How to run a reliable reactive HIPIMS process over a target lifetime

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Motivation
High metal ion density is responsible for enhanced layer properties

High-power pulses produces metal ions

Degree of ionization is related to peak current

Example: Copper, $A_{\text{target}}$: 300 cm$^2$, $t_{\text{on}}$: 50 µs
Motivation

Reactive gas and target erosion affects peak current i.e. metal ion density

Reactive gas flow changes peak current and pulse form

Target erosion influences peak current and peak voltage

Independent control of control reactive gas flow and metal ion density is essential to maintain process stability over target life time


Realization and Setup
Combining spectroscopic plasma monitoring and pulse voltage/current measurement

Plasma spectrum (pulse averaged)

Cathode 1  Cathode 2

Rotatable cathodes in bipolar configuration
500 mm length

Triggered and synchronized measurement realized in EMICON system
Features:
- Stable gas flow control despite target rotation and arcing
- Pulse peak current increases with reactive gas flow
- Pulse voltage decreases with reactive gas flow

Application:
- Al/O₂/Ar reactive HIPIMS plasma
- Average power: 3 kW bipolar pulsed,
  - \( t_{\text{on}} \): 40 µs, \( t_{\text{off}} \): 300 µs
- 5 Pa, 200 sccm Ar, 0-20 sccm O₂
- Control of oxygen flow with Al line
- Arc handling at 900 A

Spectroscopic monitoring & pulse peak current and voltage
Reactive gas flow control
Simultaneous control of reactive gas flow & pulse peak current

Stabilizing pulse peak current while controlling reactive gas flow

**Application:**
Al/O₂/Ar reactive HIPIMS plasma
Control of oxygen flow with Al line
Control of pulse peak current by changing pulse-off time

**Features:**
Stable gas flow control despite target rotation and arcing
Same pulse peak current at different reactive gas flow
Long-term control of reactive HIPIMS process

Continuous control of reactive gas flow and pulse peak current

Application: Ti/O₂/Ar reactive HIPIMS plasma
Average power: 6 kW bipolar pulsed
\( t_{\text{on}} \): 50 µs, \( t_{\text{off}} \): 780 µs
Peak current: 320 A
0.5 Pa, 125 sccm Ar, 0-20 sccm O₂
Arc handling at 800 A

Process control: Oxygen flow by Ti line
Peak current by charging voltage

Process time: 164 hours (almost 7 days)
Uninterrupted controlled plasma process

Coating samples: Samples coated throughout process time
Long-term control of reactive HIPIMS process

Full data coverage of spectroscopic and pulse signals

Features:
- Uninterrupted process for 164 hours (almost 7 days)
- Stable gas flow control on Ti line
- Stable peak current control
- Process deviation when moving substrate carrier
- Return to setpoint after moving substrate carrier
- Process deviation on oxygen gas flow malfunction

Benefits:
- Constant peak current  ► stable pulse power
- Constant Ti and O signals  ► stable stoichiometry in plasma
- Process fault detection and documentation
Long-term control of reactive HIPIMS process

Additional process information from signal ratios

Features:
- Real-time ratios of: $O / Ti$ signal ratio → verification of stoichiometry
- different $Ar$ line signals → process parameter
- $Ti^+ / Ti$ ratio → ionization degree

Benefits:
- Constant ratio of $Ar$ lines
  - stable process parameter
- Constant $O / Ti$ signal ratio
  - verification stoichiometry
- Slightly drift in $Ti^+ / Ti$
  - indication of target erosion (to be verified)
Long-term control of reactive HIPIMS process

Coating samples:

Features:
- Coating samples taken at various times during process
- Moving substrate carrier in and out causes process deviation
- Process stable during coating process

Benefits:
- Confirmation of reactive setpoint
- Verification of process control stability
- Check of uniformity across target length
Long-term control of reactive HIPIMS process

Coating sample results

Coating samples: 11 coating samples throughout process time

Deposition rate: 27 nm/min ± 3 nm/min

Optical properties: $n_{550} = 2.49 \pm 0.1$
$k = 0.004 \pm 0.0005$

Layer uniformity: gradient from top to bottom
gas flow control at center manifold only

Sectional gas flow control along cathode length required for uniform layer deposition
Long-term control of reactive HIPIMS process

Control setup for uniformity control

Features:
- Main reactive gas flow control at center
- Balancing gas flows at top and bottom related to center gas flow
- Real-time balancing control using spectroscopic line ratios

Plasma spectrum (pulse averaged)
Long-term control of reactive HIPIMS process

Full process control by simultaneous real-time measurements in single tool

Additional process parameters:
- Average DC power
- Charging voltage
- Charging current
- Lambda probe
- Gas flows
- Process pressure
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Conclusion

Reliable long-term control of reactive HIPIMS processes by combining spectroscopic and electrical pulse measurements
Stabilizing peak current by controlling charging voltage or pulse-off time of pulse generator
Stabilizing reactive working point by controlling reactive gas flow

► Combined control of power and particle densities → securing deposition rate and layer properties

Monitoring process drifts from spectroscopic signals
Monitoring process stability from process parameters, e.g. process pressure, DC power, etc.
Detecting process faults

► Advanced and reliable control technique to run HIPIMS processes in long-term production
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Turn-key solution for advanced and reliable HIPIMS process control

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