On electron heating in magnetron sputtering discharges

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The magnetron sputtering discharge is a highly successful tool for deposition of thin films and coatings.
It has been applied for various industrial applications for over four decades. Sustaining a plasma in a magnetron sputtering discharge requires energy transfer to the plasma electrons. In the past, the magnetron sputtering discharge has been assumed to be maintained by cathode sheath acceleration of secondary electrons emitted from the target, upon ion impact. These highly energetic electrons then either ionize the atoms of the working gas directly or transfer energy to the local lower energy electron population that subsequently ionizes the working gas atoms. This leads to the well-known Thornton equation, which in its original form [1] is formulated to give the minimum required voltage to sustain the discharge. However, recently we have demonstrated that Ohmic heating of electrons outside the cathode sheath is typically of the same order as heating due to acceleration across the sheath in dc magnetron sputtering (dcMS) discharges [2]. The secondary electron emission yield γ_see is identified as the key parameter determining the relative importance of the two processes. In the case of dcMS Ohmic heating is found to be more important than sheath acceleration for secondary electron emission yields below around 0.1. For the high power impulse magnetron sputtering (HiPIMS) discharge we find that direct Ohmic heating of the plasma electrons is found to dominate over sheath acceleration by typically an order of magnitude, or in the range of 87 – 99 % of the total electron heating. A potential drop of roughly 80 - 150 V, or 10 - 20 % of the discharge voltage, always falls across the plasma outside the cathode sheath [3]. We compare discharges with Al and Ti targets and find that for high currents the discharge with Al target develops almost pure self-sputter recycling, while the discharge with Ti target exhibits close to a 50/50 combination of self-sputter recycling and working gas-recycling [4]. We also explore the effect on the magnetic field strength on the electron heating mechanism [4]. In the discharge with Ti target the B-field was reduced in steps from the nominal value, which resulted in a corresponding stepwise increase in the discharge resistivity.

References

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