SVC TechCon 2019 Long Beach
April 27 - May 2, 2019
62nd Annual SVC Technical Conference • Long Beach Convention Center, Long Beach, California, USA

Conformal coatings deposited on microstructured substrates using HiPIMS and a Full Face Erosion Cathode

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SVC TechCon2019, Long Beach, CA
Paper PP3
May 2nd 2019, 2:40 pm, Room 104-A

Content of presentation

- Importance of conformal coatings in industry/research
- HiPIMS and Plasma ionization
- Positive pulse addition to drive charged particles (rates, guidance)
- Evaluation of coating deposited via HiPIMS with an FFE magnetron
- Conclusions and future work

Company overview - Gencoa

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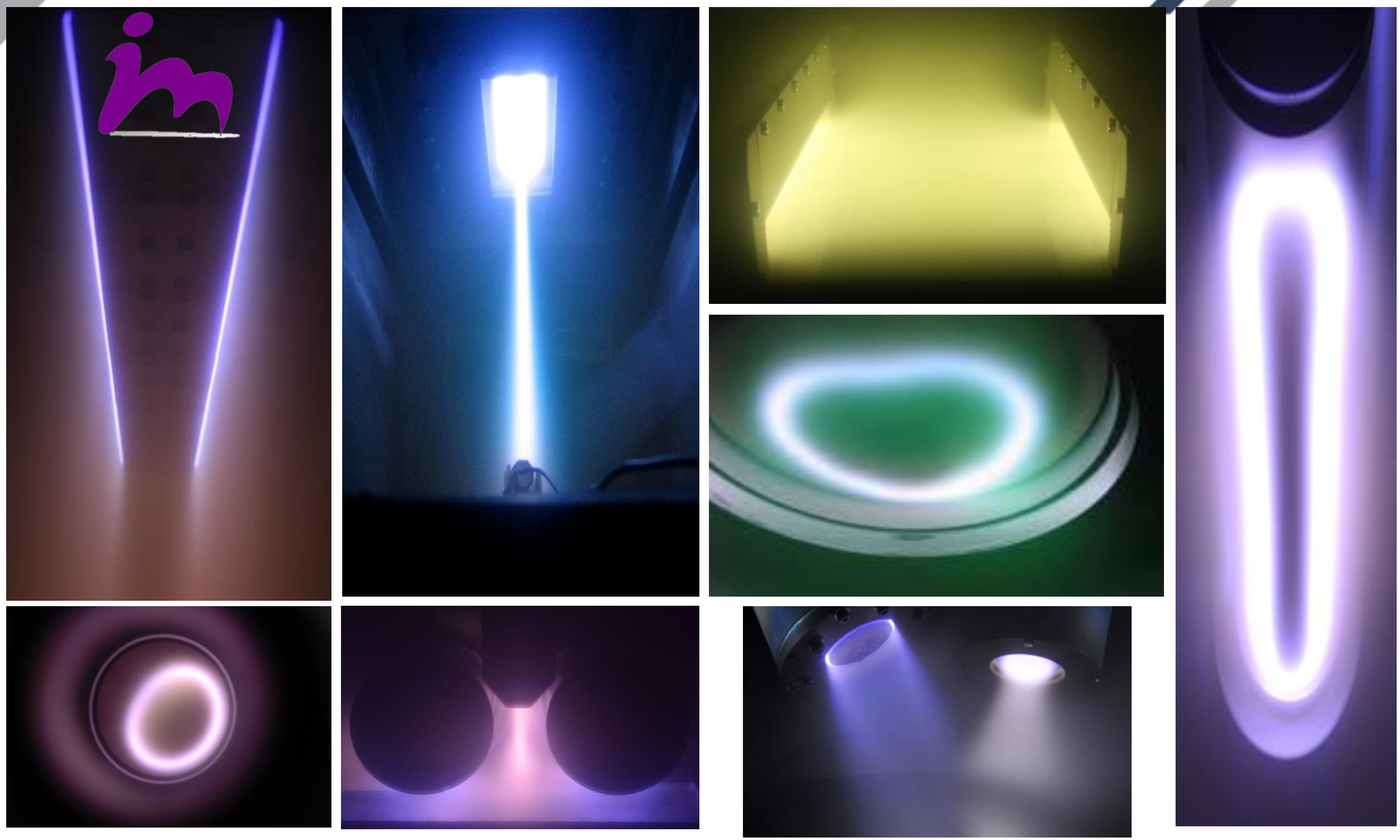


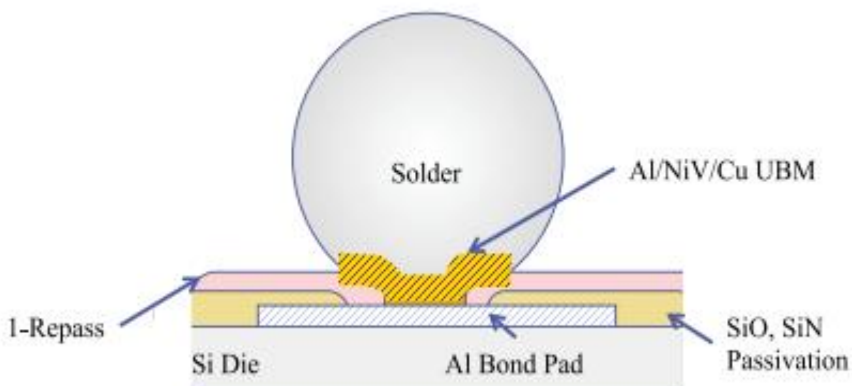
Company overview – N4E

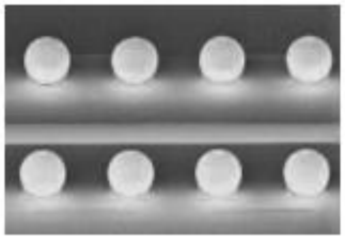
- In house PVD facilities.
- Developing processes and HiPIMS power supply (hip-V partner).
- Access to characterization and analysis tools .

Introduction – Coating uniformity on micro-structured substrates

Importance of coverage/uniformity to ensure continuity of properties, especially in the semiconductor industry

Example: power devices



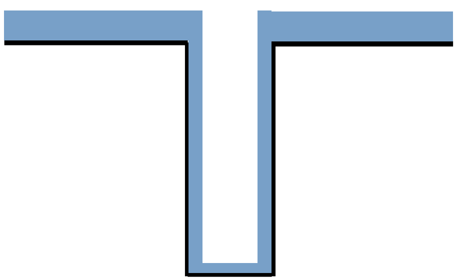


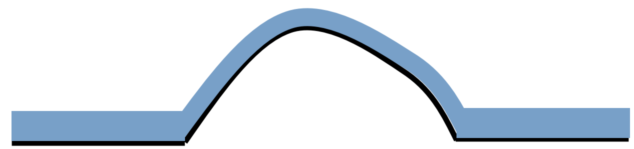
Standard Solder Bumping Process.

https://www.semitracks.com/newsletters/march/2014-march-newsletter.pdf

Introduction – Coating uniformity on micro-structured substrates

Challenge: coverage/uniformity on complex morphologies (3D parts)





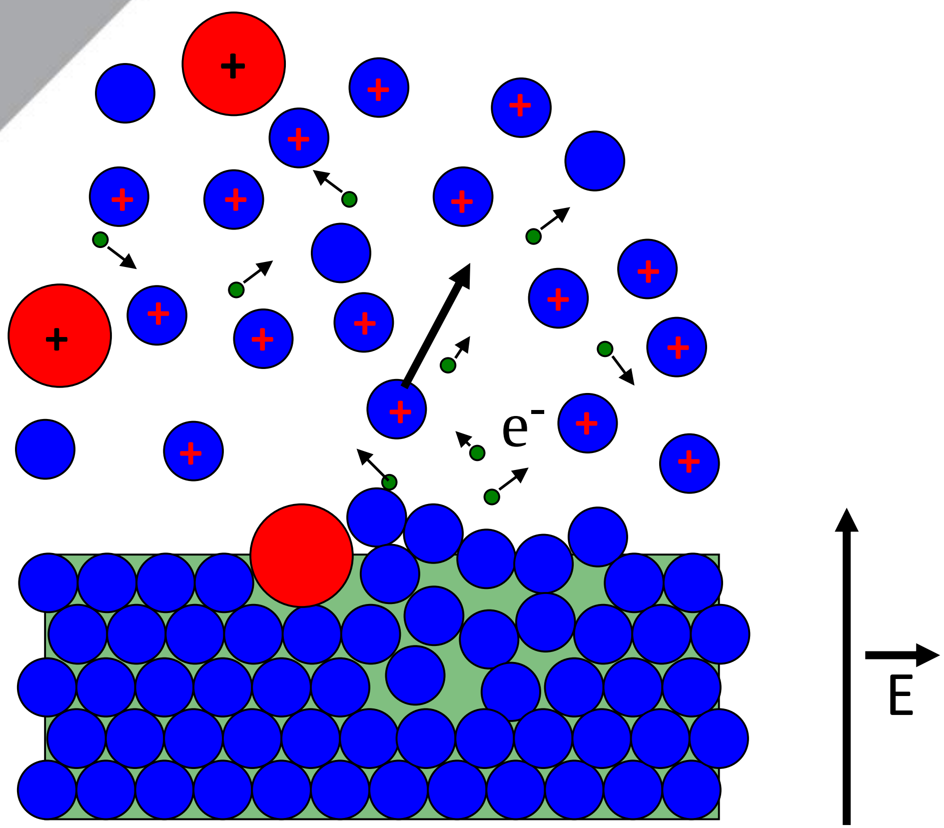
Negative / Positive features

Aspect ratio, Curvature radius

In standard magnetron sputtering, homogeneous coverage difficult to achieve

Approach: guiding of charged particles

Introduction - HiPIMS and Ionization



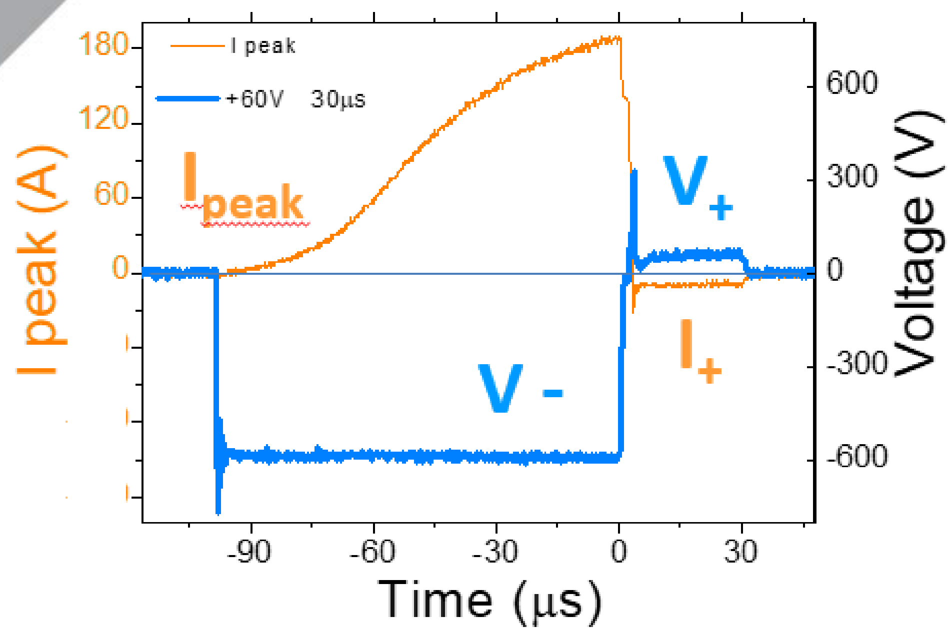
In magnetron sputtering, 5% of gaseous species is ionized

In HiPIMS, ionization degree can reach 90%

Possibility of guiding the ions towards the substrate (electric field)

Ion bombardment (e.g. for coating density and Deposition rates)

HiPIMS discharge with positive voltage reversal



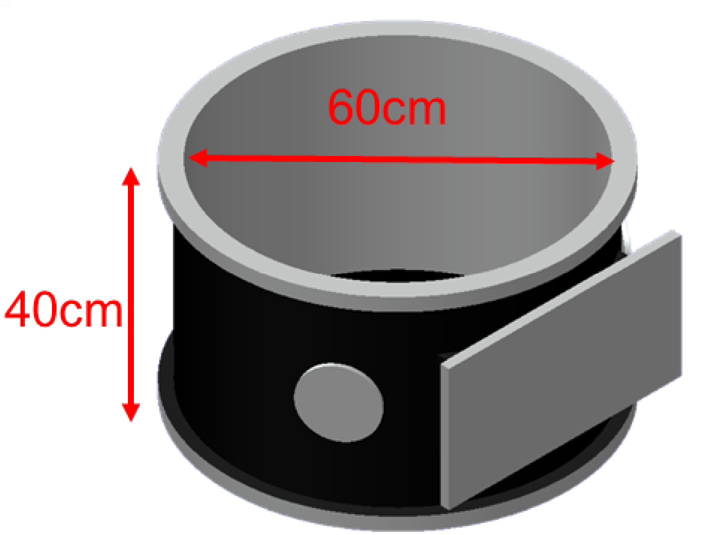
Positive pulse period plasma extinguish → fast plasma potential raise → positive ion acceleration towards grounded/biased/floating substrates

Nature of the discharge (HiPIMS) guarantees an increased degree of ionization (ion availability)

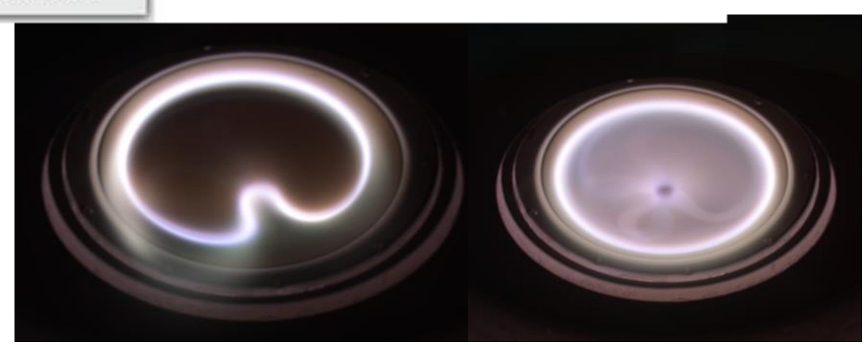
Control of the discharge, specifically of the positive pulse part (duration, intensity) allows an optimization of the substrate exposure to incoming ions.

L. Velicu et al., Surface & Coatings Technology 359 (**2019**) 97.
J. Keraudy et al., Surface & Coatings Technology 359 (**2019**) 433.
N. Britun et al., Appl. Phys. Lett. 112 (**2018**) 234103.
F. Avino et al., Plasma Sources Sci. Technol. 28 (**2019**) 01LT03.
J.A.Santiago**, I Fernandez-Martinez** et al., Surface & Coatings Technology 358 (**2019**) 43.
B.Wu et al., Vacuum 150 (**2018**) 216.
G. Eichenhofer, **I Fernandez-Martinez et al.,** UJPA 11(3), (**2017**) 73.

Experimental setup



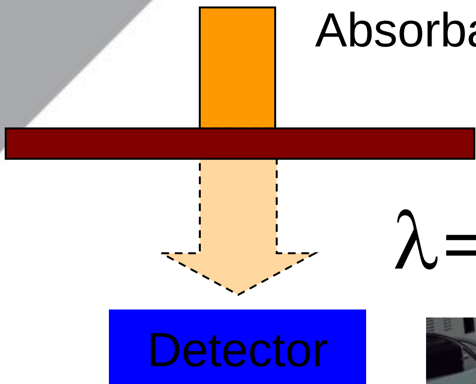
Gencoa's FFE300 magnetron



Moving magnetic array maximizes target utilization.

Uniformity of coating is determined by magnetic trap, but also type of plasma discharge and angular velocity of the magnetic array rotation.

FFE300 - Uniformity



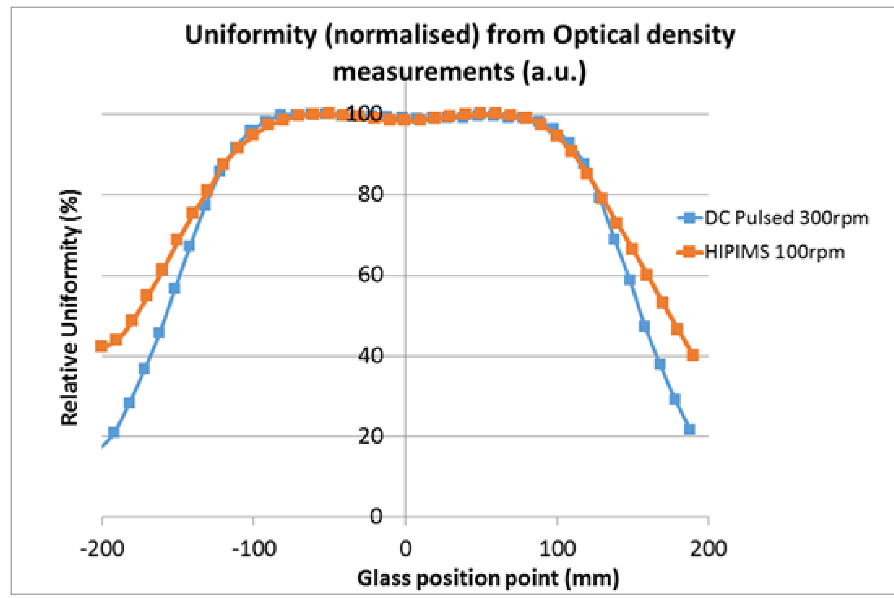
Absorbance/Transmittance based

$\lambda = 550$ nm

Optical density

$OD = -\log(T) = \alpha\, t$

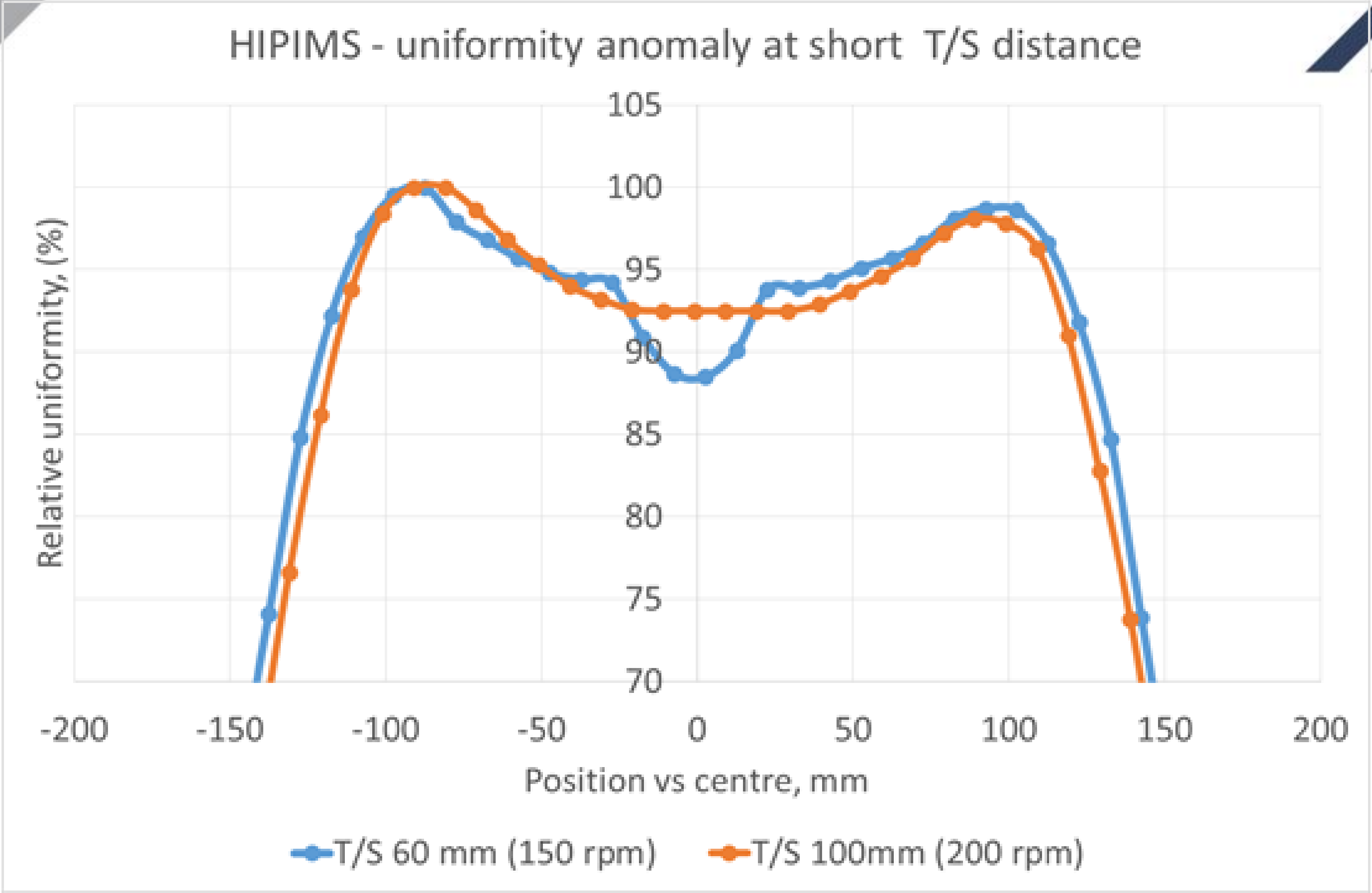
Cu target



HiPIMS and DCMS discharges induce different ionization distribution in the plasma, thus typically produce different coating distribution

FFE300 - Uniformity

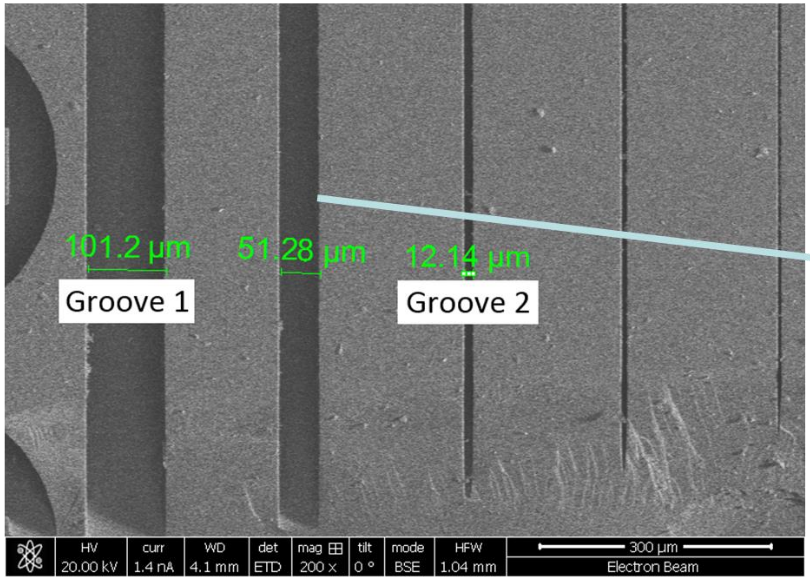
Cu target

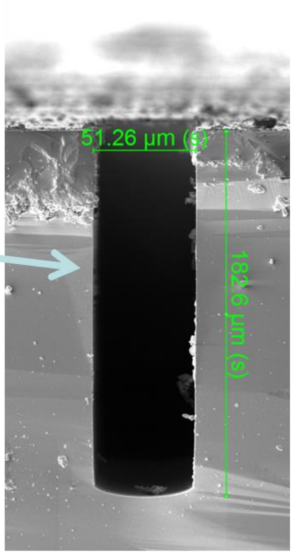


In HiPIMS, etching effects might prevail at shorter target-substrate distances

Samples

Silicon samples with high aspect ratio trenches

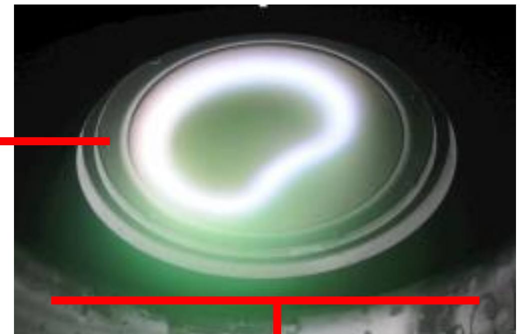




*University of Applied Sciences Berlin (HTW-Berlin), Berlin, Germany and Fraunhofer Institut IZM, Berlin, Germany

Plasma conditions

10kW

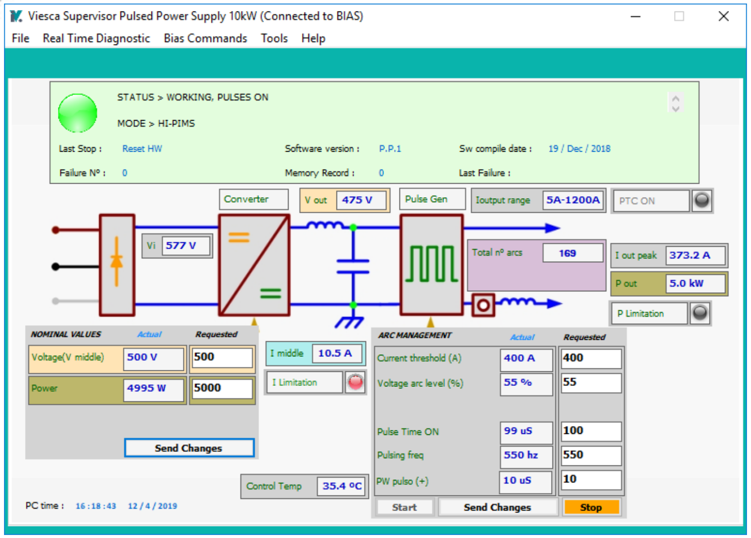


Substrate
Bias

10kW

HiPIMS 1.5 kW – 5 kW, 550 Hz, 100 µs
I peak - 300A peak ($2A/cm^2$)
Ar – 100sccm
Substrate at RT
-100V Bias (in case of silicon samples)

In-trench Titanium coating

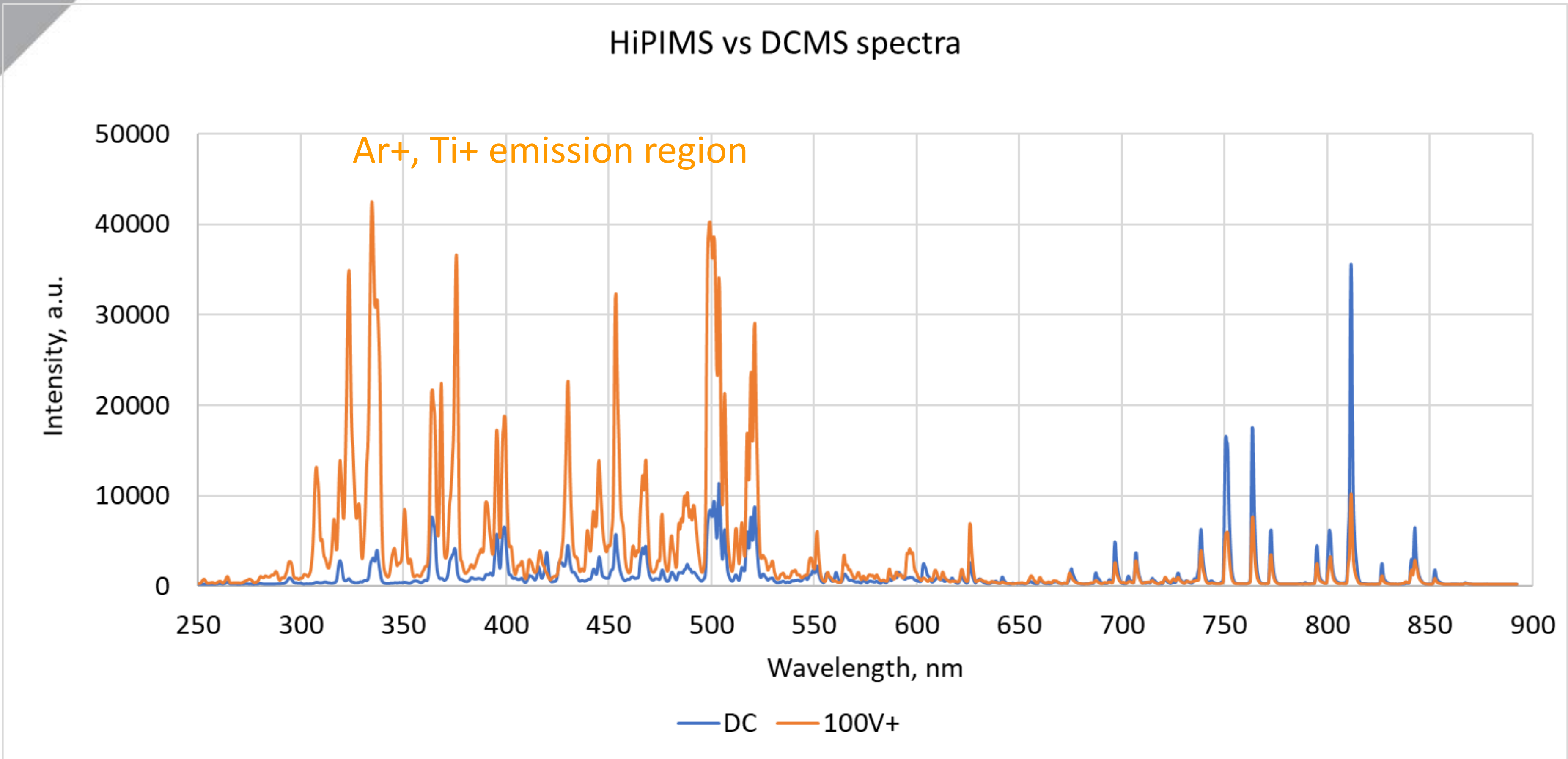


- Choice of Titanium coating (high degree of ionization in HiPIMS)
- DCMS vs HiPIMS & coating
- Effect of the positive voltage reversal (HiPlus)
- Deposition rates, Degree of ionization, Trench-filling properties

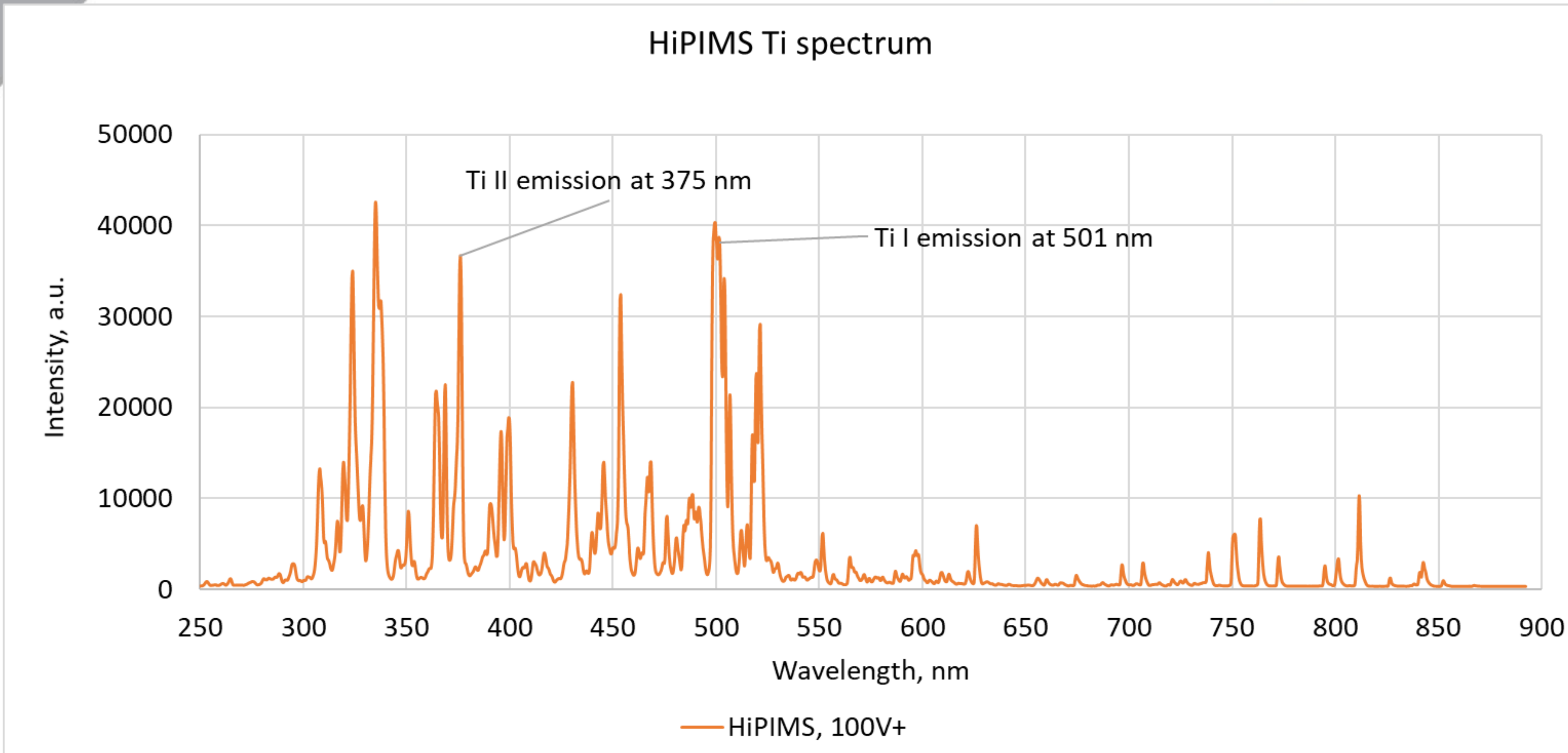
Samples are pretreated with a short HiPIMS glow discharge prior to any depositions.

During depositions, samples are constantly biased (-100V, DC)

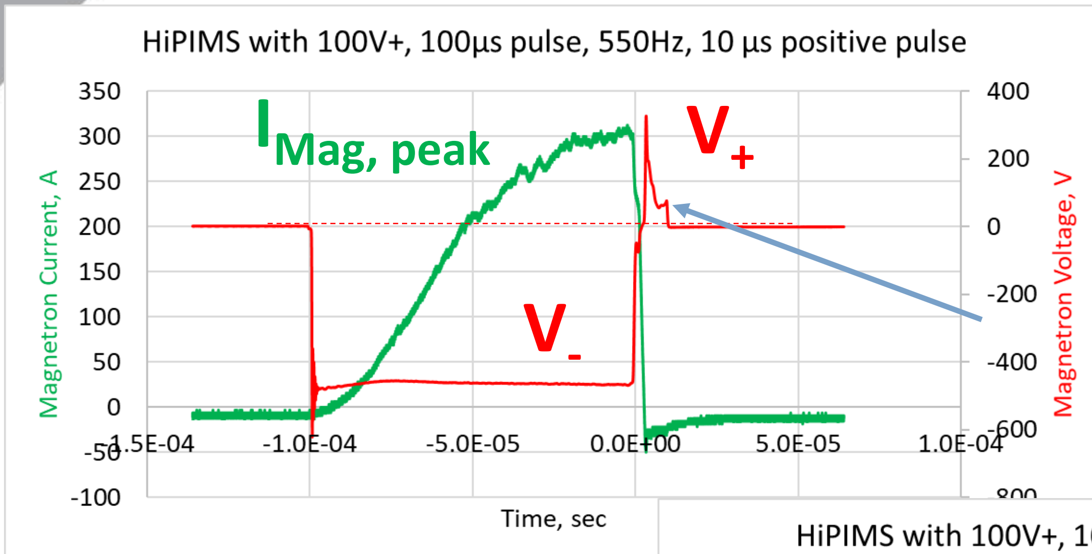
Ionization (HiPIMS vs DCMS)



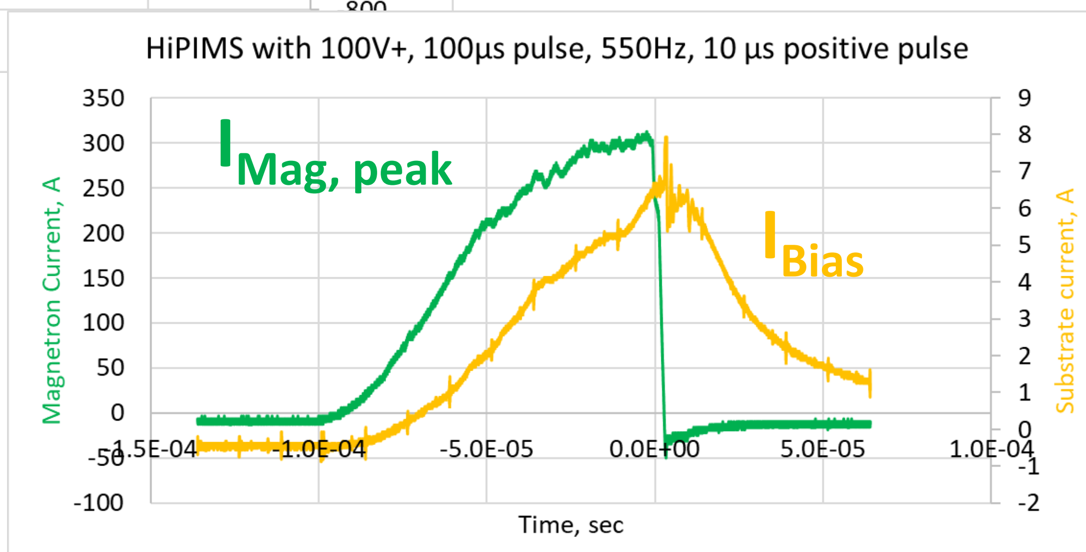
Ionization (HiPIMS)



Magnetron & Bias I/V

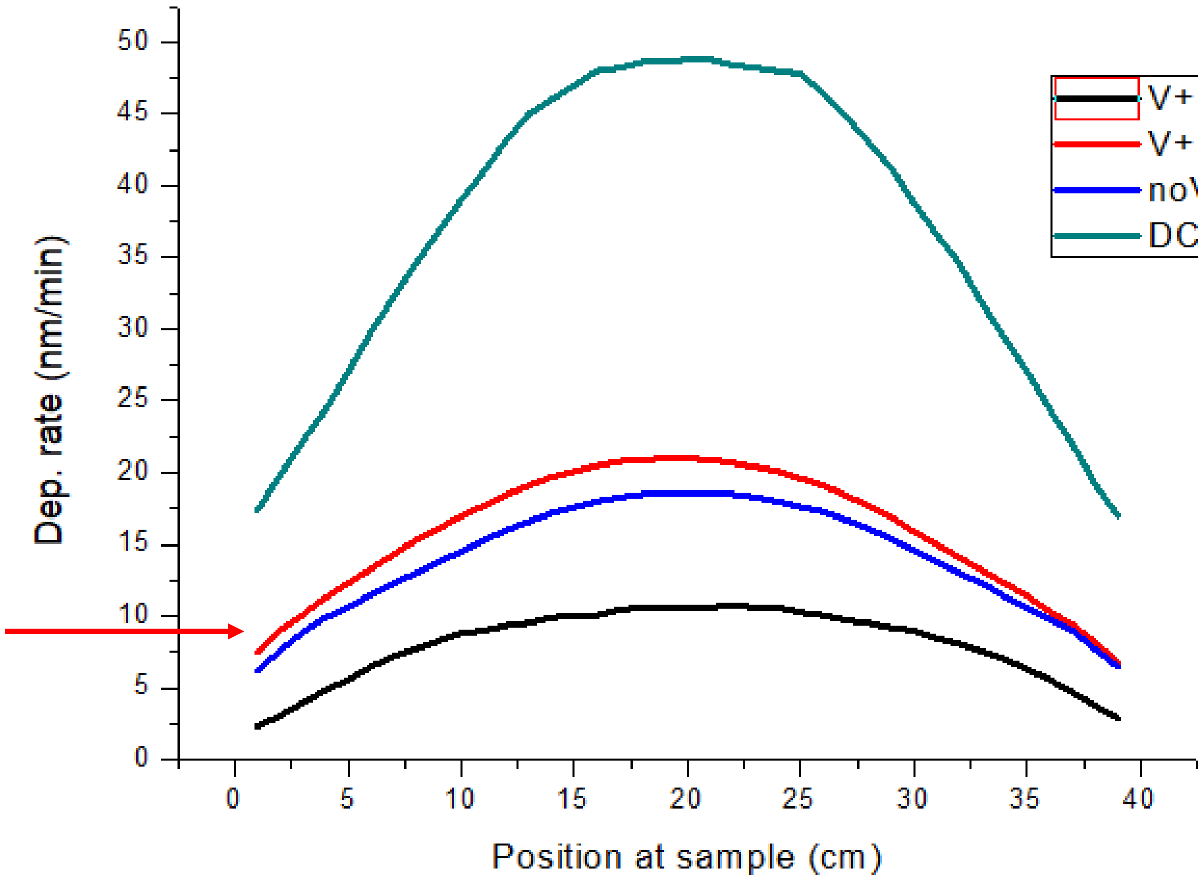


MAGNETRON



SUBSTRATE AT -100V

Deposition Rates



T-S distance 100 mm

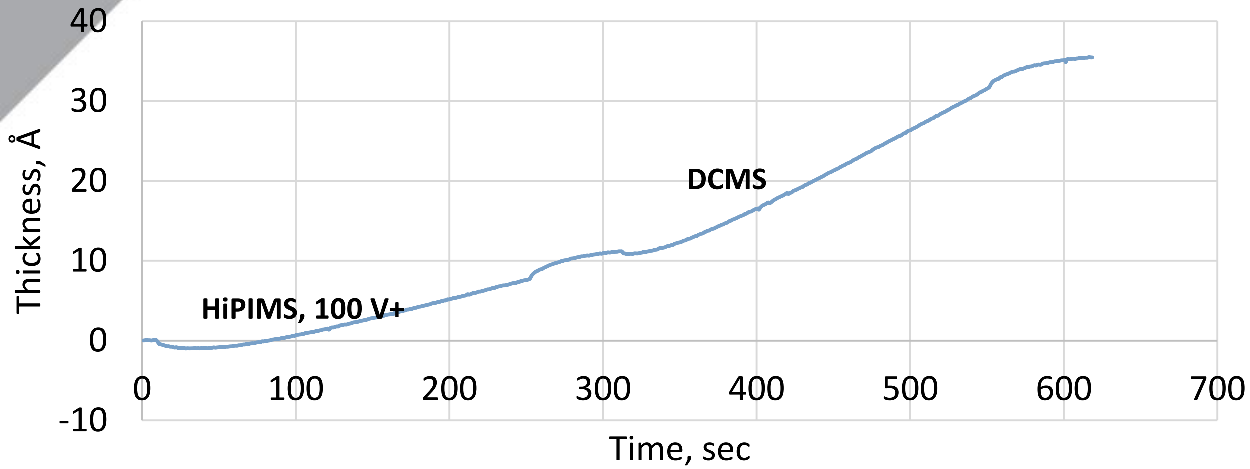
Rates are estimated via optical density measurements

A positive voltage reversal pulse of +100V increases deposition rates by 9%.

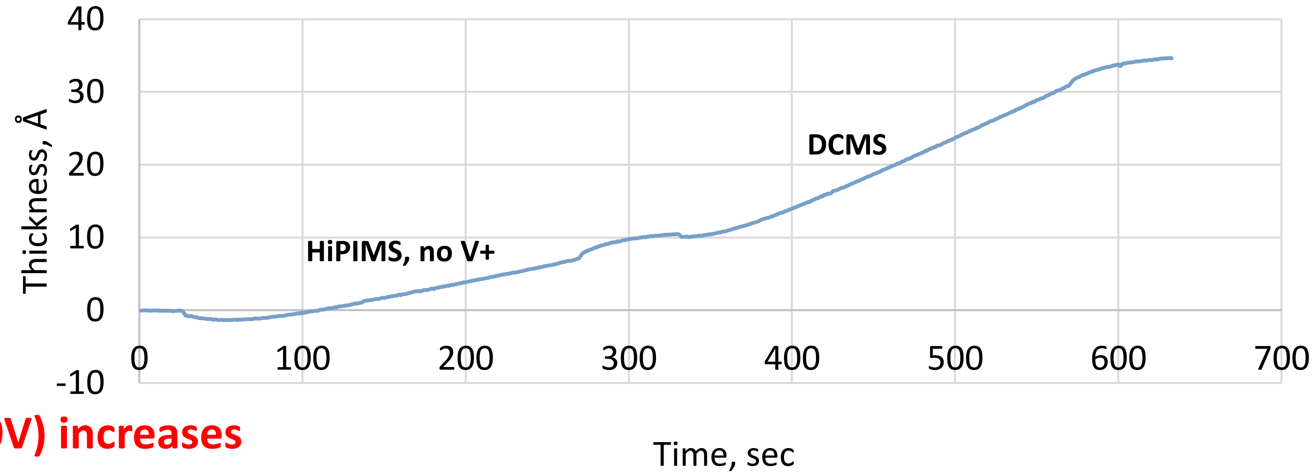
Higher positive voltages cause etching, thus deposition rates go down

Deposition Rates

In-situ monitoring of deposition (quartz microbalance)



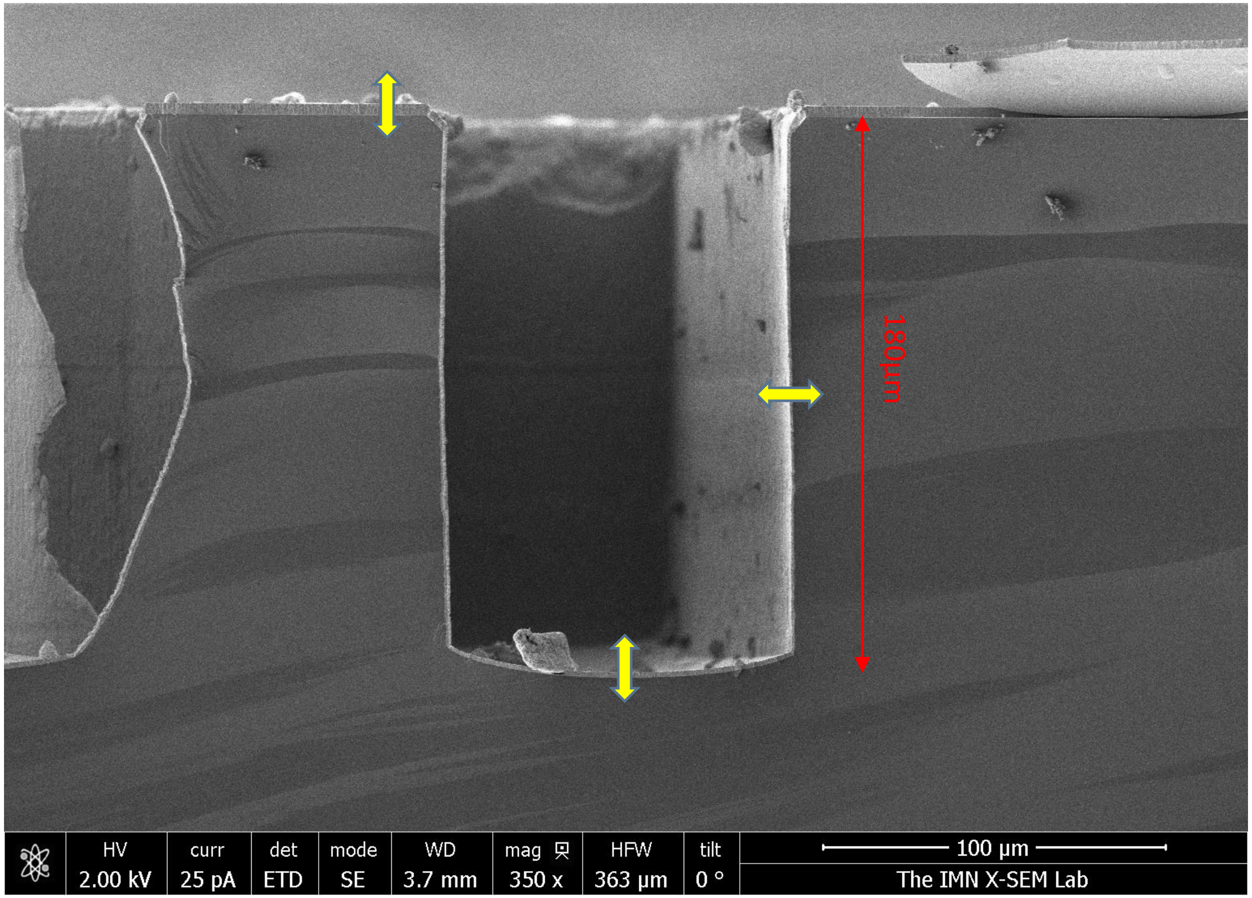
DC/HiPIMS V+ ratio 2.18



DC/HiPIMS ratio 2.28

Positive voltage (100V) increases deposition rates by 6.5%

Trench-filling – SEM images

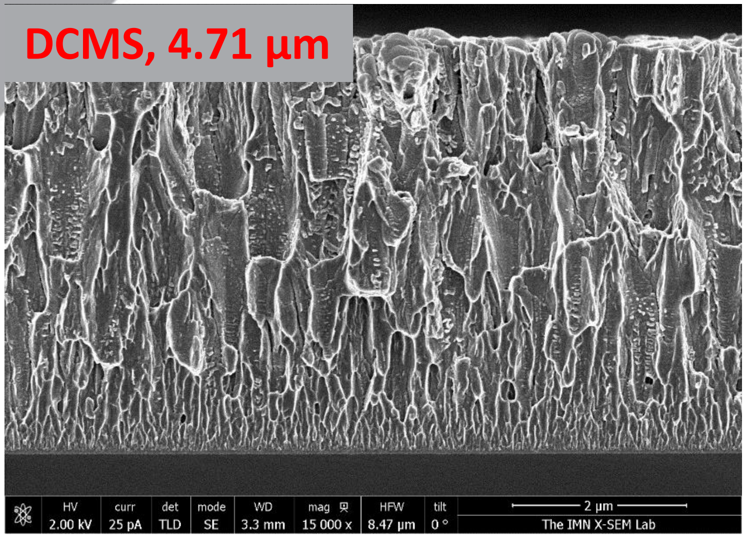


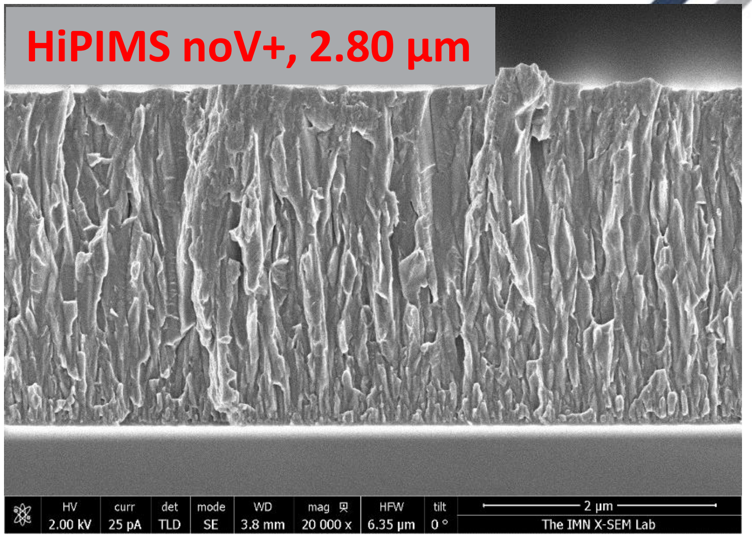
Trench widths:
100µm, 50µm and 12µm

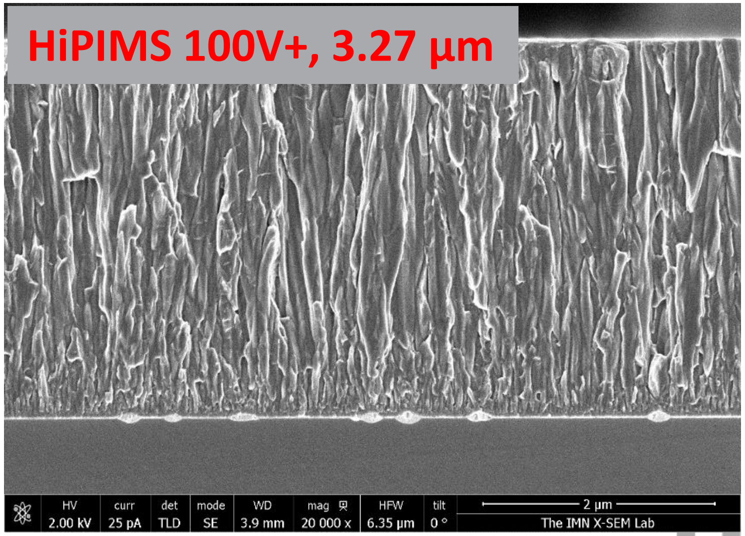
Power delivery modes:
DCMS,
HiPIMS (100V+, 0V+)

Ti coating thickness is measured on the top surface, at middle and bottom of trenches

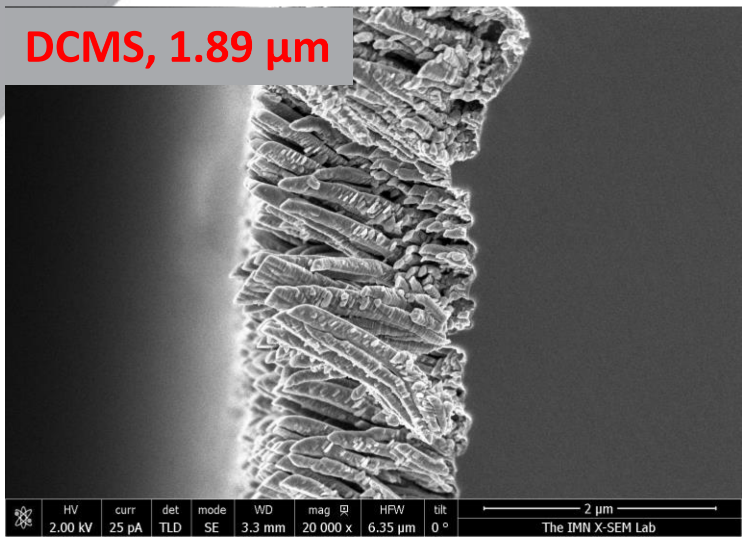
SEM images - top

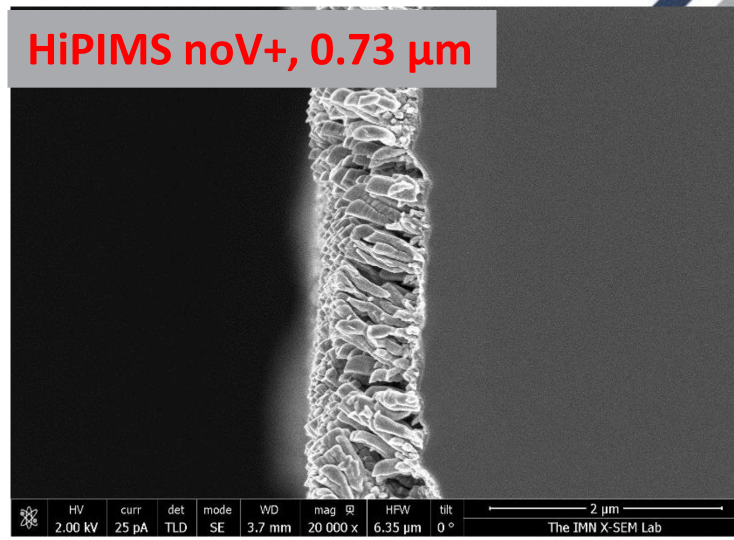


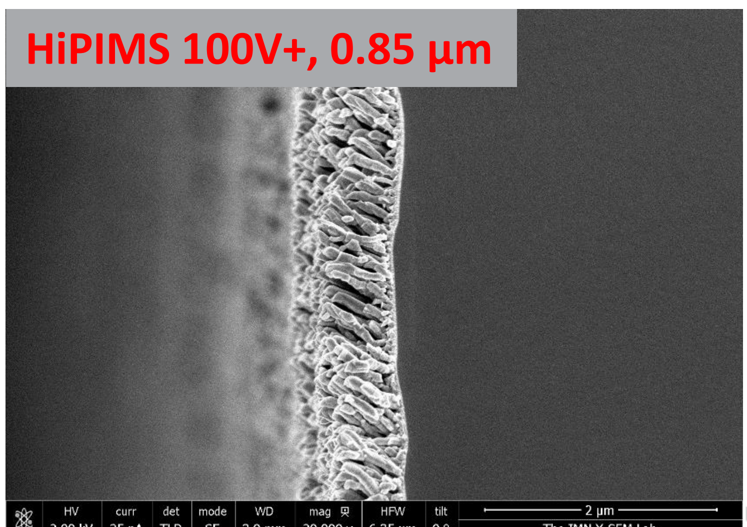


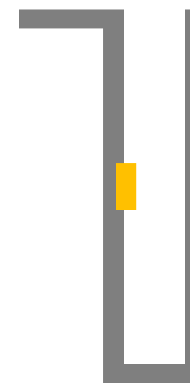


SEM images - 100µm, side

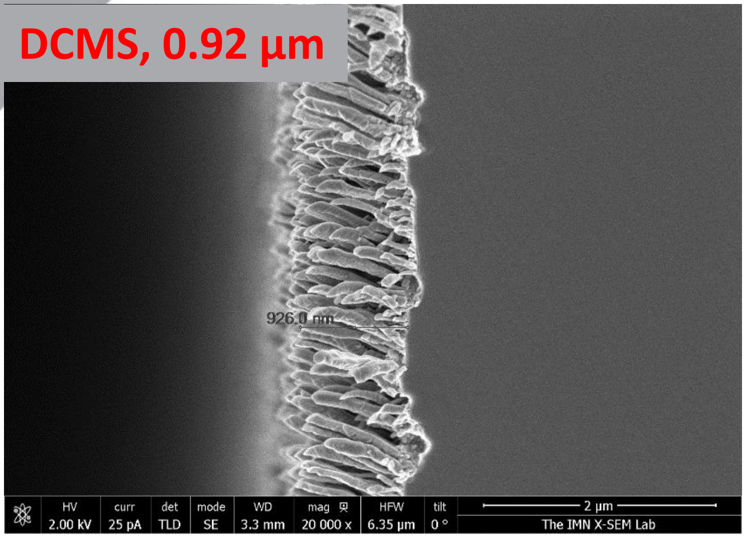




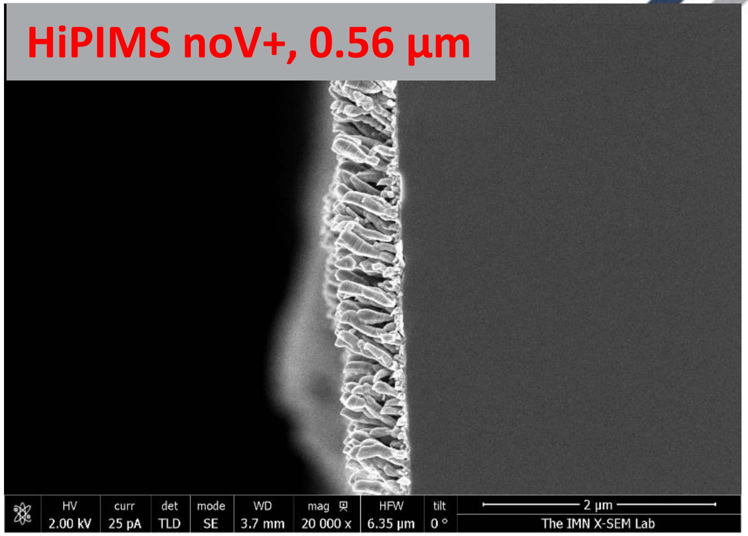




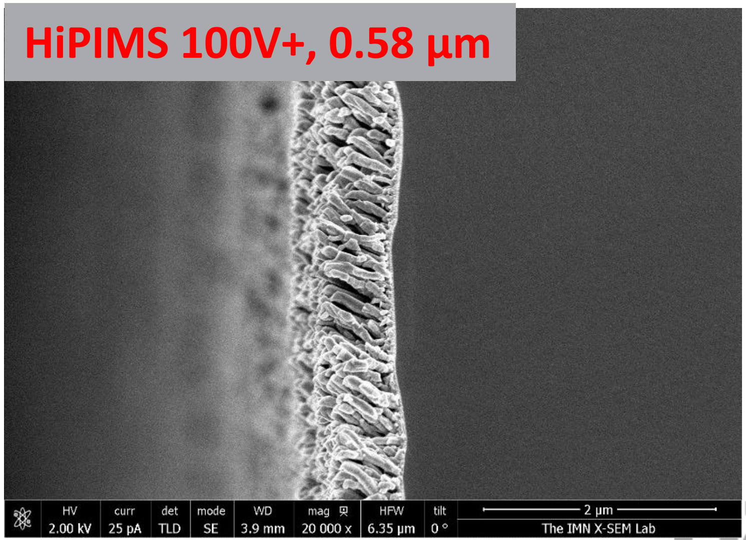
SEM images - 50µm, side



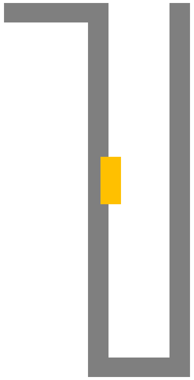
DCMS, 0.92 µm



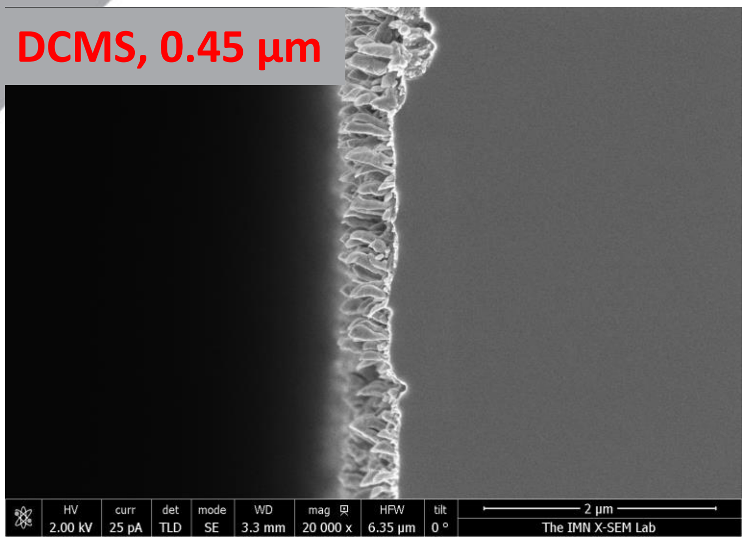
HiPIMS noV+, 0.56 µm

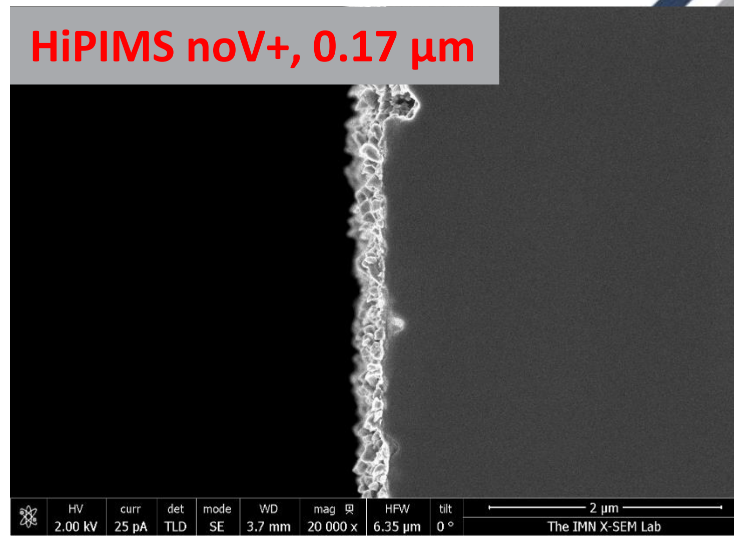


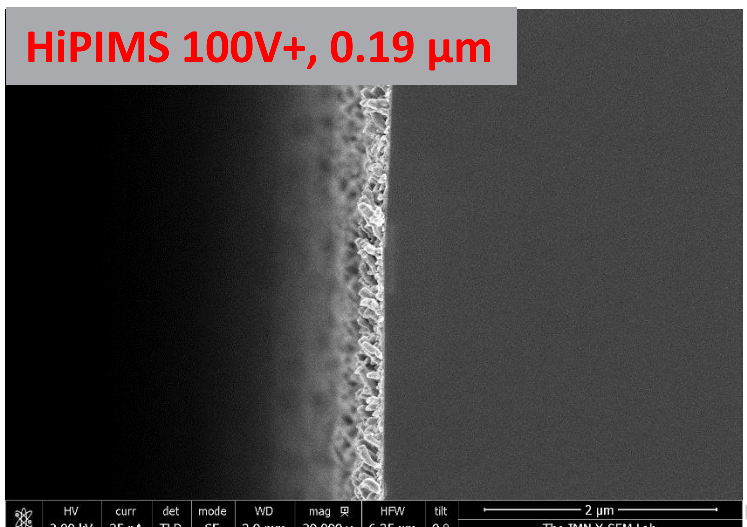
HiPIMS 100V+, 0.58 µm

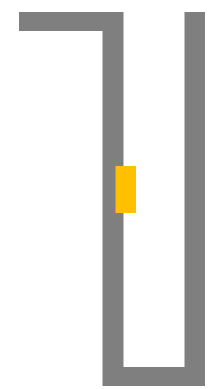


SEM images - 12µm, side



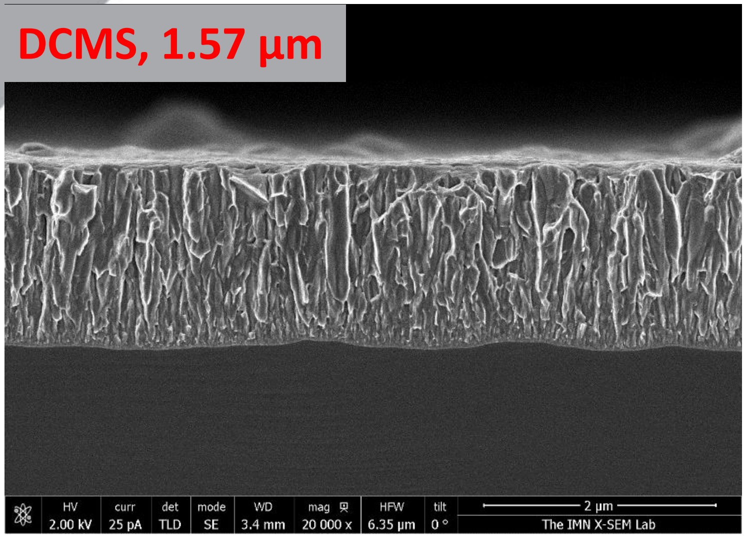




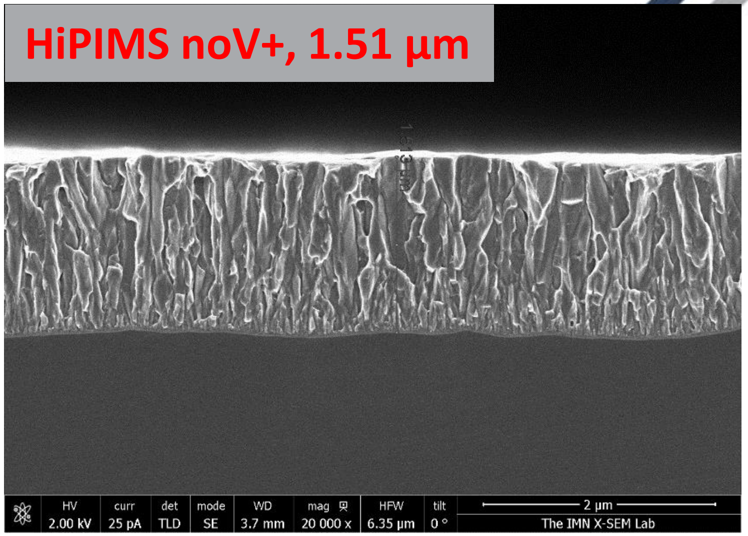


SEM images - 100µm, bottom

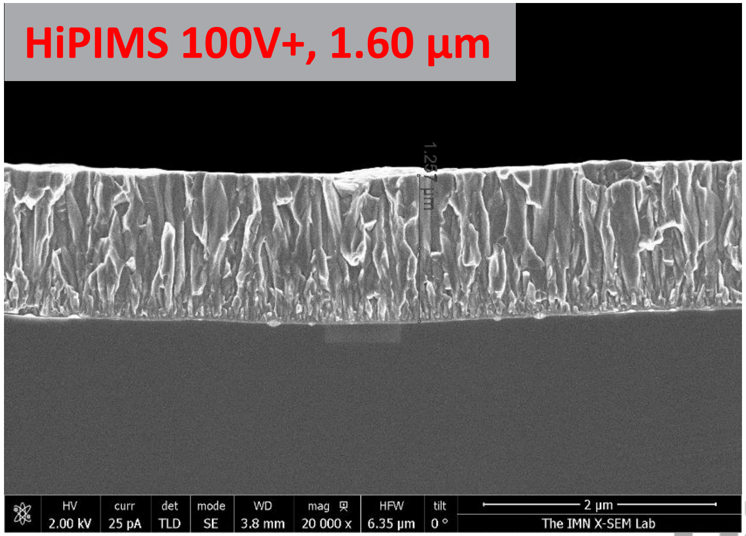
DCMS, 1.57 µm



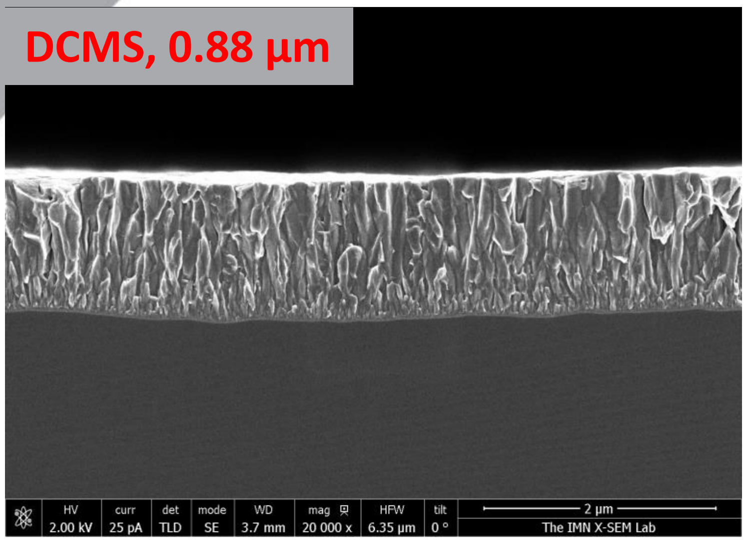
HiPIMS noV+, 1.51 µm

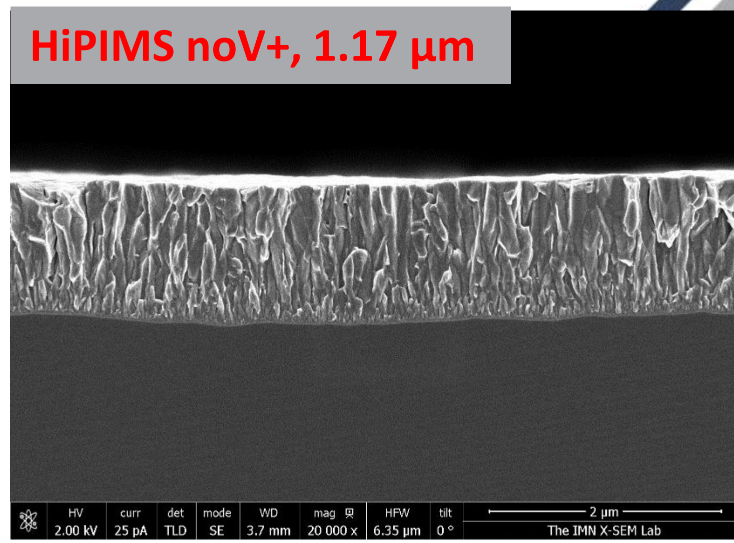


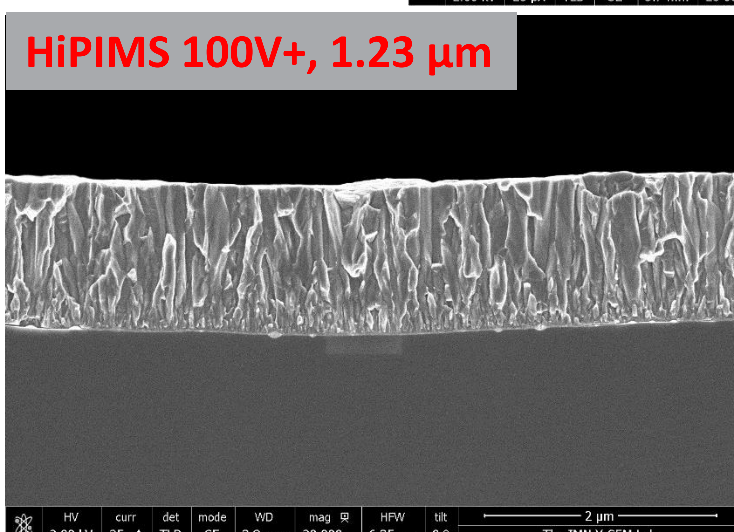
HiPIMS 100V+, 1.60 µm

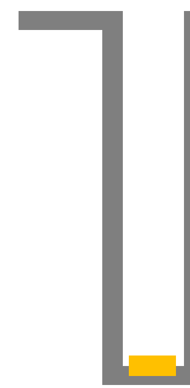


SEM images - 50µm, bottom

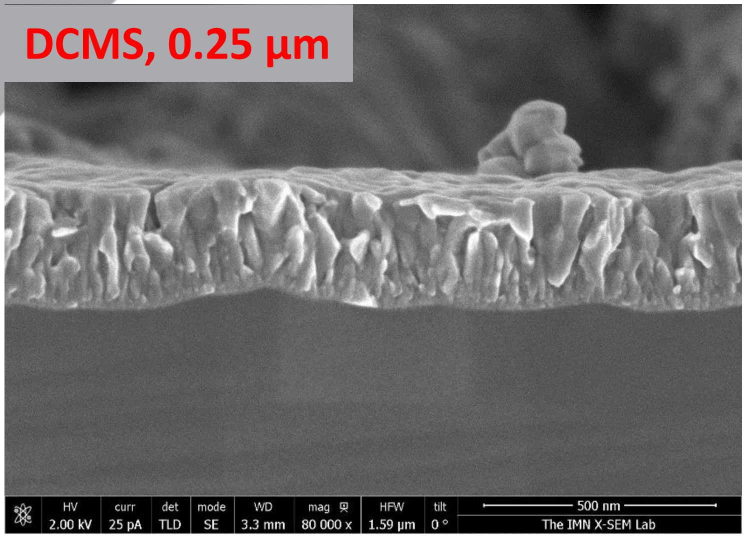


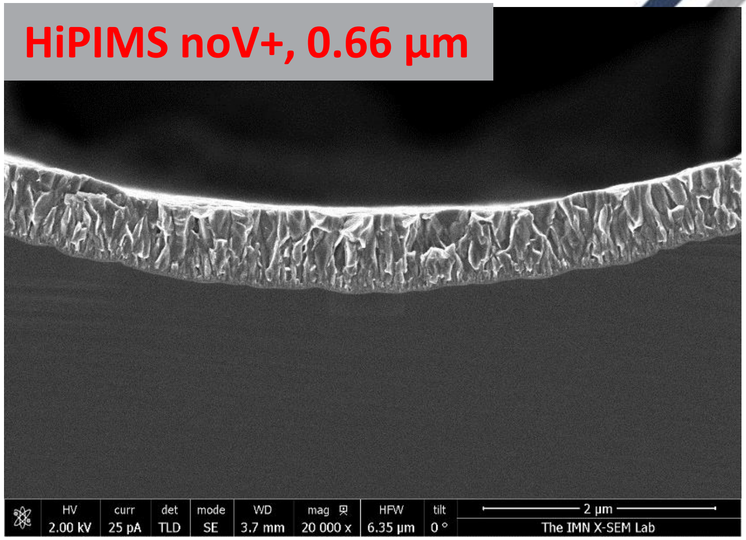


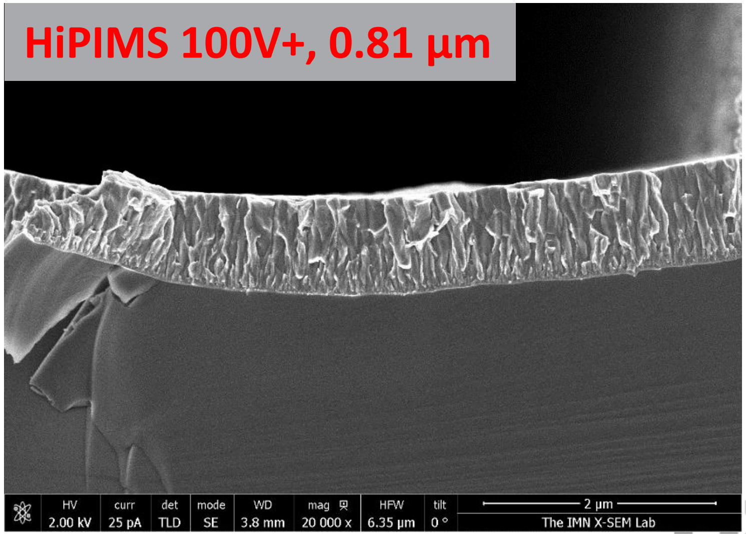


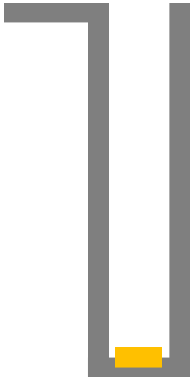


SEM images - 12µm, bottom





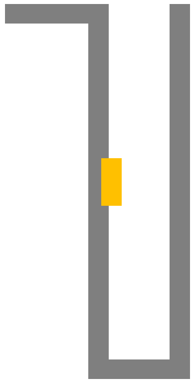


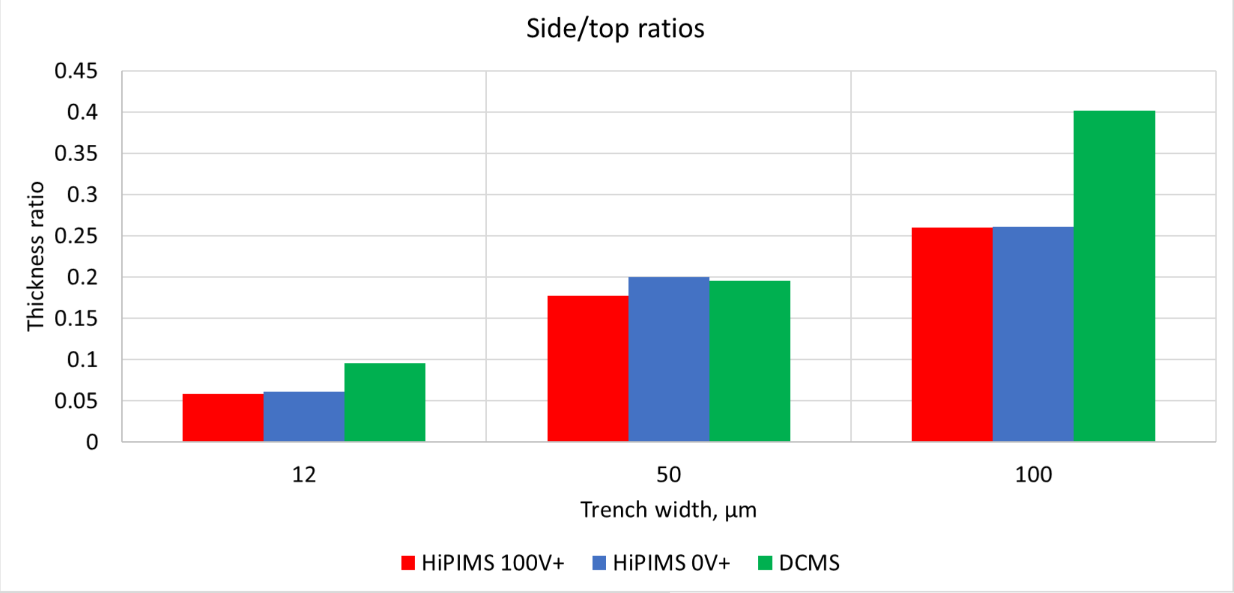


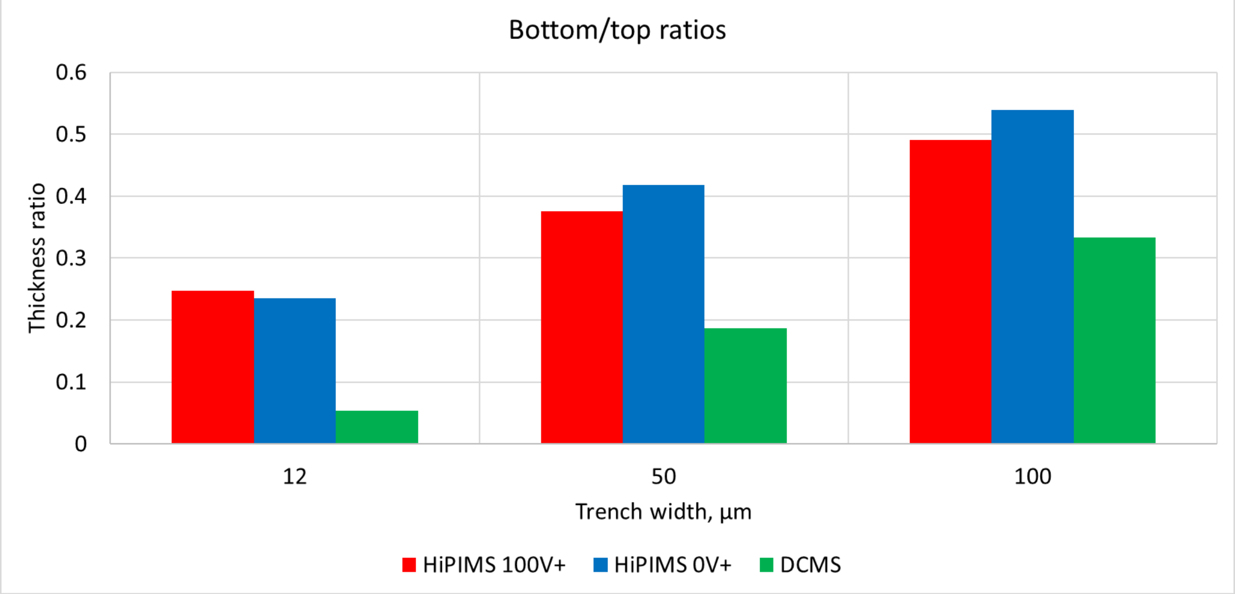
Thickness

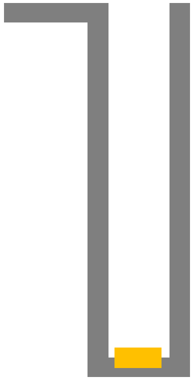
100µm	Top	Side	Bottom	Bottom/top ratio	Side/top ratio
HiPIMS 100V+	3.27	0.85	1.604	0.49	0.26
HiPIMS 0V+	2.8	0.73	1.51	0.54	0.26
DC	4.71	1.89	1.57	0.33	0.40
50µm	Top	Side	Bottom	Bottom/top ratio	Side/top ratio
HiPIMS 100V+	3.27	0.58	1.23	0.38	0.18
HiPIMS 0V+	2.8	0.56	1.17	0.42	0.20
DC	4.71	0.92	0.88	0.19	0.20
12µm	Top	Side	Bottom	Bottom/top ratio	Side/top ratio
HiPIMS 100V+	3.27	0.19	0.81	0.25	0.06
HiPIMS 0V+	2.8	0.17	0.66	0.24	0.06
DC	4.71	0.45	0.25	0.05	0.10

Thickness ratios

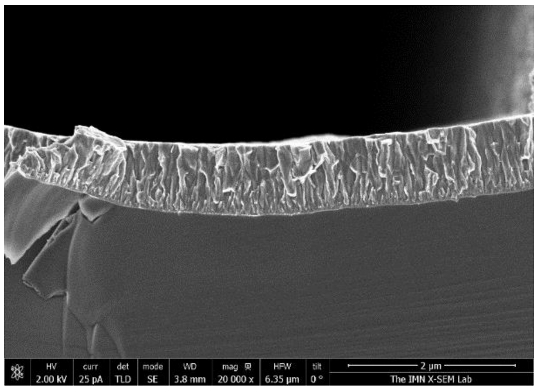


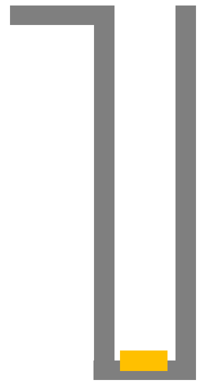




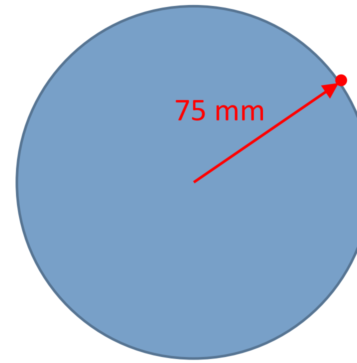


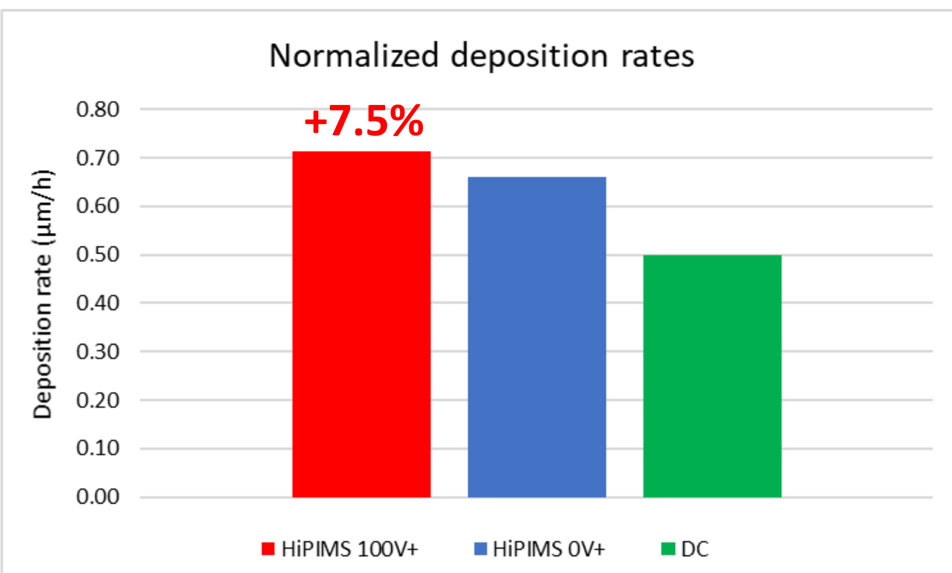
Deposition rates in high aspect ratio trenches





5kW
12µm wide trench,
aspect ratio 12.5





HiPIMS 100V+ vs DCMS: +42%

HiPIMS 100V vs HiPIMS: +7.5%

HiPlus V+ ffe nano4ENERGY

Conclusions

- The capability of in-trench filling of a deposition system consisting of an FFE magnetron (Ti target) and an HiPIMS power supply has been evaluated
- HiPIMS depositions display a better bottom/top coverage ratio. This is particularly true for negative features with high aspect ratio (12µm wide trenches)
- The introduction of a positive pulse within the HiPIMS discharge increase deposition rates (+5-10%)
- HiPIMS technology with positive pulse (HiPlus) is the most promising technology for 3D coverage

Outlook

- Introduction of a tailored sample bias (e.g. synchronization with magnetron duty cycle)
- Tests to be performed of features with higher aspect ratios
- Systematic study of coating structures
- Tests in reactive mode (e.g. TiN)

Acknowledgements

- H. D. Ngo, K. Kroehnert, O. Ehrmann (University of Applied Sciences-Berlin and Fraunhofer Institut IZM, Berlin, Germany)

- MiNa Laboratory at IMN-CSIC, Madrid, Spain