Laboratory for plasma spectroscopy and lasers

SPATIAL AND TEMPORAL RESOLVED STUDY OF SOME ATMOSPHERIC PRESSURE DISCHARGES

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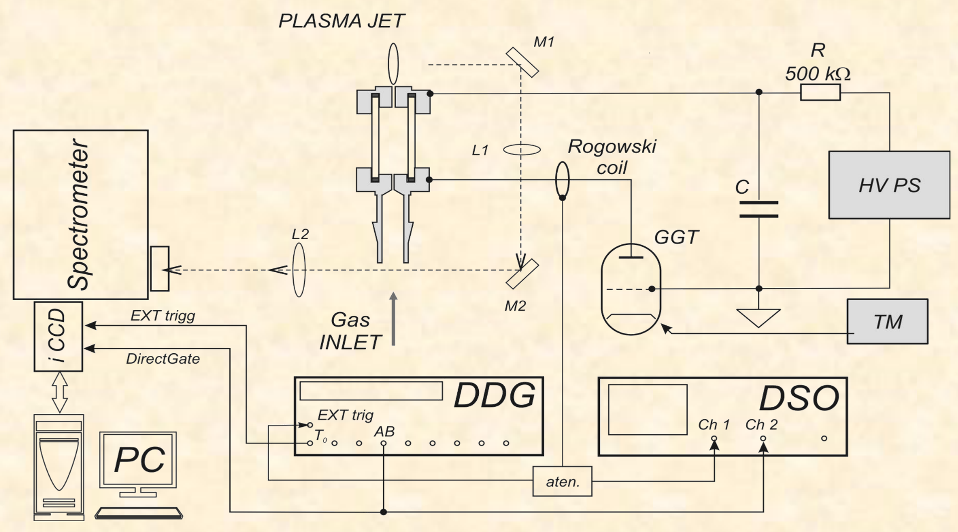
Abstract

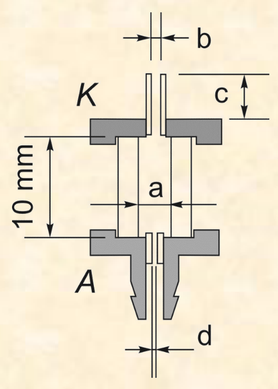
To visualize development of an atmospheric pressure discharge, short exposure time images were recorded using an iCCD camera coupled to an imaging spectrometer. Beginning and duration of discharge can be estimated from time-resolved images of discharge. This is very significant because plasma volume and temperature evolves over time causing changes in line intensity. Spatial distribution of neutrals, ions and electrons is always present in this type of sources forming different areas, so-called layers of plasma. Using of time-resolved images allow choosing of proper area for recording spectra. In this work, two types of discharges were analyzed. In first case, our source was microjet. In second case, plasma is created by combining laser pulse and spark discharge. The ultimate goal was to shed light on how the discharge morphology and emission intensity evolves over time.

Experiment

Microjet

In microjet gas is fed through a hole in center of lower electrode (d), with passage trough glass tube and output through hole in an upper electrode (b). Glass tubes with various inner diameters were used (a). In some cases, stainless steel tubes (SST) of different lengths were placed in upper hole (c).

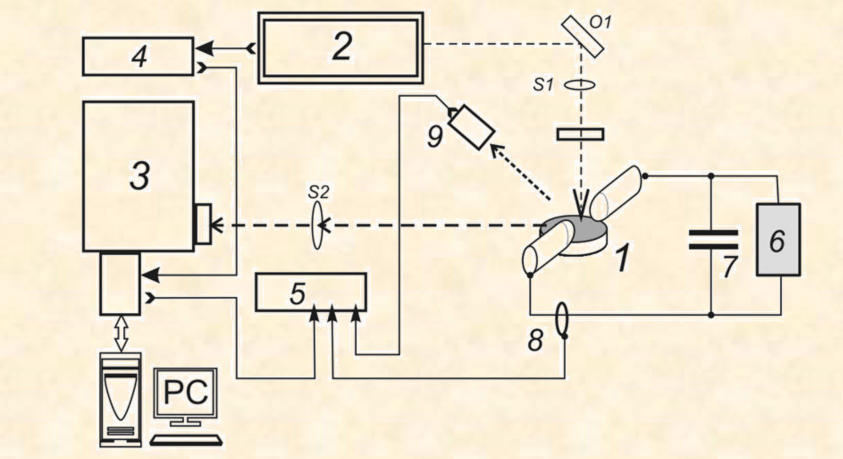


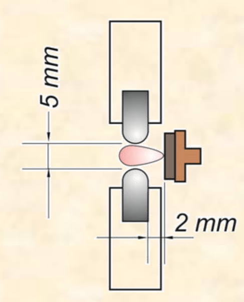


Light emitted from microjet was focused by the use of lens L_1 having focal length of 32 cm. For the recordings of plasma jet images an additional lens L_2 was used having focal length of 17 cm. Plasma image was projected on the 20 µm wide entrance slit of the 0.3 m imaging spectrometer Andor Shamrock 303 equipped with ICCD camera. The camera gating was performed with digital delay generator (DDG) by processing signal from Rogowsky coil which was used for current pulse measurements. The spectra were recorded at different delay times in respect to beginning of current pulse monitored by digital storage oscilloscope (DSO). The fast pulse discharge is driven by a different capacitors - C, charged with high voltage power supply - HV PS.

Combined technique - laser pulse + spark discharge

Laser energy - 50 mJ
Laser pulse duration - 20 ns
Laser beam diameter - 6 mm
Focal length C1 - 10 cm
Focal length C2 - 17.2 cm
Laser fluence - 1.5 J/mm^2
Target position - 1.5 mm in front of focus
Slit width - 10 mm and 2 mm
Capacity C_1=6nF; C_2=330nF
Cameras - Andor DH 720 mounted on spectrometer
- Andor DH 734 for fast photography

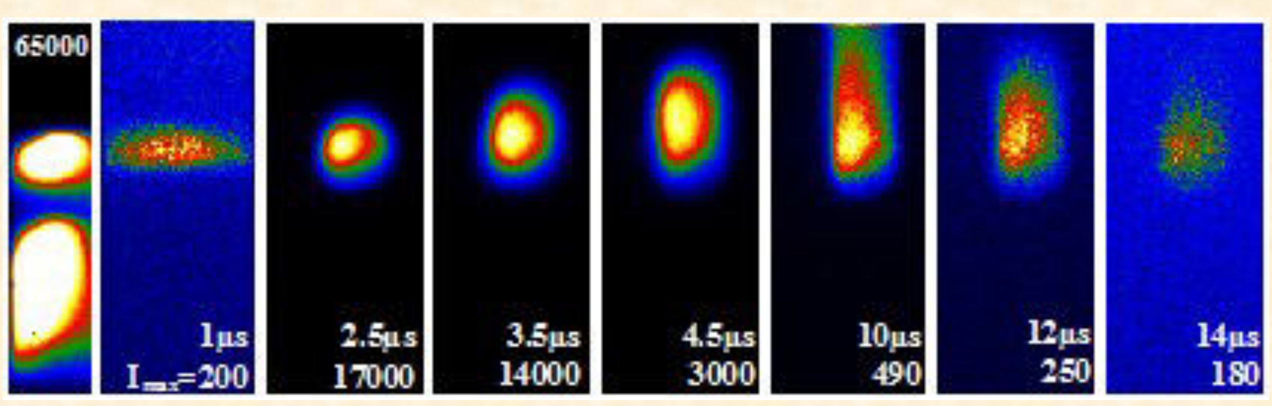




1 — ROTATING TARGET
2 — Nd-YAG LASER Molectron MY34
3 — SPECTROMETER Andor Shamrock 303-i
4 — DELAY UNIT -Stanford Researh Systems
5 — OSCILLOSCOPE - Tektronix TDS360
6 — HV POWER SUPPLY
7 — CONDENSATOR
8 — CURRENT PROBE
9 — PHOTO DIODE

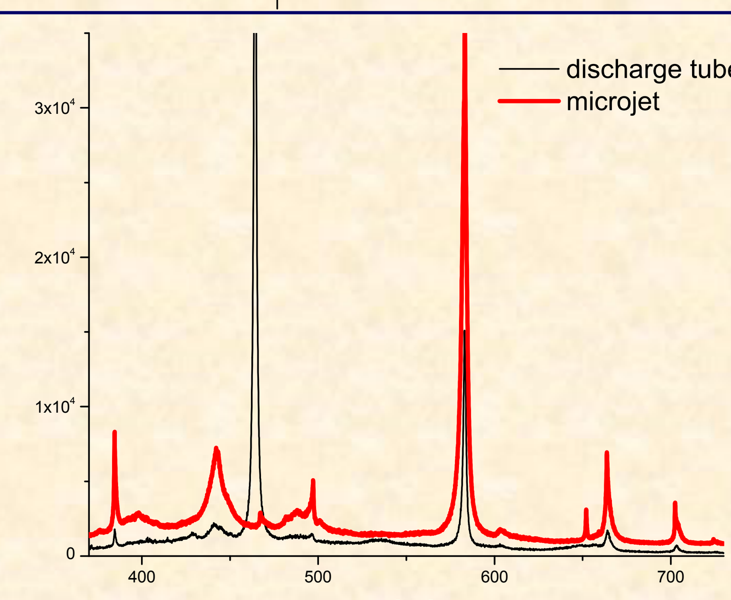
Results

Images of microjet evolvement. Each image is normalized to max light intensity.

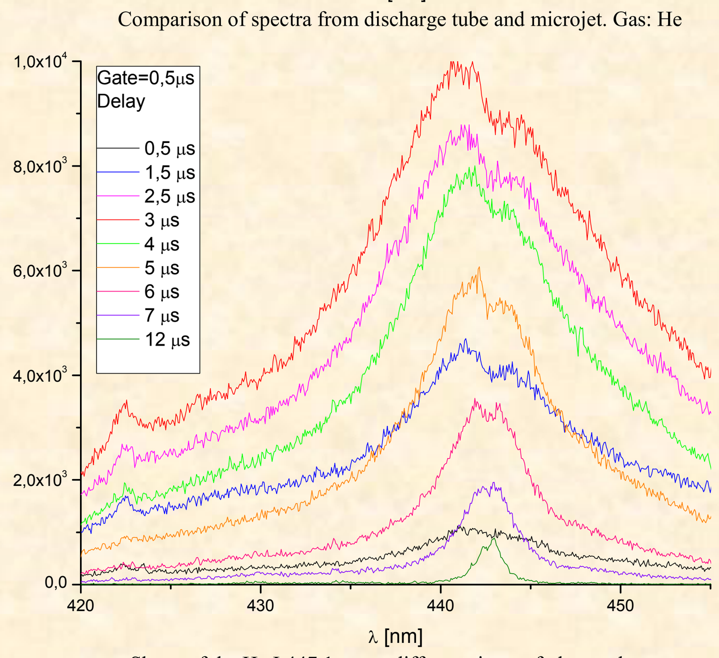


These images are classical example of temporal evolution of plasma. In this particular case, several conclusions about microjet evolvement can be made. First image depicts emission from discharge tube and microjet which is in contact with upper electrode. Images of jet were recorded by selecting spatial area that contains only emission from jet, so influence of the emission from the discharge tube was eliminated. It was discovered that microjet appears 1 µs after beginning of discharge current, reaches maximum intensity at 2.5 µs and lasts until 14 µs. Based on these observations time and spatial position of subsequent measurements were selected.

Spatial distribution of present species mostly depends of temperature which is different in every layer of plasma. It means that two spectra recorded in same time but from different layers would be dissimilar.



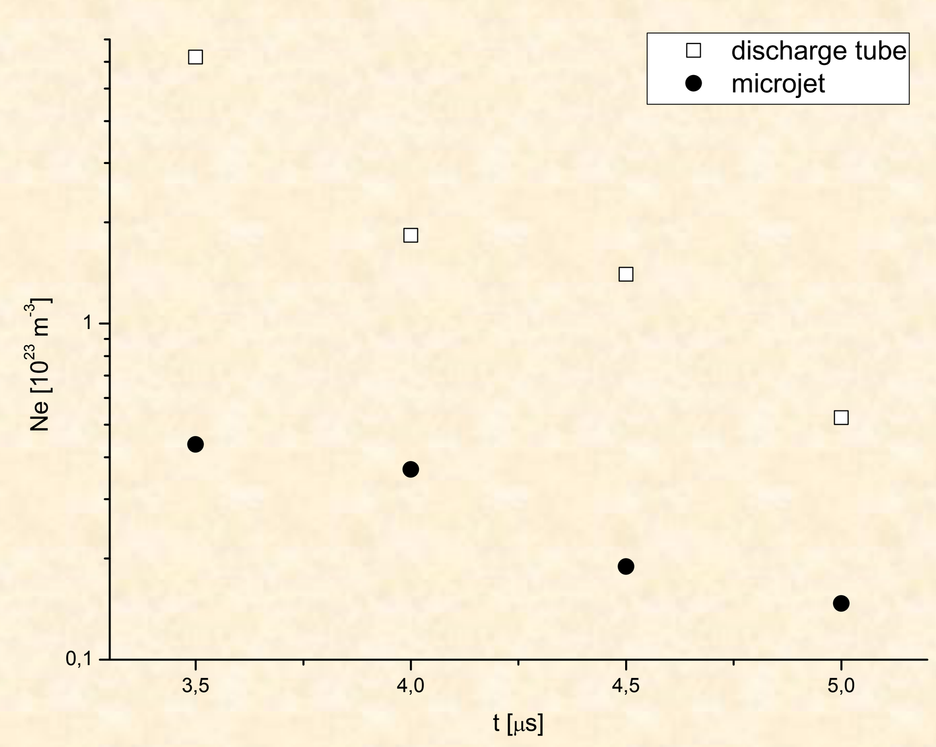
Comparison of spectra from discharge tube and microjet. Gas: He



Shape of the He I 447.1 nm at different times of plasma decay

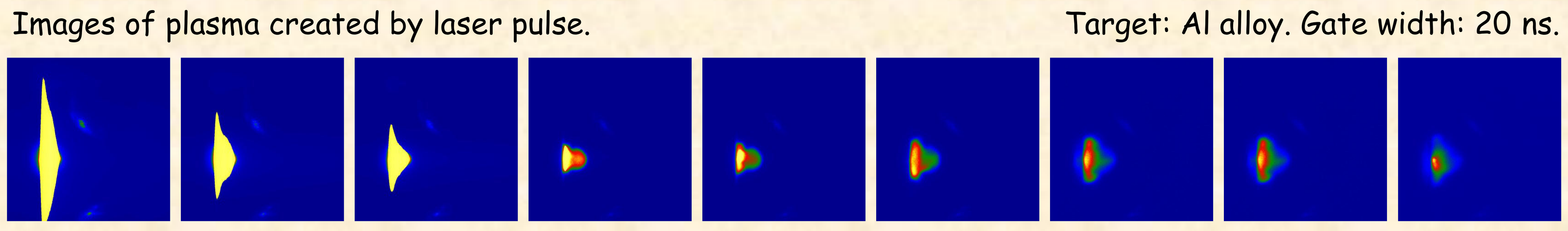
The line profiles of the 447.1 nm line with its forbidden component were recorded for different times of the plasma decay. The main line parameter is the separation between peaks of allowed and forbidden component (s). The following formula is used to calculate the electron density Ne:

$$\log Ne\ [m^{-3}] = 23.056 + 1.586 \times \log(s[nm] - 0.156) + 0.225 \times (\log(s[nm] - 0.156))^2$$

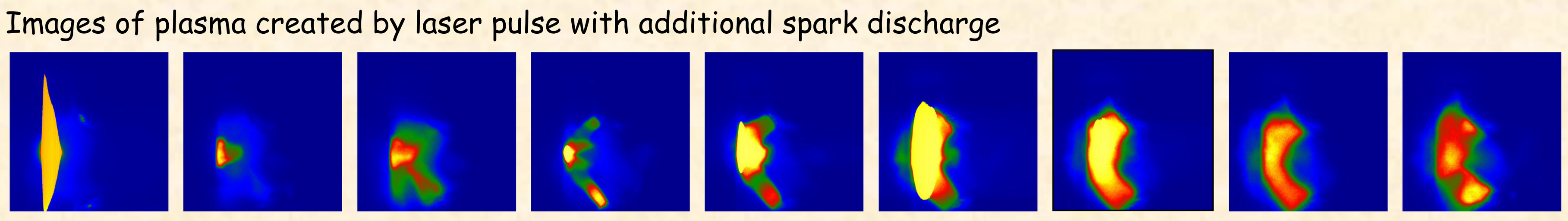


Temporal dependence of electron density for discharge tube and microjet

Images of plasma created by laser pulse. Target: Al alloy. Gate width: 20 ns.

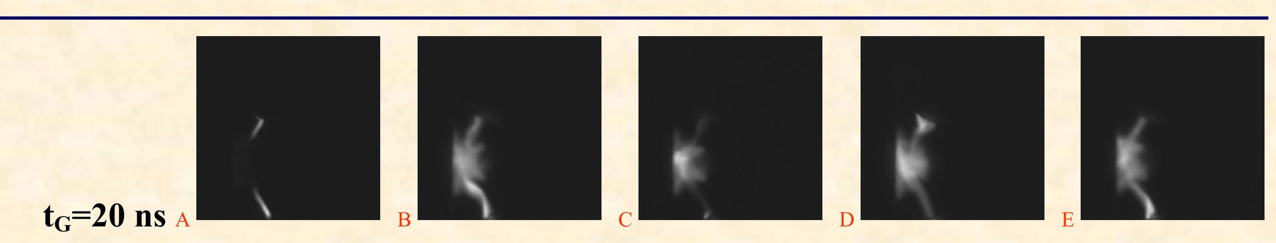


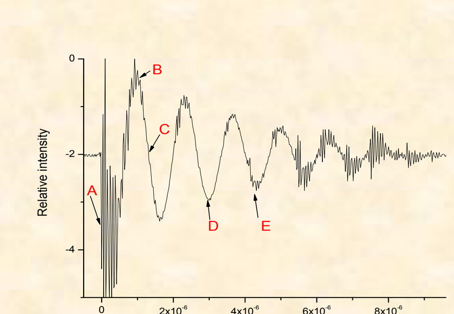
Images of plasma created by laser pulse with additional spark discharge

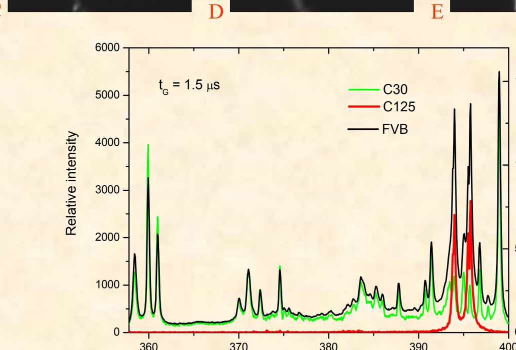


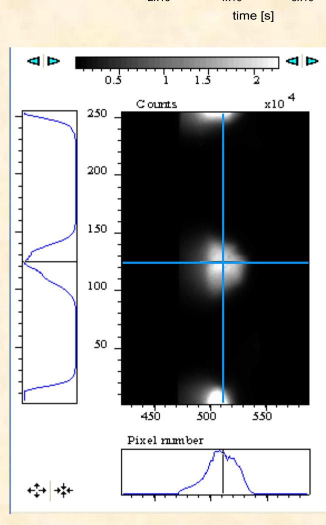
In time resolved images of plasma induced by laser pulse with additional spark discharge three discrete zones are observed. The zones in the vicinity of the electrodes are rich with lines of the electrode material. On the contrary, the central zone is characterized with the spectral lines of target content. Clearly, spectra of these two areas will be notably different. Thus, limiting the recording volume improves signal to background ratio and enhances the analytical possibilities of such plasma.

Comparison of recorded emission spectra from plasma induced by laser and plasma induced by combined technique demonstrated enhancement of analytical lines intensities. These images reveal the reason - plasma volume and plasma duration increase when spark discharge is included.





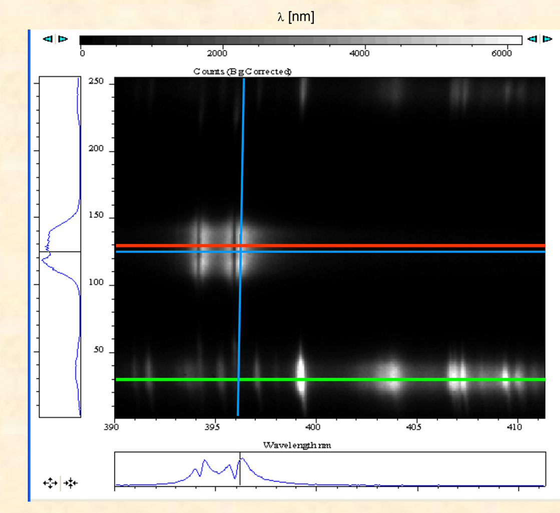




Andor DH720 camera mounted on exit slit of Andor Schamrock 303

Left: slit w = 2 mm
λ = 0 nm

Right: slit w = 10 µm
λ = 400 nm



Conclusion

Time-resolved images of discharge were used to monitor plasma evolvement. Analysis of these images allows us to determine beginning of plasma formation and plasma duration, but also changes in the shape of plasma. Based on these observations time and spatial position of subsequent measurements were selected.

Spatially resolved spectra show that limiting the recording volume improves signal to background ratio, enhances the analytical possibilities of such plasma and enable study of conditions for enhancement of analytical lines intensity. Thus, fast imaging enables choosing proper area for recording spectrum lines with good intensity and signal to noise ratio.

From recorded spectral lines it is possible to do analytical measurement, but also to determine plasma parameters such as electron density and temperature. For the electron density determination, measurement of the distance between allow and forbidden component of He I 447.1 nm neutral line were used. The plasma temperature may be estimated through the relative emission intensities of spectral lines using Boltzmann plot.

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