CARS diagnostics of atmospheric microwave plasmas

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Introduction

Non-thermal plasmas at atmospheric pressure have begun to play an important role for chemical processes. For this application different types of discharges especially dielectric barrier discharges, corona discharges and microwave discharges are under developement [1]. In this paper we give a description of a microwave excited plasma. There is not yet much information about the behavior of high pressure microwave plasmas. In order to investigate the gas temperature a coherent anti-Stokes Raman scattering (CARS) set-up was developed. Appling this technique on a nitrogen plasma, the temperature profiles were performed with a high spatial resolution. In this paper we focus on CARS measurements near the nozzle orifice of the plasma source.

Experimental arrangement

The microwave plasma source used and the whole experimental set-up are nearly the same as were reported in Pott et al. [2]. Therefore we give only a short summary here and describe some modifications. The experimental arrangement is shown in figure 1. The microwave power (P = 550 - 800 W) is generated by a commercial magnetron (Toshiba E3327, f=2.45 GHz),

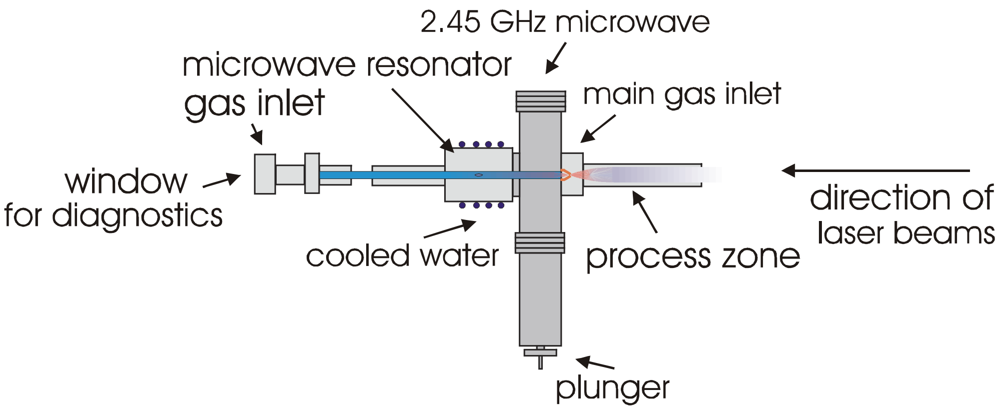
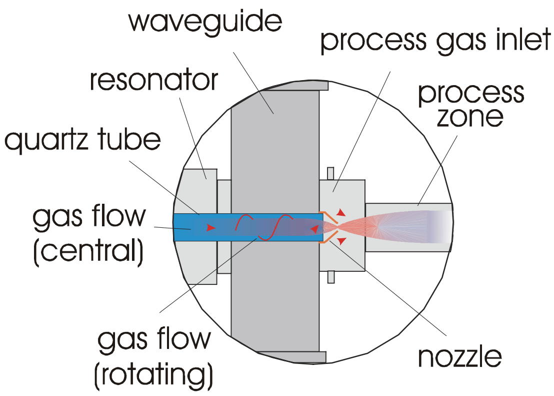
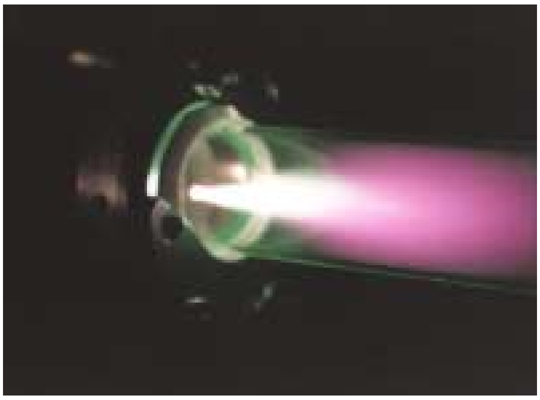


Figure 1: Experimental arrangement.

which is mounted on one end of an R26 waveguide. The other end is shut off by a tuning plunger. The discharge starts inside a cavity coupled to the waveguide. After the breakdown the discharge burns inside a quartz tube (inner diameter 26.7 mm), which intersects the cavity and the waveguide perpendicularly. The working gas nitrogen which is supplied to the quartz tube has two parts: A central flow and a rotating flow. This is necessary to avoid wall burning. The plasma leaves the quartz tube through a nozzle with an orifice diameter of 2 mm. Just behind the nozzle orifice the process gas is mixed with the plasma in the process zone. Figure 2 illustrates the gas flow in more detail.





2a) 2b)

Figure 2a: Schematicaly illustration of the gas flow.
Figure 2b: Photo of the burning discharge behind the nozzle.

CARS set-up

A scanning CARS technique with a folded BoxCARS configuration was applied to detect the coherent Raman signals from nitrogen molecules [3]. With this technique we measured the rotational and vibrational population from nitrogen molecules as shown in figure 3 and figure 4. Fitting the theortical CARS spectra to the experimental data we determined the gas temperature inside the fluorescence volume.

An injection seeded, frequency-doubled Nd:YAG laser (λ=532 nm, E=200 mJ, τ=9 ns, Δv=0.003 cm^{-1}) is used to generate the two CARS pump beams (25 mJ each) and to pump a narrow bandwidth dye laser (E=20 mJ, Δv=0.035 cm^{-1}), which delivers the Stokes beam with an appropriate wavelength for N_2 detection (588<λ<615 nm). These three laser beams are focussed by a lens (f=500 mm) into the plasma under a BoxCARS angle of 1.2°. The focus length of about 10 mm and the diameter of typically 300 µm limited the spatial resolution. The anti-Stokes Raman beam generated in the overlap volume is focussed on a gated photomultiplier (Hamamatsu, R1477), after passing a double monochromator (Acton Research, SI500), which suppresses background plasma radiation. The signals are recorded with a digital storage oscilloscope (LeCroy, LC574A). For reference purposes about 10% of the laser beams are focussed into a reference cell, filled with $3 \cdot 10^5$ Pa argon, to generate a non-resonant CARS signal. This, in the spectral range of interest here, nearly frequency independent signal, is used for referencing the resonant CARS signals.

Results of the temperature measurements from CARS experiments

For an easy test of the CARS diagnostic N_2 spectra of the laboratory air can be measured. Figure 3 shows a typical CARS spectra. The measured spectrum and the theoretical fit of 308 K shows a good agreement.

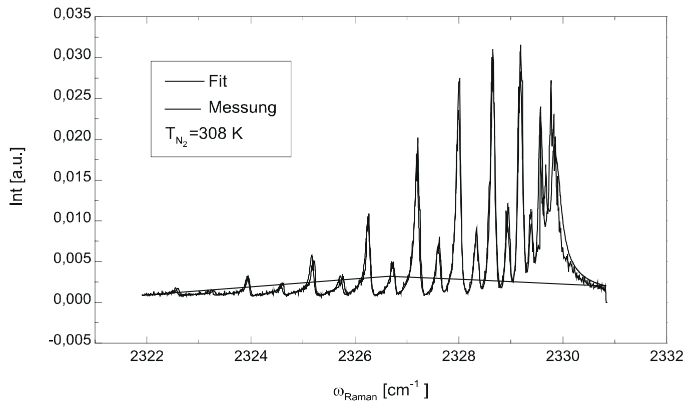


Figure 3: CARS spectrum (Q-branch v=0 → v=1) of N_2 at room temperature.

For our experiments we used 550 - 800 W microwave power. The gas flow rates are 40 standard litres per minute (slm) N_2 supplied on the quartz tube and 70 slm main gas flow. Figure 4 shows the CARS spectrum of N_2 measured at the center of the quartz tube. The CARS spectrum delivers a core temperature of 3500 K at 800 W microwave power.

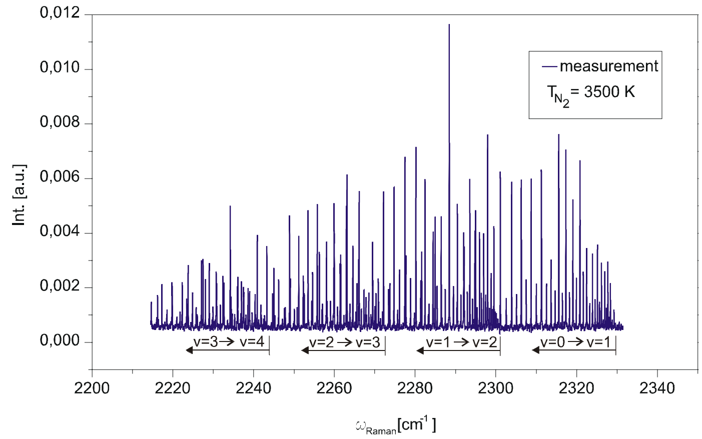
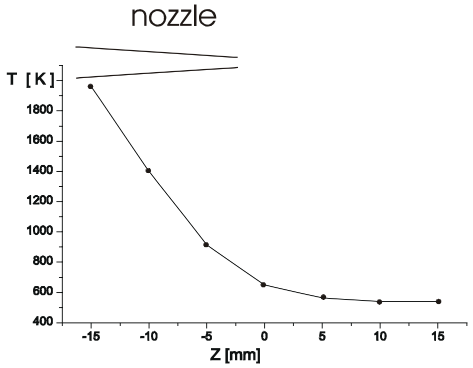
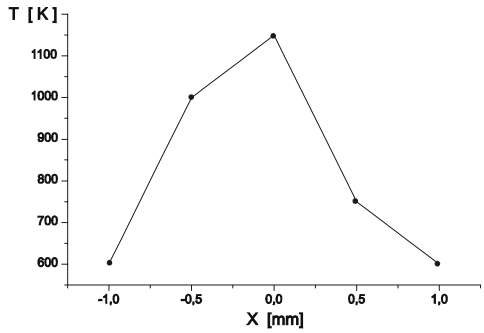


Figure 4: Measured CARS spectrum at the center of the microwave discharge. Experimental data of several hot bands together with their rotational lines are shown. The spectra delivers a gas temperature of 3500 K at 800 W microwave power.

Both the radial and axial temperature distributions near the nozzle are measured with CARS diagnostics. Therefore the laser focus is at a fixed position and the plasma source is moved. As an example figure 5a) shows such an axial temperature profile. In figure 5b) a radial temperature profile near nozzle orifice is shown.



5a)



5b)

Figure 5: Axial temperature profile (fig. 5a) and radial temperature profile (fig. 5b) near nozzle orifice at 800 W microwave power.

Summary

The common CARS diagnostic is quite appropriate to measure the temperature of N_2 with high spacial resolution. Applying this technique at the process zone near the orifice nozzles, the gas kinetic temperature of the nitrogen plasma was investigated. At 800 W microwave power the gas temperature drops from T=3500 K to T=500 K after passing the nozzle.

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