thorough, fundamental understanding of the physics and chemistry of these low-temperature plasmas is established to guarantee the effectiveness and safety of these devices in healthcare applications. This is a challenging aim since these plasmas are extremely difficult to diagnose because of their small size, highly transient nature, and most importantly the complex interactions and transport of the different plasma particles, surrounding air and biological material.

We are studying an RF-APPJ in helium with small admixtures of nitrogen and/or oxygen. The low-temperature APPJ contains high concentrations of reactive species such as atomic nitrogen and oxygen, ozone and singlet delta oxygen. These N and O radicals play a crucial role in the plasma chemistry and discharge dynamics, but are unfortunately difficult to measure experimentally.

We present a two-photon absorption laser-induced fluorescence (TALIF) technique (Fig. 1) for measuring atomic nitrogen species with spatial and temporal resolution. It uses 206.65 nm photons for excitation of ground-state N atoms and observes fluorescence of 3 lines in the range 742-746 nm. We use the 3rd harmonic of a 10 Hz Nd:YAG laser at 355 nm to pump a dye laser operated with Exalite 411 dye. The output of the dye laser is frequency-doubled using a BBO crystal to achieve the required 206.65 nm wavelength at an energy of about 0.5 mJ per pulse. The laser is sent through the plasma jet at an angle of about 45 degrees at a point 1 cm from the output of the plasma channel. A 10 nm FWHM interference filter around 745 nm is used to filter the fluorescence light that is measured with an intensified CCD camera. The gate width of the camera is 25 ns and it is synchronised with the laser.

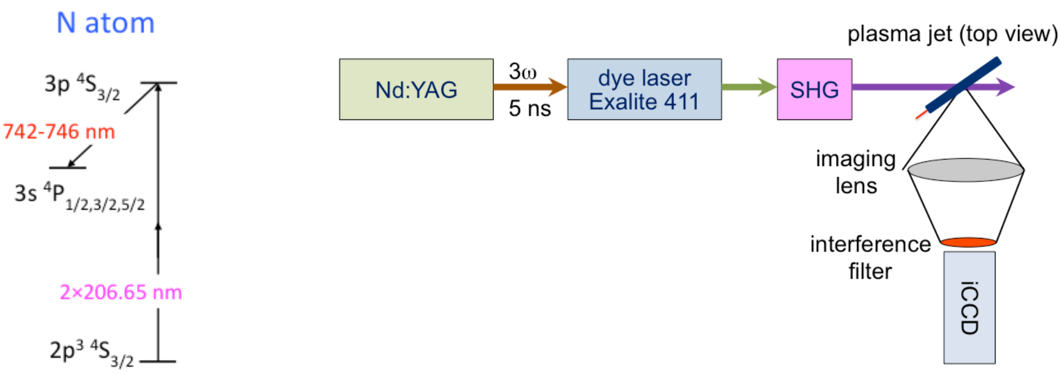

Fig. 1: Left: Excitation scheme for TALIF measurements on atomic nitrogen. Right: Experimental arrangement for TALIF measurements.

Our plasma jet is a micro-scaled APPJ device designed for optimal access for optical diagnostics [1,2]. It has been studied extensively in the past with for instance measurements of gas temperature, helium metastable, ozone, singlet delta oxygen and atomic oxygen densities [1-6]. The plasma setup consists of 2 plane parallel stainless steel electrodes with quartz windows to enclose the discharge region along both sides, but allowing access with the 206.65 nm laser beam. The core plasma channel is typically 30 mm long and has a 1x1 mm cross-section. Helium gas at 1 slm with a molecular nitrogen admixture of up to a few percent are fed through the channel. The plasma is created by applying a 13.56 MHz voltage to the top electrode via an impedance matching network.

Figure 2 shows two ICCD images, one with the laser tuned to the 2-photon resonance (206.6505 nm) and one with the laser 0.0075 nm away from the resonance. Both images are accumulations of 500 laser shots. The emission in the off-resonance case (left) is due to laser scatter off the windows of the plasma jet. The plasma channel is located in between these windows, where the bright fluorescence emission is observed in the right-hand image (for both cases the plasma jet is on, so plasma self-emission is negligible). These measurements show a good signal-to-noise ratio and an achievable spatial resolution of about 80 μm. The observed fluorescence intensity is directly proportional to the atomic nitrogen density.

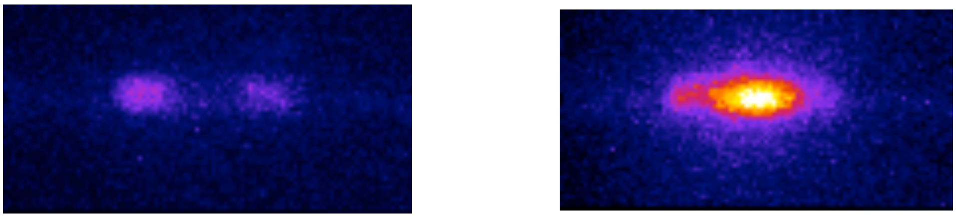

Fig. 2: Left: ICCD image taken with the laser tuned 0.0075 nm off resonance. The observed light is due to scatter of the laser from the windows of the plasma jet, leaking through the interference filter. Right: ICCD image taken with the same settings but with the laser tuned to the 2-photon excitation at 206.6505 nm.

Subsequently, the influence of the nitrogen admixture concentration on the fluorescence intensity, and therefore the N atom density, was investigated. In Fig. 3 the total fluorescence intensity (integrated over the plasma area in the ICCD image) for different nitrogen admixtures is presented and it is clear that there is an optimum in the fluorescence intensity at about 0.2% nitrogen admixture.

Further investigations will include the investigation of the spatial distribution of N along the discharge channel and in the effluent of the jet.

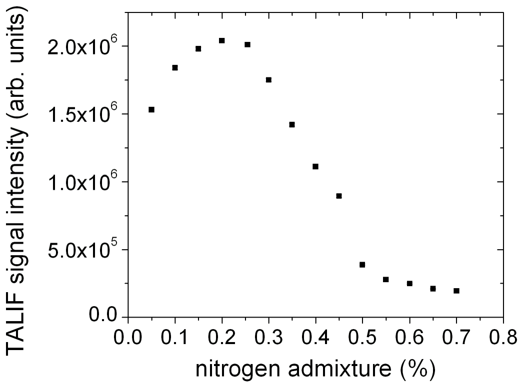

Fig. 3: Observed TALIF signal intensity as a function of nitrogen concentration in the feed gas for the plasma jet.

References

[1] V. Schulz-von der Gathen *et al., Contrib. Plasma Phys.* **47** (2007) 510-519.
[2] V. Schulz-von der Gathen *et al.*, *J. Phys. D: Appl. Phys.* **41** (2008) 194004.
[3] K. Niemi *et al.*, *J. Phys. D: Appl. Phys.* **43** (2010) 124006.
[4] K. Niemi *et al.*, *Plasma Sources Sci. Technol.*, **20** (2011) 055005.
[5] J.S. Sousa *et al., J. Appl. Phys.* **109** (2011) 123302.
[6] J. Waskoenig *et al.*, *Plasma Sources Sci. Technol.*, **19** (2010) 045018.