Determination of electron densities by stark broadening of hydrogen lines in an electrosurgical argon plasma

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Abstract: The argon plasma coagulation (APC) is a contactless electrosurgical procedure for the treatment of biological tissue. By conducting argon gas through the APC instrument to the treatment area and applying a high voltage a plasma is ignited. Although this technique is well-established and frequently-used, physical parameters of the plasma are rarely scientifically investigated. Optical emission spectroscopy is used to determine the gas temperature and the electron density.

Keywords: electrosurgery, APC, stark broadening.

1. Introduction

Electrosurgery is the usage of high-frequency electric current for the cutting or the coagulation of biological tissue. As this technique is frequently used since the mid of the 19th century, many different types of electrodes and current waveforms have been developed for various clinical issues [1]. With electrosurgical knifes the alternating electric current is applied to the tissue through a needle shaped active electrode with a small area of contact to the tissue. A second electrode, called passive electrode with a bigger contact area is affixed to the patient's skin and used to complete the circuit to the electrosurgical device (monopolar technique). These knives enable to perform precise cuts, e.g. in order to remove malignant tissues, such as tumours, while the resulting blood flow is stopped simultaneously. Bipolar instruments, like electrosurgical scissors or clamps provide the closure of blood vessels as both active and passive electrode are of the same size and in contact with the tissue. For all these techniques the frequency of the alternating current that is flowing through the patient needs to be higher than 100 kHz due to undesired muscle and neural stimulations of lower frequencies.

A monopolar contactless electrosurgical procedure for superficial hemostasis, devitalisation and ablation of biological tissue is the so called argon plasma coagulation (APC). Argon gas is lead through the APC instrument to the surgical field and due to an applied high voltage a plasma is ignited (see Fig. 1). The main advantage of the APC is the possibility to treat a great area within a short time period by moving the device across the tissue. Because this treatment technique is contactless, tissue sticking to the electrode is prevented, which plays a major role by the hemostasis of bleeding wounds. As it can be used endoscopically there are many applications in hollow organs like the devitalization of early cancers in the bladder or intestine.

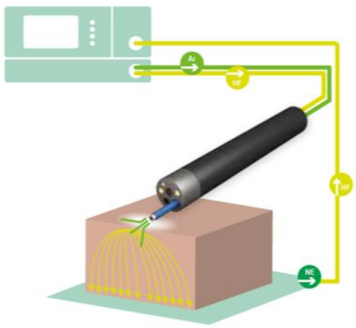

Fig.1: Circuit for the monopolar APC technique [2]

Although this technique is well-established, physical parameters of the plasma during argon plasma coagulation are rarely scientifically investigated. Especially the impact of variations of the surrounding gas atmosphere is not well known. Minimal invasive laparoscopically interventions often take place after carbon dioxide insufflation to create a working and viewing space. Additionally, the argon plasma coagulation itself is carried out by conducting argon gas through the instrument into the patient's body. This results in gas atmospheres with temporarily changing argon admixtures. Therefore, a plasma characterization under these working conditions is highly relevant to ensure the patients safety and to improve the coagulating effects of the APC.

2. Experimental setup

The plasma is characterised using optical emission spectroscopy (OES) with an absolutely calibrated Echelle spectrometer. The resolution of 15 – 60 pm offers the possibility to resolve rotational molecular bands. The application takes place in a vessel of 200 cm³ volume. A continuous gas flow of 1 slm through the vessel allows stable conditions. In contrast to commercial applications, an admixture of 5 % H_2 was added to the process gas (argon) through the APC probe to increase the hydrogen emission for diagnostic purposes. Porcine muscular tissue with a thickness of 4 mm is used as sample and a typical probe distance of 2 mm from the sample is chosen. Measured spectra originate from applications on untreated parts of the sample only as the tissue changes its water content and degree of carbonisation during coagulation. The exposure time is triggered to the beginning of the plasma ignition and 36 single spectra are averaged for each data point to improve the signal to noise ratio. As the discharge shows a great inhomogeneous behaviour also space-resolved measurements are performed. The viewing angle of the spectrometer fibre is here restricted by an aperture of 5 cm length and an entrance hole with a diameter of 1 mm to increase the spatial resolution. Three different axial measurement positions in the plasma channel are chosen.

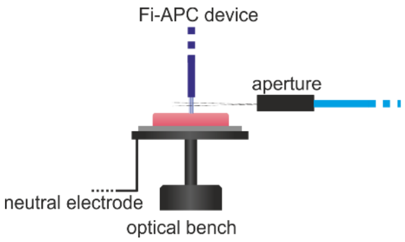

Fig. 2: Experimental setup for spectral measurements of the APC

3. Diagnostics

Gas temperatures can be derived from the comparison of measured emission bands of molecular nitrogen ($N_2(C-B)$) or molecular carbon (C_2 Swan) with simulated spectra (see figure 3).

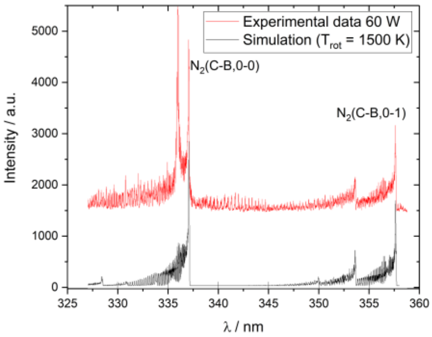

Fig. 3: Spectra simulation for 1500 K

The electron densities are obtained by stark broadening of the hydrogen lines H_α ($\lambda = 656.3$ nm) and H_β ($\lambda = 486.1$ nm) using Voigt profiles for fitting data points. As these line profiles are convolutions of Gaussian (G) and Lorentzian (L) line profiles described by

$$V(n_e, \lambda) = L(n_e, \lambda) * G(\lambda) \quad (1)$$

the width of the Lorentzian is gained from the fitting procedure when the Gaussian width is known. Latter results from the combination of Doppler width $\Delta\lambda_D$ and the width of the instrumental profile $\Delta\lambda_I$ by:

$$\Delta\lambda_G^* = \sqrt{\Delta\lambda_D{}^2 + \Delta\lambda_I{}^2} \quad (2)$$

The Doppler width can be calculated taking the measured gas temperature into account whereas the instrumental profile is obtained by measuring the emission of a deuterium lamp. As line broadening mechanisms for this lamp can be neglected and the emission lines of D_α and D_β are located right next to the used hydrogen emissions the instrumental profile in these wavelength regions is indicated by their line widths. After fitting the data an estimation has to be done if the Lorentzian profile can be used directly to calculate the electron density or if it is influenced as well by different broadening mechanisms, such as van-der-Waals or resonance broadening [3].

4. Results and Discussion

By comparing measured and simulated spectra a gas temperature of $T_g \approx 1500$ K can be obtained (see fig. 3). Similar results are shown in [4]. This can be used to calculate the Gaussian contribution to the Voigt profile fitting process. It shows that using a combination of two Voigt profiles for fitting results in a much lower residual. As these two profiles show different widths, this might indicate a density gradient in the plasma (see fig. 4). Comparing the spectra whereby the whole discharge channel contributes to the measured signal to those of the space-resolved measurements it becomes more obvious that there is a high density region near the active electrode. Calculated values for the electron densities lie in the range of $3.5 \cdot 10^{21}\ \mathrm{m^{-3}}$ up to $1.5 \cdot 10^{22}\ \mathrm{m^{-3}}$ (high density part near the electrode) with a relative error of about 30 %.

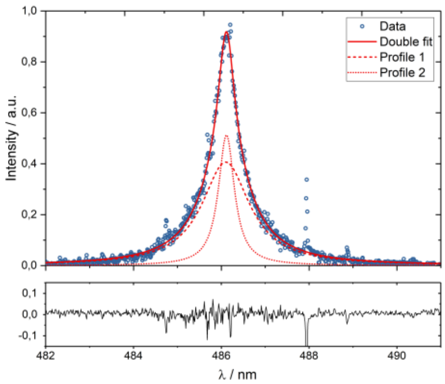

Fig. 4: Fitted line profile

5. References

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