High Power Pulsed Magnetron Sputtering (HPPMS)

S. Calatroni, W. Vollenberg

(several slides taken from
B. Sproul, Advanced Energy)

Introduction: ionic coatings

The thin films industry has taken great advantage from ion-assisted coating techniques such as biased sputtering, unbalanced magnetron, ion assisted deposition, post ionization. This allowed them to obtain:

- Denser coatings
- Tailored-structure coatings
- Better results in reactive coatings

Now they are moving towards ionized coatings. Advantages:

- Higher adhesion
- No texture
- Conformal coatings

Introduction: HPPMS

- Pure ionic techniques already exist:
  - Arc plasma etc. (ask R. Russo for all these..)

- A new emerging technique (first paper Kouznetsov et al. Surf. Coat. Technol. 122 (1999) 290–293) called High Pulsed Power Magnetron Sputtering (HPPMS) allows re-use of existing industrial sputtering equipment, changing only the power supply

- This technique has of course a strong economical interest, provided the film quality is comparable with other techniques

Operating principle

Principle: high power pulses of short duration

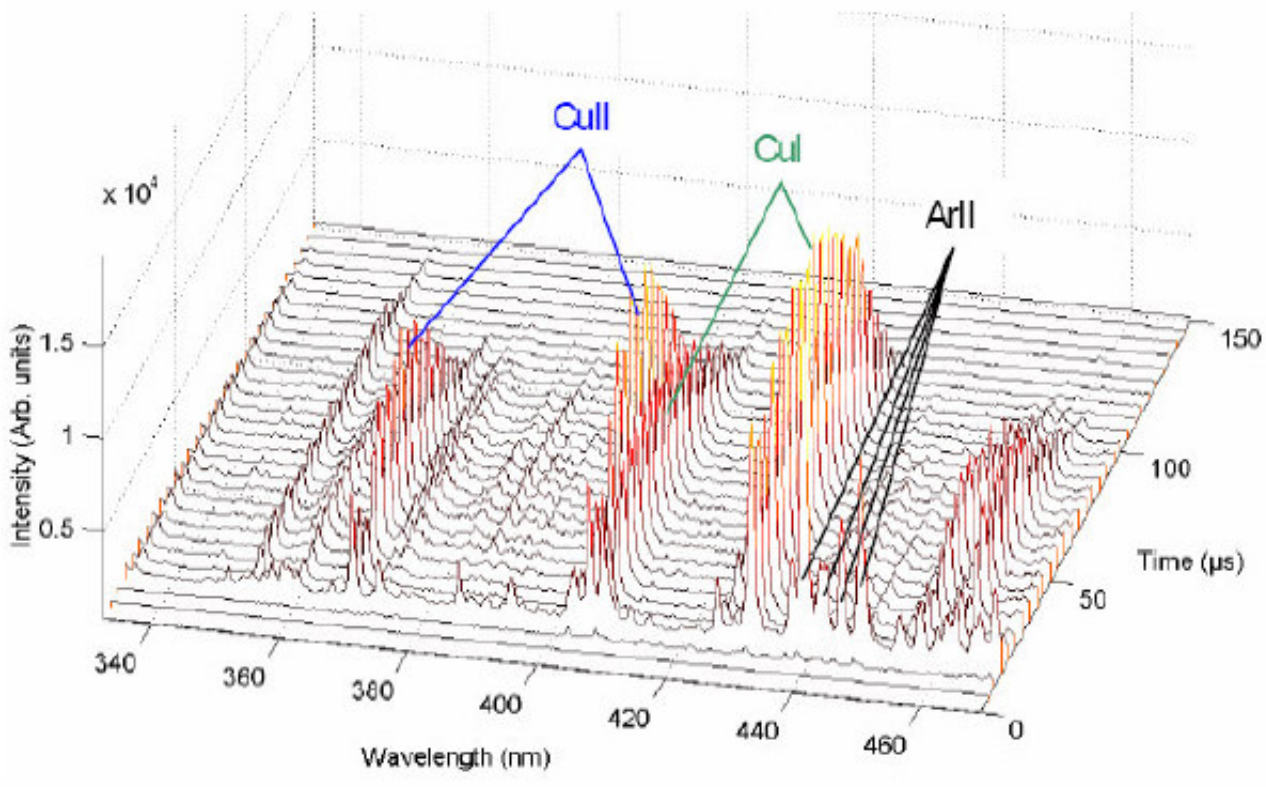
- Peak value typically 100 times greater than conventional magnetron sputtering
- Pulse width of 100 - 150 µsec, repetition rate ~50 Hz
- Peak power densities of 1-3 kW/cm^2
- Discharge voltages of 500-1000 V
- Peak current densities ~ A/cm^2

Consequences

- High degree of target material ionization
- High secondary electron current
- Promotes ionization of sputtered species
- Can approach 100%, vs. ~1% for conventional sputtering
- An applied bias allows attracting ions to the substrate

Optical spectroscopy

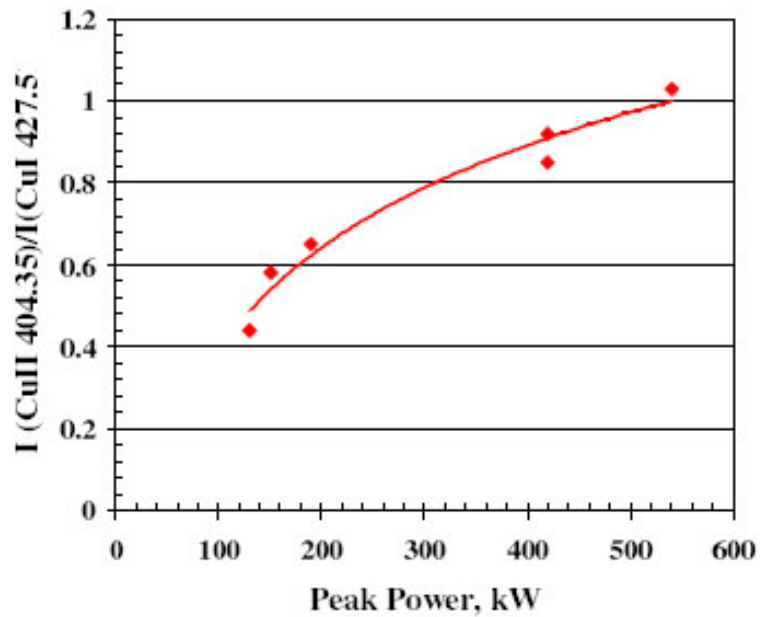
Time Evolution of the Spectrum of a HPPMS Copper Discharge



From W. Sproul, AEI

Effect of Peak Power on Ionization

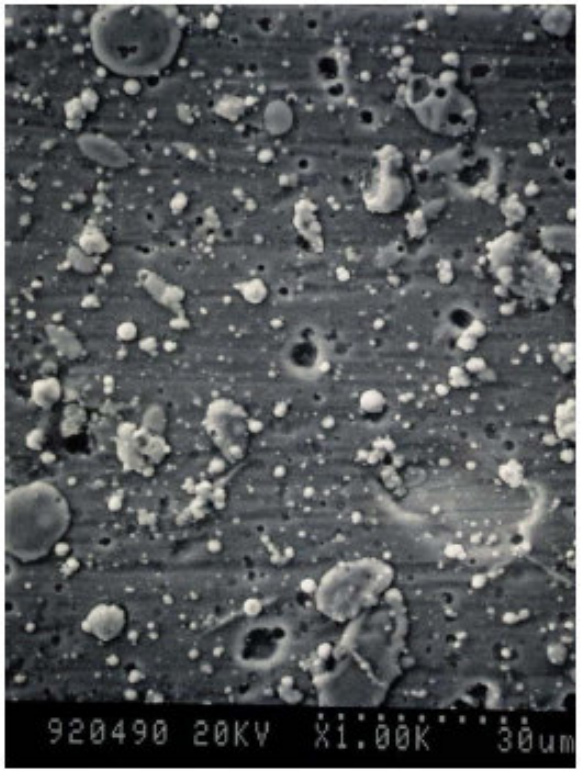
- Function of peak power
- Material dependant
- Good ionization when peak power density in 2-3 kW/cm^2 range



From W. Sproul, AEI

HPPMS vs. Arc Source

- Both generate highly ionized fluxes
- Arc source generates macroparticles
  - Size varies from sub-micron to > 50 µm
  - Detrimental to many applications
- HPPMS source can be virtually arc free
  - Few if no macroparticles



Arc deposited TiN

From W. Sproul, AEI

HPPMS coatings in trenches (valid for any ion coating technique)

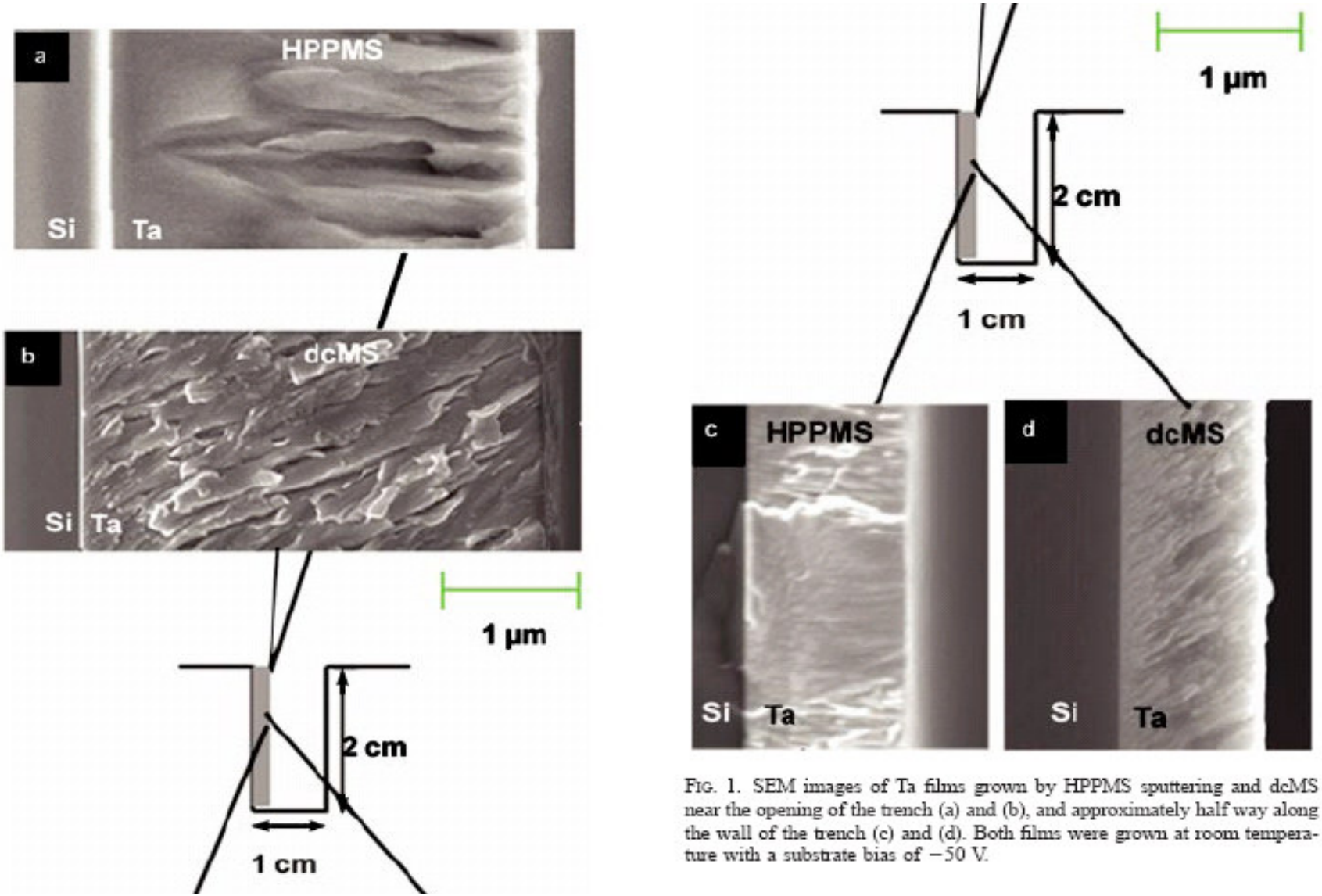
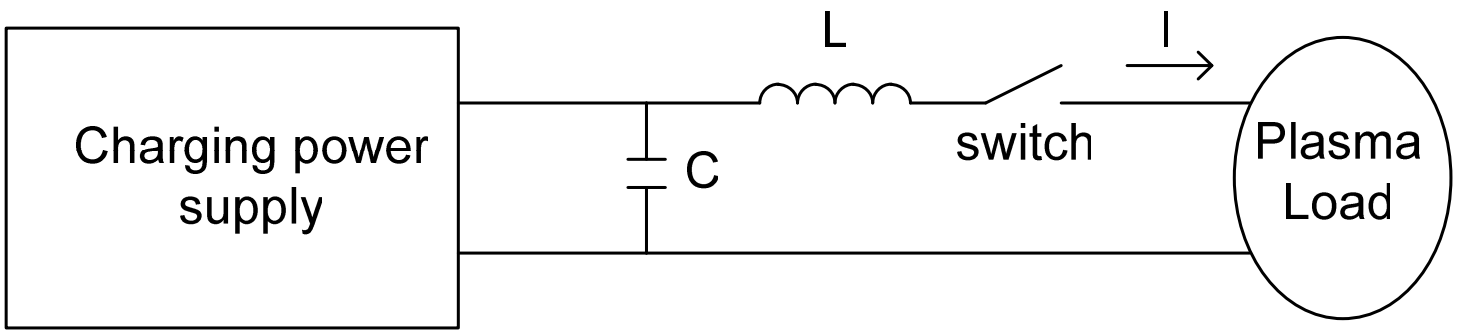


FIG. 1. SEM images of Ta films grown by HPPMS sputtering and dcMS near the opening of the trench (a) and (b), and approximately half way along the wall of the trench (c) and (d). Both films were grown at room temperature with a substrate bias of −50 V.

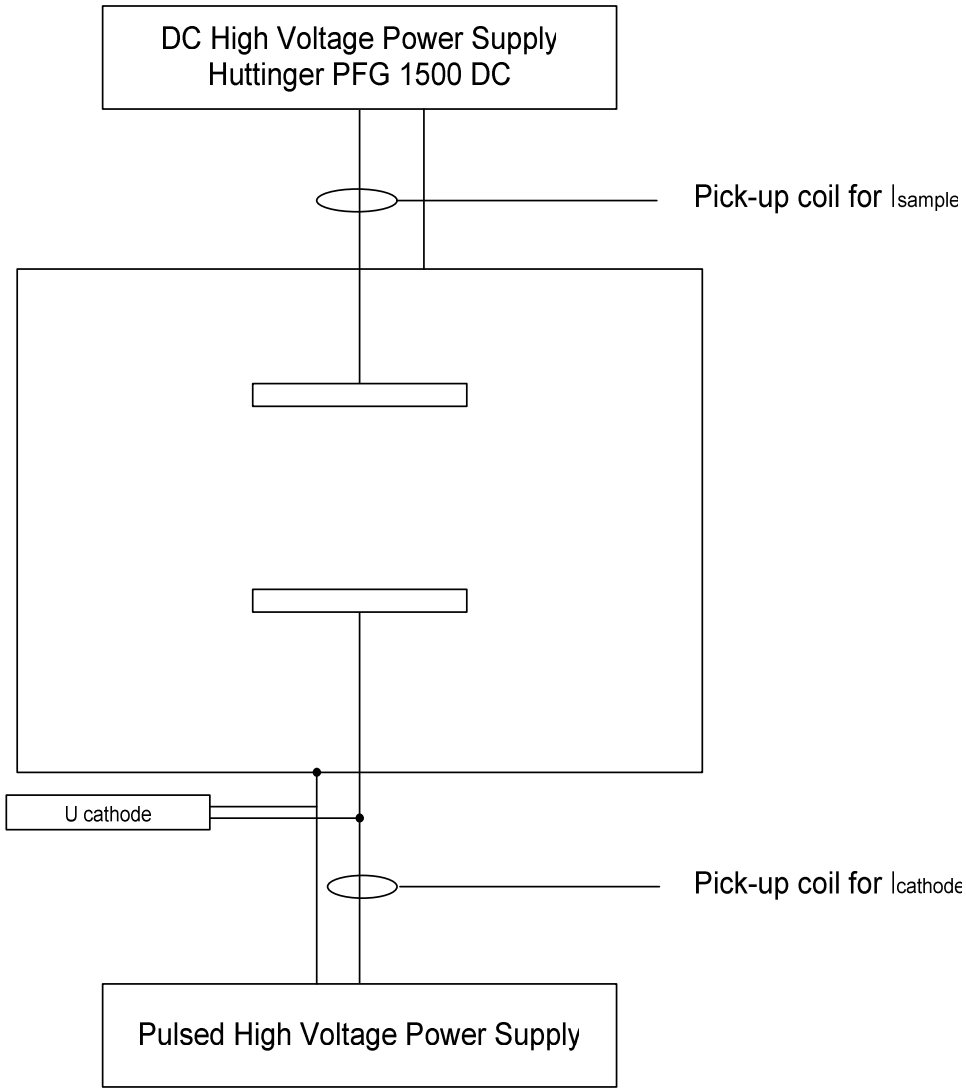
J. Alami et Al, J.Vac.Sci.Technol. A23(2005)278

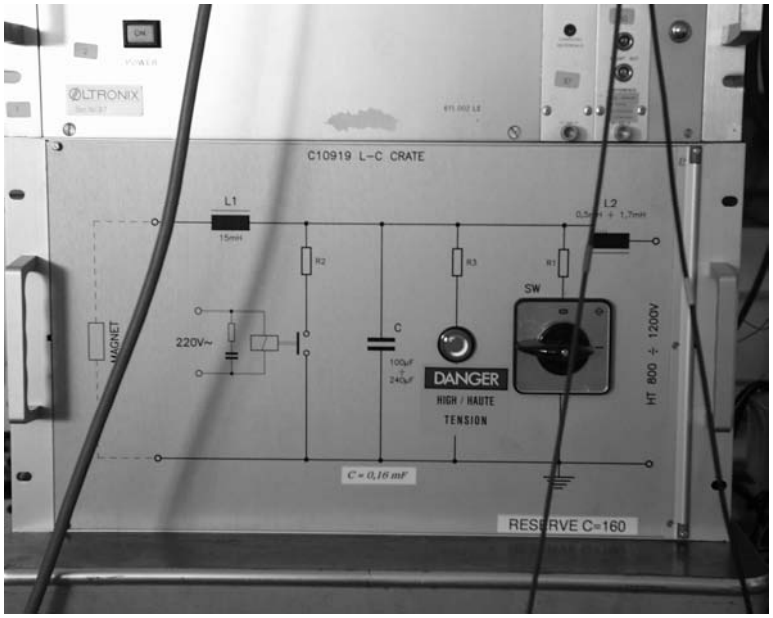
Power supply circuit



Basic inductor/capacitor discharge circuit

CERN setup





Power supply from LINAC2 quadrupoles, ~1200V – 200A (depends on load), 1.25 Hz

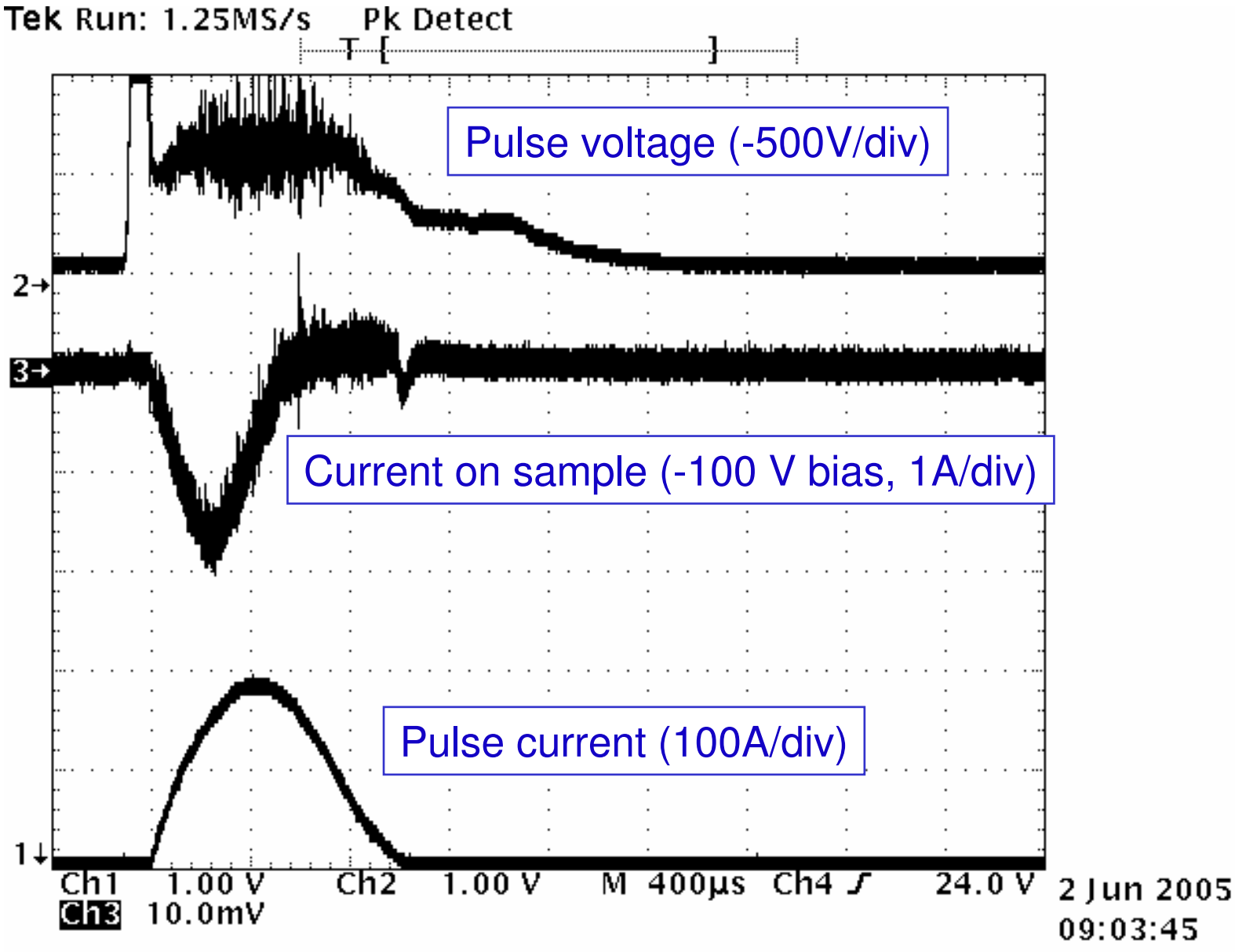
The advantage of being in an accelerator lab…

First results 1

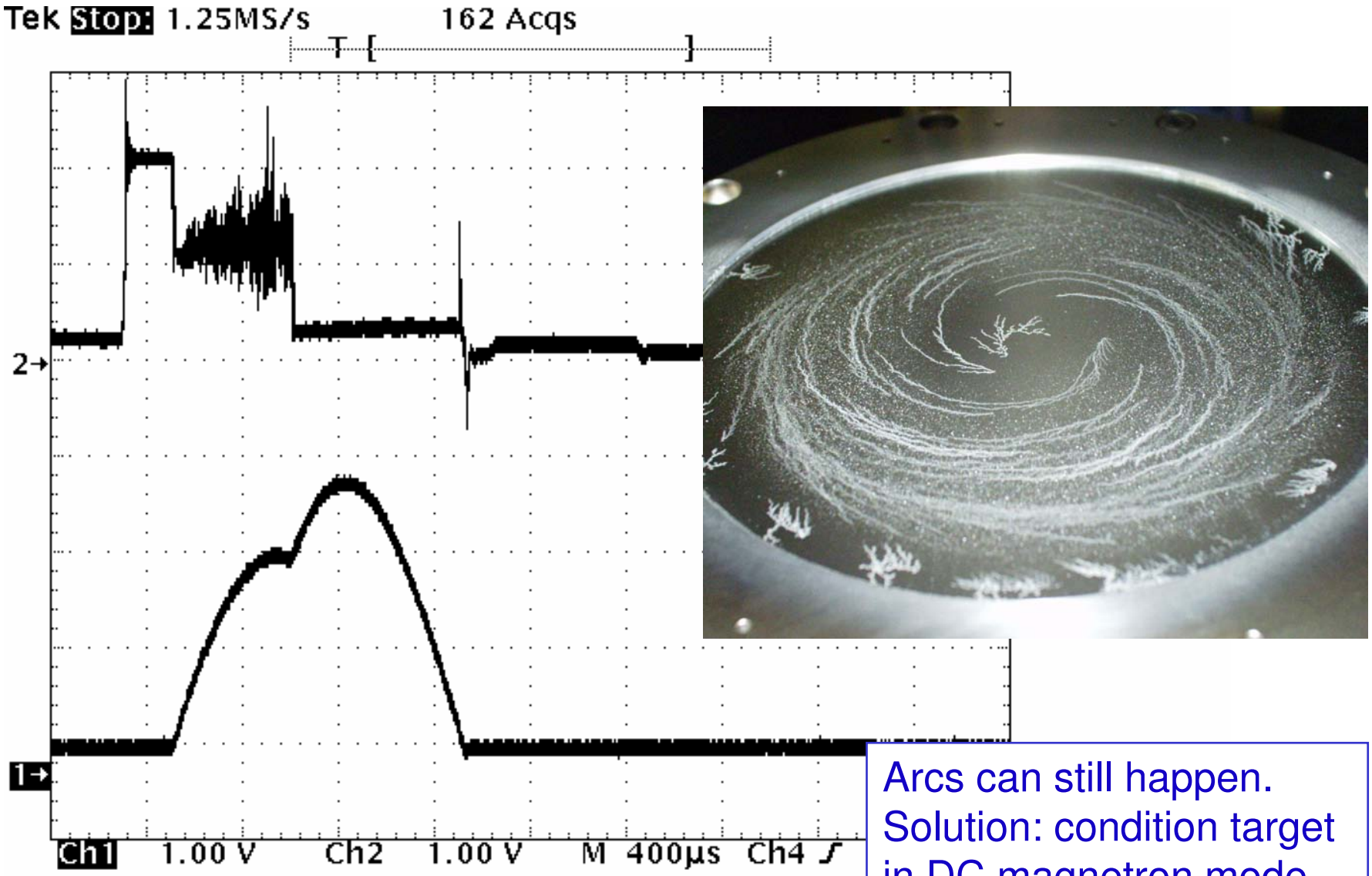
- The repetition rate of the available power supply is too low for serious work, but adequate for first testing
- Test carried out on standard planar magnetron, 75 mm radius (racetrack radius 45-65 mm approx)
- Argon pressure 2.1×10^{-3} mbar, niobium target, copper samples
- Various bias voltages

- …it works at the first trial, no tricks

First results 2



First results 3

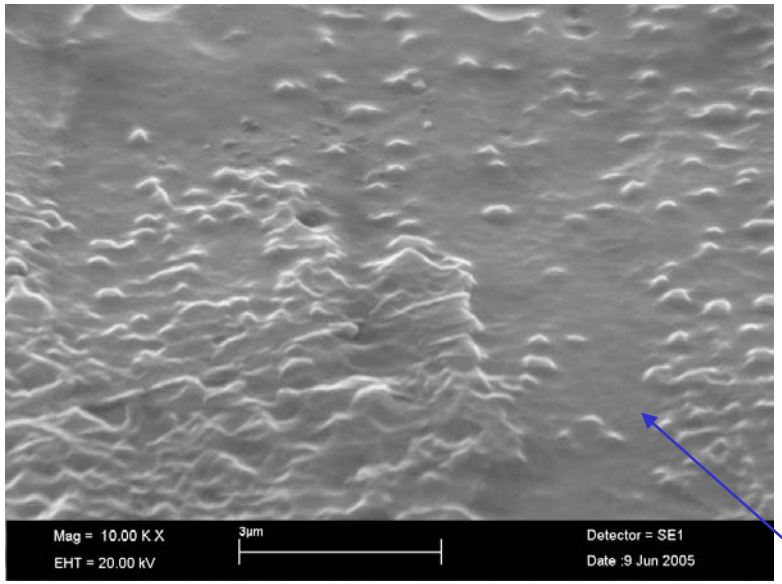


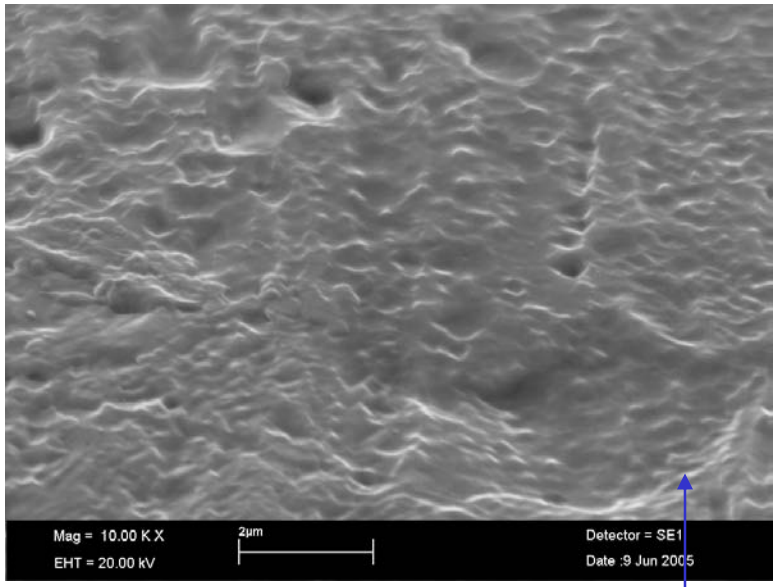
Arcs can still happen.
Solution: condition target in DC magnetron mode

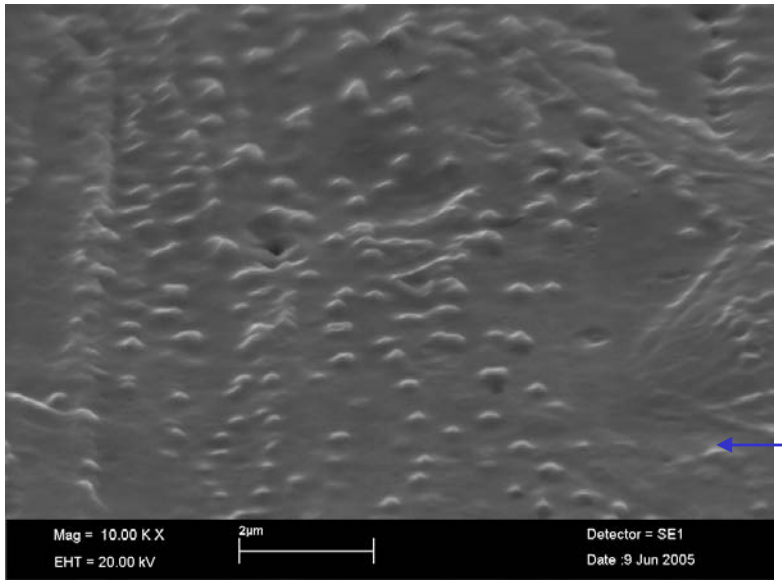
Plasma characteristics

- Peak current ~ 180 A
- Ignition voltage 1000V, sustained voltage 500V
- Peak power 90 kW, peak power density ~1.3 KW/cm^2
- Coating rate 1.6 nm/min (0.3 Å/sec), very low but one should remind that the repetition rate is only 1.2 Hz. About 30 times lower than our standard DC magnetron sputtering parameters

First SEM pictures (all films ~100 nm thick)







Substrate floating

Substrate grounded

Substrate biased -100V

Note: poor substrate preparation

Conclusion and next steps

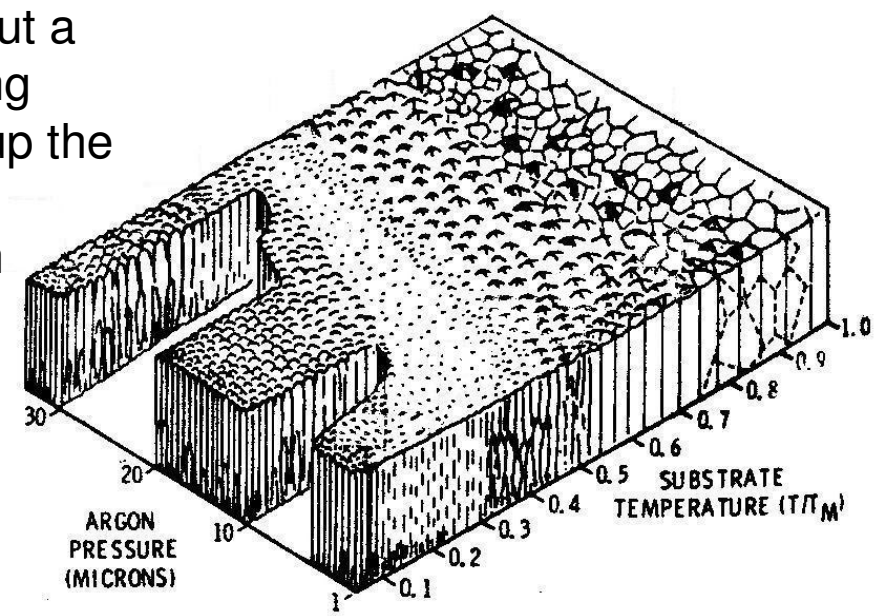
- HPPMS works at first trials
- Thicker films on EP copper are in preparation at different bias voltages, together with some DC magnetron reference films.
- Analyses that will be performed:
  - SEM
  - XRD
  - RRR measurement
- If promising, a couple of 1.5 GHz cavities will be coated (with bias). A peak power density of ~2kW/cm^2 should be attained.

High-energy deposition techniques

- Crystalline defects, grains connectivity and grain size may be improved with an higher substrate temperature which provides higher surface mobility (important parameter is $T_{substrate}/T_{melting\_of\_film}$)
- However the Cu substrate does not allow heating

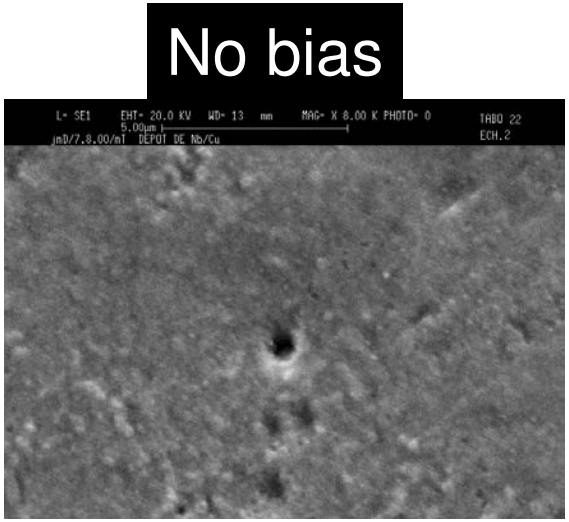
➢ The missing energy may be supplied by ion bombardment

- In bias sputter deposition a third electron accelerates the noble gas ions, removing the most loosely bound atoms from the coating, while providing additional energy for higher surface mobility
- Other techniques allow working without a noble gas, by ionising and accelerating directly the Nb that is going to make up the coating
- These techniques allow also to obtain "conformal" coatings that follow the surface profile better filling voids.



"Structure Zone Model"

Nb/Cu bias deposition – First SEM images at CERN



5 µm