Plasma model for high power impulse magnetron sputtering (HiPIMS) with helium

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The use of helium as a working gas in High power impulse magnetron plasma (HiPIMS) is being considered as an alternative to the heavier gases commonly used such as argon. HiPIMS plasma in helium has interesting properties. The most striking is a much higher operating current densities ($6\ \mathrm{A\,cm^{-2}}$) [1, 2] than the conventional pulses (typically $2\ \mathrm{A\,cm^{-2}}$). Moreover, when using a molybdenum target, the peak discharge current increases with the pulse voltage [2]. The peak current is characterised by a very fast rise time ($< 5\ \mu$s) followed by a decay and a plateau (see fig.1(a) solid line).

To better understand this specific current pulse shape, the ionization region model (IRM) has been used for HiPIMS with helium instead of Ar/O_2 as before [3]. Cross sections [4, 5] and rate coefficients of inelastic collisions in helium HiPIMS were implemented in the model. IRM uses current and pulsed voltage measurements as inputs and replicates the waveform of the discharge current. As outputs, IRM gives the time evolution of plasma species and electron temperature. As a global model, the physical quantities obtained are averaged over the volume of the ionisation region (IR).

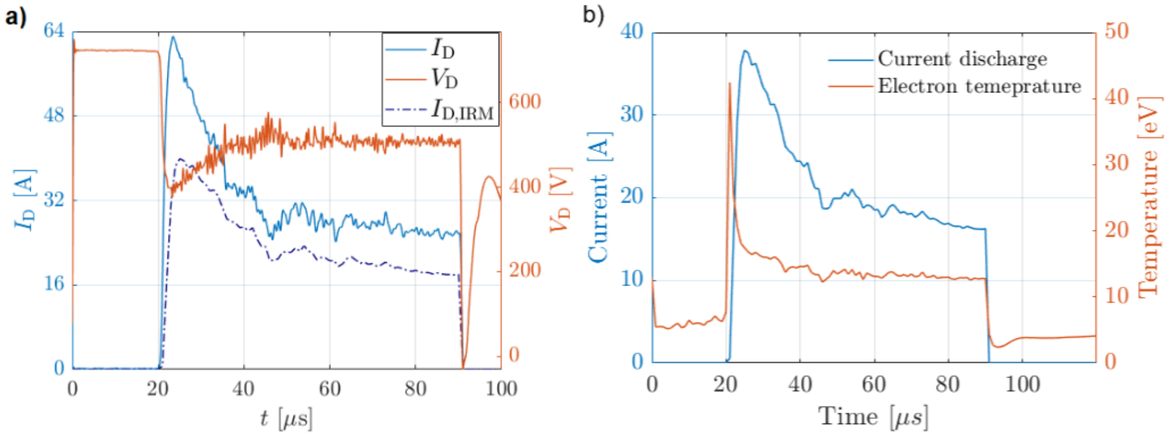

Fig. 1: (a) Measured discharge current (I_D) for a 700 V voltage pulse (V_D), with modeling result $I_{D,IRM}$ for a typical He/Mo HiPIMS pulse. (b) IRM current and electron temperature. evolution during the HiPIMS pulse.

One of the main fit parameters for the IRM is the voltage drop across the IR, which is set as a constant value during the pulse discharge. The equation for this voltage drop writes:

$$V_{IR} = f \times V_D : 0 < f < 1 \tag{1}$$

For Helium-Molybdenum IRM (He/Mo-IRM), f was modified to vary during the pulse by multiplying (1) with the ratio $I_D(t)/I_{Peak}$, which provides a better fit in case of helium and required by the sharp and fast variation of the discharge current. Fig.1(b) reports the time evolution of the current and electron temperature. The model accurately reproduces the rapid rise time of the peak and the subsequent decrease to a plateau. However, the IRM peak current is smaller than in experiments. Figure 1(b) shows that the peak current follows a peak in the cold electron temperature. The temperature increases from 10 eV to 40 eV, significantly surpassing the ionization energy of the ground state helium for a short time (< 5 µs). This spike in T_e has already been reported but using the PIC modeling [6].

Furthermore, the model provides the current composition of the discharge. As can be seen in fig.2, the peak current is carried solely by helium ions, while the current associated with metal ions is comparably low due to the low sputtering yield of helium. At the beginning of the discharge, only helium can be ionized by the secondary electrons, which gain enough energy to ionize the ground state (24.58 eV). After the current peak, the He metastable states (19.6 eV) formed simultaneaously with the first peak current, will start to play via a two-steps ionization, which requires much less energy (4.76 eV and 3.96 eV). Consequently, the electron temperature decreases and so does the discharge current.

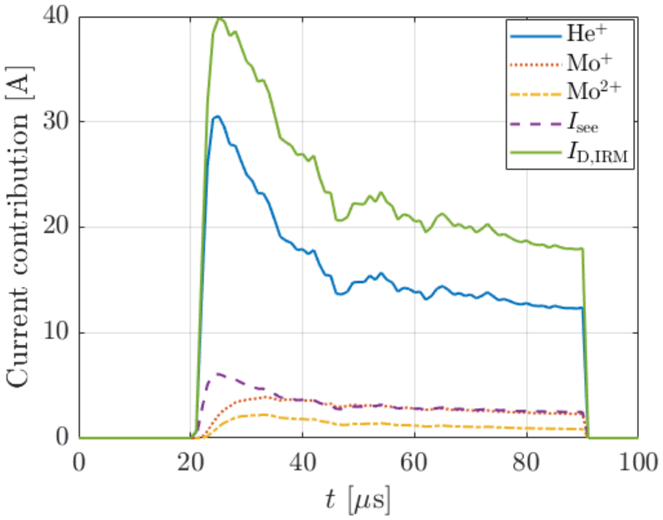

Fig. 2: Current composition of the IRM current for a 700 V HiPIMS discharge

The results of He/Mo-IRM will be presented in more detail, discussing the other fit parameters that have been adjusted to match the helium HiPIMS kinetics. The experimental results, including peak currents, the decrease to a plateau, weak current contributions from metal ions, and the cooldown of the electron temperature, will also be explained.

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