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A new ionization process in the afterglow of pulsed hollow cathode discharge

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We report a new ionization process occurring in the afterglow of high density current hollow cathode pulsed discharge. The process involving the atomic and ionic metastables may be of practical interest in the investigation of population inversion and lasing on noble gases ion transitions in the temporal afterglow plasmas.

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1. Introduction

It is already known that the afterglow plasmas of pulsed discharges are very convenient for investigation of the kinetic processes occurring in plasma, mainly for those involving the atomic and ionic metastables.

In previous paper we propesed an optical absorption technique with an intense pulsed calibrated lamp one determined the neao metastable density in the negative glow of a hollow cathode disharge [1]. We reported also on the ionizing role played by atomic metastables in sustaining for long time high densities in inductive coupled plasma modulated by short high current pulsed discharges [2]. Thereafter we reported in [3] on a new population mechanism of Ar II energy levels in a high density current hollow cathode pulsed discharge.

In the present paper, we attempt to elucidate the presence of a large hump in the early temporal profile of ionic spectral lines emitted in the afterglow of pulsed high current hollow cathode discharges in noble gases. For this purpose, we performed spectroscopic measurements with temporal resolution for certain neon, argon and xenon atomic and ionic transitions and for H_β line emitted by hydrogen impurities added to the noble gases.

The obtained experimental results suggest that atomic and ionic metastables play an important role in ionizing processes occurring in the early afterglow of the pulsed discharge, particularly in the generation of multiple-ionized ions.

2. Experimental set-up

The schematic of our experimental set-up is presented in Fig. 1 [4].

The discharge tube, made of glass, contains a cylindrical hollow cathode of Titanium (150 mm length and 4 mm diameter) and an anode consisting of two stainless steel rings (4 mm diameter) placed symmetrically at the two ends of the cathode. High current pulses of short duration were obtained by discharging a storage capacitor C through a rotary spark gap with a commutation time below 10 ns [5]. Working at 1-5 torr filling gas pressure, we obtained peak current pulses in the range of 20-100 A with duration of 60 ns (at half-width) depending on the charging voltage of the main capacitor. This pulsed high current density provides a large amount of excited atoms, ions and long-lived atomic and ionic metastables.

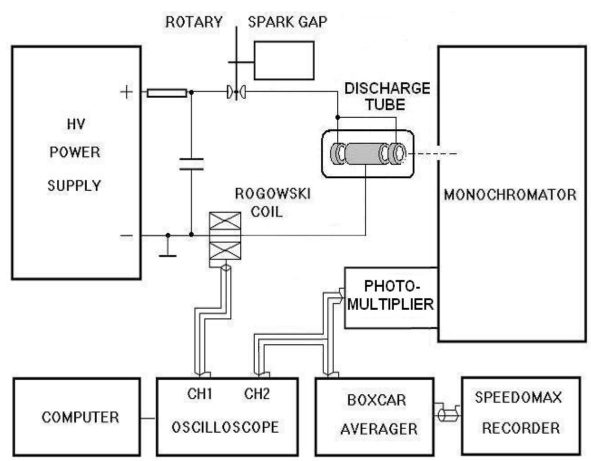

Fig. 1. Experimental setup.

3. Results and discussion

The temporal spectral distributions of NeII, ArII and XeII point out the existence of a hump in the early afterglow of ionic lines (see Fig. 2), whose intensities increase with the discharge current.

Analyzing both spectra recorded with a variable electronic gate positioned during the current pulse and during the hump, leads to the conclusion that ion levels are populated by different mechanisms in the two time ranges. We suppose that during the hump period the energy levels of ions are mainly populated by recombination of double-ionized ions, in contrast to the current (discharge) period, when ions excitation is caused by impact with energetic electrons. For example, Fig. 3 (a) and (b) present the Ne spectra recorded in the range of 3500 – 3830 Å.

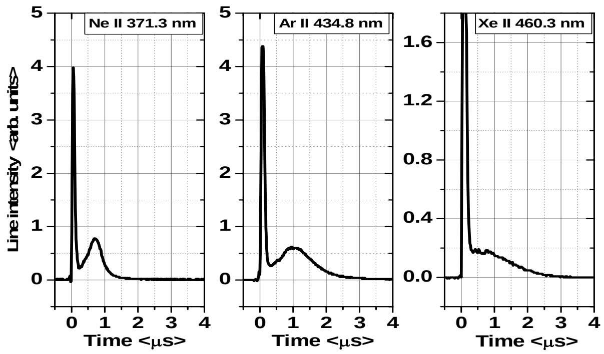

Fig. 2. Temporal profiles of neon, argon and xenon ion spectral lines.

The windows attached to spectra pictures present the temporal evolution of 3713 Å Ne II line and the electronic gate positioned on the current respectively on the hump.

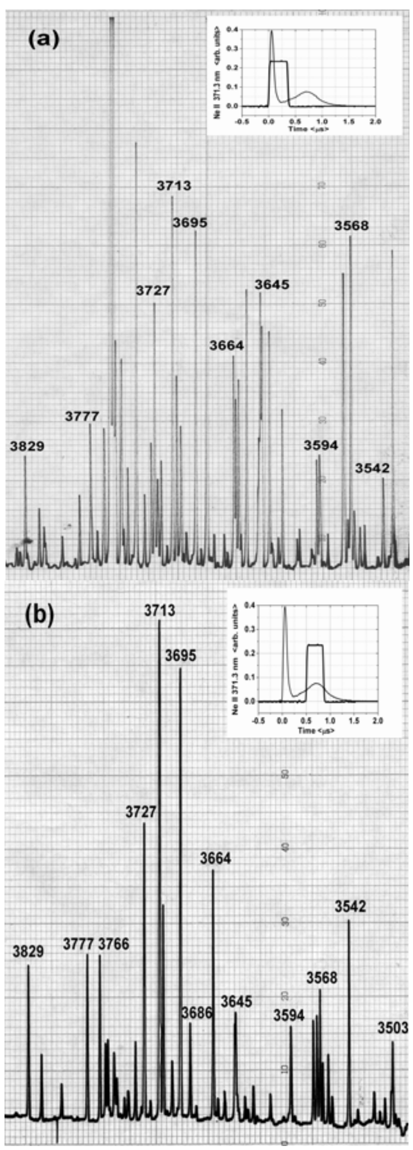

Fig. 3. Neon emission spectra recorded during the current pulse (a) and during the after glow hump (b).

The recombination processes may lead even to a population inversion as it can be seen in the case of the Ar II energy levels 4p $^4D_{7/2}$ (19.49 eV) and 5s $^4P_{5/2}$ (22.51 eV), (see Fig. 3).

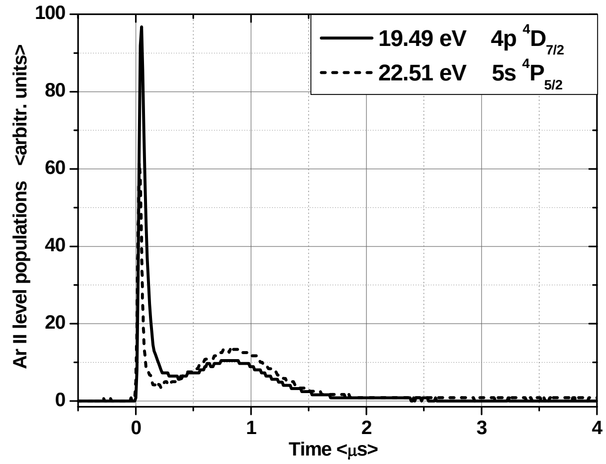

Fig. 4. Population inversion of the 4p $^4D_{7/2}$ (19.49 eV) and 5s $^4P_{5/2}$ (22.51 eV) Ar II energy levels.

The shape of the hump and the experiments we have made reveal that the double-ionized ions involved in the recombination processes are generated in the afterglow. The ions produced during the current pulse are assumed to be quickly lost by recombination and ambipolar diffusion. Also, we proved that long-lived atomic and ionic metastables are involved in their generation.

Thus we presumed that in the afterglow of the high current hollow cathode pulsed discharge the energy levels of the noble gases ions, are populated by the following mechanism

$$A^{++} + e + M \rightarrow A^{+*} + M \qquad (1)$$

where A^{++} is generated by

$$A^{m} + A^{+m} \rightarrow A^{++} + e \qquad (2)$$

In order to sustain our supposition regarding the process (2), we investigate the temporal evolution the Ne, Ar and Xe atomic and ionic metastables.

It was shown in our previous papers [1] that in the afterglow of the pulsed discharges in neon the atomic metastables are responsible for levels population of the hydrogen impurities ($Ne^m + H_2 \rightarrow Ne + H_2^+ + e$, $\sigma = 2.65\times10^{-16}$ cm^2 [6], $H_2^+ + e \rightarrow H_2^* \rightarrow H^*$ (n=6, 5,4,3) + H). Similarly, in argon afterglow plasma the ionic metastables are involved in the population process of hydrogen impurity energy levels ($Ar^{+\,m} + H_2 \rightarrow Ar^m + H_2^+$, $\sigma = 3.6\times10^{-16}$ cm^2 [7], $H_2^+ + e \rightarrow H_2^* \rightarrow H^*$ (n = 6, 5, 4, 3) +H).

More than that, we have shown [8] that the peak position of the H_β line in the neon afterglow may be taken as a marker for hydrogen impurity concentration in the discharge.

Fig. 4 presents the temporal evolution of Ne II 3713 Å line and H_β line of hydrogen in a pulsed discharge in neon (5 torr) with hydrogen traces at partial pressures 7×10^{-2} Torr (dashed line) and 1.2×10^{-1} Torr (solid line), for the same experimental conditions.

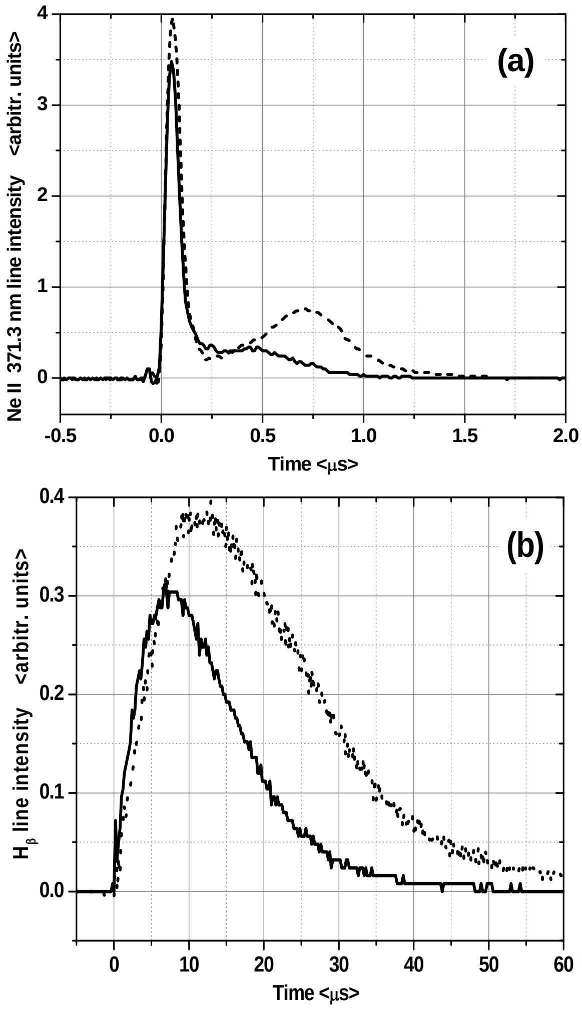

Fig. 5. Temporal evolution of 3713 Å Ne II line (a) and H_β line (b), for hydrogen partial pressures: 7×10^{-2} Torr – dashed line, respectively 1.2×10^{-1} Torr - solid line.

The above figures show that the increase of hydrogen concentration influences in the same way the temporal evolution of both, the H_β line and ionic hump, namely the peaks decrease and shift toward earlier afterglow. This behaviour is due to the intensification of neon atom metastable destruction by Penning effect ($Ne^m + H_2 \rightarrow Ne + H_2^+ + e$), with increasing the hydrogen concentration.

The time evolution of Ar II line at 4348 Å and H_β line emitted from pulsed discharges in argon (1.3 torr) with hydrogen impurities at partial pressures 7×10^{-2} Torr (dashed line), respectively 1.2×10^{-1} Torr (solid line) are presented in Fig. 5 (a) and (b).

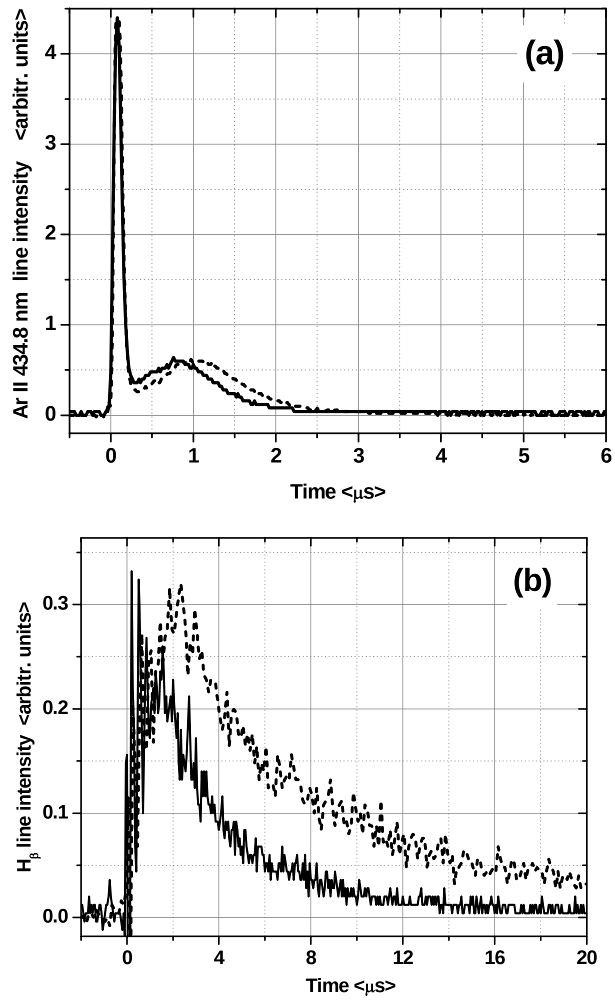

Fig. 6. Temporal evolution of 4348 Å Ar II line (a) and H_β line (b), for hydrogen partial pressures: 7×10^{-2} Torr- dashed line, respective 1.2×10^{-1} Torr - solid line.

Like in the neon case, the changes of hydrogen concentration, affect in the same way the ionic hump and H_β line. Nevertheless, the argon case is somehow different because the temporal evolution of the argon ion metastables is affected by the Penning effect, not the atom metastables.

In Xenon there is no Penning effect on hydrogen molecules, neither on atomic metastables nor ionic metastables. The temporal evolution of Xe II 4603 Å line in xenon discharge at 1 torr remains unchanged when hydrogen is added, Fig. 6. and the H_β line do not appear at all in the afterglow.

This fact represents a further argument sustaining the population mechanism of ionic energy levels involving the metastables states.

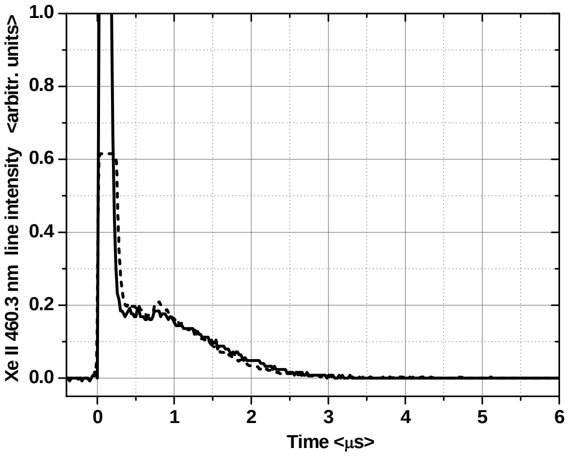

Fig. 7. Temporal profile of 4603 Å Xe II line for hydrogen partial pressures: 7 × 10^{-2} Torr – dashed line, respective 1.2×10^{-1} Torr - solid line.

4. Conclusions

Starting from the observation of a large hump in the afterglow profile of ionic lines, we have proposed a new population mechanism of the ions energy levels in the afterglow of the pulsed high current noble gases hollow cathode discharges.

This new mechanism justified by the formation of large amount of atomic and ionic metastables in the presented pulsed discharge may be of practical interest in the investigation of population inversion and lasing on noble gases ion transitions in the temporal afterglow plasmas.

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