

IONIZING ROLE PLAYED BY ATOMIC METASTABLE SPECIES IN RF PLASMA MODULATED BY SHORT HIGH CURRENT PULSED DISCHARGES

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Langmuir probe measurements were used to demonstrate the ionizing role of atomic metastables in inductively coupled rf plasma modulated by short high current pulsed discharges. Transient plasma generated in gases without metastable levels (H_2) decays much faster than that generated in gases having atomic metastable levels (Xe, Ar and Ne).

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1. Introduction

Since last decades, radio-frequency (rf) plasma has been proved as a powerful tool widely used in processing of semiconductor materials. Moreover, it was demonstrated that modulating the rf plasma brings many benefits to processing performance [1-3]. Usually, rf plasma is modulated by pulsing the input rf power. In this case, plasma density decreases from a certain value obtained when rf power is on, to almost zero when rf power is off.

Another possibility to modulate rf plasma was suggested by experimental studies on discharges obtained by superposition of short high current pulses over a continuously generated capacitive coupled rf plasma (CCP) of argon [4]. In this case plasma density is rapidly increased with few orders of magnitude during the short pulses and then it slowly decreases to normal values specific to rf plasmas. High density plasma measured for much longer time (hundreds of microseconds) than pulse duration (few tens of nanoseconds) led to the assumption that metastable-metastable processes acts like a supplementary source of ionization. The large amount of metastable atoms created during the pulse stores an important energy, which is then delivered after the pulse ceases, effectively ionizing the gas hundreds of microseconds [4].

The aim of the present work is to clearly demonstrate the ionizing role of atomic metastable in sustaining for long time high densities in inductive coupled plasma (ICP) modulated by short high current pulsed discharges.

2. Experimental setup

The plasma chamber consisted of a cylindrical glass vessel 7 cm in diameter and 33 cm in length (see Fig. 1).

Inductively coupled rf plasma was continuously generated in various gases using a 5 turns coil wound on the external surface of the chamber. The coil was driven by a home-made rf generator with output power ~ 25 W at 35 MHz.

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The modulation of the rf plasma was achieved by superposition of repetitively short high current pulsed discharges generated by a pair of parallel electrodes placed at the ends of the chamber, 20 cm one from the other. The pulse generator is capable to generate short pulsed discharges (150 ns) with a current peak of about 25 A at a repetition rate of 50 Hz.

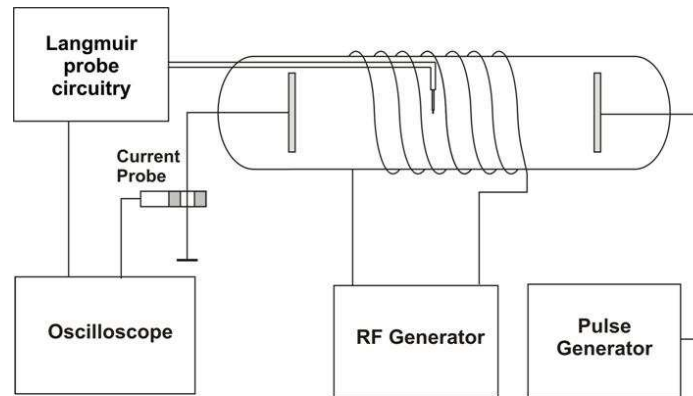


Fig. 1. Experimental setup.

Current and voltage of the pulsed discharges were measured using appropriate fast response probes (Tektronix).

The transient plasma resulted from the modulation of rf discharge, was experimentally investigated by recording the current signals collected by a cylindrical Langmuir probe (0.3 mm diameter and 3 mm long) on a digital oscilloscope. Low pass filtering circuits and attenuation voltage probe were used, in order to reduce the effect of the inherent short high current pulse signals collected by the Langmuir probe.

3. Results and discussion

In order to investigate the ionizing role of metastable atoms in ICP modulated plasma, the experimental measurements performed in gases having atomic metastable levels were compared to those performed in a gas that have no such atomic metastable levels.

It is well known that xenon, argon and neon have long-lived atomic metastable levels, while hydrogen has no such atomic metastable levels. That is why we chose these gases for our experiments. The working pressure for each gas was determined by optimal condition in which plasma uniformly spreads in almost entire volume of the discharge chamber. However, the pressure was not lower than 50 Pa and not higher than 170 Pa. For all these gases, in this pressure range, the current pulse had almost the same length (~150 ns) having a temporal profile as shown in Fig. 2.

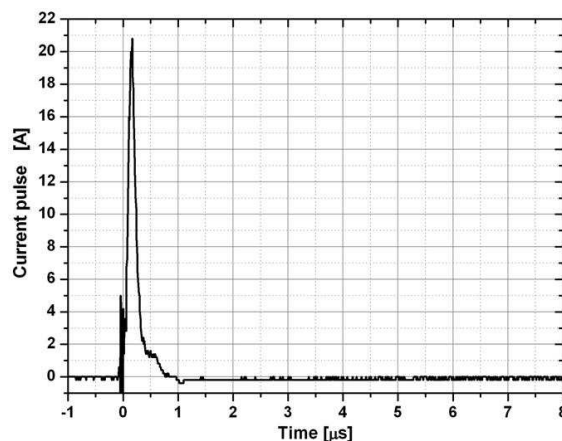


Fig. 2. Current pulse.

The current signal collected by a Langmuir probe positive biased (+ 30 V) was considered as a relative measure of plasma density time evolution. Fig. 3 shows probe current temporal evolutions recorded with an oscilloscope for both, pulses superimposed on rf discharges and pulsed discharges alone in argon. This figure suggests that plasma density obtained in combined discharges is much higher than plasma density obtained in pulsed discharges alone.

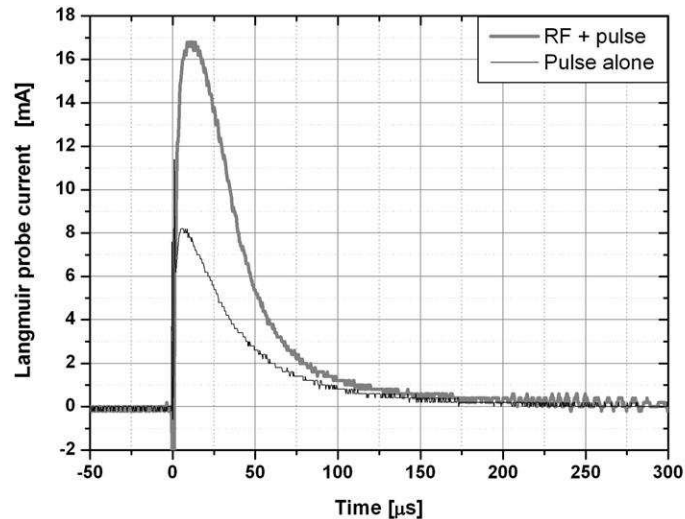


Fig. 3. Current signals drawn by Langmuir probe positive biased at 30V in argon plasma.

The most important results are presented in Fig. 4, where it is clearly seen that Langmuir probe current time distribution is much shorter in hydrogen compared to those in Xe, Ar and Ne. So, in the absence of metastables, plasma decays shortly (few tens of microseconds) unlike it happens in gases with metastables where the decay is much longer (few hundreds of microseconds). That could be a good prove for the assumption that metastable-metastable ionization ($\text{Ar}^* + \text{Ar}^* \rightarrow \text{Ar}^+ + \text{Ar} + e$) plays an important role in sustaining very high density plasma after the pulse ceases.

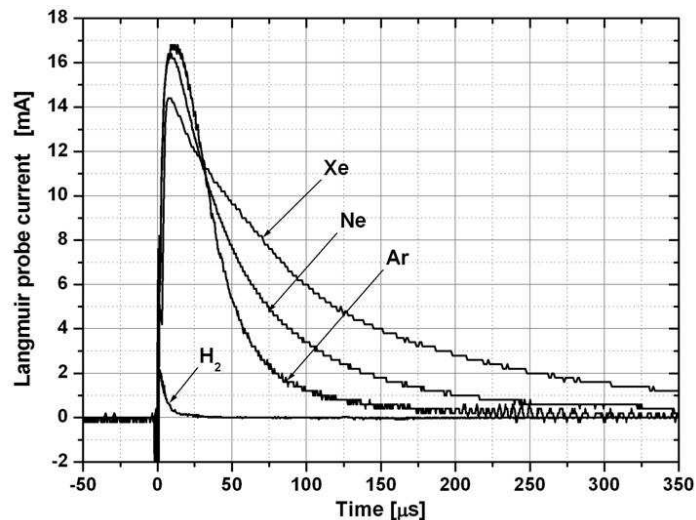


Fig. 4. Langmuir probe current signals.

4. Conclusion

Decay of the transient plasma produced by superposition of high current pulsed discharges over a background rf discharge depends on the presence of the metastables.

Time resolved Langmuir probe measurements showed that plasma decays much faster in gases without metastables (H_2) than in gases with metastables (Xe, Ar and Ne). It was assumed that the metastable-metastable ionization plays an important role in sustaining very high density plasma after the pulse ceases.

References

- [1] R. W. Boswell, R. K. Porteous, *J. Appl. Phys.* **62**, 3123 (1987).
- [2] L. J. Overzet, T. Verdeyen, *Appl. Phys. Lett.* **48**, 695 (1986).
- [3] Y. Watanabe, M. Shiratani, Y. Kubo, I. Ogawa, S. Ogi, *Appl. Phys. Lett.* **53**, 1263 (1988).
- [4] C. Diplasu, E. Diplasu, H. Fujita, *Proceedings of Joint Conference XVI-th ESCAMPIG and V-th ICRP (Grenoble, France, 2002) Vol. II*, p. 117.