# Effects of pulse shape tailoring on the properties of a pulsed capacitively coupled radiofrequency discharge

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We present a study carried out on a capacitively coupled radiofrequency pulsed plasma with the aim of determining the effect of different pulse shapes on the overall discharge properties. A set of differently shaped pulses were used to generate discharges in a low pressure radiofrequency discharge and measurements of electron density, made using microwave resonance hairpin probes, and optical emission spectra, made using a spectrometer and a gated ICCD, were used to characterise the discharge. The study was carried out in a capacitively coupled radiofrequency discharge generated in a Gaseous Electronics Conference (GEC) reference reactor with gas pressure in the range of $6 - 70$ Pa, radiofrequency power in the range of $1 - 100$ W, and pulse duration in the range of $10\ \mu s - 100$ ms. Tailored pulses can be used to control the development of electron energy and electron density.

## 1. Introduction

Low pressure pulsed-plasma sources are used to achieve good etching performance in a dense structure patterning, and meet the need for ultra-fine structures [1]. Varying the pulse conditions can change the gas phase chemistry, modify the energy of ions bombarding substrates, and thereby meet the requirements for highly selective and anisotropic notch-free etching processes [2–4]. A further feature of pulsed discharges is that the ion bombarding energy can be controlled independently of the ion flux by modulating the pulse frequency and duty cycle which allows the optimization and more control over the performance of processing plasmas [5].

The research reported here aims to investigate the possibility of tailoring the shape of the applied pulses in order to achieve greater control over plasma properties (electron energy & density). In this work, the effect of tailoring the pulse shape in a low pressure radiofrequency discharge was studied using a combination of electron measurements and plasma spectroscopy. In the first part of the work, pulse tailoring in a pure argon plasma was investigated. In the second part, measurements were made in an Ar/Kr/Xe gas mixture in order to use trace rare-gas spectroscopy to study ignition and decay mechanisms for each pulse shape. In the final part, measurements made in an $Ar/O_2$ discharge were analysed in order to study the effect of pulse tailoring in an electronegative, molecular discharge.

## 2. Experimental Setup

This research was carried out on a radiofrequency capacitively coupled pulsed discharge created in a Gaseous Electronics Conference (GEC) reference reactor. The discharges were generated between stainless steel planar electrodes with a radius of 101.6 mm and a separation of 25.4 mm. Figure 1 presents a schematic representation of the experimental setup used in the study including the data acquisition techniques. The radiofrequency power had a frequency of 13.56 MHz, and was generated as well as modulated using an Agilent 3250A Arbitrary Waveform Generator whose output was then amplified.

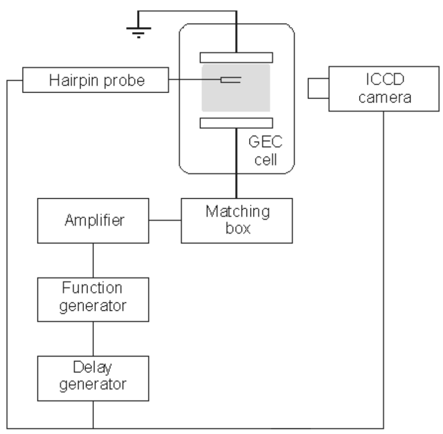


Fig. 1: The experimental setup used in this study.

Experiments were performed over gas pressure ranging from 6 to 70 Pa (50 and 500 mTorr), and radiofrequency power ranging from 1 to 100 W. Between different measurements and gas mixtures the chamber was pumped down to a base pressure of $10^{-5}$ Pa (approximately $10^{-4}$ mTorr). MKS mass flow controllers were used to control and systematically vary the gas flow.

The local electron density was measured using microwave resonance hairpin probes, by simply measuring the probes' resonance frequencies [7–9], whilst plasma emission spectra were measured using a simple optical system [6] consisting of a Stanford Computer Optics ICCD camera (Model 4Picos ) and a Horiba TRIAX320 spectrometer.

## 3. Results & Discussions

In the first stage of the experiments the electron density and plasma emission of pure argon plasma were measured for a square radiofrequency pulse of frequency 1 kHz and 50% duty cycle. This provided a reference with which later measurements could be compared. Figure 2 shows the total light emission and electron density for this pulse shape. The plasma conditions were gas pressure of 27 Pa, radiofrequency power of 50 W, pulse frequency of 1 kHz, and duty cycle of 50%. These results are consistent with those reported by other authors [5], with the emission indicating a transient phase of high electron energy at the start of the pulse, and the electron density increasing gradually over the first part of the pulse and then remaining constant.

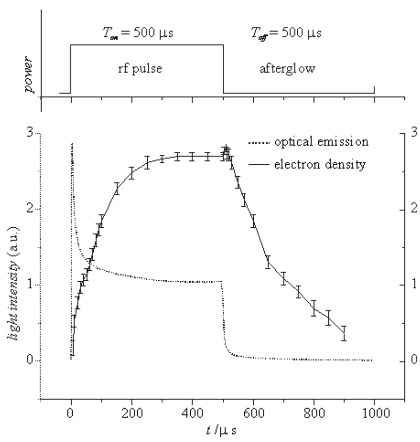


Fig. 2: Total light emission and electron density in the reference pulse.

Figure 3 shows the effect of one particular pulse shape on the discharge properties. Part (a) of the figure shows the pulse shape, which consisted of a linear increase in the first 25% of the duty cycle and then a constant value for the next 25% of the cycle. The density results shown in part (b) indicate that the electron density rises much more slowly for this pulse shape, as might be expected. The emission measurements shown in part (c) of the figure indicate that the time dependence of the electron energy is significantly different for the two pulse shapes, with the tailored pulse avoiding the short-lived high electron energy feature observed for the case of the standard square-wave pulse. This indicates that the ignition phase of the discharge can be controlled by varying the shape of the radiofrequency pulse, and the sudden increase in electron energy is avoided without significantly affecting the final value of electron density [6].

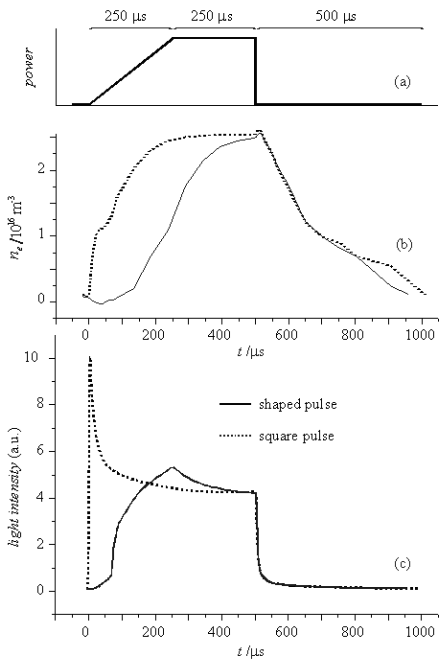


Fig. 3: Comparison of the results of both the reference and modulated pulses.

These results were obtained for the case of a pure argon discharge. Additional results will be presented for discharges with different gas mixtures, in order to further study ignition and decay processes by examining emission from different gas species. Finally, results for an $Ar/O_2$ discharge will be presented, and the effect of these pulses on an electronegative discharge will be discussed.

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**References**

[1] T. H. Ahn, K. Nakamura, and H. Sugai, J. Plasma Sources Sci. Technol. 5 (1996) 139.

[2] S. Samukawa, T. Mieno, J. Plasma Sources Sci. Technol. 5 (1996) 132.

[3] J. P. Booth, G. Cunge, N. Sadeghi, R. W. J. Boswell, J. Appl. Phys. 82 (1997) 3785.

[4] S. J. Pearton, D. P. Norton, J.Vac Sci. Technol. B 24 (2005) 16.

[5] M. A. Lieberman, S. Ashida, J. Plasma Sources Sci. Technol. 5 (1996)145.

[6] V. Šamara, M. D. Bowden, N. St. J. Braithwaite, J. Phys. D: Appl. Phys. 43 (2010) 124017.

[7] R. B. Peijak, V. A. Godyak, R. Garner, B. M. Alexandrovich, N. Sternberg, J. Appl. Phys. 95 (2004) 3785.

[8] R. B. Piejak, J. Al-Kuzee, N. St. J Braithwaite, J. Plasma Sources Sci. Technol. 14 (2005) 734.

[9] J. Conway, N. Sirse, S. K. Karkare, M. M. Tuner, J. Plasma Sources Sci. Technol. 19 (2010) 065002.