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Optogalvanic spectroscopy applied to the study of hollow cathode discharges devices

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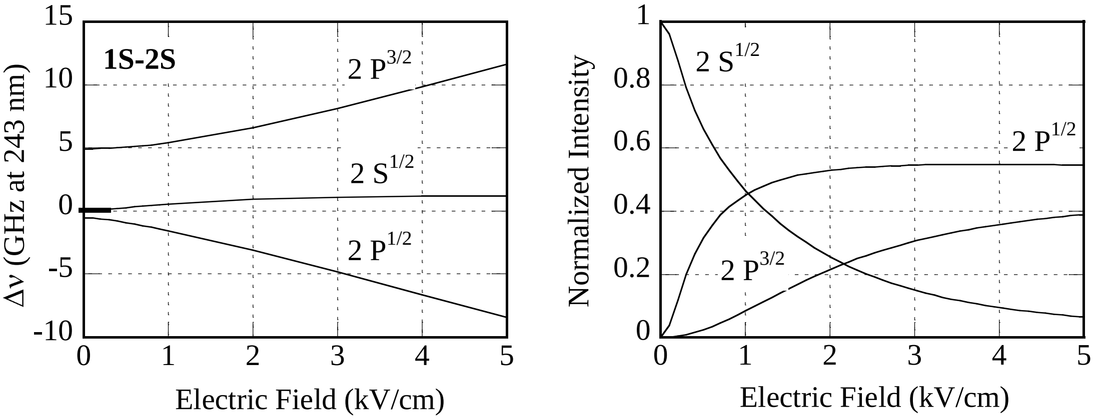
Abstract. Doppler free two-photon optogalvanic spectroscopy has been applied to measure the electric field strength in the cathode fall region of a hollow cathode discharge, via the Stark splitting of the 2S level of atomic hydrogen. Important improvements in the experimental arrangement and in our understanding of the discharge, have allowed us to measure accurately the dependence of the electric field with different parameters like the cathode material (stainless steel and tungsten), geometry (10 and 15 mm inner diameter) and the buffer gas. The study is done for different pressures and currents. The first results seem to reveal different behaviour in the electric field, depending on the material and geometry of the cathode and the discharge conditions.

1. Introduction

Hydrogen plasmas have been studied for many years due to its multiple applications to industry and research. In particular, the hydrogen plasmas generated in a hollow cathode discharge (HCD) are plasmas widely used in industry, and as they present low pressure, low kinetic temperature and out the local thermodynamic equilibrium, they result very attractive in order to investigate the application of different diagnosis techniques. In hollow cathode devices the electric field (E-field) is the main parameter that controls the behavior of the discharge. In the cathode fall region the E-field shows a very strong variation; this fact makes necessary a non-invasive and high resolution method for its determination.

In this work, we determine the E-field in the cathode region in a low-pressure pure hydrogen plasma, generated in a HCD in glow-discharge regime [1, 2], using optogalvanic spectroscopy and the Stark effect in the 1S-2S hydrogen transition. This technique provides the needed resolution. In fact, its resolution is four times bigger than other kind of spectroscopy commonly use, like laser induced fluorescence (LIF), as it has been proved in [3]. According to our experimental conditions, we use Doppler-free two-photon excitation of the hydrogen 1S–2S transition provided by two counter propagating photons from circularly polarized laser beams of opposite directions at 243 nm, in accordance with the selection rule for the angular momentum $\Delta L = 0$, once the 2S level is reached, it is easy for an atom to catch a third photon and become ionized. This ionization causes a change in the plasma impedance. The optogalvanic spectra are obtained by measuring this change in plasma impedance as a function of the laser frequency.

The Stark effect causes the splitting of the fine structure of the 2S level, theoretical calculations [4] show, Figure 1a, that the intensity of the components depends on the electric field strength, as the E-field increases the intensity of the 2S component decreases, allowing growing the other two components. And the $2P^{\frac{1}{2}}$ appears much earlier than the $2P^{3/2}$ but soon it disappears. Figure 1b show that the shift of the components as a function of the E-field strength. These two figures will be used to obtain the E-field from the experimental spectra.



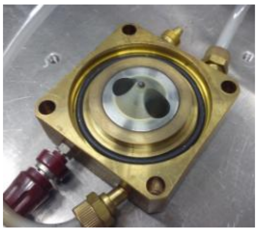
(a) (b)

Figure 1: Stark effect of the 1S-2S two photon transition of hydrogen. (a) Shows the calculated frequency shift versus electric field strength, and the corresponding two-photon absorption normalized lines intensities are given in (b)

2. Experimental arrangement

A comprehensive explanation of the whole experimental arrangement is given elsewhere [4-5]; here we only provide details concerning present work

2.1. The hollow cathode discharge



Picture 1: Peaked anode

In the HCD used in this experiment, the cathode is placed between two peaked anodes, as shown in Picture 1, this is a modified design of the one used before [6]. This new design gives more stability to the discharge. The discharge is operated at a constant gas flow of hydrogen entering at one anode side and leaving at the opposite. The anodes are water-cooled while the cathode is mounted in water-cooled holders made of copper. Thanks to a new system of load resistors, the applied current is equally distributed in both anodes. This device provides symmetric, stationary and stable non-LTE hydrogen plasma with low density and temperature. The power supply allows for discharge currents up to 480 mA, and the pressure can be varied from 0.25 to 1.35 kPa.

2.2. *Experimental set-up*

A schematic view of the whole experimental set-up can be seen in Figure 2. The full potential provided by two-photon spectroscopy is accessible, if a pulsed UV laser radiation of sufficient peak power and SLM spectral quality is available. The system consists of a 10 Hz injection seeded Q-switched Nd:YAG laser (Continuum, Powerlite) and a substantially modified OPO–OPA system (Continuum, Mirage 500). The required 243 nm radiation is obtained by sum-frequency generation (SFG) of 772 nm and the third harmonic radiation in a BBO crystal. This concept provides up to 10 mJ pulse energy in 3 ns and 300 MHz bandwidth that allows resolving the hyperfine structure of 2S level of hydrogen.

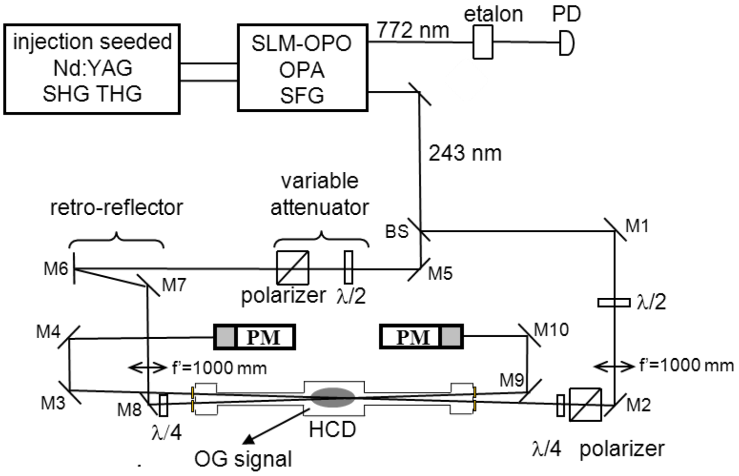


Figure 2: Schematic view of the experimental set-up

The laser beam is divided in two opposite circularly polarized beams. The measurement volume, given by the spatial overlap in focus (f′ = 1 m) of these two beams, is about 30 mm in length and 150 µm in diameter. In order to measure the variation of the electric field strength in the cathode fall, the HCD was mounted on an x–y translator. Displacements of the HCD allow performing measurements in the entire plasma: from the axis up to the cathode-fall region close to the inner surface of the hollow cathode. In order to get the best spatial resolution, the two beams were crossed in a horizontal plane and measurements were performed in the upper central part of the cathode-fall region. The beams direction is counter-propagating, allowing Doppler free measurements. The retroreflector, in Figure 2, assures the spatial stability in the overlap volume by cancelling small displacements of the laser direction. The laser power and the size of the focus (overlap volume) have been chosen according to [3], in order to get the best spectra and spatial resolution.

3. Measurements and first results

Before doing the optogalvanic measurements, it is necessary to make a complete study of the V-I characteristics of the discharge for the four cathodes: stainless steel (10 and 15 mm) and tungsten (10 and 15 mm). Figure 3 is the result of the V-I measurements, this study allow us to verify the high reproducibility of the discharge.

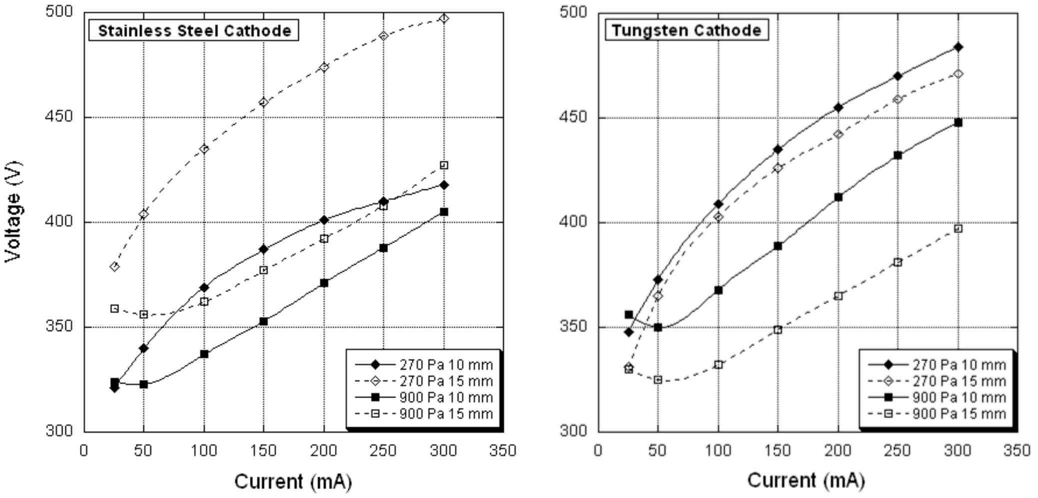


Figure 3: V-I characteristics for stainless steel and tungsten cathodes (10 and 15 mm inner diameter) for different pressures

The main objective of the present work is to measure the variation of E-field in the cathode fall region of a HCD, and to determine its dependence with the cathode geometry and material, with the buffer gas, and for different discharge characteristics: pressures and currents. As it was mentioned before, the E-field in the cathode fall region causes the Stark splitting and shifting of the components. According to Figure 1a, the shifting of the components is directly related to the E-field. Figure 4 shows a typical experimental spectrum (tungsten, 10 mm diameter, 600 Pa and 50 mA and a distance from de cathode of 0.350 mm) without any manipulation acquired shot by shot of the laser. The hyperfine structure of the three components is clearly visible; this means that the laser keeps the SLM mode during a scan. And also confirms the plasma stability.

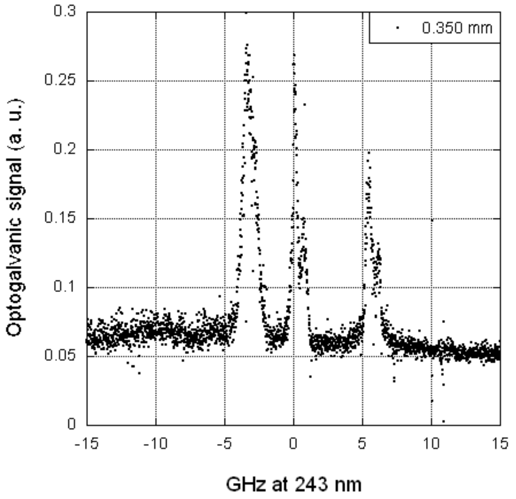


Figure 4: Experimental spectrum**.** The hyperfine structure of the three components is visible

In figure 5 there are the E-field values obtained for stainless steel for a pressure of 600 Pa and a current of 100 mA vs. the distance from the cathode surface, the parabolic tendency has been obtained before [6]. Nevertheless, the first results seem to reveal different trends of the E-field strength obtained with the two cathode materials for different experimental conditions.

But it is a work still in progress; the immediate project is to complete the measurements in different pressures and currents, in stainless steel and tungsten cathodes with different geometry, in order to compare experimental data with theoretical models and get more accurate conclusions.

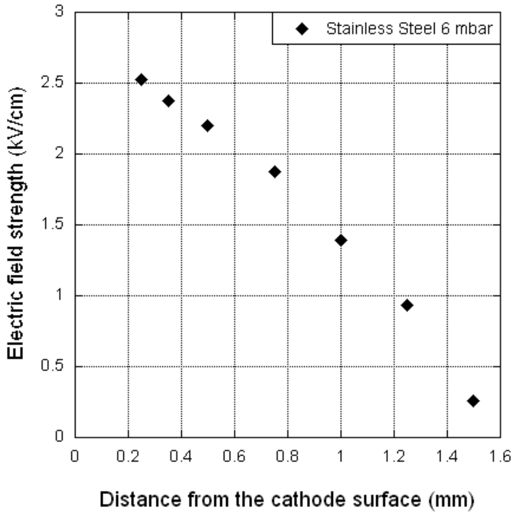


Figure 5: Variation of the E-field in the cathode fall region versus the radial distance from the cathode surface

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