LASER ATOM ABSORPTION SPECTROSCOPY ON MICRO HOLLOW CATHODE DISCHARGES IN XENON

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1 Introduction

Vacuum ultraviolet radiation sources are current of interest in many research fields and in some modern technologies as well. For several years, excimer molecules of rare gases have attracted great interest because of their ability for generating uv- and vuv-radiation. An excimer lamp based on dielectric-barrier discharges, is known [1] and commercially available within a few years. Another possible realization of such a radiation source is a micro hollow cathode discharge in the pressure range up to 1 atm. This discharge is a suitable instrument to reach sufficient yields of excimer radiation because of producing high electron densities, connected with high population densities at the lowest excited atomic states. Much effort continues toward understanding the complex physical processes involved in this miniaturized hollow cathode discharges due to a possible commercial importance of this system. On the other hand less data are available about the dependence of the particle number density of metastable and resonance state from the discharge parameters. In this purpose we have investigated at first the absolute metastable Xe $6s[3/2]_2$ density in a miniaturized hollow cathode discharge by means of laser atom absorption spectroscopy.
Absorption spectroscopy recently records great interest with the invention and now widespread availability of relatively inexpensive, narrow line width, tunable diode lasers as background source. The application of these lasers to a plasma gives the possibility to study the atomic population densities.

2 The Experiment

2.1 The hollow cathode

The discharge chamber is the same one that was used previously for measuring the time behavior of metastable atoms in dielectric barrier discharges [2] with the exception of the electrodes. Now it consists of a nickel hollow cathode, a ring anode (spaced 2 mm from the cathode) and a quartz glass envelope around the cathode and anode. The inner diameter of the hollow cathode is 2 mm and the length is 8 mm. This glass tube with the electrodes is mounted in a special stainless steel chamber with two windows mounted at the Brewster angle. This allows the laser beam to pass axially through the hollow cathode. The entire chamber is mounted on a translation stage, which enables the translation of the tube in the direction perpendicular to its axis so that the laser beam may traverse the discharge at different radial positions.
Standard HV techniques are used to evacuate the discharge tube. The whole chamber is evacuated to 10^{-7} Torr. After that high purity xenon (99.99%) is introduced through a mass flow controller so that the system is operated in a gas flow mode. The gas flow is controlled to keep the desired pressure constant. The pressure is measured by capacitive gauges and varies from 10 to 100 Torr. A dc voltage power supply in series with a 10 kΩ ballast resistor is used to excite the hollow cathode discharge. The experimental arrangement used for the diode laser absorption measurements is schematically illustrated in Figure 1.

2.2 The diode laser

The radiation for the absorption measurements is provided by a temperature stabilized tunable GaAlAs laser diode with external cavity in Littrow configuration. The radiation is collimated and propagated through the absorption tube. The output intensity from the laser is well above the saturation intensity of the optical transition for the pressure used in the experiment. For that reason the power incident on the discharge tube is reduced by neutral filters, a pinhole and a beam splitter. This pinhole and a configuration of two lenses act to collimate the laser beam and define the spatial resolution. The beam splitter divides the laser beam into two parts. One part traverses the discharge and the second reference beam passes into a wavemeter (Burleigh model WA 4500) and is used for monitoring the laser output spectrum and to calibrate the wavelength scale of the absorption line shape measurements.

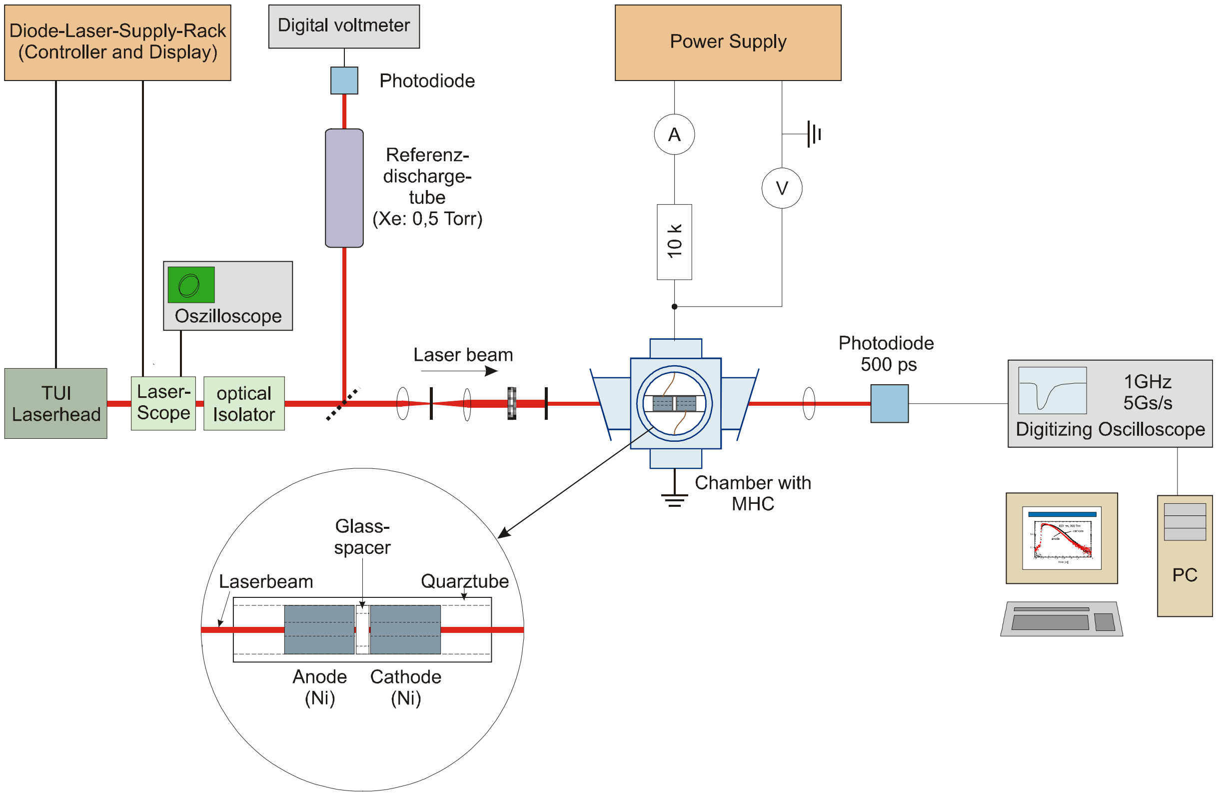

Figure 1: Experimental setup used to measure the absorption in a miniaturized hollow cathode discharge.

A dc current was applied to coarsely tune the laser mode wavelength approximately to the range of the resonant radiation, 823.16 nm in the case of the metastable level. Precise frequency matching was achieved by applying a long sawtooth wave (6 Hz) from a function generator to the diode laser power supply. This gives the possibility to sweep the diode laser through the entire absorption line for the absorption line shape measurements. Typical values of the absorption at this wavelength ranged from 1% to 80% for the metastable level. The absorption signal was detected by a photodiode and digitized and stored by using a digital oscilloscope (Tektronix model TDS 7104) averaging the signal 10-100 times.

3 Experimental results and discussion

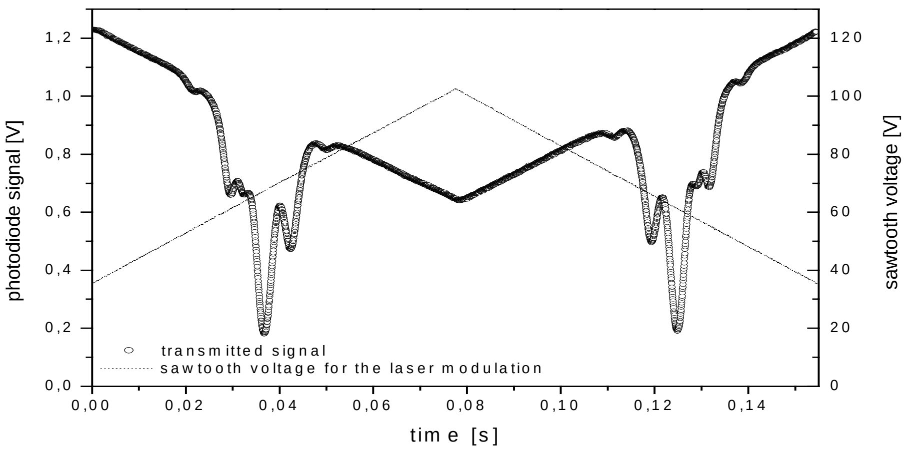

Figure 2: Absorption spectra of the $6s[3/2]_2 - 6p[3/2]_2$ Xe transition at 30 Torr xenon and 1 mA and the temporal behavior of the sawtooth voltage controlling the laser modulation.

Figure 2 shows the correspondence of the transmitted laser signal to the laser modulating sawtooth voltage for a discharge at 30 Torr and 1 mA. Additionally measurements using the wavemeter have been shown a linear dependence of the wavelength shift of the laser radiation on the modulation voltage. Therefore the sawtooth voltage can be used to calibrate the transmitted laser signal on wavelength units. To calculate normalized line profiles and population densities the Lambert-Beer's-Law is used. For that the transmitted laser signal (I) has to be subtracted by the spontaneous emission of the plasma and has to be divided by the incident laser intensity (I_0), which was measured without ignited plasma.

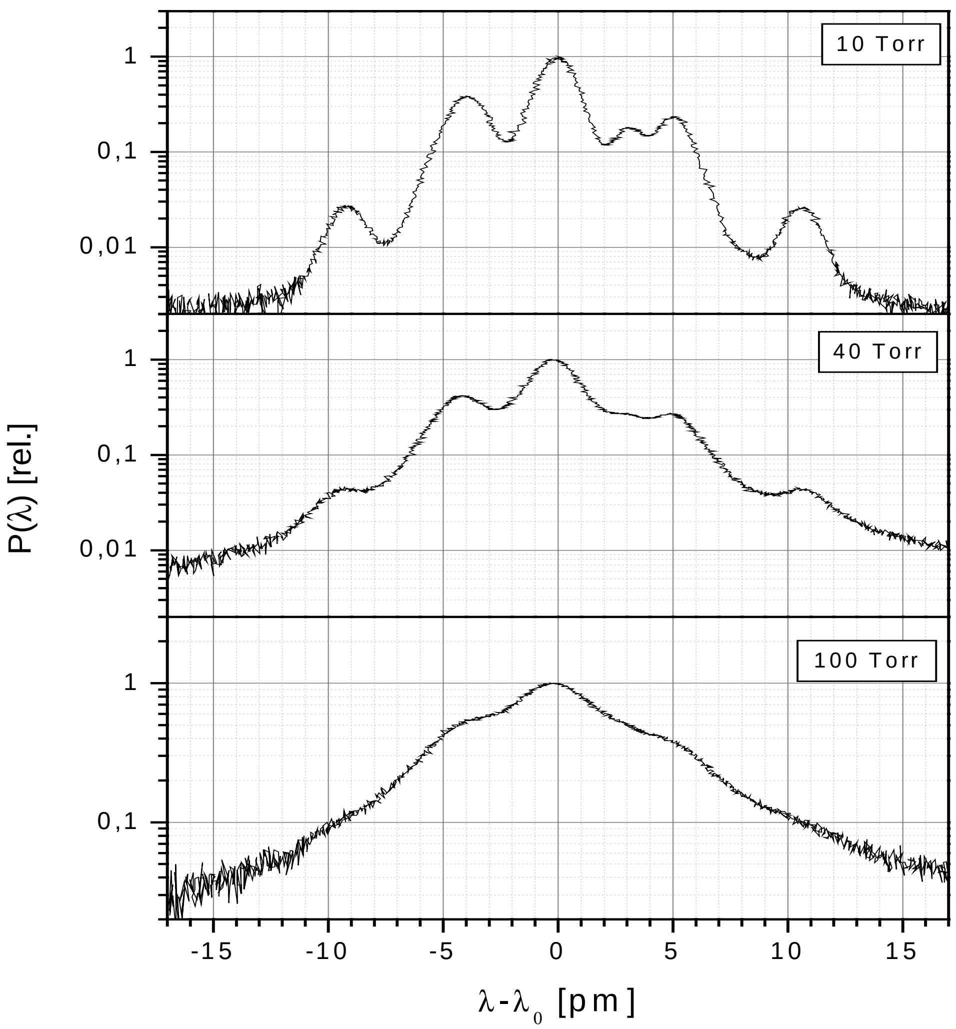

Figure 3: Normalized line profile of the $6s[3/2]_2$ - $6p[3/2]_2$ transition at 823 nm in xenon for 3 gas pressures**.**

In Figure 3 the influence of collisional broadening on the normalized line profile of the $6s[3/2]_2$ - $6p[3/2]_2$ transition is shown. At a pressure of 10 Torr the hyperfine components of the investigated transition of xenon are noticeable. The profile structure is caused by the presence of different xenon isotopes. The normalized line profile of this transition consists of a superposition of all line shapes of each isotope. All even numbered isotopes are responsible for the central maximum of intensity. Outer peaks are caused by components of both odd numbered isotopes (^{129}Xe and ^{131}Xe). Natural line shape and only Doppler broadening in the case of low pressure give the line shape of each component. The core of such a line shape can be fitted by means of a gaussian function. The FWHM of this function is connected to the gas temperature.

At increasing pressure (cf. line profile for 40 Torr and 100 Torr) the influence of the collisional broadening becomes important. The linewidth grows and the wings of the line drift apart from each other. Since, here the wings of each line become more important and the superposition of lines result in a profile that is more homogeneous. Therefore, passing over to higher pressures only the envelope of all hyperfine-components can be detected.

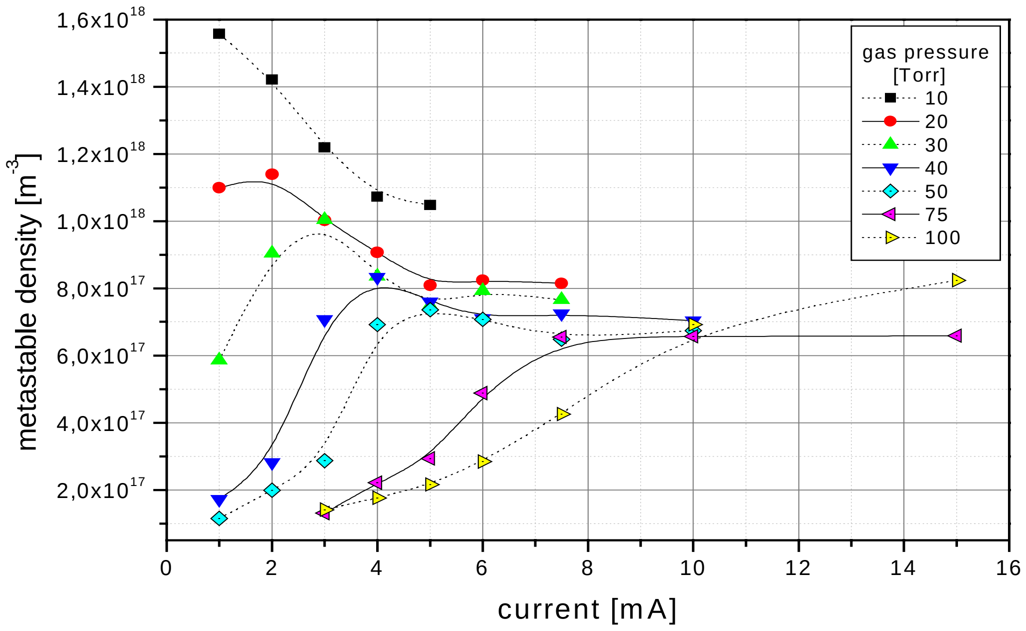

Figure 4: Development of population densities of the 6s[3/2]2-state of xenon, depending on discharge current and gas pressure.

Figure 4 shows the behavior of population density of the Xe-6s[3/2]$_2$-level in dependence on pressure and discharge current. For smaller discharge currents a considerable pressure dependence of the population density is given. With increasing current all curves strive for a common value.
An increase of the pressure leads to higher probabilities for collisional processes. Caused by these collisions the plasma suffers losses that are noticeable in a decreasing population density.

4 Conclusions and future work

We have demonstrated a tunable laser diode absorption technique for measuring the xenon metastable density in a miniaturized dc hollow cathode discharge. First results for metastable densities are shown. From the determined normalized line profile we plan to calculate the gas temperature inside the hollow cathode.
In future work we will use this technique to measure the densities of the resonant level and the radial profile of these particle number densities for calculating the vuv output.

5 References

[1] U. Kogelschatz, B. Eliasson and W. Egli, Proc. of the XXIII. ICPIG, Toulouse 1997, Invited Papers, C4-47.
[2] R. Wendt and H. Lange, J. Phys. D:Appl. Phys. 31 (1998) 3368