Tuning the ion energy by bipolar HiPIMS to control of Mg thin film microstructure

F. Moens\textsuperscript{1,2}, Matthieu Michiels\textsuperscript{2}, S. Konstantinidis\textsuperscript{2}, D. Depla\textsuperscript{1}

Dedicated Research on Advanced Films and Targets

\textsuperscript{1}Ghent University

\textsuperscript{2}UMons
Introduction

![Graph of Direct Current](image1.png)

- Direct Current + Substrate bias

![Graph of HiPIMS](image2.png)

- HiPIMS

![Graph of Bipolar HiPIMS](image3.png)

- Bipolar HiPIMS

DC growth

- 70 sccm Ar
- 0.8 Pa Ar pressure
- TS distance = 10 cm
- Pole figure measurement = 32° tilt

- Si 001 substrate
- Deposition rates increase linearly with discharge current
  - 0.07 μm/min → 0.25 μm/min

![SEM Image](image4.png)
DC growth

- 70 sccm Ar
- 0.8 Pa Ar pressure
- TS distance = 10 cm
- pole figure measurement = 32° tilt
- Si 001 substrate
- Deposition rates increase linearly with discharge current
  0.07 μm/min → 0.25 μm/min

Introduction

Direct Current

+ Substrate bias

HIPIMS

Bipolar HIPIMS
**Experimental conditions**

- DC Mg growth
- I = 0.4 A
- Bias at substrate
- 0 to -100 V in steps of 20 V
- 0 to -1000 V in steps of 200 V

**Fractions 0 to -1000V**
SEM images substrate bias

![SEM images substrate bias](image)

**Introduction**

![Graphs showing Direct Current and Bipolar HIPIMS](image)

- **Direct Current**
  - Substrate bias

- **Bipolar HIPIMS**

---

**Table:**

- **Introduction**
  - DC growth
  - DC + Bias
  - HIPIMS increasing peak power
  - Bipolar HIPIMS
  - Comparison
  - Conclusion
HiPIMS Experiments

- What is the effect of increasing peak power density?
- Varying off time while keeping on time constant 20 μs
- Constant average current
  - Amplitude V increases
  - I increases
  - Power during peak increases
  - Deposition rate constant 0.05 μm/min

![Graph showing current and voltage over time with peak power density values]

![Graph showing orientation fraction vs. off time with (002) and (103) orientations]
HiPIMS Experiments

Energy of magnesium ions
Energy of magnesium ions

- In D.C. magnetron putting energetic particles from reflection on target
- Mg on Mg same mass reflection is unlikely and favors low energetic particles
- Sputtering does not offer an explanation
- Sputtered particles follow a Thompson energy distribution
- Peak at U₂J followed by a tail

\[ \frac{E}{(E + U_s)^3} \, dE \]

Mg⁺ vs Ar⁺ ions

![Graph showing Mg⁺/Ar⁺ ratio vs. Off time (μs)]
**Introduction**

Direct Current

- Voltage (V) vs. Time (µs)

HiPIMS

- Voltage (V) vs. Time (µs)

Bipolar HiPIMS

- Voltage (V) vs. Time (µs)

**Bipolar pulse shape**

- Voltage (V) vs. Time (µs)

- Parameters: \( \tau_+ \) and \( \tau_- \)
Bipolar pulse shape

\[ \text{current (A)} \]
\[ \text{Voltage (V)} \]

\[ \text{Time (µs)} \]

Bipolar pulse: ion energy distribution

\[ \tau = 20 \mu s \quad \tau = 100 \mu s \quad V_+ = 50 \text{ V} \quad V_- = -700 \text{ V} \]
Bipolar pulse: ion energy distribution

\[ \tau_+ = 20 \mu s \quad \tau_- = 100 \mu s \quad V_+ = 50 \text{ V} \quad V_- = -700 \text{ V} \]

\[ \tau_+ = 20 \mu s \quad \tau_- = 100 \mu s \quad V_+ = 50 \text{ V} \quad V_- = -700 \text{ V} \]

\[ \text{Ar}^+ \]

- HiPIMS
- \( \tau_+ = 50\mu s \)
- \( \tau_- = 600\mu s \)
Bipolar pulse: ion energy distribution

\[ \tau_+ = 20 \, \mu s \quad \tau_- = 100 \, \mu s \quad V_+ = 50 \, V \quad V_- = -700 \, V \]

![Graph showing ion energy distribution with Mg ions and different time constants.]

\[ \text{Counts per second (c/s)} \]

![Energy (eV) scale from 0 to 300.]

**Legend**:
- HiPIMS
- \( \tau_+ = 50 \, \mu s \)
- \( \tau_- = 600 \, \mu s \)
Bipolar pulse: ion energy distribution

\[ \tau_+ = 20 \mu s \quad \tau_- = 100 \mu s \quad V_+ = 50 \text{ V} \quad V_- = -700 \text{ V} \]

![Graph showing ion energy distribution with Mg ions and different time constants.

Mg thin film depositions

![Graph showing orientation fraction of Mg thin films as a function of positive bias voltage with different orientations labeled.

Regular HiPIMS

(002) (101) (102) (100) (110) (103)
**Mg thin film depositions**

![Image of Mg thin film depositions with voltages +0 V, +25 V, +100 V, +125 V, +150 V, +200 V.]

**Comparison Bipolar Hipims – DC with substrate bias**

Bipolar Hipims
Positive bias at target
Electrons attracted at target
Positive ions increase the plasma potential
Ions are accelerated at potentials 0 V → +V₀
Entire volume between target and substrate

DC with negative substrate bias
Ar⁺
A sheath is formed around the substrate
Ions have to fly into the sheath (volume is smaller)
Ions will be accelerated to negative voltage
**Comparison Bipolar HiPIMS – HiPIMS**

Bipolar HiPIMS

Positive bias at target
Electrons attracted at target
Positive ions increase the plasma potential
Ions are accelerated at potentials $0 \, V \rightarrow +V_0$
Entire volume between target and substrate

HiPIMS increasing peak power
Mg+/Ar+ increases
Mg transfers energy more efficiently
Implanted Mg can be incorporated in the lattice
Low energy reflected Mg can be incorporated at the surface
When increasing peak power Mg⁺ ions can get very high energetic

---

**Conclusion**

- Bipolar HiPIMS offers an alternative to substrate biasing
- BHiPIMS and DC+Bias: a porous film can be grown
- Ions are accelerating at energies up to bias voltage
- Likely more substrate heating
- DC+Bias: columns oriented in the (002) direction
- Increasing power in HiPIMS results also in energetic bombardment
- Mg ionization is increased
- Very dense films can be grown
Acknowledgements

- Matthieu Michiels: Materia Nova power supply