Fluid modeling of electrically asymmetric capacitively coupled silane / hydrogen plasma discharges

T..Zhang [1], J.-M. Orlach[2], V. Giovangigli[3], E. V. Johnson[1], P. Roca i Cabarrocas[1] and T. Novikova[1]

[1]LPICM, CNRS, Ecole polytechnique, IPParis, Palaiseau, France
[2]Laboratoire EM2C, CNRS, Ecole CentraleSupélec, Gif-sur-Yvette, France
[3]CMAP, CNRS, Ecole polytechnique, IPParis, Palaiseau, France

Abstract: The use of tailored voltage waveforms in radio-frequency capacitively-coupled plasma (RF-CCP) discharges allow to control independently the ion flux and the ion energy reaching the substrate, which can be a decisive advantage for silicon thin film deposition. In this work, we present the results of fluid modeling of a silane-hydrogen RF CCP discharge excited by temporally asymmetric waveforms, and discuss the discharge parameters (ion densities, direct current (DC) bias, etc) calculated for the excitation waveforms with different number of harmonics. We show that both chemical and electrical parameters of silane / hydrogen RF CCP discharge can be controlled by changing the number of harmonics in tailored voltage excitation waveforms.
Keywords: silane / hydrogen plasma, 1D fluid model, tailored voltage waveform

1. Introduction

Silane / hydrogen RF-CCP discharges are widely used in technology for various practical applications (e.g. heterojunction solar cells, thin film transistors, detectors, etc.). The excitation of the plasma with tailored voltage waveforms (TVW) in such type of discharges allows to control independently the ion flux and ion energy reaching the substrate[1], which can be a decisive advantage for silicon thin film deposition using plasma enhanced chemical vapor deposition (PECVD) [2].

As shown in prior studies [3], the effect of tailored voltage waveforms is highly dependent on discharge chemistry. However, while pure hydrogen discharges excited by TVW have been largely addressed in the literature [4], few studies have been devoted to silane discharges excited by TVW.

In this work, a numerical study of the effect of tailored voltage waveforms on a silane / hydrogen RF discharge is proposed for the first time. We use a fluid model to simulate a 1D silane / hydrogen RF discharge excited by TVW and discuss the discharge parameters (ion densities, DC bias, etc) simulated for the excitation waveforms with different number of harmonics.

2. Model

The RF-CCP discharge reactor is represented in **Fig.1**. A mixture of silane and hydrogen is injected through a showerhead with a normal inlet velocity.

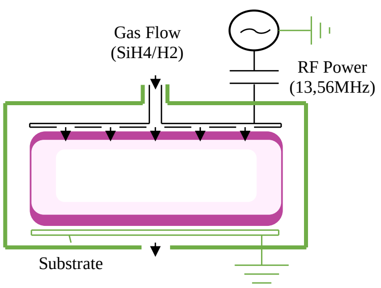

Fig.1. Schematic representation of the axis symmetric radio-frequency reactor.

The lower electrode is grounded while the upper electrode is driven by a periodic applied potential. In our model, the external circuit is reduced to a RF generator and a blocking capacitor. The working pressure is 2.28 Torr, the working temperature is 300°K, and the excitation signal frequency is 13.56MHz.

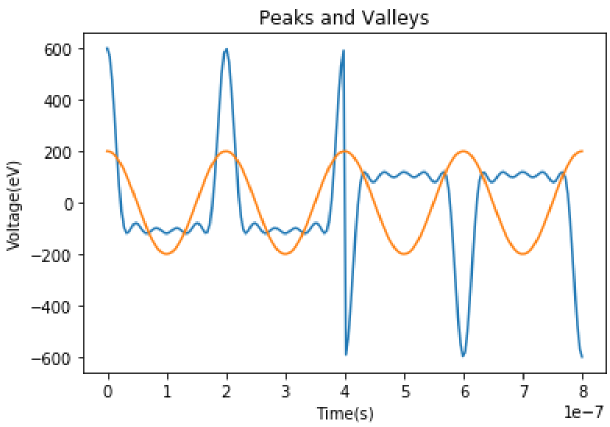

Fig.2. Peaks and Valleys waveforms for different harmonics. The blue curve corresponds to N_{RF}=5, the orange curve corresponds to N_{RF}=1. [5].

Peaks and valleys waveforms are defined by the following applied potential,

$$\varphi_{AP}(t) = \varphi_{RF} \sum_{k=1}^{N_{RF}} \frac{N_{RF}-k+1}{N_{RF}} \cos(k\omega t + \phi) \qquad (1)$$

and are very useful because they have the maximum possible amplitude asymmetry. Here, N_{RF} is the number of harmonics and ϕ is a phase shift which is varied between 0 and π. Sawtooth-like waveforms are also used in this study. These waveforms possess no amplitude asymmetry but have a maximal slope asymmetry. Similar to peak and valley waveforms, the latter waveforms induce a self-bias potential on the powered electrode even in geometrically symmetric systems,

$$\varphi_{AP}(t) = \varphi_{RF} \sum_{k=1}^{n} \frac{1}{k} \sin(k\omega t) \quad (2)$$

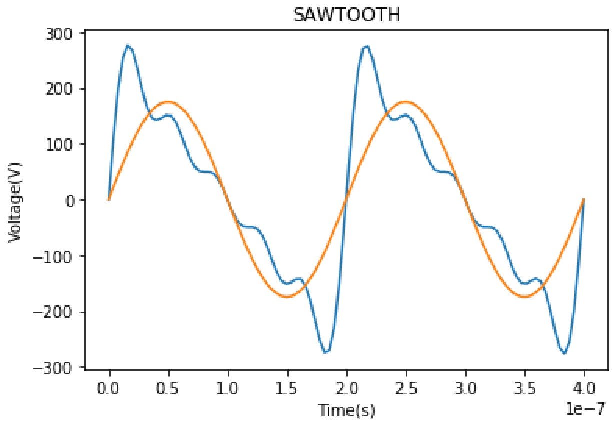

Fig.3.Sawtooth-like waveforms. Sine (orange line) and refined (blue line) waveform across two periods. The number of harmonics for the sawtooth-like waveform (blue curve) is n = 5 [6].

As the DC self-bias potential is the main indicator of the effect of TVW on a discharge, the computed values of the DC bias are compared for TVWs with different number of harmonics, and a sensitivity study is carried out to identify the main parameters influencing the value of the DC bias.

3. Results

The simulations were carried out under typical conditions for plasma enhanced low-temperature epitaxy of silicon [7]. The geometry of the discharge is shown in **Fig.1.** The interelectrode distance was set equal to 2.5 cm. For the base case, the inlet gas mixture consists of 80% of hydrogen and 20% of silane. The neutral gas temperature was equal to T=300° K. We present the results for sawtooth TVWs with varying number of harmonics n= 1, 3, 5.

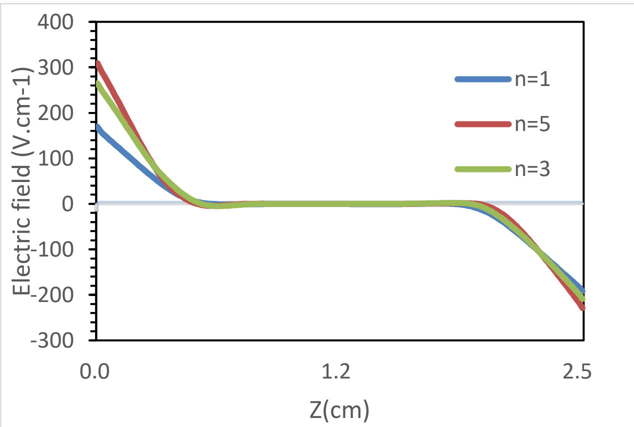

Fig.4. Time-averaged electric field along the axis of symmetry of reactor for different numbers of harmonics, namely n=1, 3, 5.

As expected there is no electric field in the center of discharge (bulk plasma), while the electric field is high in the vicinity of electrodes - plasma sheath regions (see Fig. 4).The increase of electric field at the left electrode with increase of number of harmonics reflects the increase of DC bias.

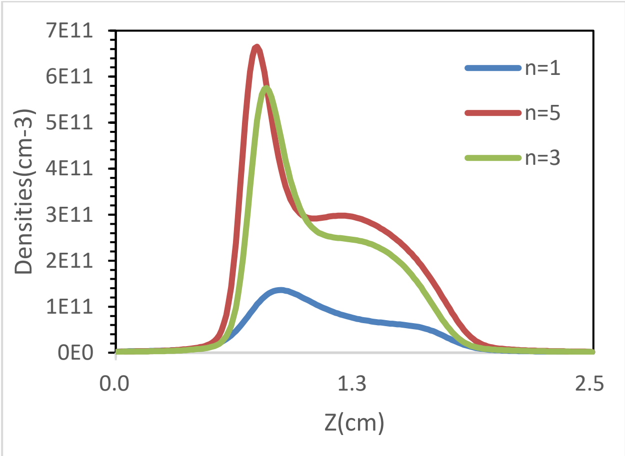

Fig.5. Time-averaged density of SiH_3^+ along the axis of symmetry of reactor for different numbers of harmonics, namely n=1, 3, 5.

Fig.5. shows that density of SiH_3^+ ions along the axis of symmetry of reactor changes with number of harmonics n=1, 3, 5. The maximum of density increases as n increases from 1 to 5. In particular, the ion density near the left sheath increases dramatically with n.

In conclusion, we found that changing the number of harmonics in TVW can be used as an extra knob to adjust silane / hydrogen RF CCP discharge parameters, such as ion densities and electric field, which is beneficial for silicon thin film deposition using PECVD.

4. References

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