Plasma Chamber

Fortgeschrittenes Praktikum I

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Abstract

The aims of this experiment are to be familiar with a vacuum chamber, to understand what a plasma is and characterize a plasma optically and electrically. For this you will use a vacuum system with several pumps, a plasma source, a Langmuir probe and an optical spectrometer.

You will have to create a plasma using several gases, calculate the characteristics of this plasma like temperature, electron density… and determine the present species. It is also possible to modulate this plasma using some magnets.

At the end of this practical training, you will get acquainted with some basic fundamentals of low temperature plasma and be able to set up a plasma igniting device by yourselves.

Contents

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1 Theory

1.1 Plasma [1]

Plasmas are quasi-neutral particle systems and they are fluid-like mixtures of free electrons and ions together with neutral particles (atom, molecules). The charge carriers and their electromagnetic interactions have a substantial effect on the system properties. There are two aspects of the interactions between the plasma components and the electrical charges. The first one is Coulomb interactions among charge carriers where each charge carrier interacts simultaneously with many others. The second one is the formation of macroscopic space charges as a consequence of external influences (e.g. due to thermal movement). The most intrinsic attribute of plasma is minimization of external electric and magnetic fields inside its bulk. Plasmas may be divided into two groups as low and high temperature plasmas. A further subdivision among low temperature plasmas can be made as thermal and non-thermal plasmas. The type of plasma used in this experiment is non-thermal low temperature plasma ($T_i \sim T \sim 300K$; $T_i \ll T_e \leq 10^5K$; low-pressure). The most important component of non-thermal low temperature plasma (LTP) is the hot electron gas. The production of ionized, excited and dissociated species with increased chemical activity and the generation of electromagnetic radiation lines and continua are results of these electrons with high kinetic energies. The occurrence of the charge carriers in plasma results in the following: 1) Occurrence of electrical conductivity 2) Interaction with magnetic fields 3) Occurrence of multitude of oscillations and waves 4) Screening of the electric fields and 5) Formation of characteristic boundary sheaths at the plasma material contacts.

1.2 Langmuir Probe [2, 3, 4]

Langmuir Probe is basically a wire electrode placed in the plasma, where a constant time-varying electrical potential is applied on and the current of the electrode is read. The plasma characteristics such as ion flux and electron temperature can be determined from the I-V curve obtained from the Langmuir Probe.

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. Below is an example of how the transition region is used to obtain T_e (electron temperature). The rest can easily be find it the references.

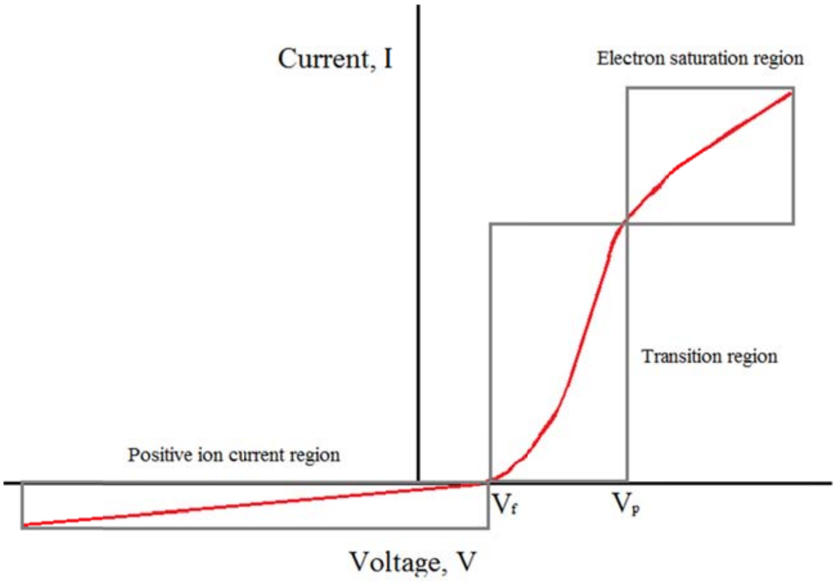

Fig 1 Three different regions of the I-V curve of a typical Langmuir Probe data

$$\mathbf{k}\ is\ the\ Boltzmann\ constant, \mathbf{e}\ is\ the\ electron\ charge, m\ is\ the\ electon\ mass$$

$$T_e\ is\ the\ electron\ temperature\ in\ K, \qquad T_{eV}\ is\ the\ electron\ temperature\ in\ eV$$

$$n_e\ is\ the\ electron\ density\ when\ V = V_p, \qquad n\ is\ the\ electon\ density\ when\ V < V_p$$

$$A\ is\ the\ area\ of\ the\ probe, \bar{v}\ is\ the\ average\ electron\ speed, I_p is\ the\ electron\ current\ diffusing\ in\ the\ probe$$

$$n = n_e exp\left(\frac{-(V_p - V)}{T_{eV}}\right), where\ T_{eV} = \frac{kT_e}{e}$$

$$I_p = \frac{1}{4}Ane\bar{v},\ from\ the\ kinetic\ theory$$

$$\bar{v} = \sqrt{\frac{8eT_{eV}}{\pi m}}$$

$$if\ you\ take\ the \ln of\ the\ equation\ and\ plug\ in\ the\ components, the\ equation\ becomes:$$

$$\ln(I_p) = \ln(I_{pp}) - \frac{V_s}{T_{eV}} + \frac{V}{T_{eV}}, where\ I_{pp}\ is\ simply\ \frac{1}{4}An_e e\bar{v}$$

$$so, \frac{dln(I_p)}{dV} = \frac{1}{T_{eV}}$$

This means, the semi log graph of the transition region of the I-V curve gives us the electron temperature.

1.3 Optical Emission [1]

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, which they may be detected from outside of the plasma. The spectral distribution of photons may contain information of different plasma species, their density and temperature and the strength of the internal and external fields.

2 Experimental

For this experiment you have a vacuum chamber (with the pumping system), a gas system, a plasma generator, a Langmuir probe and an optical spectroscope.

2.1 Vacuum

Vacuum is described in the Fortgeschrittenes Praktikum: 43 Vakuum

2.2 Pumping Down and Venting the System

<u>To pump</u>

Open completely the valve which is above the turbo pump

Switch on the primary pump

Switch on the turbo pump (when it is full speed the LED is lightening green)

Base vacuum is in the range of 10^{-5} mbar

<u>To vent</u>

Switch off the turbo pump (Stop > 2s)

Switch off the primary pump

Open slowly the valve to let air into the chamber. When it is vented, close the valve

2.3 Gas system

The gas system is composed of: 3 bottles (Ar, Ne, and He), a valve, mass flow controller and another valve.

The full system should be pumped when the gas bottles are closed.

Open the different parts to let gas flowing, control the flow (CH1).

Reduce the opening of the valve above the turbo to reach 10^{-2} mbar.

2.4 Plasma Generator (13.56 MHz)

Switch on the RF generator and the match box; ignite the plasma in the chamber.
Set the power.

2.5 Magnet

Some magnets are in the chamber and could be used to modify the shape of the plasma.

2.6 Langmuir probe

There is a Langmuir probe in the chamber. The height of the probe is adjustable; several tip shapes can be used.

2.7 Optical spectroscopy

An optical spectrophotometer should be used to record the optical emission of the plasma. A software (Plasus) could be used to analyze the data.

3 Exercises

3.1 Answer the following questions very briefly (not more than a sentence).

a) What are the states of matter? What defines the state of a matter? Which is the most abundant state of matter in the universe?

b) Name some of the important parameters of plasma.

c) Are plasmas neutral? Are plasmas in steady state? Are electrons (generally) in thermal equilibrium? Are ions (generally) in thermal equilibrium?

d) Why do plasmas emit light and why different color for different gases?

e) Why do plasmas emit light even if the electron temperature is smaller than the ionization temperature?

f) Make a rough estimation of the ion temperature, gas temperature and the electron temperature of the plasmas you have created in this work.

3.2 Plot the IV 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).

3.3 Plot the OES (optical emission spectrum) of one of your plasmas. Specify each peak (or zones).

3.4 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.

A1 Scope

Become familiar with pumping down, venting the system, the gas system, the plasma generator, the Langmuir probe and the optical spectroscopy.

Characterizations of the plasma using the Langmuir probe the optical spectroscopy: Effect of pressure, gas, power, magnet, position and shape of the tips.

A2 References

[1] Low Temperature Plasma Physics, R. Hippler, S. Pfua, M. Schmidt, K. H. Scoenbach, Wiley-Vch (2000, Berlin), consult to Baran Eren for access to this book

[2] Lecture Notes on Langmuir Probe Diagnostics, Francis F. Chen, University of California, Los Angeles, online available: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.115.3656&rep=rep1&type=pdf

[3] http://en.wikipedia.org/wiki/Langmuir_probe

[4] Hiden Analytical ESPsoft user manual

References not cited

[5] Plasmaphysik, Vorlesung an der LMU München, Hartmut Zohm, online available:

http://www.physik.uni-muenchen.de/lehre/vorlesungen/sose_10/A_Plasmaphysik/vorlesung/skript.pdf

[6] Classnotes of ‘Low Temperature Plasma Physics: Basics and Application’, October 9-14, Bad Honnef, consult to Baran Eren for access to these classnotes

During your further education in University of Basel you will have the chance to take the course ‘Einführung in die Plasmaphysik’. We strongly encourage you to take this course to learn the basics of the physics of plasmas.

You will also have the chance to do the semester and master projects in the applications of plasmas like thin film coatings or plasma treatment of surfaces.

You may also become a great plasma physicist and work for ‘Tokamak à Configuration Variable’ in Lausanne, ‘Joint European Torus’ in Oxford or even for the largest scientific project ‘ITER’ in Cadarache.