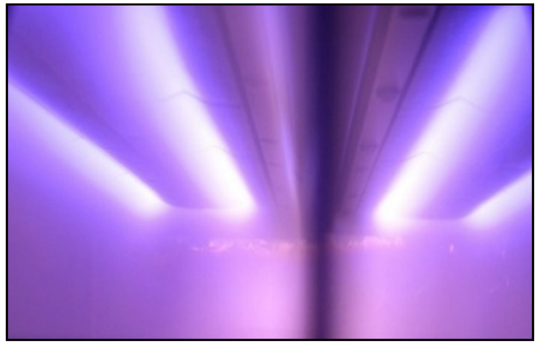
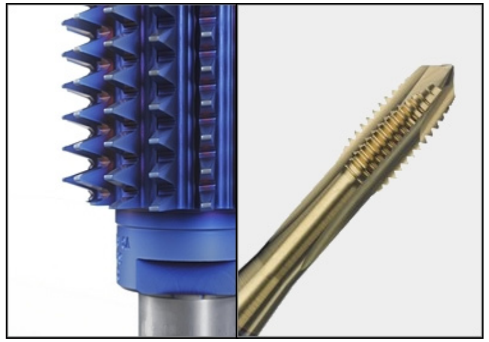
How to run a reliable reactive HIPIMS process over a target lifetime

Thomas Schütte[1], Peter Neiß[1]
Julius Rieke[2]
Holger Gerdes[3], Ralf Bandorf[3], Michael Vergöhl[3], Günter Bräuer[2,3]



1 PLASUS – Spectroscopic plasma monitor and process control systems
2 IOT – Technische Universität Braunschweig, Institute for Surface Technology
3 Fraunhofer IST

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Federal Ministry for Economic Affairs and Energy
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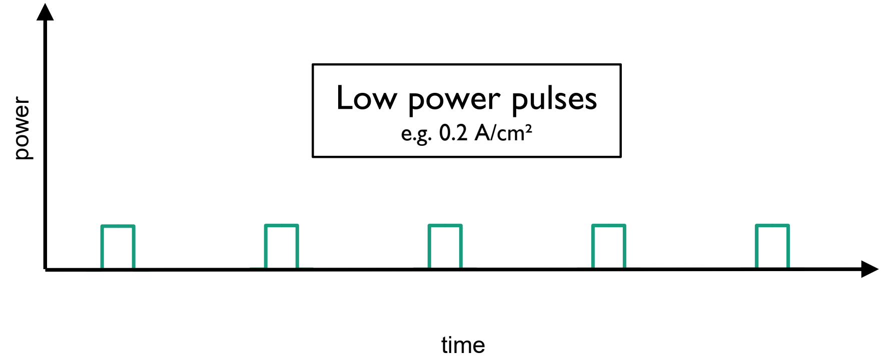
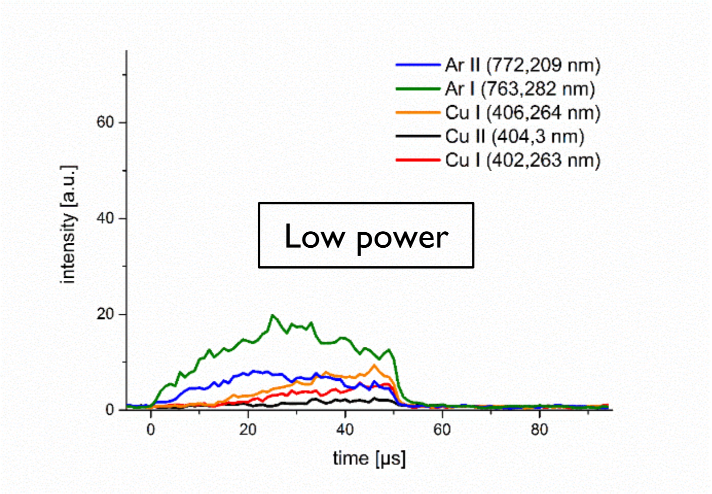
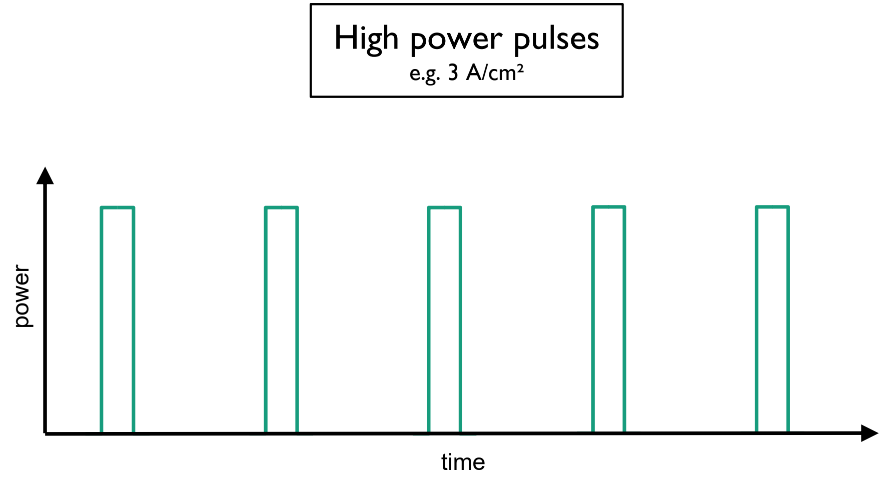
Motivation

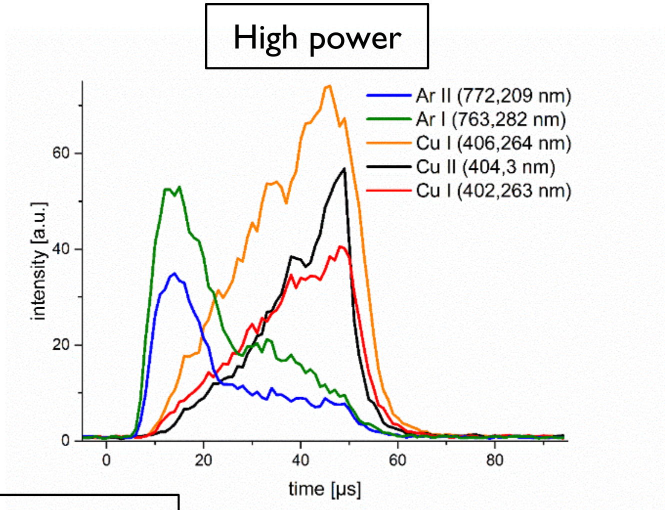
High metal ion density is responsible for enhanced layer properties

High-power pulses produces metal ions



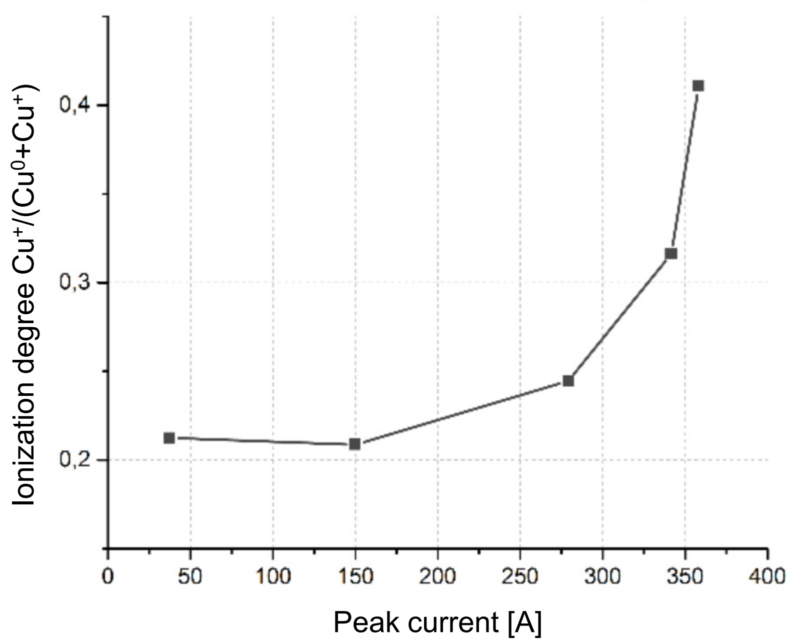






Example: Copper, A_{Target}: 300 cm², t_{on}: 50 µs

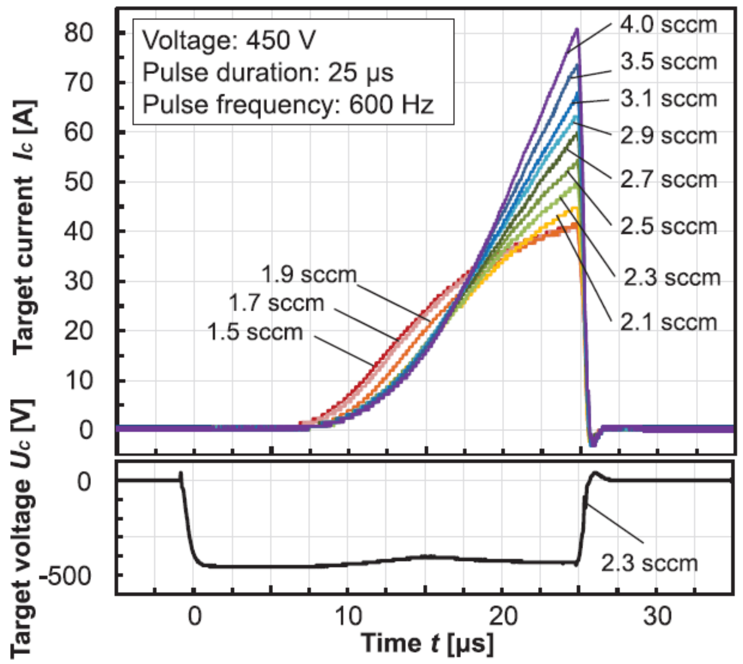
Degree of ionization is related to peak current



Motivation

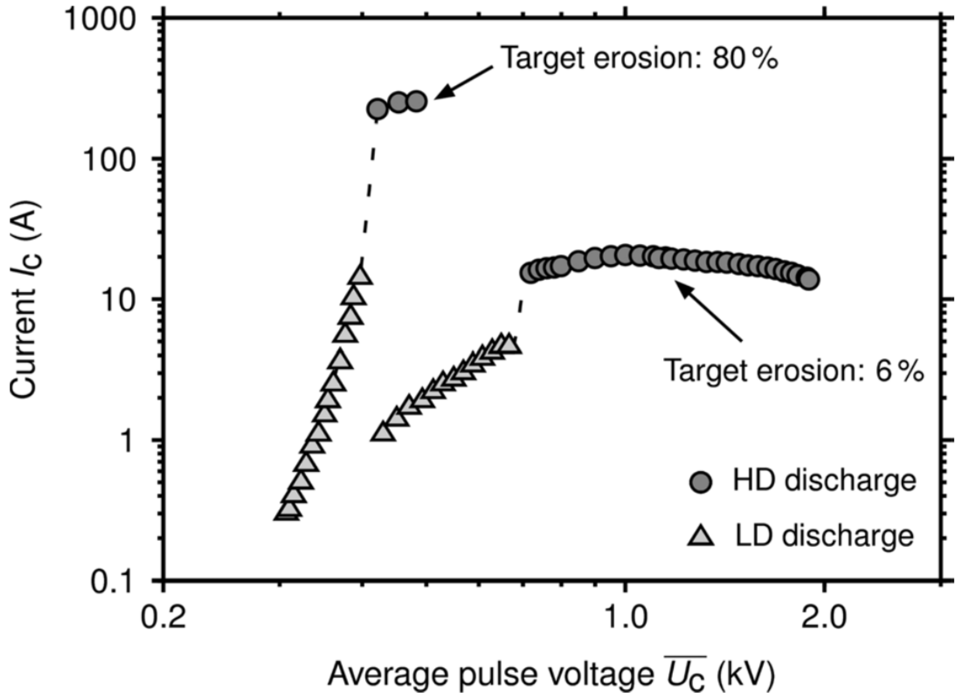
Reactive gas and target erosion affects peak current i.e. metal ion density

Reactive gas flow changes peak current and pulse form



T. Shimizu et al. J. Phys. D: Appl. Phys. 49 (2016) 065202

Target erosion influences peak current and peak voltage



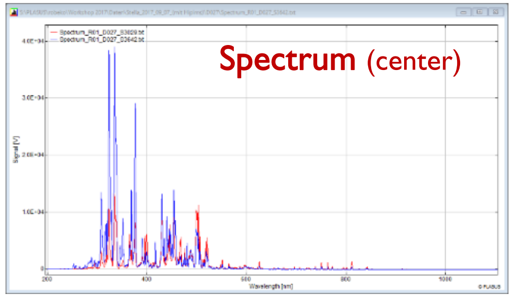
J. Capek et al. J. Appl. Phys. 111 (2012) 023301

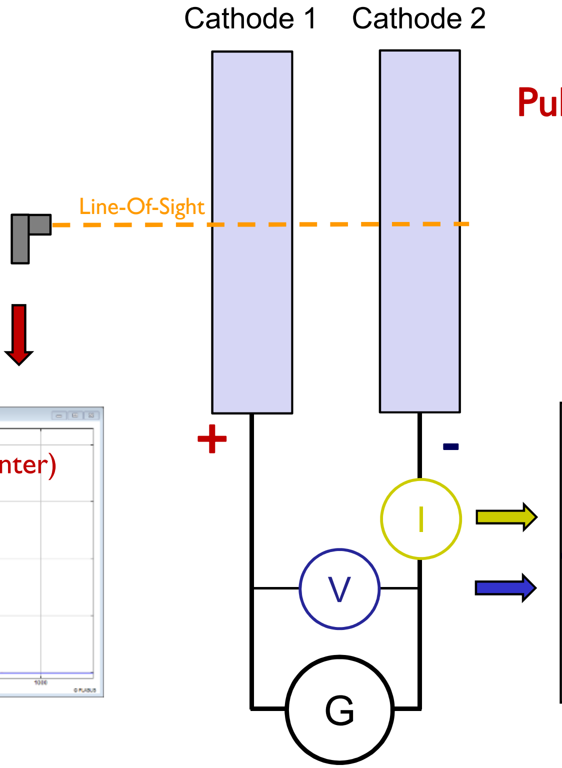
Independent control of control reactive gas flow and metal ion density is essential to maintain process stability over target life time

Realization and Setup

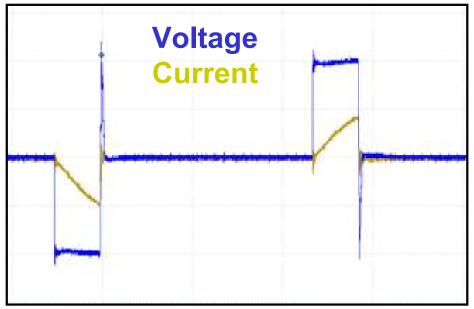
Combining spectroscopic plasma monitoring and pulse voltage/current measurement

Plasma spectrum
(pulse averaged)

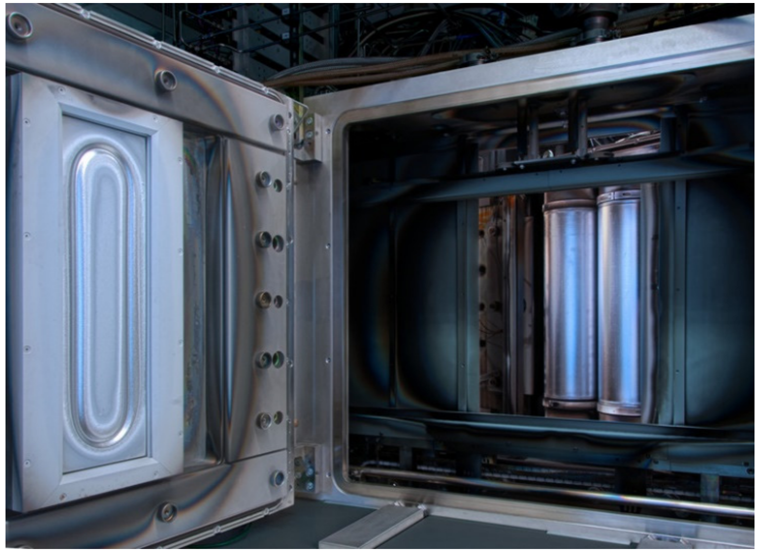




Pulse voltage and current curves
(40 MHz sampling rate)



Rotatable cathodes in bipolar configuration
500 mm length

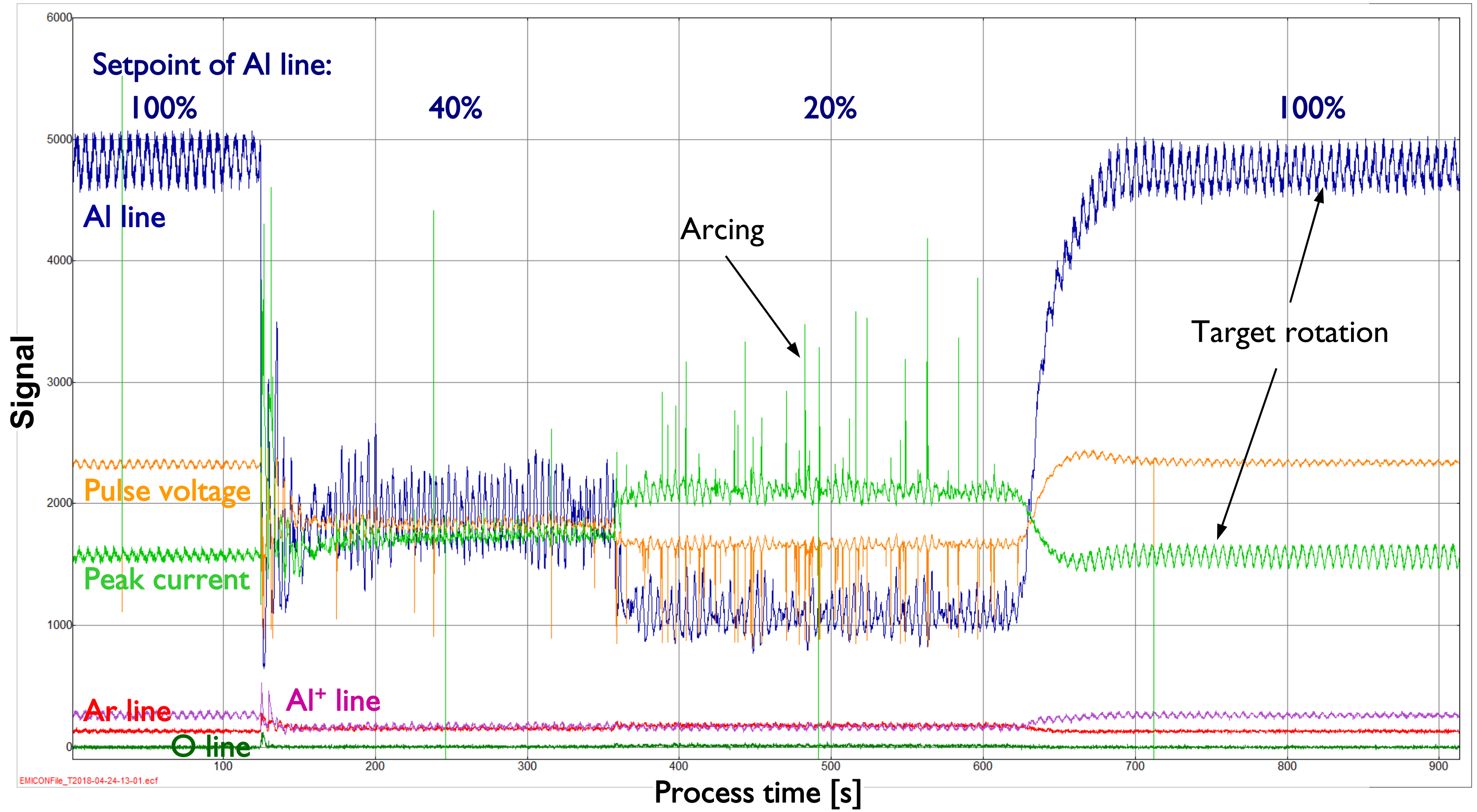


Fraunhofer Institute for Surface Engineering & Thin Films IST

Triggered and synchronized measurement realized in EMICON system

Spectroscopic monitoring & pulse peak current and voltage

Reactive gas flow control



Application:

$Al/O_2/Ar$ reactive HIPIMS plasma

Average power: 3 kW bipolar pulsed,

t_{on}: 40 µs, t_{off}: 300 µs

5 Pa, 200 sccm Ar, 0-20 sccm O_2

Control of oxygen flow with Al line

Arc handling at 900 A

Features:

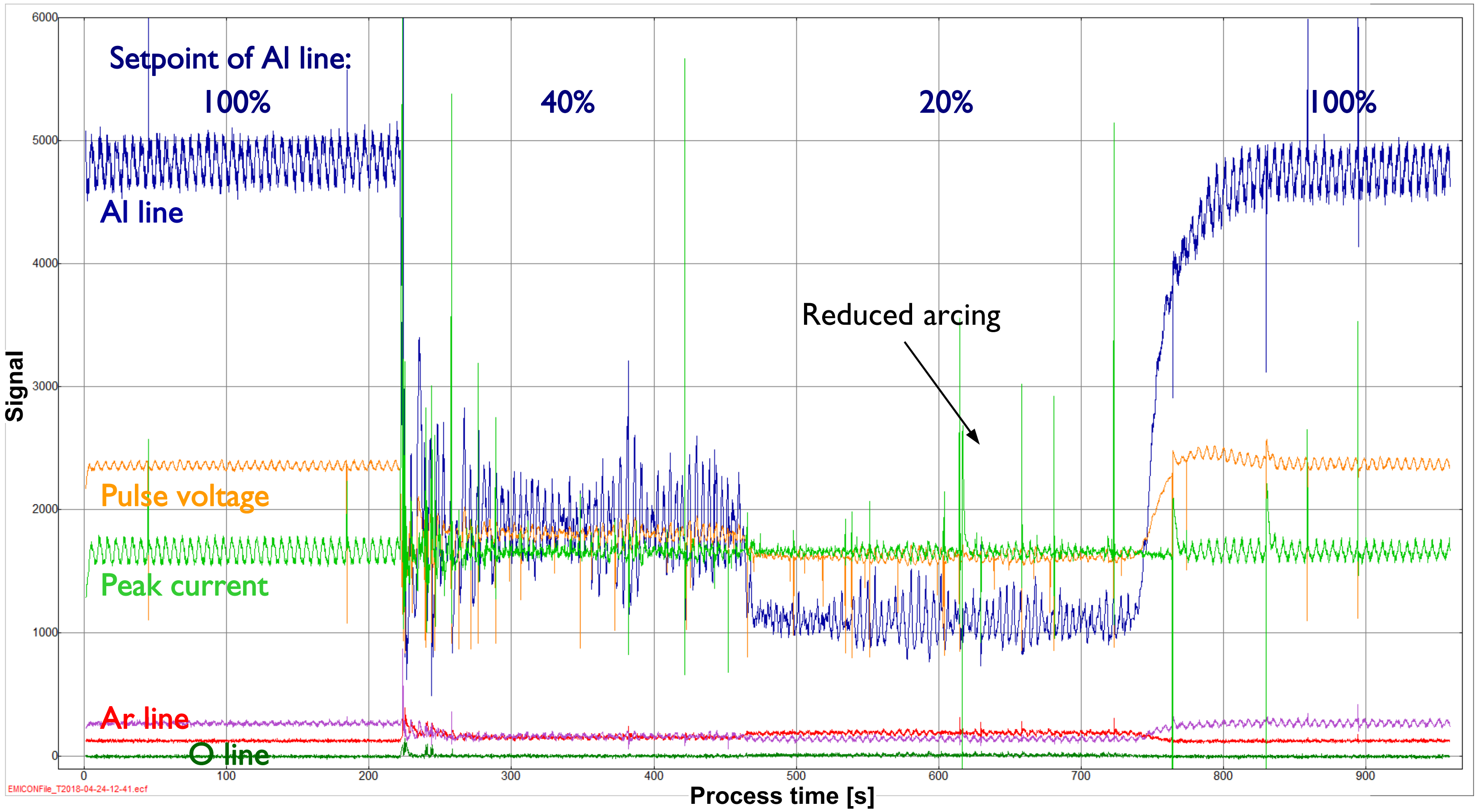
Stable gas flow control despite target rotation and arcing

Pulse peak current increases with reactive gas flow

Pulse voltage decreases with reactive gas flow

Simultaneous control of reactive gas flow & pulse peak current

Stabilizing pulse peak current while controlling reactive gas flow



Application:

$Al/O_2/Ar$ 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

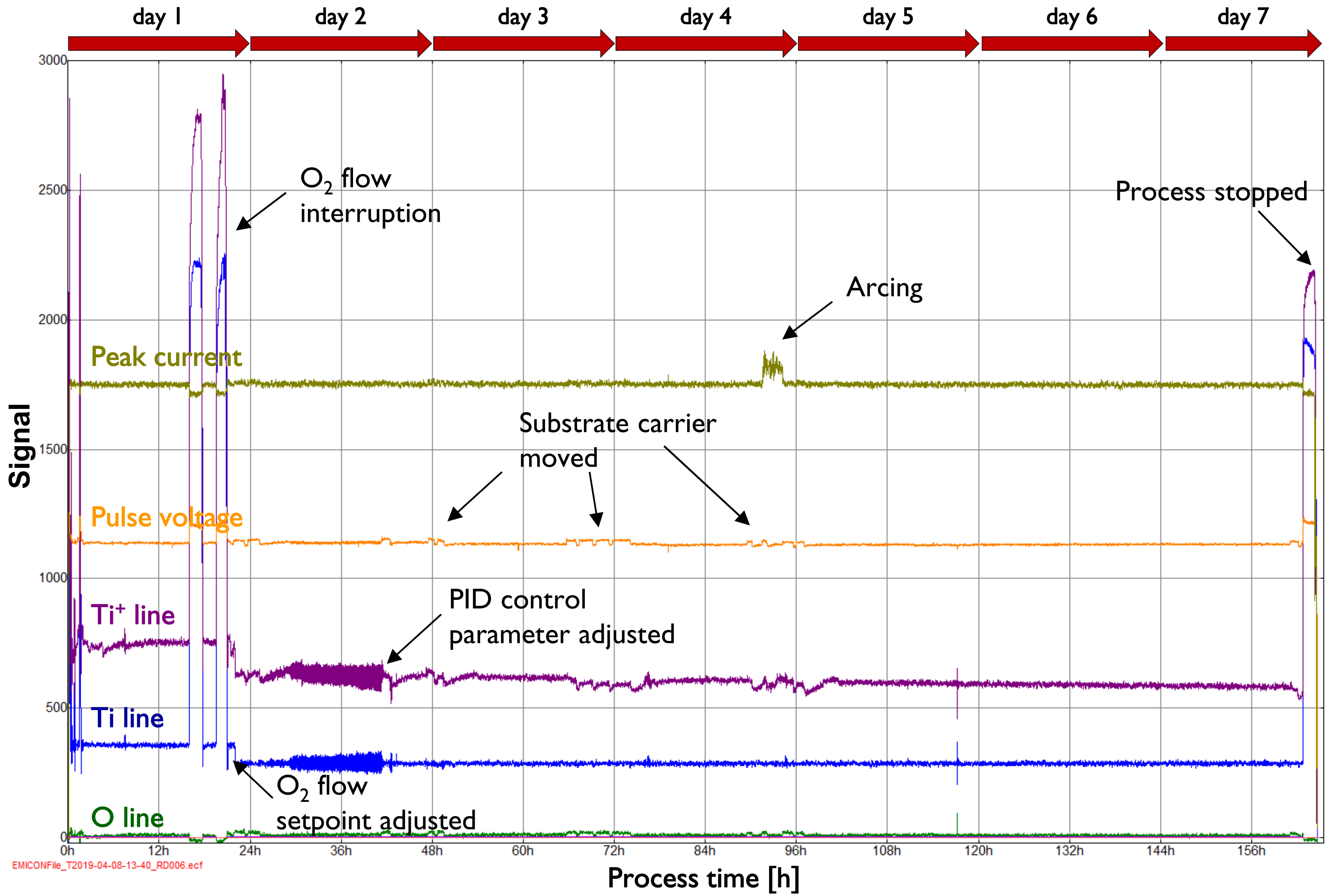
Long-term control of reactive HIPIMS process

Continuous control of reactive gas flow and pulse peak current

Application:	$Ti/O_2/Ar$ reactive HIPIMS plasma Average power: 6 kW bipolar pulsed t_{on}: 50 µs, t_{off}: 780 µs Peak current: 320 A 0.5 Pa, 125 sccm Ar, 0-20 sccm O_2 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

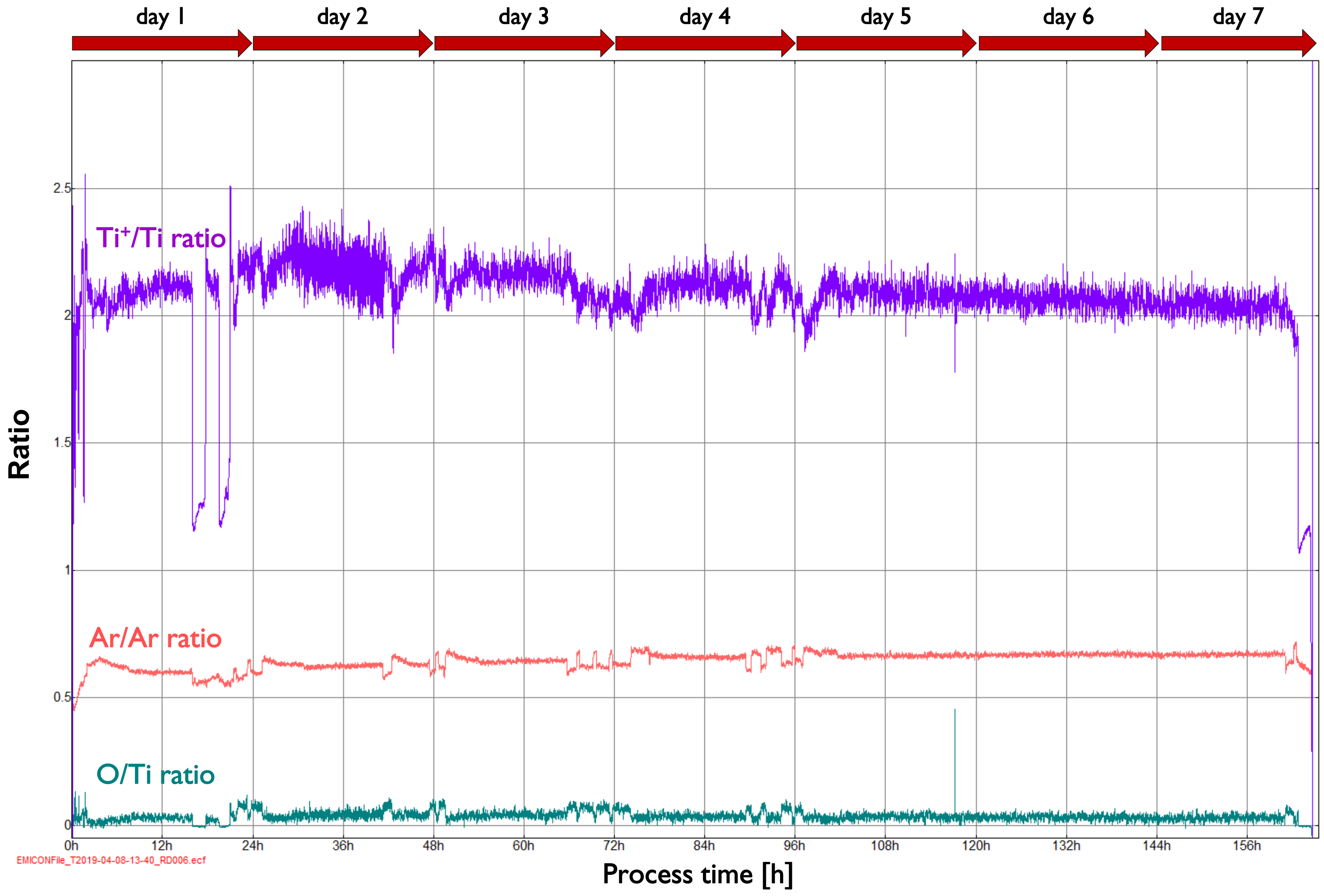
Constant Ti and O signals

▶ 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

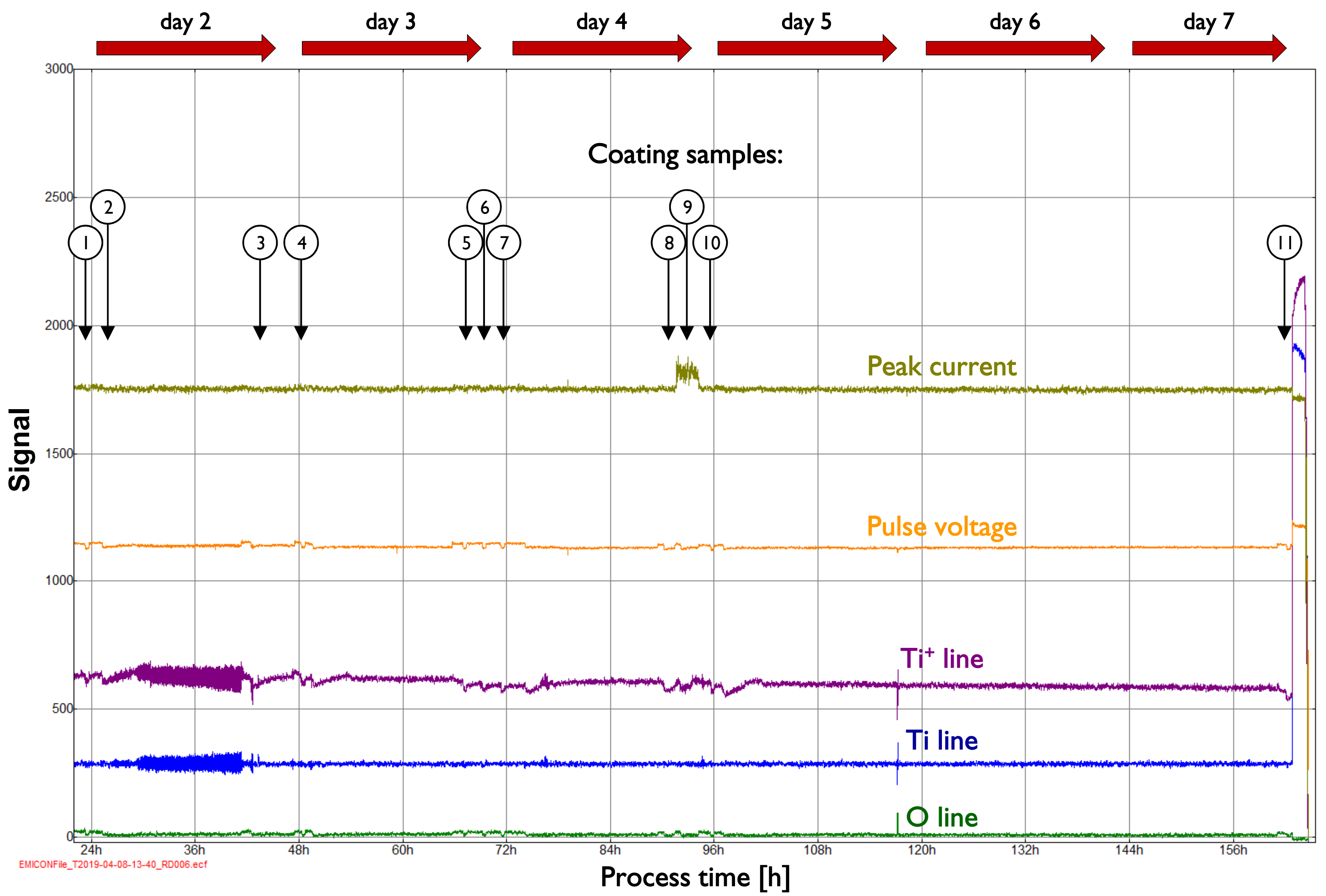
► verification stoichiometry

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

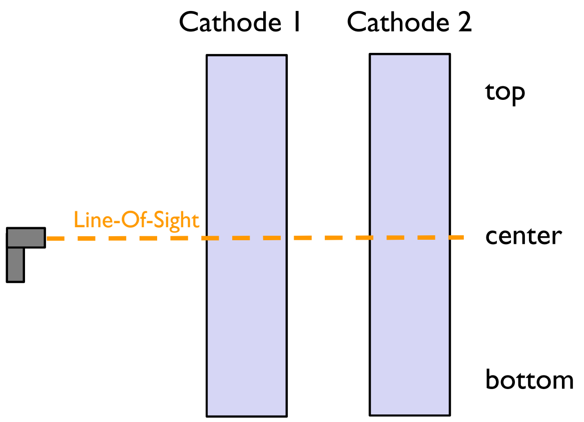
Coating sample results

Coating samples: 11 coating samples throughout process time

Deposition rate: 27 nm/min ± 3 nm/min

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

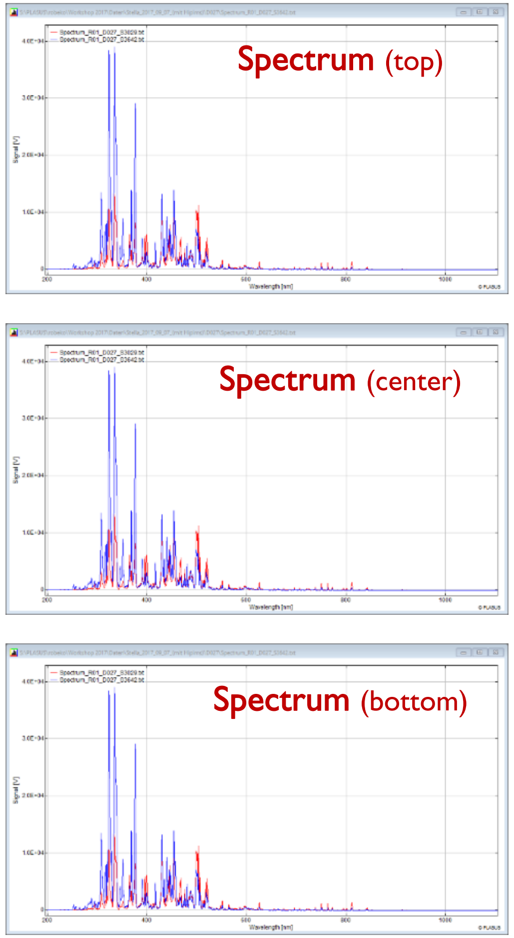
Layer uniformity: gradient from top to bottom
gas flow control at center manifold only



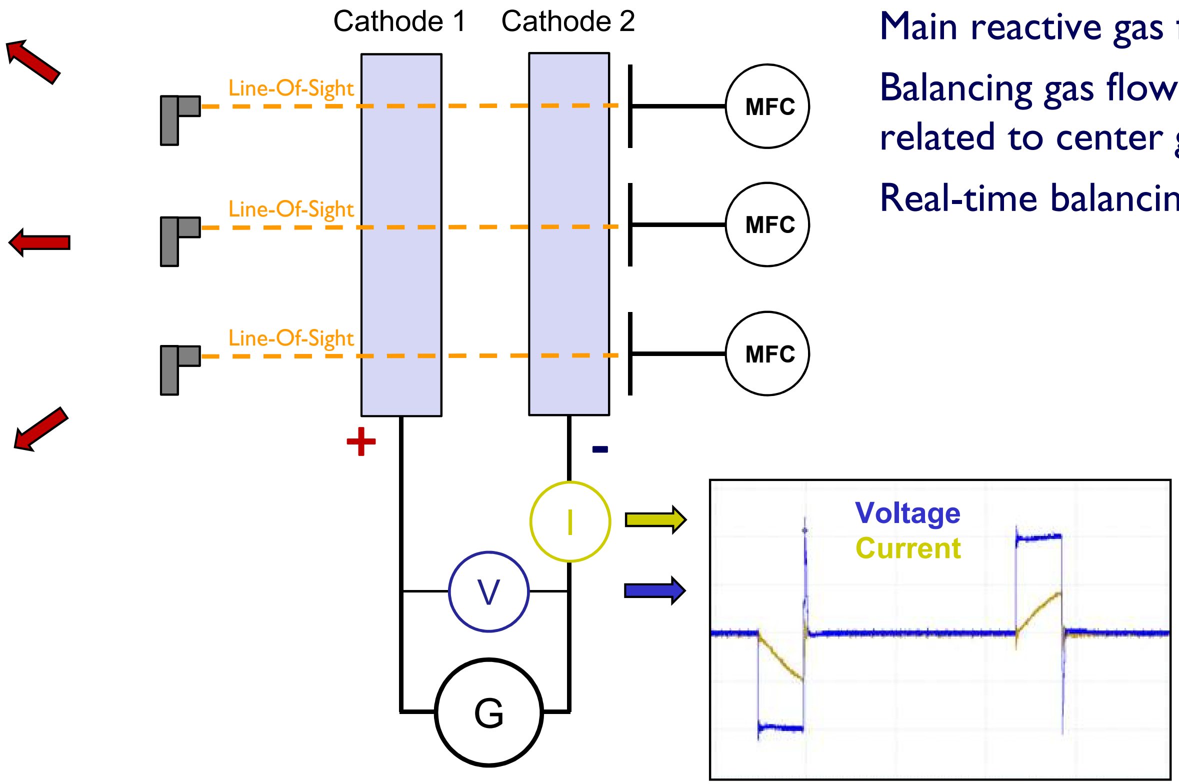
Sectional gas flow control along cathode length required for uniform layer deposition

Long-term control of reactive HIPIMS process

Control setup for uniformity control



Plasma spectrum
(pulse averaged)



Pulse voltage and current curves
(40 MHz sampling rate)

Features:

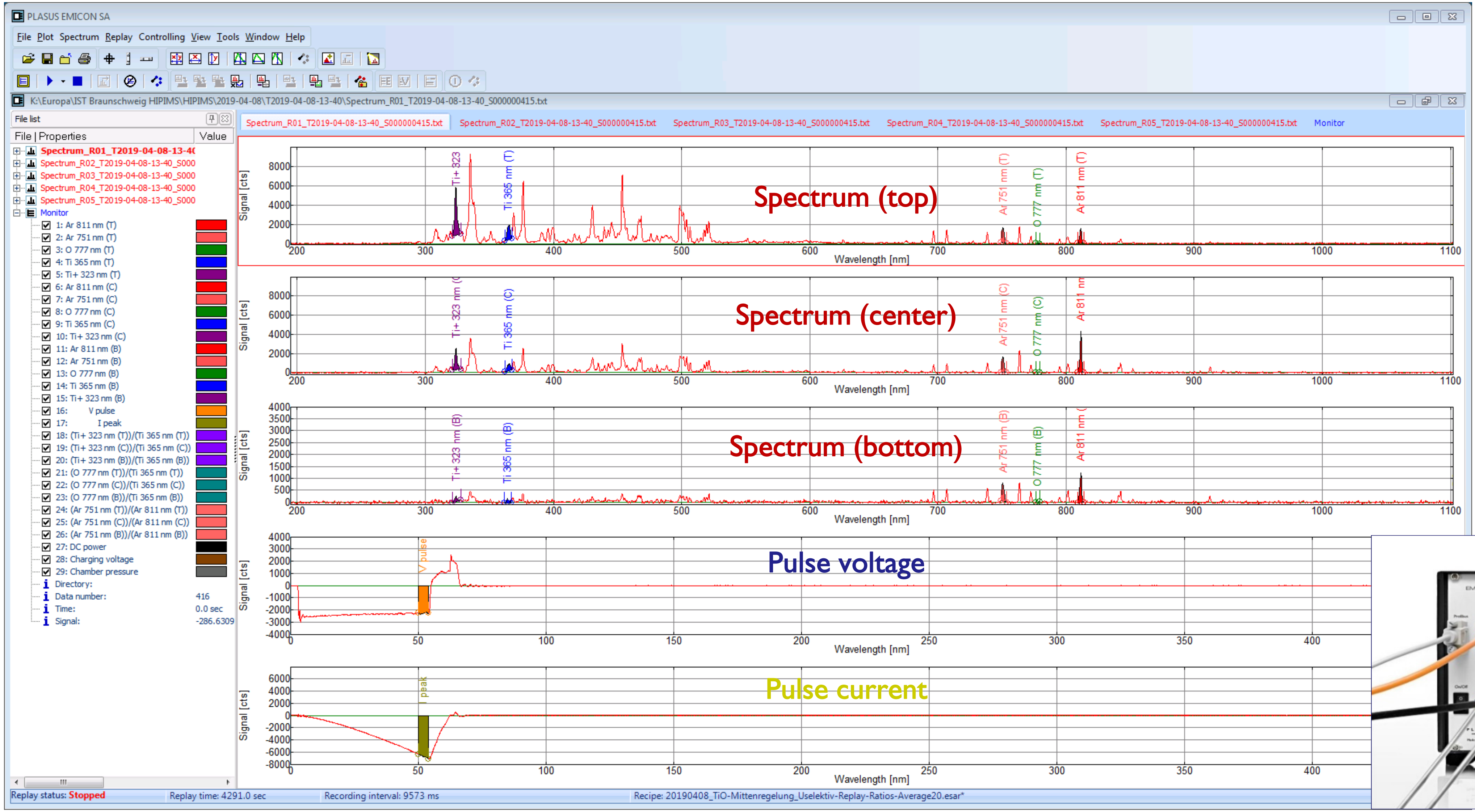
Main reactive gas flow control at center

Balancing gas flows at top and bottom related to center gas flow

Real-time balancing control using spectroscopic line ratios

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

…

EMICON SA System

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

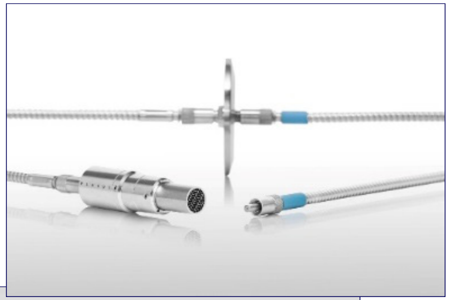
Monitoring process stability from process parameters, e.g. process pressure, DC power, etc.

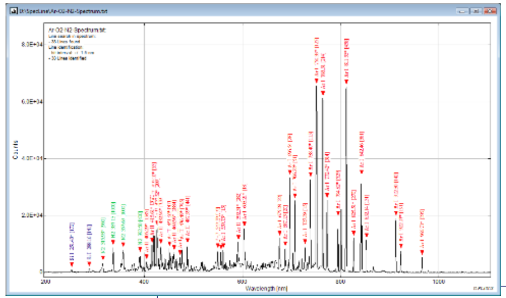
Detecting process faults

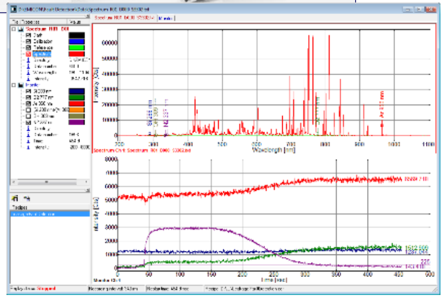
► **Advanced and reliable control technique to run HIPIMS processes in long-term production**

EMICON SA System

Turn-key solution for advanced and reliable HIPIMS process control







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