# The influence of field reversals on the DC self bias in capacitive RF-discharges

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In capacitively coupled radio-frequency discharges, no net current can flow due to the presence of a blocking capacitor. To ensure this, a DC self bias can develop. Externally, this DC self bias can be controlled by the reactor geometry or specific voltage waveforms. Internally, sheath properties like the mean ion density in the sheaths influence the DC self bias. We investigate the effect of field reversals in hydrogen plasmas on these sheath properties and the DC self bias.

In capacitively coupled radio-frequency (CCRF) discharges, the energy of ions hitting the surfaces is determined by the temporally averaged sheath potential. This potential can be influenced by the amplitude of the applied voltage waveform. However, this also changes the input power. Therefore, the ion density and fluxes to the surfaces also change which is not desirable for industrial applications. Another possibility is to induce a DC self bias which raises or lowers the sheath potential. An analytical model shows, that the DC self bias, $\eta$, is given by [1]

$$\eta = -\frac{\phi_{max} + \varepsilon\phi_{min}}{1+\varepsilon}. \tag{1}$$

Here $\phi_{max,min}$ is the maximum or minimum of the applied voltage waveform and $\varepsilon$ is the symmetry parameter given by

$$\varepsilon = \frac{\bar{n}_{sp}}{\bar{n}_{sg}} \left(\frac{Q_{mg}}{Q_{mp}}\right)^2 \frac{I_{sg}}{I_{sp}}. \tag{2}$$

$\bar{n}_{sg}$ and $\bar{n}_{sp}$ are the spatially averaged ion densities in the grounded and powered sheath, respectively, $Q_{mg}$ and $Q_{mp}$ the maximum charges in the respective sheaths, and $I_{sp}$, $I_{sg}$ the sheath integrals, whose values describe the shape of the ion density profiles in the sheaths. Equation 2 assumes equal surfaces for both the powered and grounded electrode.

If the electrons are mainly heated by the sheath expansion ($\alpha$ - mode), $\varepsilon$ can be assumed to be constant at sufficiently high pressures. According to equation 1, $\eta$ can then be controlled by choosing voltage waveforms which exhibit different absolute values of maximum and minimum. These waveforms $\phi(t)$ can be realized by

$$\phi(t) = \phi_0 \left[sin\left(2\pi f t + \theta\right) + sin\left(4\pi f t\right)\right]. \tag{3}$$

Here $\phi_0$ is the voltage amplitude, $f$ the driving frequency, and $\theta$ a fixed phase angle between the two sines. $\theta$ controls the shape of the voltage waveform and the value of $\eta$. Assuming a constant $\varepsilon$, $\eta$ is a monotonically increasing, linear function of $\theta$ for $45^\circ \leq \theta \leq 135^\circ$ [1]. This is called the Electrical Asymmetry Effect.

It has been shown, that the dependence of $\eta$ on $\theta$ differs, if the discharge is not operated in $\alpha$ - mode. For example, secondary electrons ($\gamma$ - mode) can influence $\varepsilon$ and consequently $\eta$ [2]. In this paper, we discuss the influence of field reversals [3] which lead to ionization in the sheaths which can alter the sheath properties. We systemically study the effect of field reversals on $\eta$ by simulating electrically asymmetric hydrogen plasmas with HPEM [4], varying pressure, the applied voltage amplitude, and the geometry. This paper briefly presents the variation of the voltage amplitude as an example. These

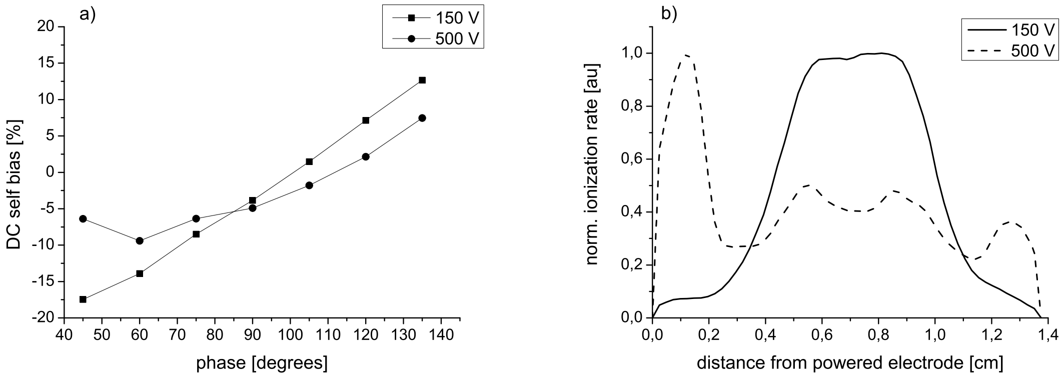


Fig. 1: a) DC self bias as a function of θ for different voltage amplitudes $\phi_0$. b) temporally averaged, normalized ionization profiles for $\theta = 90^\circ$. pressure $p = 100$ *Pa*, electrode gap $d = 1.4$ *cm*, electrode radius $r = 10$ *cm*.

simulations were carried out at a pressure of 100 Pa. The computational mesh was designed, so that the areas of powered and grounded electrode are equal.

Figure 1 shows η as a function of θ and the temporally averaged, normalized ionization profiles for two voltage amplitudes. At a voltage amplitude of 150 V, the ionization is dominated by the sheath expansion. As figure 1 shows, this leads to a monotonically increasing, linear dependence of the DC self bias on θ. However, if the ionization is dominated by the field reversals, as is the case at a voltage amplitude of 500V, the DC self bias behaves vastly differently as a function of θ. Firstly, the control range is significantly diminished, and secondly, at phase angles between 45° and 60°, a strong deviation from the monotonic linear dependence is observed.

This is caused by the asymmetric distribution of field reversals between the sheaths due to the asymmetric voltage waveforms; depending on the specific voltage waveform, field reversals might only occur or be more pronounced in one of the sheaths. The resulting asymmetric ionization profiles alter the ion densities in the respective sheaths differently. The asymmetry induced by the asymmetric field reversals generally tends to compensate the electrically induced asymmetry, hence the reduced control range of the DC self bias.

The decreasing behaviour of η between 45° and 60° is not directly caused by the altered ion density profiles, but also by the charge dynamics [5]. Usually, the maximum charge ratio $\left(\frac{Q_{mg}}{Q_{mp}}\right)^2$ can be considered to be close to unity. This assumption is based on the idea, that the total charge is nearly constant and concentrated in one sheath once during each rf-cycle at the moment of maximum sheath expansion. In our case however, the field reversals lead to a significantly varying total charge. How severely this affects $\left(\frac{Q_{mg}}{Q_{mp}}\right)^2$, depends on the specific voltage waveform. The biggest change of $\left(\frac{Q_{mg}}{Q_{mp}}\right)^2$ occurs at phase angles between 45° and 60° causing the decreasing behaviour of η in this region.

In conclusion, field reversals have a significant influence on the sheath properties and the asymmetry of CCRF-discharges. Generally, the geometrically or electrically induced asymmetry is compensated and η is consequently reduced.

## References

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