University of Basel
Department of Physics

Fortgeschrittenenpraktikum I/II

Plasma Chamber

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Experiment Overview

This experiment introduces the operation of a vacuum chamber and the fundamentals of low-temperature plasma physics. You will generate a capacitively coupled plasma using different gases and a Radio-Frequency generator. After visually observing the plasma, you will characterise it both optically and electrically with an optical spectrometer and a Langmuir probe. You will identify the species present and determine key plasma properties, such as electron temperature and electron density. Finally, you will observe how magnetic fields affect the discharge. By the end of this practical session, you will be familiar with the basic principles of low-temperature plasma and able to set up a plasma ignition device independently.

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1 Theoretical Background

1.1 Plasma and capacitively coupled discharges

A plasma is a partially ionised gas composed of electrons, ions, and neutral particles. It is quasi-neutral in the bulk and exhibits collective behaviour. In this experiment, we study a low-temperature plasma, meaning that the electron temperature is much higher than the ion temperature. A capacitively coupled plasma (CCP) is generated by applying an RF voltage (here, 13.56 MHz) between electrodes. The plasma bulk remains quasi-neutral, meaning that the densities of positive and negative charges are approximately equal. Because electrons are much hotter than ions, the plasma naturally acquires a potential that is higher than that of any surface in contact with it. This leads to the formation of a so-called plasma sheath between the bulk plasma and the electrodes [1].

1.2 Optical Emission Spectroscopy

In a low-temperature plasma, many atoms, molecules, radicals and ions are in excited states due to processes such as electron collisions, ion molecule reactions and charge exchange. The photons are generated mainly due to relaxation of these species, and can be detected through the plasma and the vacuum chamber. The spectral distribution of photons contains numerous information on the discharges including the different plasma species, their density and temperature (energy).

1.3 Langmuir Probe

A Langmuir probe is an electrostatic probe made of a single wire inserted in the plasma. By sweeping the voltage and measuring the resulting current, one can measure the probe current–voltage (I–V) characteristics, a typical probe measurements is shown below (Figure 1). A typical I-V curve consists of 3 regions; namely the positive ion current region, transition region and the electron saturation region (see figure below). These regions are exploited separately to obtain the plasma parameters.

This I–V curve is directly related to key plasma parameters, in particular the probe floating potential V_f, the plasma potential V_p, the plasma density n_0, and the electron temperature T_e. Among these, the floating potential is usually the easiest to determine with an electrostatic probe. It is defined as the probe potential at which the net collected current is zero, and it corresponds to the natural potential reached by an unbiased probe immersed in the plasma.

A planar surface inserted in a quasi-neutral plasma in the absence of an external magnetic field biased below the plasma potential ($V < V_p$) collected a net current I :

$$I = eA \left[-\frac{n_0 v_e}{4} exp\left(\frac{e(V - V_p)}{k_B T_e} \right) + n_s u_B \right] \tag{1}$$

where A is the probe surface area, n_s is the plasma density at the probe sheath bound-

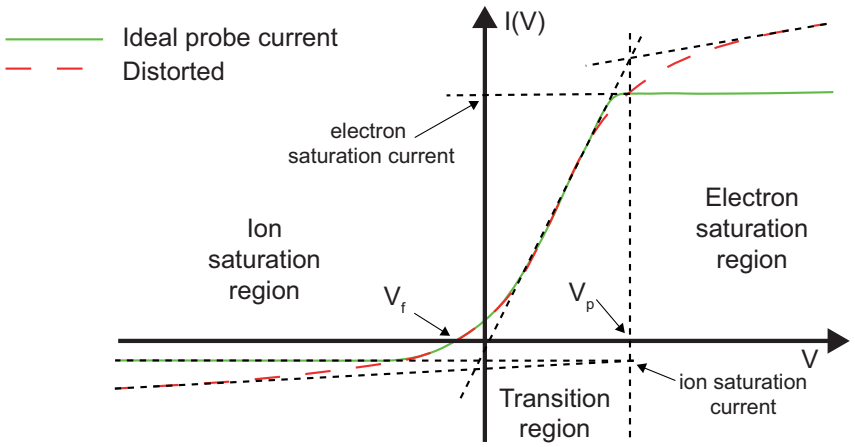


Figure 1: Ideal and real measurement of probe IV curves and parameters directly accessible from the probe IV characteristics. Figure from Hiret 2024 [2].

ary, v_e is the electron thermal velocity and $u_B = \sqrt{k_B T_e / m_i}$ is the Bohm velocity. In non-magnetised capacitively coupled discharges, the sheath edge density is accurately described by $n_s = \alpha n_0$ with α =0.61 [1].

One can see that if the probe is strongly biased with respect to the plasma potential ($V \ll V_p$) (*i.e* in the ion saturation region), the probe collects a saturating current $I_i^s = eAn_s u_b$. The plasma density can then be determined from the ion saturation current and the electron temperature. While removing from the net current the ion current, one can obtain:

$$I_e = eA\frac{n_s v_e}{4} exp\left(\frac{e(V - V_p)}{k_B T_e}\right) \tag{2}$$

Taking the logarithm of the electron current:

$$ln(I_e) = ln\left(\frac{eAn_0 v_e}{4}\right) + \frac{e(V - V_p)}{k_B T_e} \tag{3}$$

Then, it appears that the electron temperature is related to the slope of the logarithm of the electron current collected by the planar probe below the plasma potential (in the transition region).

The potential of the plasma V_p is more challenging to get from the I–V curve than the other parameters. At a more positive bias than the floating potential, the electron current increases until there is no retardation of electrons. At higher potentials, the exponential retardation current is replaced by the collection of electrons under orbital motion, which changes less rapidly with potential. This region is called the saturation region. The transition between these two contrasting regimes of electron collection can be identified as a "knee" in the probe characteristic. It is possible to highlight the changeover by taking the derivative of the characteristic (dI/dV). The "knee" makes the derivative peak close to the DC plasma potential. Other parameters, such as the electron energy distribution function, can also be deduced from the current-voltage probe characteristic second derivative.

2 Experimental apparatus

The setup consist of glass and metal vacuum chamber evacuated using a turbo molecular pump and a rotary vane pump. A mass flow controller allows controlling the flow of the different gases introduced to the chamber. Different gases can be used, mainly Ar and N2 but some others can be use if planned with the assistant. An RF generator and its matchbox are controlled using the computer and allows igniting and maintaining the plasma. A spectrophotometer and a Langmuir probe are also available.

3 Questions

1. What are the states of matter? What defines the state of a matter? Which is the most abundant state of matter in the universe?
2. Name different kind of plasma natural and human-made plasma. When was the last time you saw one?
3. Why is plasma studied by the humankind? What are we producing with it?
4. Name some of the important parameters of plasma.
5. Are plasmas neutral? Are plasmas in steady state? Are electrons (generally) in thermal equilibrium? Are ions (generally) in thermal equilibrium?
6. Why do plasmas emit light and why different colour for different gases?
7. Why do plasmas emit light even if the electron temperature is smaller than the ionization temperature?
8. Ignite a plasma with different input parameters and observe visually the changes.
9. Characterise optically the plasmas with OES (optical emission spectrum). Specify the largest peaks (or zones).
10. Make a rough estimation of the ion temperature, gas temperature and the electron temperature of the plasmas you have created in this work.
11. Plot the I–V curve determined from the Langmuir Probe. Specify each region. Calculate the plasma parameters using the program and explain the physics behind the mathematics used in the program (like in the transition region example above).
12. In the experimental part, you have changed several parameters like the plasma power, the gas and the magnetic confinement. You have also played with the height of the electrical probe to obtain data from different locations. Present these results with tables or plots and comment briefly on them.

3.1 Research Question

Define a research question you would like to study with this experiment. State your hypothesis in the introduction. Describe qualitatively what you expected. In the discussion part of your report discuss:

- Whether your results confirm your hypothesis
- Influence of your variable on plasma properties

- Sources of error
- Consistency with theory

References

[1] Chabert P and Braithwaite N 2011 *Physics of Radio-Frequency Plasmas* (Cambridge: Cambridge University Press)

[2] Hiret, Paul. "Radiofrequency Magnetised and Unmagnetised Plasma Sheath/Bulk Properties and Their Influence on the Erosion Distribution," 2025. https://hdl.handle.net/20.500.14716/202539.

[3] Lieberman M A and Lichtenberg A J 2005 *Principles of Plasma Discharges and Materials Processing* (New York, NY, USA: Wiley)

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