Journal of Quantitative Spectroscopy & Radiative Transfer 148 (2014) 221–227

Contents lists available at ScienceDirect

Journal of Quantitative Spectroscopy & Radiative Transfer

journal homepage: www.elsevier.com/locate/jqsrt

Femtosecond laser enhanced current in a thermionic diode with barium vapor

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ARTICLE INFO

Article history:
Received 5 May 2014
Received in revised form
15 July 2014
Accepted 16 July 2014
Available online 28 July 2014

Keywords:
Femtosecond laser
Autoionization
Multiphoton laser ionization
Thermionic diode detection
Barium vapor
Energy conversion

ABSTRACT

We studied the signal from a thermionic diode when a femtosecond laser beam was spatially overlapped by an excimer pumped dye laser beam. The nanosecond dye laser was scanned from 435 to 438 nm in order to excite the autoionizing levels of barium by two photon absorption. The broadband ultrashort laser light was centered at 427 nm, which is also above the first ionization limit of barium. The bias voltage between the cell body and the tungsten rod (set at either 9 or 0 V) was used to collect electrons after the barium ions had been created by multiphoton (auto) ionization. The overall background of the thermionic signal was appreciably elevated due to the two photon ionization by the broadband femtosecond laser. We measured the thermionic signal with and without femtosecond laser overlap, and with a biasless and biased thermionic diode. The effect of the femtosecond laser was appreciable enhancement of the background ionization continuum. This was especially visible in the presence of noble gases at pressure of 50 mbar. Argon produced the largest and helium produced the smallest enhancement in the background continuum. In addition, we observed a few broad spectral features of a presumably collision induced nature.

1. Introduction

In our investigation of the multiphoton ionization of the dense alkaline earth vapor we used the nanosecond excimer pumped dye laser to excite Rydberg levels below or above the first ionization limit [1,2]. Ba ions were produced in the oven by two photon excitation of Ba autoionizing Rydberg states, which lie above the first ionization limit [3]. We measured thermionic signals with and without bias voltage. The sensitivity of detection was essentially decreased in the case of the bias-less voltage [4].

Study with a femtosecond laser seems to be an attractive challenge with respect to multiphoton ionization efficiency and thermionic detection that we applied throughout the work. The femtosecond laser was a frequency doubled mode-locked Ti:Sa laser (Tsunami, Spectra Physics) pumped by 15 W cw laser (Millennia, Spectra Physics).

Whereas most of the experiments with barium autoionizing lines have been performed in atomic beams [5–8], in the present experiment we used atomic vapor at high temperature (above 800 °C) and large density of barium atoms (above 10^{14} cm^{-3}). Here we studied the effect of femtosecond laser light which was superimposed onto the nanosecond dye laser beam exciting the spectral region above the first ionization limit with two photons. This simultaneous excitation of autoionizing Rydberg states above the first ionization limit modifies the thermionic diode current through the action of barium ions inside the space charge around the cathode.

Using the mode-locked femtosecond laser we did not expect any coherent accumulation effects due to the

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http://dx.doi.org/10.1016/j.jqsrt.2014.07.017
0022-4073/

interaction of the optical frequency comb with barium atoms, because the minimum pressure of the buffer noble gas was 5 mbar. Ba atoms were thus permanently perturbed by the noble gas atoms. Since the collisions smeared out all the details of the interaction between Ba atoms and the frequency comb lines, the ultrashort pulses acted as having a continuous spectral content [9]. In end effect we observed an increased continuum background current signal, which was different in size with different noble gases.

2. Experiment

Our experiments were performed inside a hot-pipe oven filled with 99% pure barium (strontium impurity was less than 1%). Heated barium vapor was excited by two laser beams and the thermionic diode system [10–12] detected the resonance signals [13]. A thermionic diode ion detector is the most sensitive tool for the detection of highly excited Rydberg states [14]. It is a positive ion detector with high sensitivity which helps to detect even a single ion [4,15]. When the diode works in the space charge limited mode, the presence of N ions in the potential well of the thermionic diode lowers the space charge and causes an increase of the diode current by Δj. This results in an amplification factor of $\Delta j/N$, therefore, with a high thermal emission of electrons from the cathode surface, the amplification factor can reach levels of 10^4–10^6 [10].

The thermionic diode detection system consists of a stainless steel tube 40 cm long, 7 cm in diameter and 1 mm wall thickness and is operated in a space charge limited mode. A tungsten rod of 15 cm in length and 3 mm in diameter was fed through glass window of the hot-pipe oven. The rod was placed along the axis of the hot pipe oven using a vacuum tight feed-through. The other side of the oven tube was vacuum sealed with a quartz window to transmit the laser beam. The cell windows were water cooled and the noble gas cushion precluded deposition of barium vapor (Fig. 1). The 20 cm central portion of the thermionic diode was heated up to 860 °C with a heater operating at 110 V dc. The temperature of the oven was monitored using a thermocouple attached to the oven

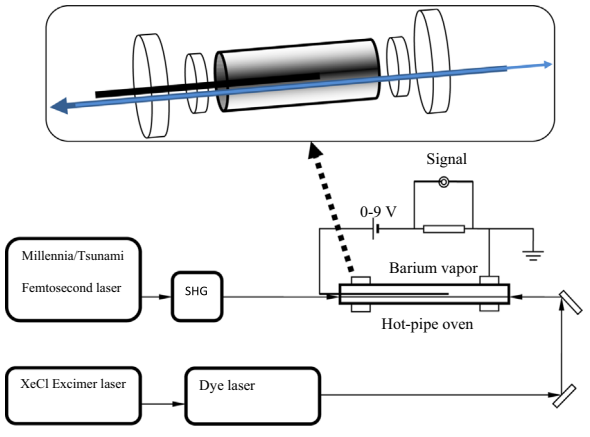

Fig. 1. The experimental setup with thermionic diode detection system.

body. The temperature profile of the heated zone of thermionic diode was studied under atmospheric conditions with peak temperature at the center of the heated zone. We estimated the density of barium atoms to be 1.14×10^{14} cm^{-3} [4]. The tungsten rod acts as a cathode for the thermionic diode and the indirect heating of the tungsten rod produces an electron cloud which enables a thermionic detection effect after the laser induced ionization. The stainless steel tube (oven body) acts as an anode whose function is to collect electrons and thus enable the diode current. The cell was initially evacuated down to 10^{-4} Torr and 5 mbar of He was then added as a buffer gas to enable reference measurements. Besides Ba spectral lines we observed Rydberg spectral lines of strontium as impurities. We increased the helium pressure up to 50 mbar in order to study collision induced spectral phenomena. 50 mbar of Ar, Kr and Xe were later introduced into the oven instead of He in order to study the effect of different perturber gases.

Experiments were performed with two lasers: excimer/dye and the second harmonic of the mode locked femtosecond laser at about 427 nm. The autoionizing Rydberg states of barium atoms were populated by two photon absorption of radiation from a tunable dye laser (Model LPD-3002) pumped by the Lambda Physik Excimer laser (Model LPX-210i) at 308 nm. Dye laser pulses of 10 ns in duration and a repetition rate of 10 Hz were used to excite the barium atoms. The femtosecond laser at 427 nm was produced in the second harmonic generation device (Spectra Model 3980 Femtosecond Frequency Doubler) from 854 nm of the fundamental femtosecond oscillator source (Tsunami/Millennia) emitting ultra short pulses of 3 W power, 120 fs duration and a repetition rate of 80 MHz. Unfortunately, in the present experiment we could not achieve a stable mode-locking at a larger wavelength than 854 nm. Both laser beams were overlapped and aligned parallel to and 5 mm below the central tungsten rod entering through the opposite sides of the hot pipe oven. With its high repetition rate, the femtosecond laser beam acted as a continuous light for our detection system. It was, therefore, locked to 10 Hz repetition rate by using a mechanical chopper and adjusting the timings using a time delay generator to match the repetition rate of both lasers.

Although the mode-locked femtosecond laser oscillator has many discrete modes within the broad spectral bandwidth, these modes could not be “seen” by the atoms at gas pressures in the present experiment. The atoms will actually be excited with continuous spectral distribution of each laser pulse. For a pulse of 120 fs duration at a wavelength of 854 nm, the corresponding bandwidth was calculated from the Gaussian fit to be 18.2 nm. A 427 nm second harmonic of the fundamental femtosecond laser at 854 nm had a half width of 5.2 nm. The energy span of the red fs laser at 854 nm and of the violet fs laser at 427 nm were 250 cm^{-1} and 280 cm^{-1} respectively (see Fig. 2). That means that the Ba atomic lines will be additionally excited in the presence of the broadband femtosecond laser, which covers 427 ± 3 nm spectral range. This interval from 422 nm to 430 nm will directly excite the group of Ba autoionizing lines with main quantum numbers larger