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High Power Impulse Magnetron Sputtering of tungsten: a modelling and experimental investigation

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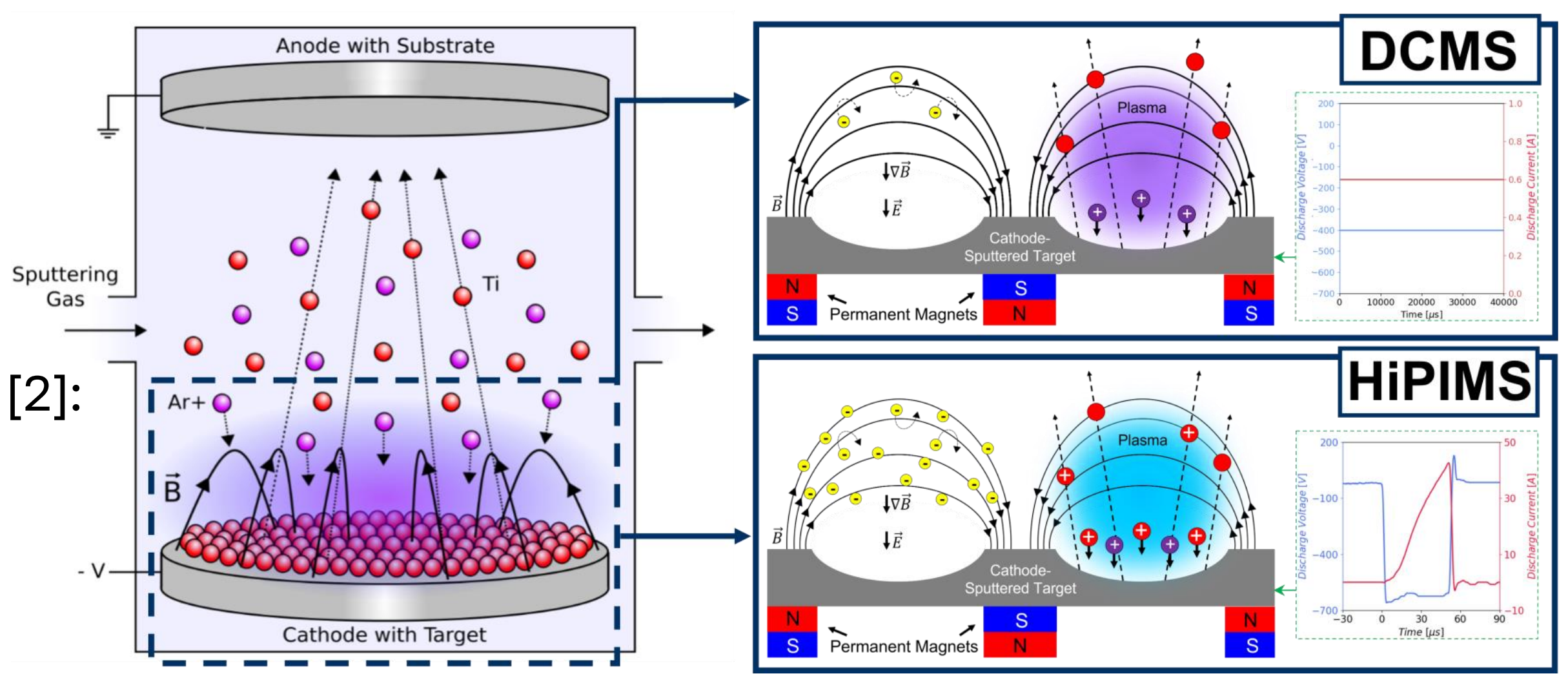
High Power Impulse Magnetron Sputtering

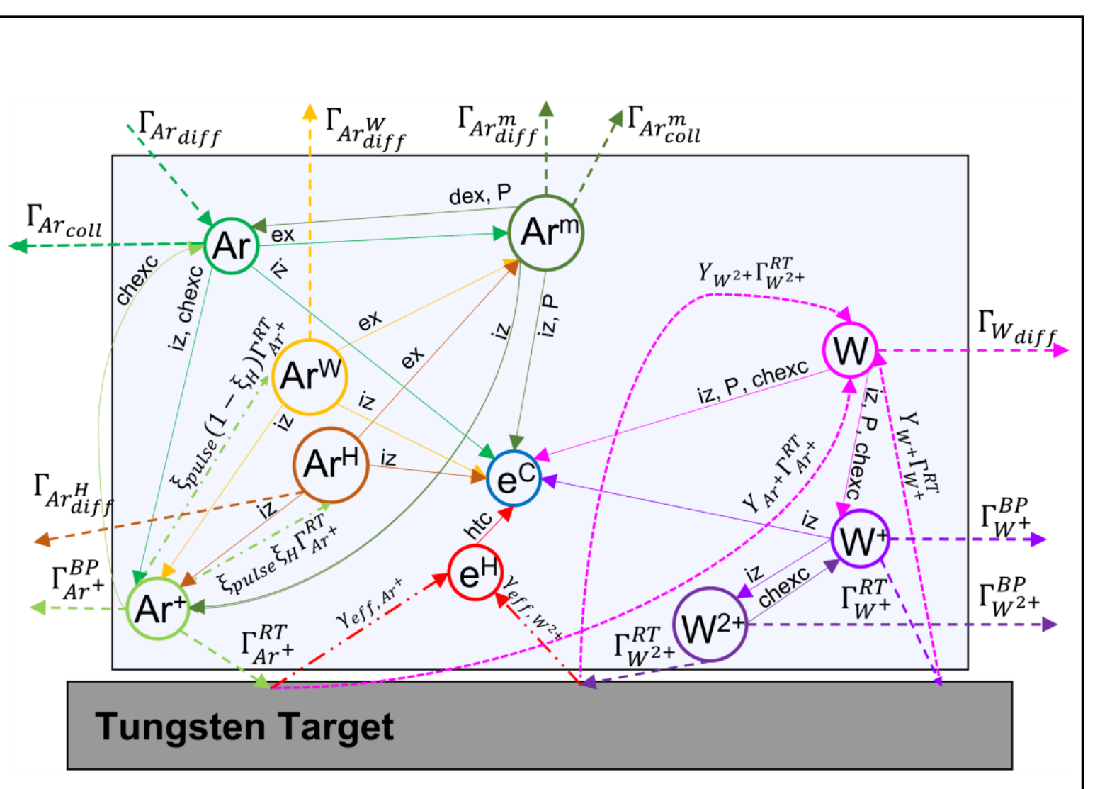
- **Magnetron Sputtering**: Ejection of atoms from a target bombarded by energetic ions generated in a glow discharge. Electrons are trapped by a properly shaped magnetic field [1].
- **Direct Current Magnetron Sputtering**:
  - Constant discharge voltage.
  - Plasma density ~ $10^{15} – 10^{17}$ m^{-3}.
  - Low fraction of ionized sputtered species.
- **High Power Impulse Magnetron Sputtering** [2]:
  - Pulsed discharge voltage.
  - Plasma density ~ $10^{18} – 10^{19}$ m^{-3}.
  - High fraction of ionized sputtered species.
  - Complex plasma physics.



Development of a model to establish a connection between HiPIMS plasma characteristics and experimental results.

Ionization Region Model

- Time-dependent volume averaged plasma chemical model of the ionization region (IR) [3].
- Evolution of plasma species and plasma parameters inside the IR.

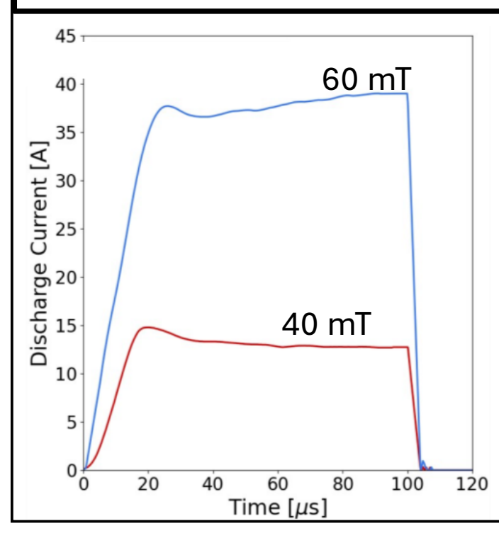


- Ordinary differential equations for:
  - Electron energy.
  $$\frac{dT_e}{dt} = \sum Q_{abs} - \sum Q_{loss}$$
  - Particles density.
  $$\frac{dn_i}{dt} = \sum R_i^{generation} - \sum R_i^{loss}$$
- Experimental input parameters (e.g., discharge current $I_D(t)$).
- $I_D(t)$ reproduced using two fitting parameters. The calculated current is:

$$I_{calc} = e \sum S_{RT} Z_i \Gamma_i^{RT} (1 + \gamma_{eff,i})$$

Modelling of Ar/W HiPIMS discharge

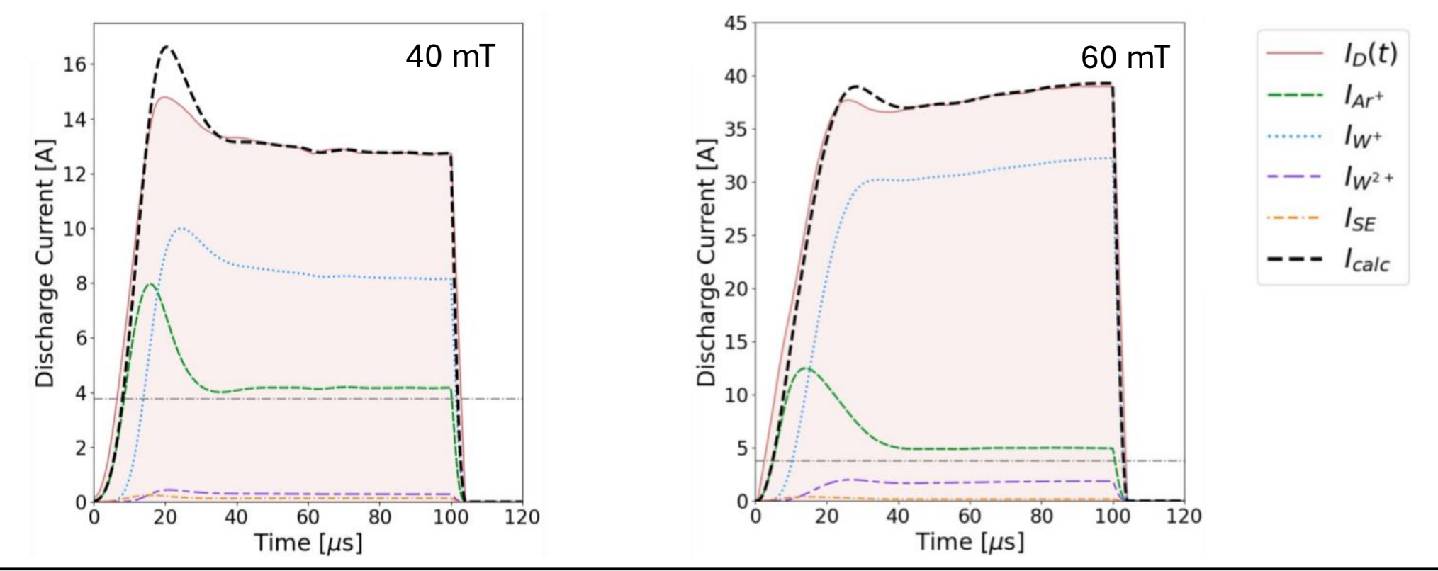
Experimental inputs



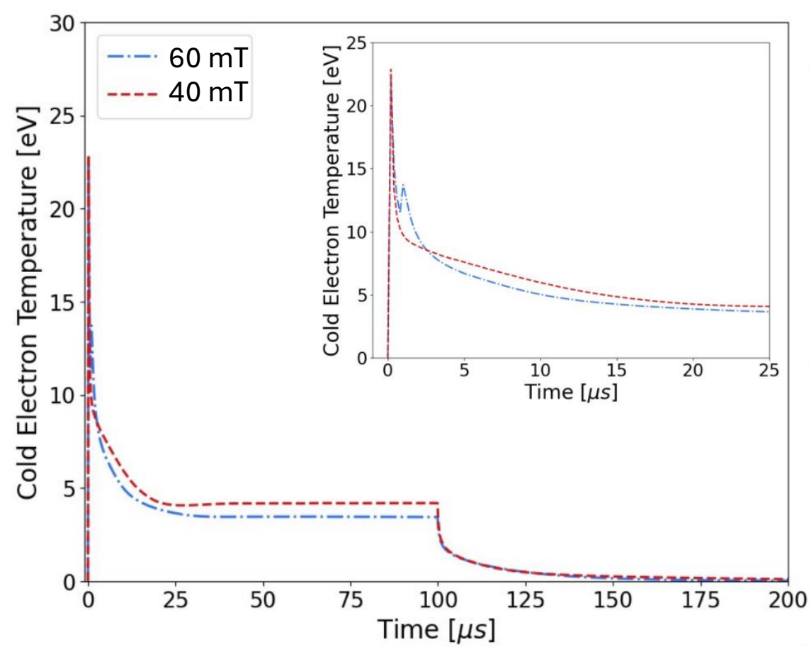
- Constant discharge voltage U_D = 900 V.
- Magnetic field strength (40 and 60 mT).
- Significant variation of $I_D(t)$.

Evolution of HiPIMS current composition

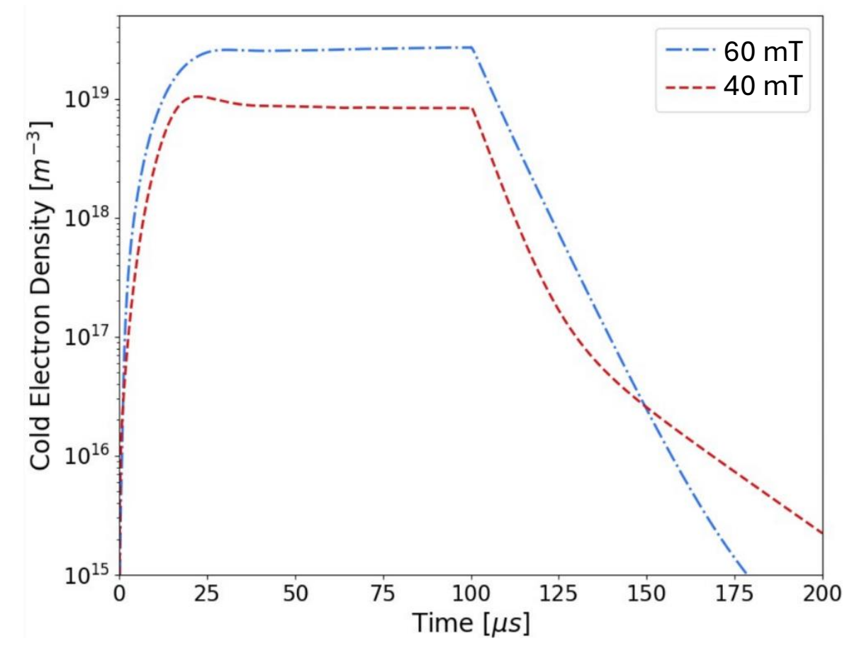
- Ar^+ ion contribution important in the ignition phase.
- Different role of W^+ ion for the two magnetic strength.
- Higher backattraction for the 60 mT case.



Cold electrons temperature and density



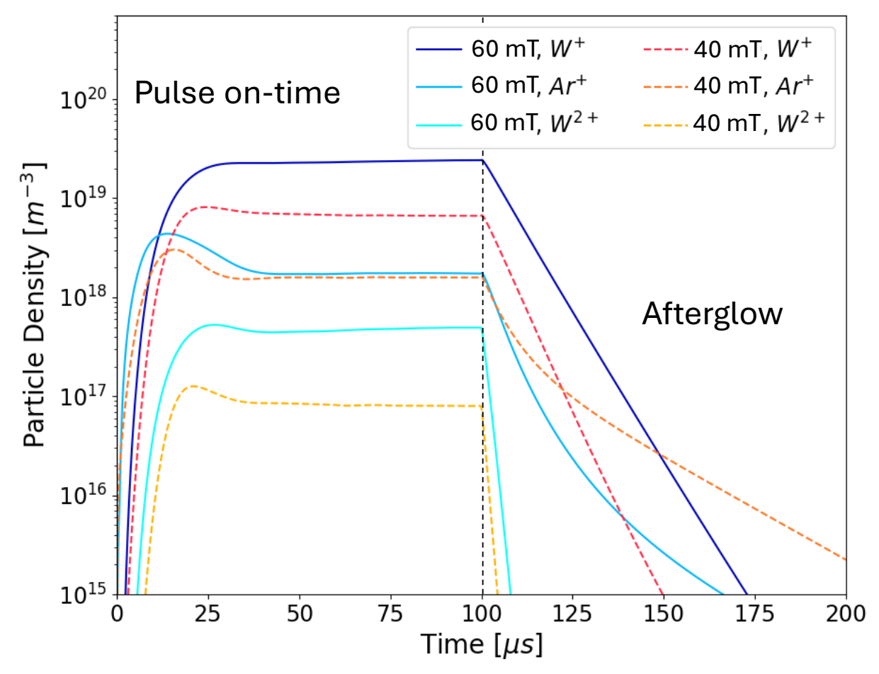
- A sharp peak appears early in the pulse.
- T_e reaches a plateau in the range 3.5–4 eV as the pulse progresses.



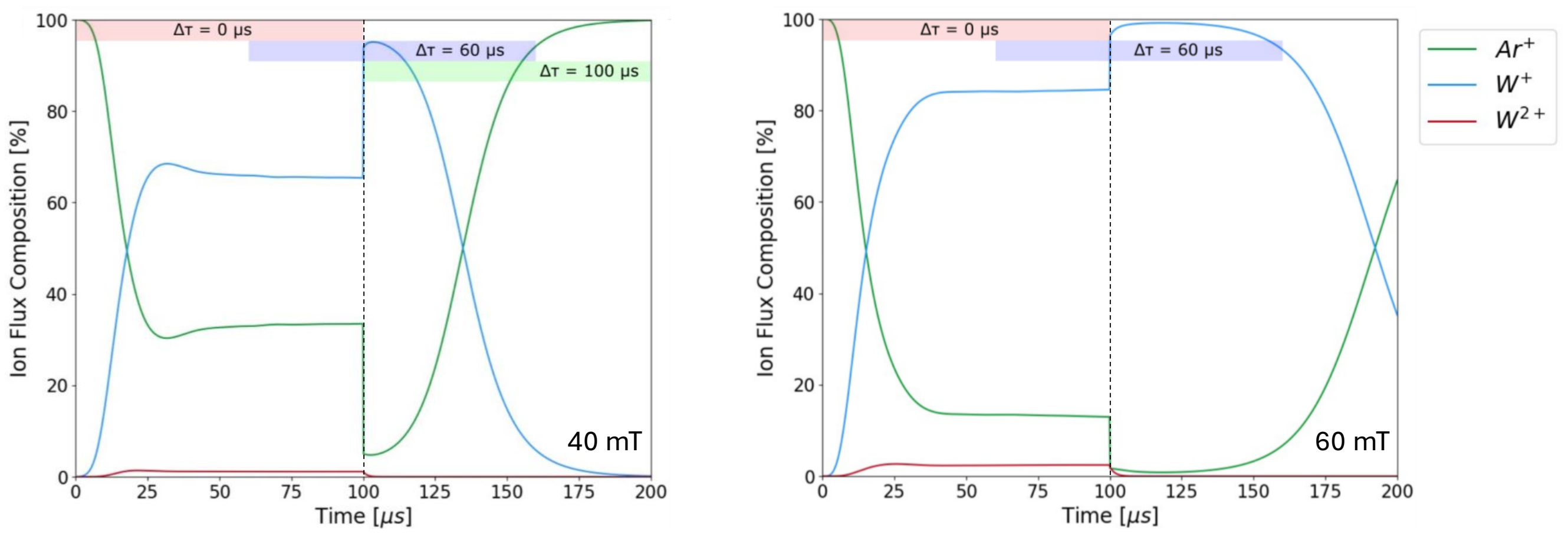
- n_e trend is similar to the one of discharge current.
- Reasonable opposite behaviour between electron temperature and density.

Ionized species density and flux

- Pulse on-time: W^+ ions dominant ionized species.
- Different evolution in the afterglow.



- Estimation of the ion flux composition at IR borders.

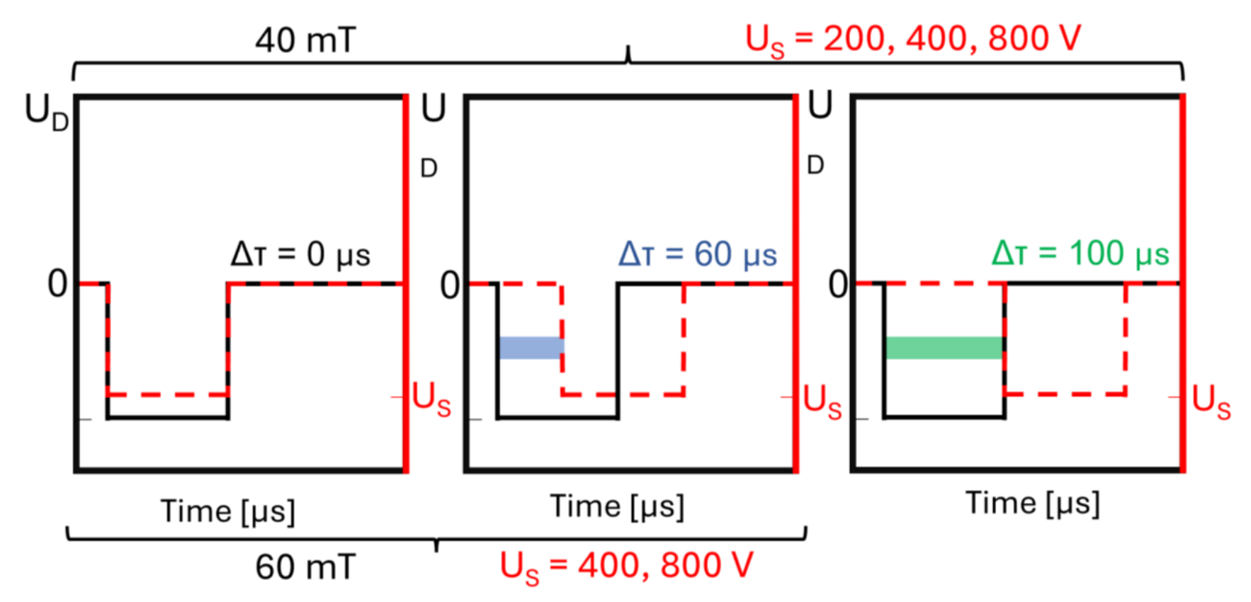


- The ion species arriving at substrate depend on the magnetic strength.

Experimental Results: plasma influence on W films growth

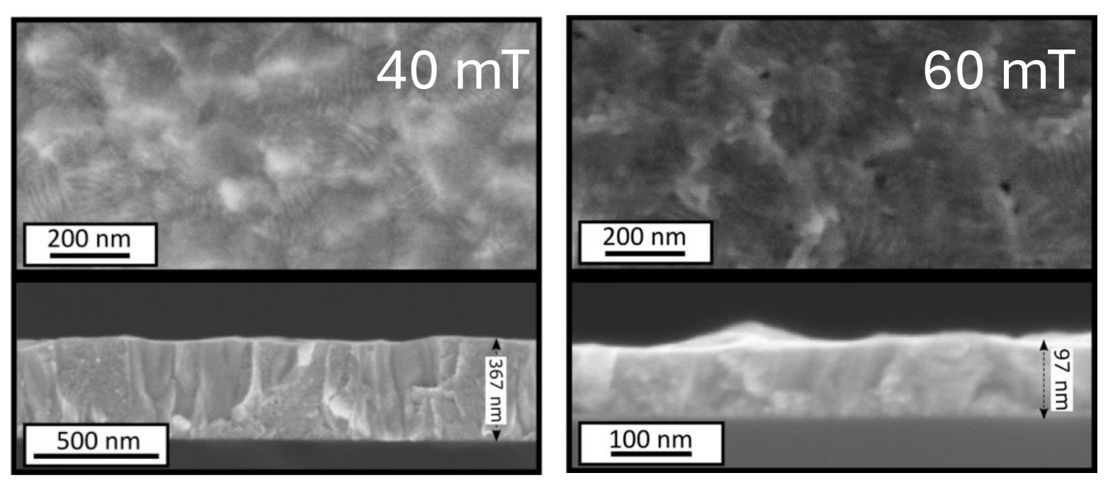
Deposition parameters: bias voltage

- Application of a substrate bias voltage.
- Variation of bias amplitude (U_S) and delay (Δτ).



Morphology analysis

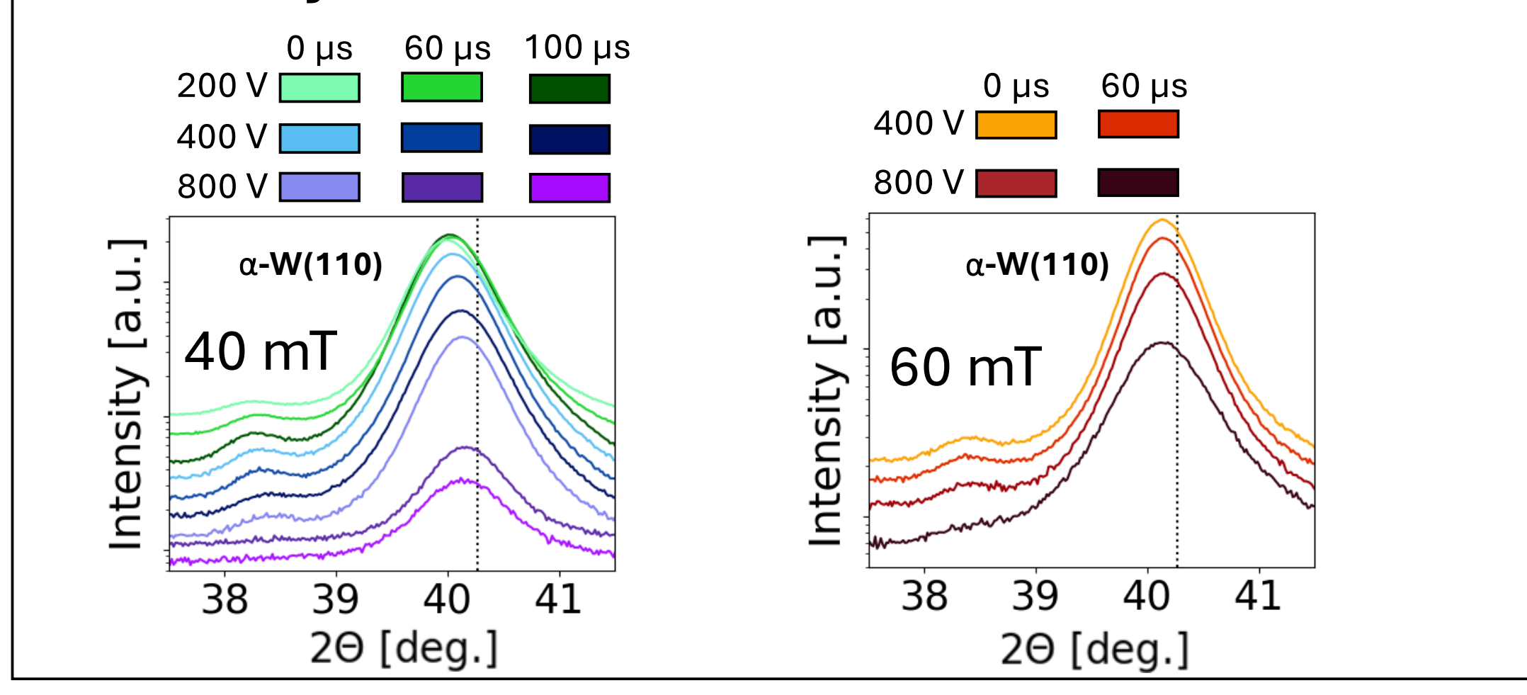
- Relevant influence of the ionized flux composition on morphology under equal bias voltage conditions.



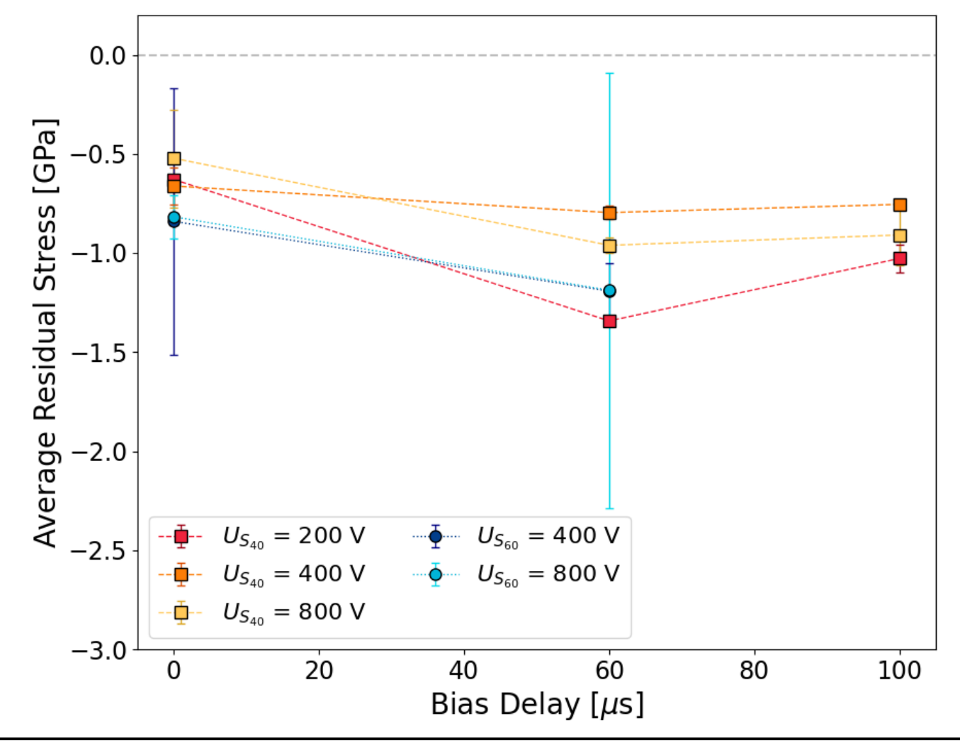
- U_S = 800 V
- Δτ = 60 μs

Microstructure and mechanical analysis

XRD analysis

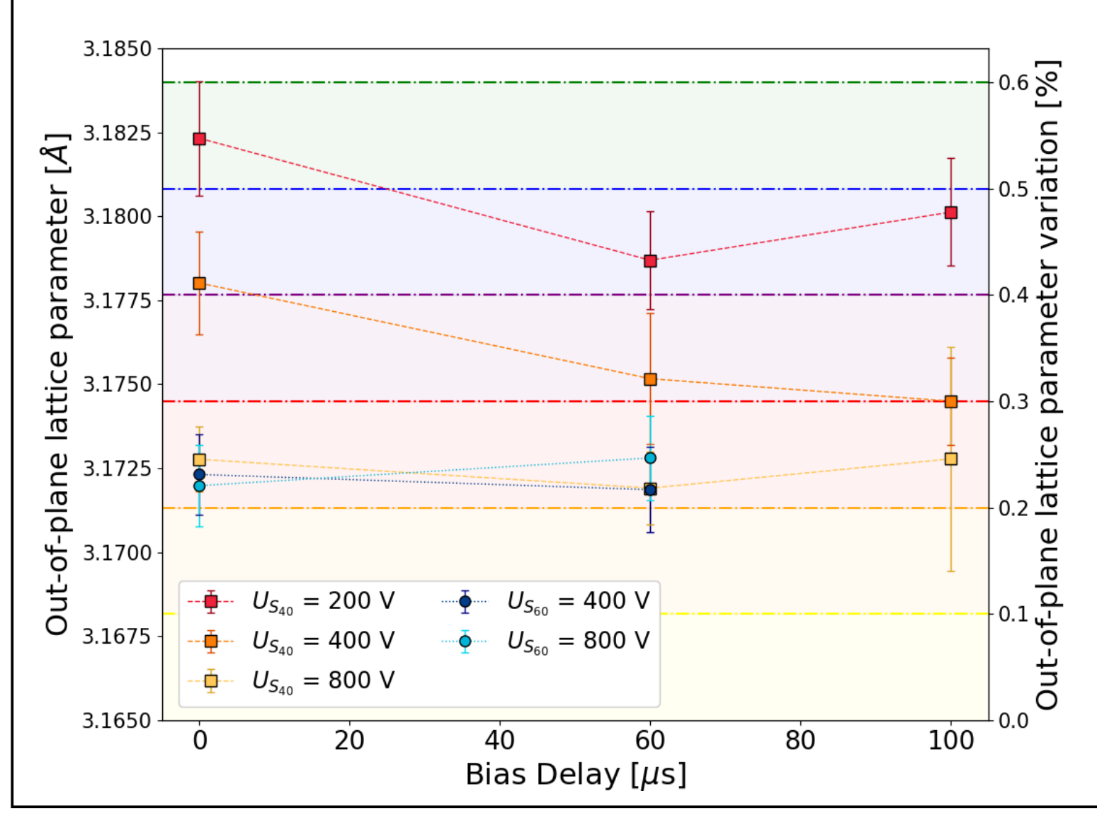


Residual stress analysis

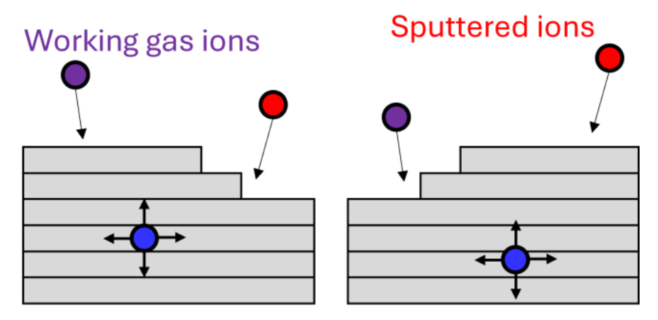


- The main XRD peak is the one related to the (110) reflection (α-W phase).
- Peaks shift indicates the presence of a compressive stress state.
- Presence of residual stress is confirmed by wafer curvature measures.

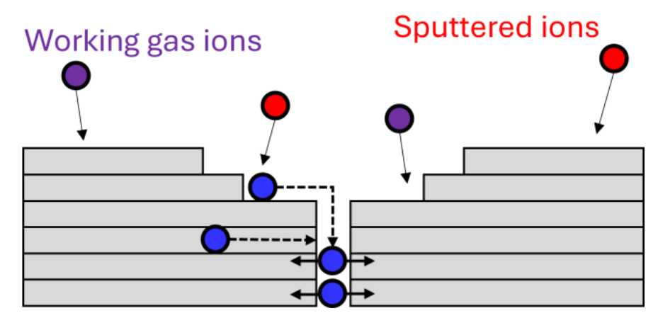
Role of ionized flux



- Different lattice parameter values despite similar residual stress trends.
- Lattice parameter variation (derived from XRD) indicative of the stress generation process.
- Different stress components depending on ionized flux characteristics.



Triaxial: implantation of bombarding gas ion species or point defects formation



Biaxial: migration of adatoms to the under-dense grain boundaries

Conclusions & Foreseen Activities

- The combined modelling and experimental approach allowed a satisfactory understanding of the connection between the characteristics of the HiPIMS Ar/W discharge and the observed film properties [4].
- An increase of the magnetic strength led to a different ion flux composition evolution both during the on-time of the voltage pulse and the afterglow.
- The specific ion flux composition accelerated significantly influences film properties since it determines mechanisms taking place at growing film surface.

- Use the model to assess the role of other relevant process parameters for the Ar/W HiPIMS discharge.
- Apply the combined approach to other HiPIMS discharges (e.g., including N_2 as working gas).
- Exploit the studied W films for magnetic nuclear fusion applications.

For further details see the poster by Luigi Bana. (Poster session II, luigi.bana@polimi.it)

References

[1] J. T. Gudmundsson, Plasma Sources Sci. Technol. 29 (2020).

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[3] C. Huo et al., J. Phys. D: Appl. Phys 50 (2017).

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