Capacitive H_2 and H_2 SiH_4 plasmas driven by electrically asymmetric voltage waveforms

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Recent studies have shown that the Electrical Asymmetry Effect (EAE) is a powerful technique to control the symmetry of capacitively coupled plasmas. Consequently, the sheath voltages and the mean ion energies at both the powered and grounded electrode can be adjusted without affecting the ion flux. In this work, we demonstrate the usefulness of the EAE under experimental conditions, which are typically used for the production of silicon thin film solar cells. The discharge is operated in a hydrogen silane gas mixture. The impact of this complex discharge environment on the control of plasma properties via the EAE is discussed and the results are compared to chemically inert (pure H_2) plasma conditions.

Capacitively coupled radio frequency (CCRF) discharges are widely used in plasma processing applications, since the etching of nanometer sized structures in the production of electronic devices or the deposition of silicon thin films for photovoltaic applications is only possible using CCRF plasmas or hybrid combinations with other types. In order to achieve separate control of the mean ion energy and the total ion flux towards the surface, CCRF discharges operated with two substantially different frequencies are typically used. However, it has been shown, that this approach is generally limited due to the frequency coupling [1] and the effect of secondary electrons [2].

A novel approach to realize this independent control is based on using a voltage waveform with different absolute values of its global maximum, $\phi_{\sim,max}$, and minimum, $\phi_{\sim,min}$, respectively. Such an asymmetric voltage waveform is realized by applying a fundamental frequency and its second harmonic to the powered electrode:

$$\phi_{\sim}(t,\theta) = \frac{1}{2}\phi_0\left[cos(\omega_{rf}t+\theta)+cos(2\omega_{rf}t)\right]. \quad (1)$$

Here, $\omega_{rf} = 2\pi f$ with f being the fundamental frequency. The symmetry of $\phi_{\sim}$ can be adjusted via the phase angle θ. This, in turn, allows controlling the symmetry of the discharge. Accordingly, a DC self bias develops even in a geometrically symmetric discharge and the time averaged sheath voltages depend on θ. Therefore, the mean energy of ions hitting the electrode surfaces can be tuned over a wide range, while the amplitude of the applied voltage is not changed. Consequently, the power absorbed by the electrons remains almost unchanged, resulting in a constant ion flux. These basic mechanisms of the Electrical Asymmetry Effect (EAE) have been successfully applied to CCRF discharges operated in argon [3, 4, 5] and electronegative gases [6, 7] and understood in great detail using an analytical model [8, 9].

Here, the EAE is tested experimentally in a more complex situation. The discharge is operated in a hydrogen silane gas mixture typically used for the production of silicon thin film solar cells. In such a chemically reactive plasma, electronegative ions and the production of dust particles might play a crucial role. Therefore, we compare it with chemically inert electropositive (pure H_2) plasma conditions. Furthermore, the mechanisms of electron heating and discharge sustainment can be remarkably altered [6, 10] due to the relatively high neutral gas pressure [11].

Figure 1 shows a comparison of the DC self bias control via the phase angle θ in a H_2 SiH_4 discharge compared to a pure hydrogen environment. Using a simple analytical model for geomtrically symmetric discharges at high pressures, i.e. assuming the same properties for the sheaths adjacent to both electrodes, the normalized DC self bias $\bar{\eta}$ can be estimated [3, 8, 9]

$$\bar{\eta}(\theta) = -\frac{1}{2\phi_0}\left[\phi_{\sim,max}(\theta)+\phi_{\sim,min}(\theta)\right]. \quad (2)$$

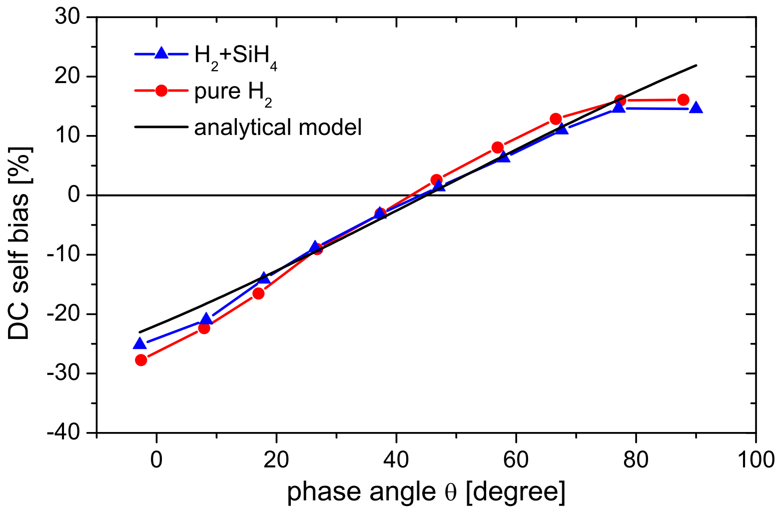

Fig. 1: DC self bias normalized by the applied voltage amplitude as a function of the phase angle θ in a geometrically symmetric hydrogen silane or pure H_2 discharge. The total gas pressure is 500 Pa using gas flows of Γ_{H2}=1000 sccm and Γ_{SiH4}=0 or 50 sccm, respectively. The applied voltage amplitude is kept constant (ϕ_0=65 V). The electrode temperatures have been set to $T_{pow} = T_{ground} = 80°C$. The model curve is obtained from equation 2.

Similar to the previous investigations of the EAE mentioned above, the DC self bias depends almost linearly on θ. Based on these results, it can be concluded that the EAE is a promising method to control plasma properties and optimize the processing conditions in hydrogen diluted silane discharges. However, it is known that the dust formation in silane plasmas can cause substantial changes in the discharge symmetry [12]. These changes will be investigated in detail and the resulting limitations will be discussed.

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