Pulsed-Nanoplating of Platinum on High Aspect Ratio-Tungsten Photonic Microsystems for High Temperature Applications

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Outline

- *Introduction to HIP and the need for pulsed-nanoplating of photonic crystals*

- *Geometry and fabrication of photonic crystals*

- Activation and oxidation states of tungsten

- *Anatomy of a periodic pulse profile*

- *Potentiostatic vs. Galvanostatic nano-plating modes*

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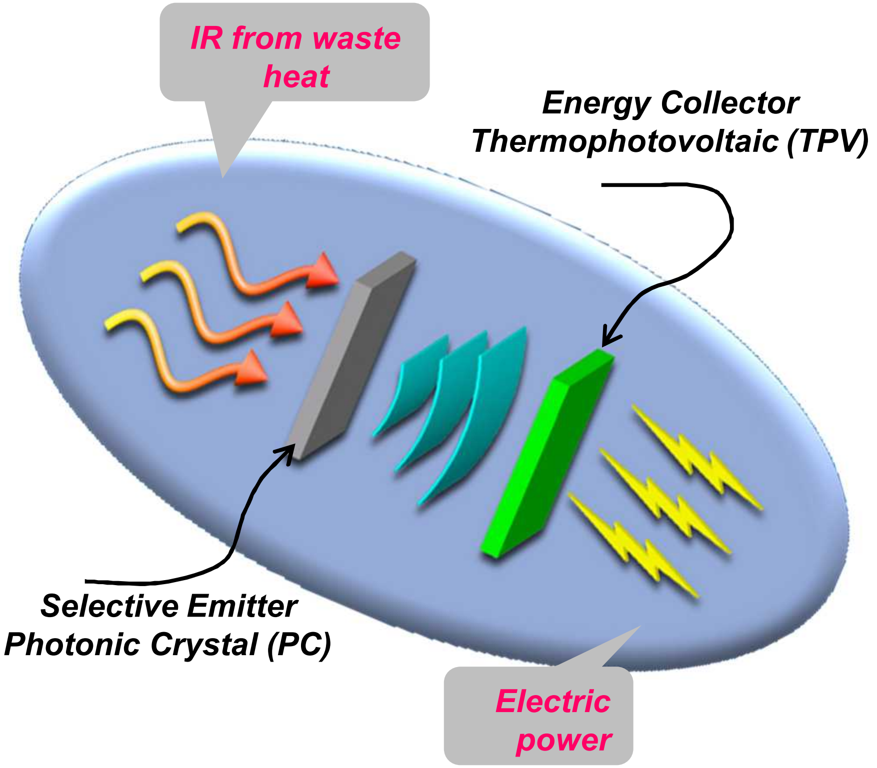
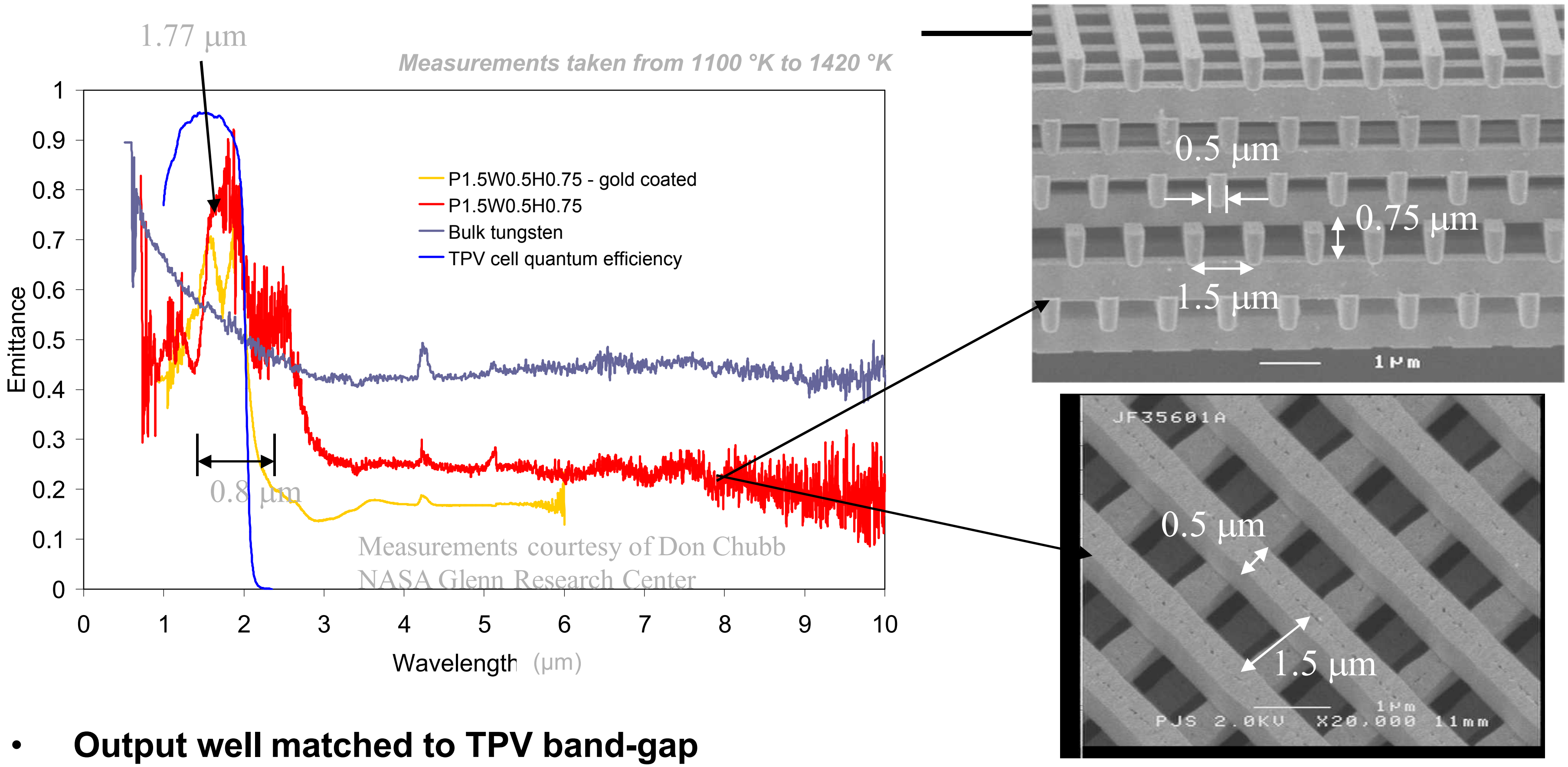
Heat-Into-Power… a Disruptive Technology Initiative

Motivation

- Two thirds of the energy aboard our platforms, aircraft and spacecraft, is discarded as waste heat
- New recycling concepts enabled by recent discoveries in nanotechnology allow for the transformation of waste heat into work

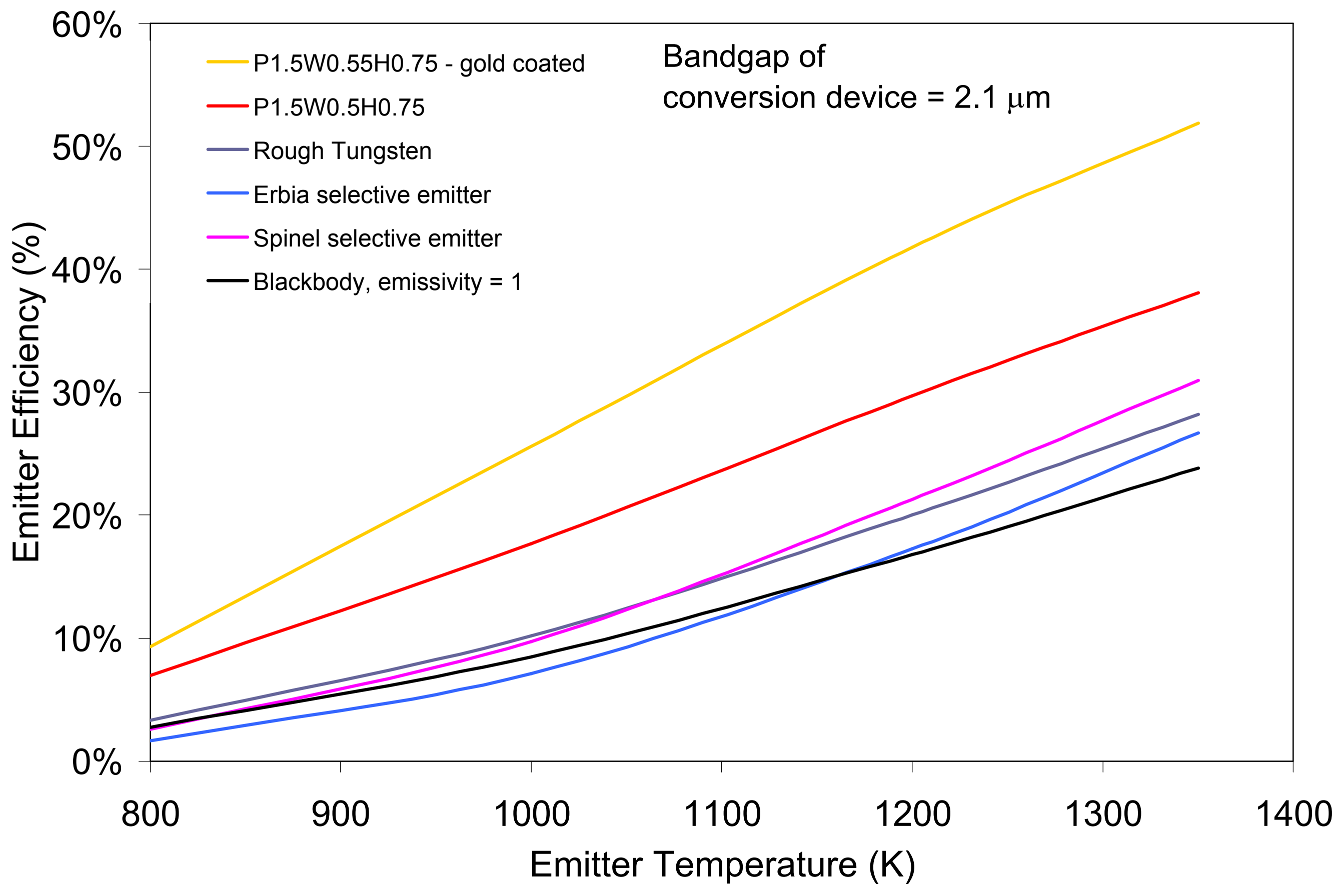


Spectral Control Components: *Photonic Crystal and Cell Responsivity*



- **Output well matched to TPV band-gap**
- **Relatively little out-of-band emissions to heat up the TPV and reduce its efficiency**

A Very Good Selective Emitter



Compared to other high-temp selective-emitters, and with a long-wave reflective coating to reduce TPV temperature, the Sandia photonic-crystal is unbeatable.

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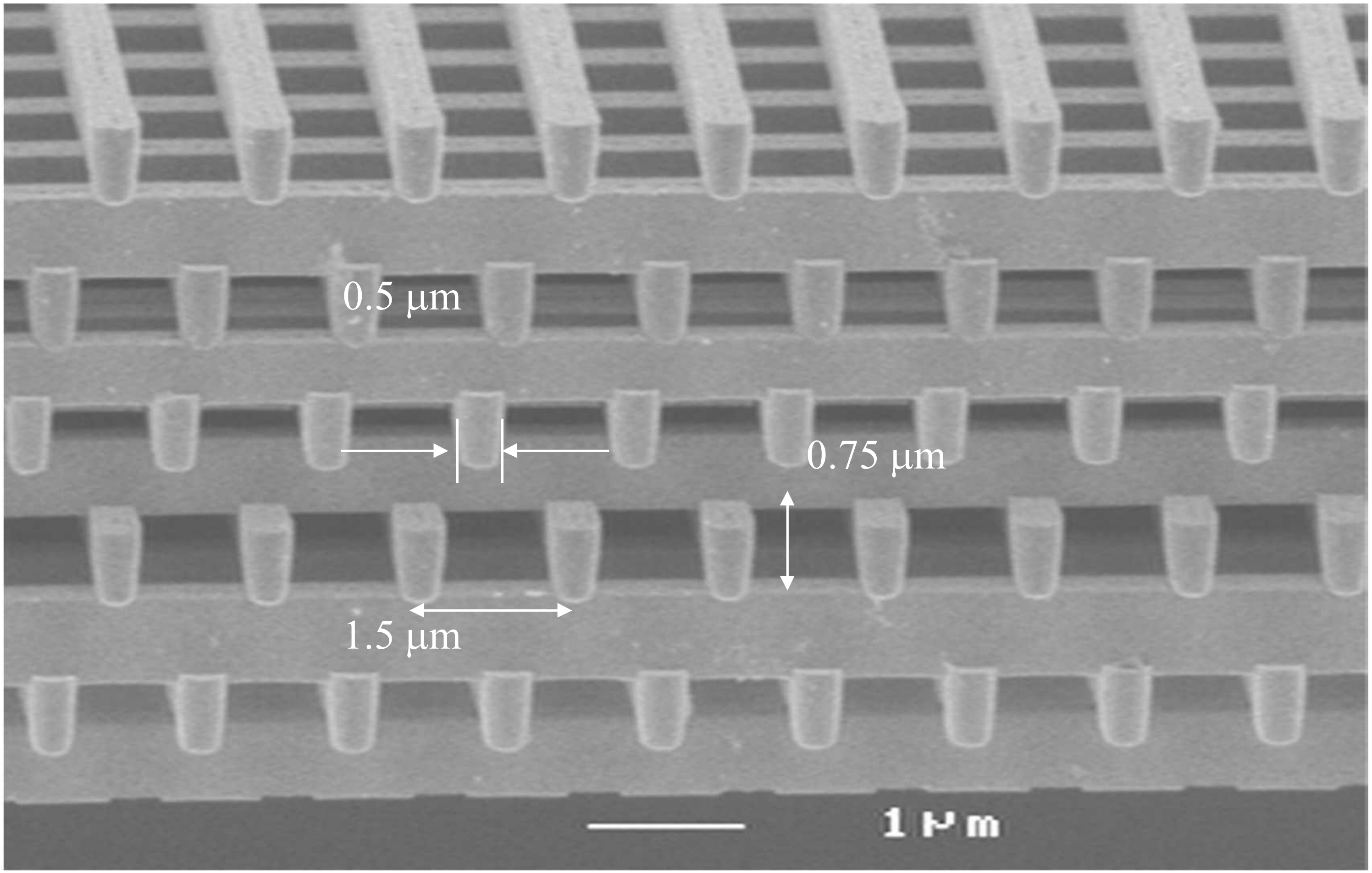
Geometry of a High Aspect Ratio Tungsten Photonic Crystal (10 layer “log pile” stack)



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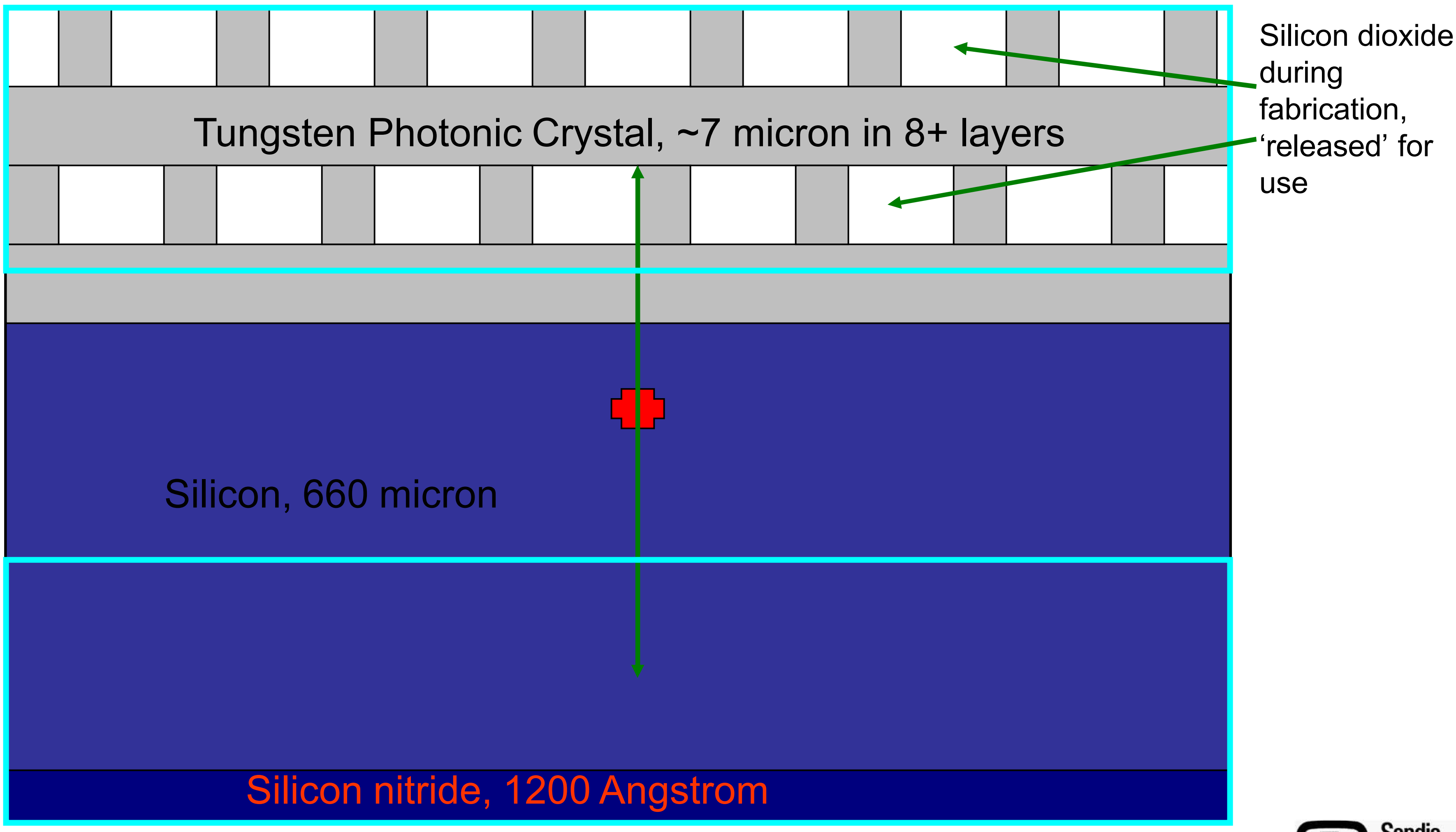
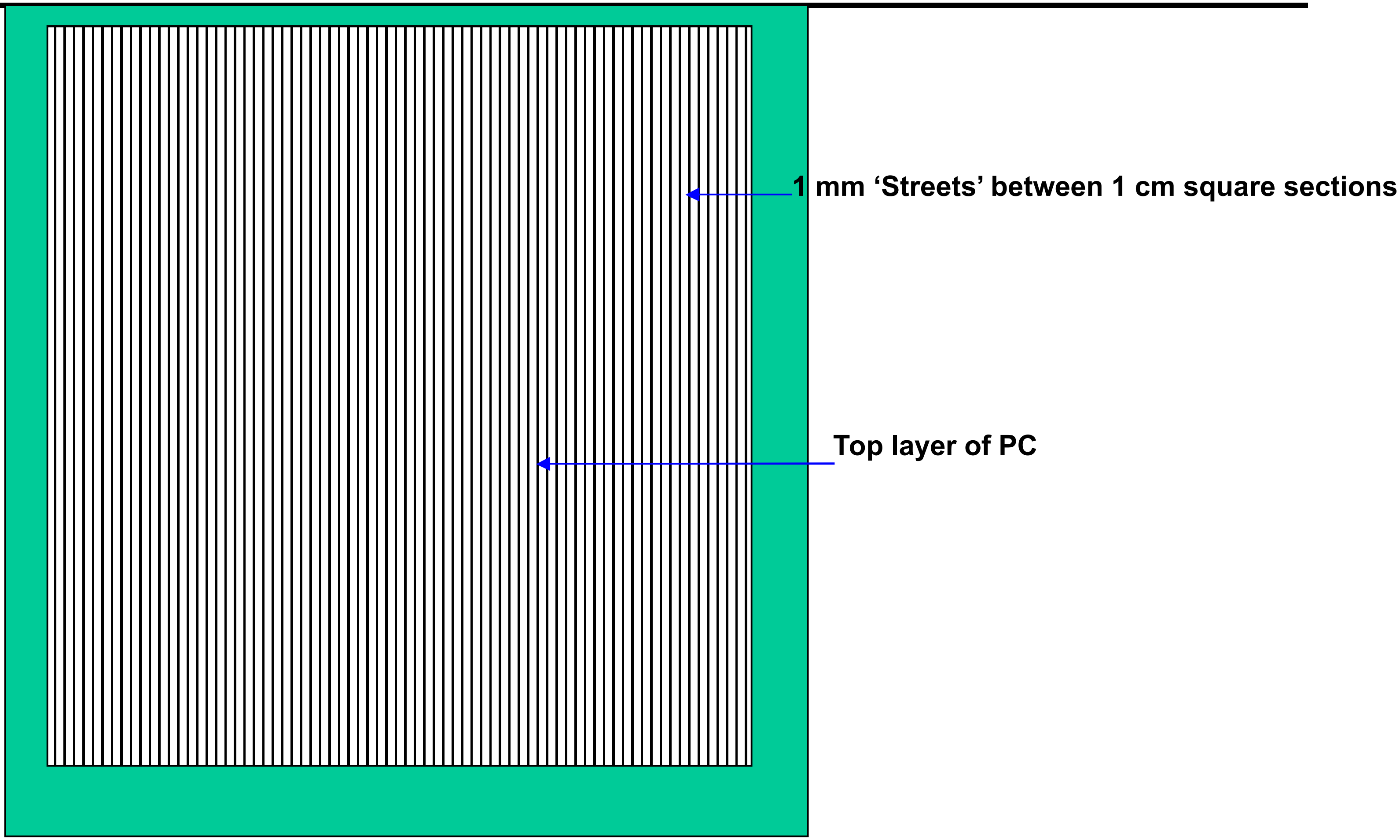
Fabrication of a High Aspect Ratio Tungsten Photonic Crystal

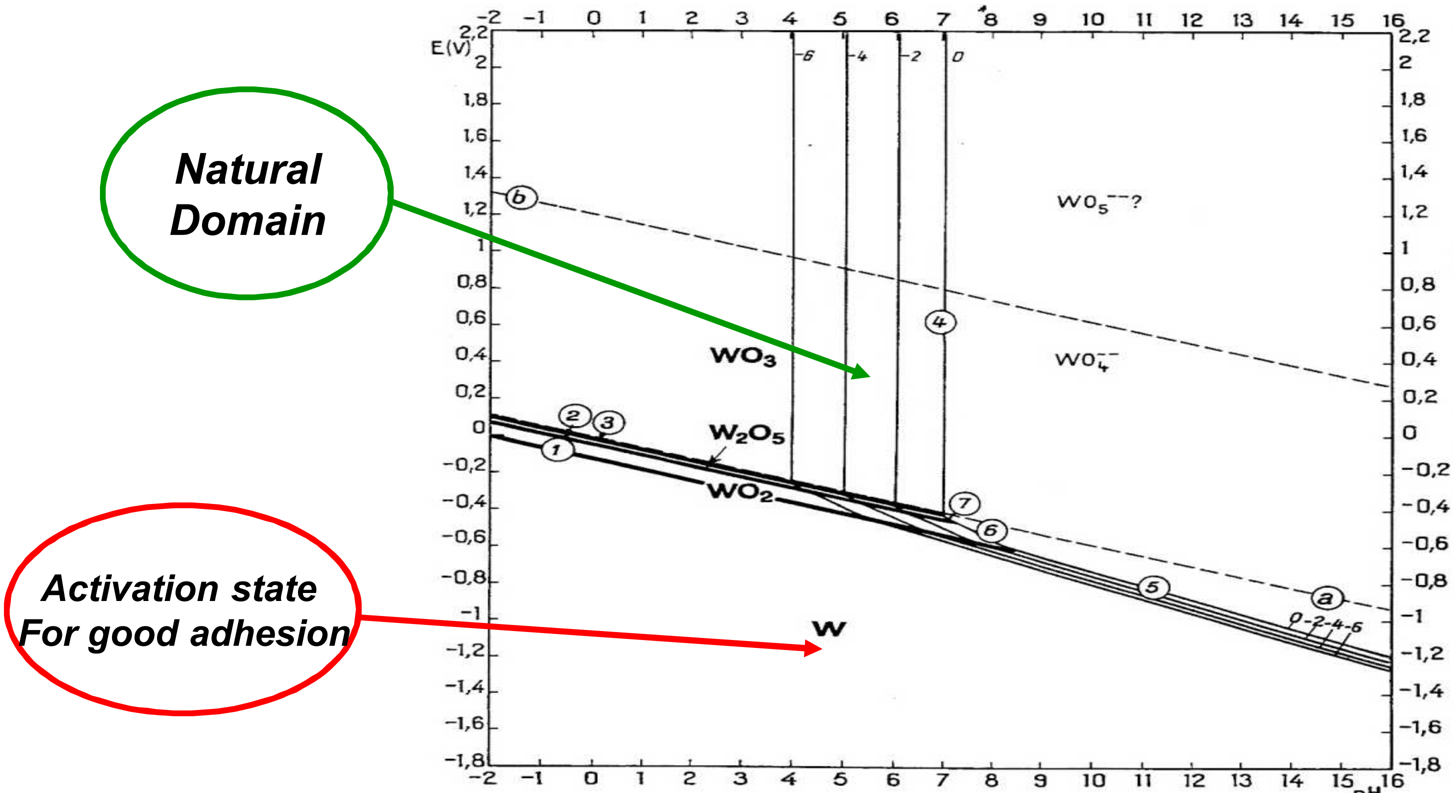


Macroview of a Tungsten Photonic Crystal



But the preferred activation state for tungsten is below the hydrolysis of water

Phase domains of the tungsten in the presence of water as a function of potential and pH. The W domain is the preferred condition of the PC surface to deposit other metals.



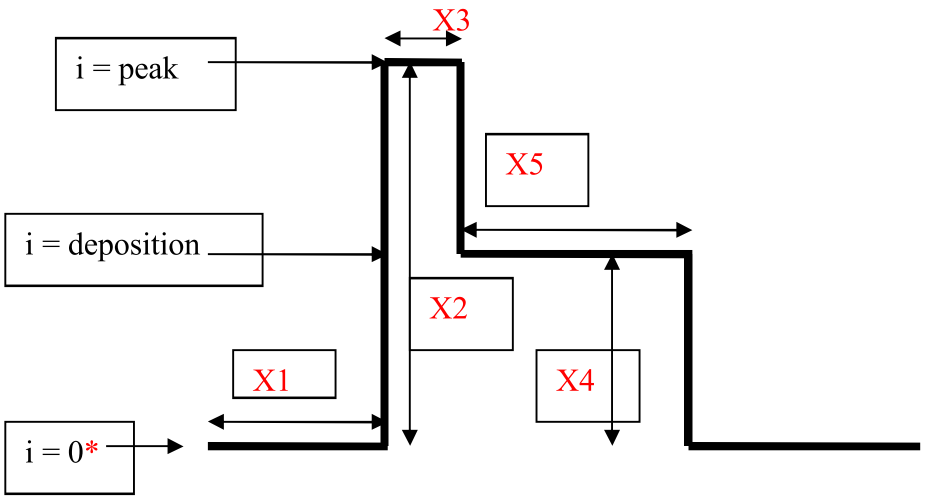
Potential–pH equilibrium diagram for the system tungsten–water, at 25°C.

The concentration of the tungstates is driven by pH, increasing as a function of pH as follows,

[log (WO42-) = -14.05 + 2pH]

Anatomy of a periodic pulse profile

- *X1 duration of relaxation cycle*
- *X2 over-pulse charging*
- *X3 duration of over-pulse*
- *X4 deposition pulse*
- *X5 duration of deposition*



Q: Why use a periodic pulse regime for nano-scale deposition?

A: Fast transience pulse deposition helps minimize the expanding area of the concentration gradient within a scale not influenced by agitation alone.

** Relaxation cycle can include a reverse pulse*

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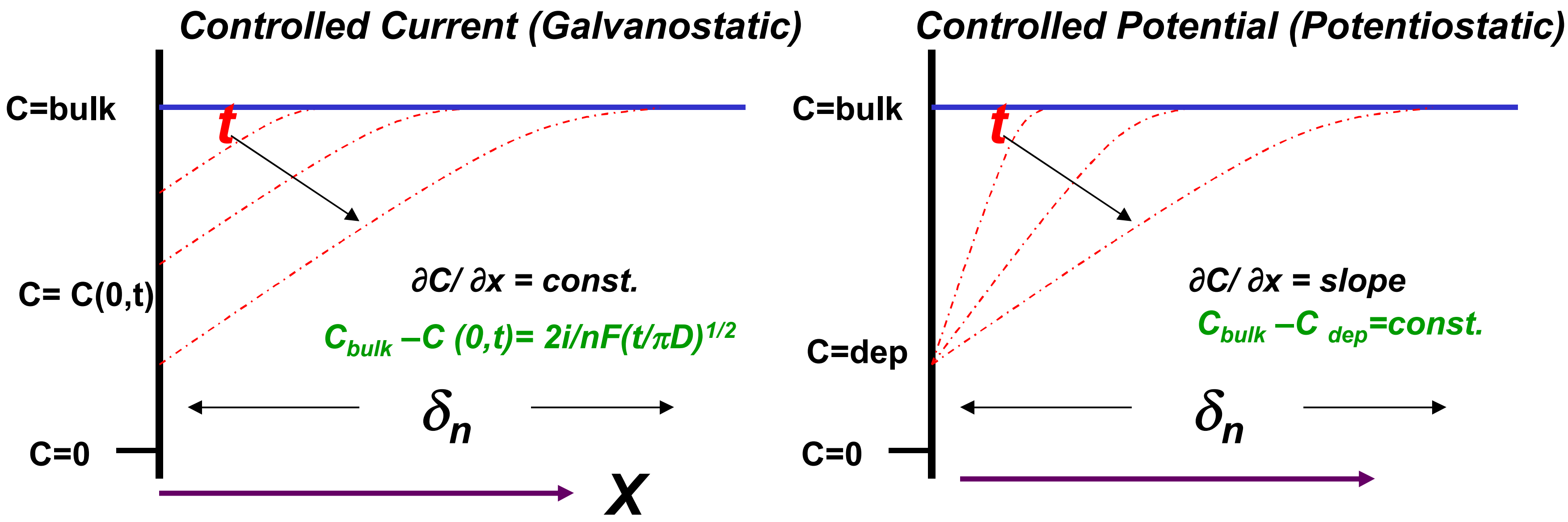
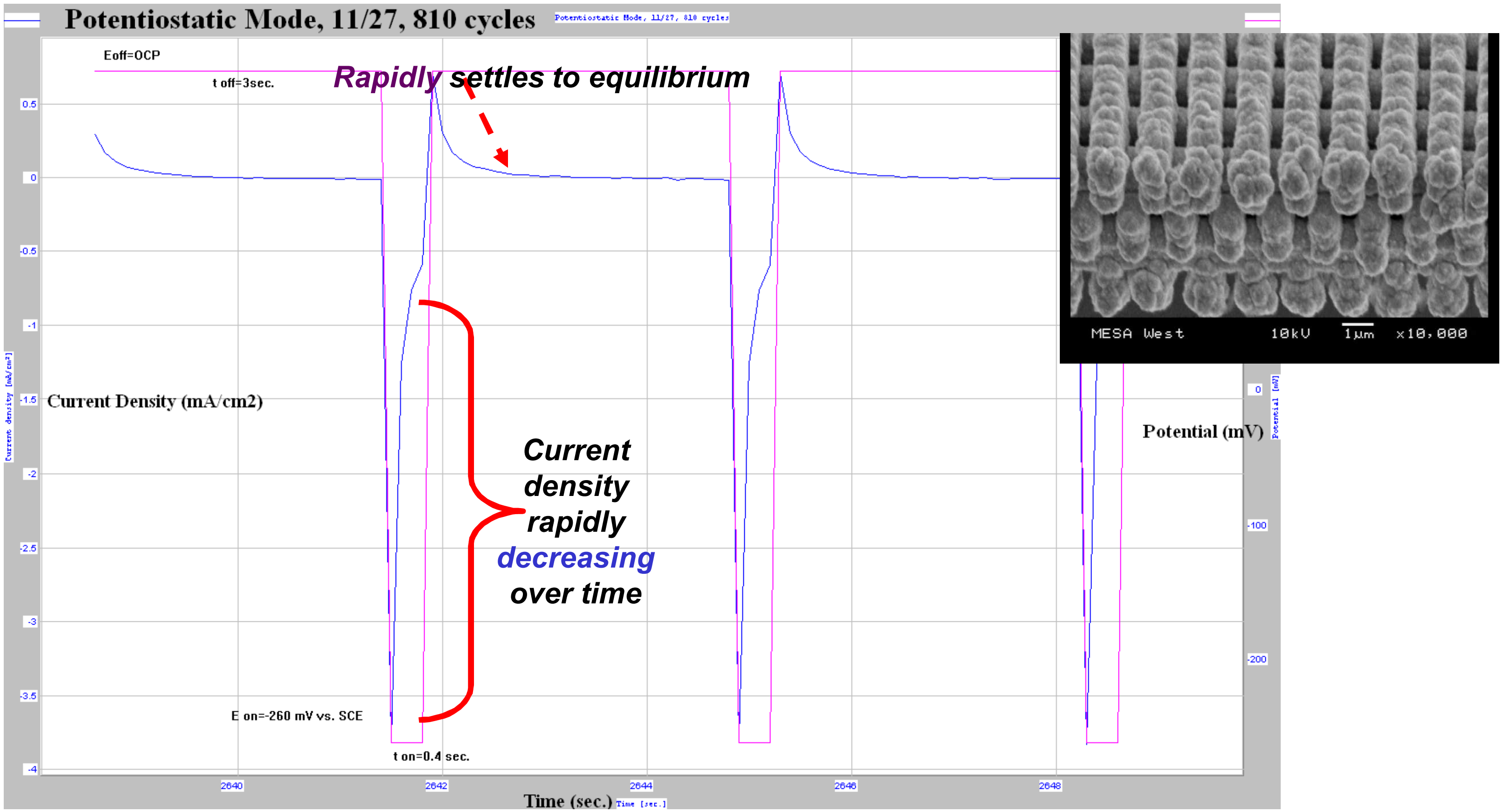
Unsteady State Current and Potential



Distance from plating surface

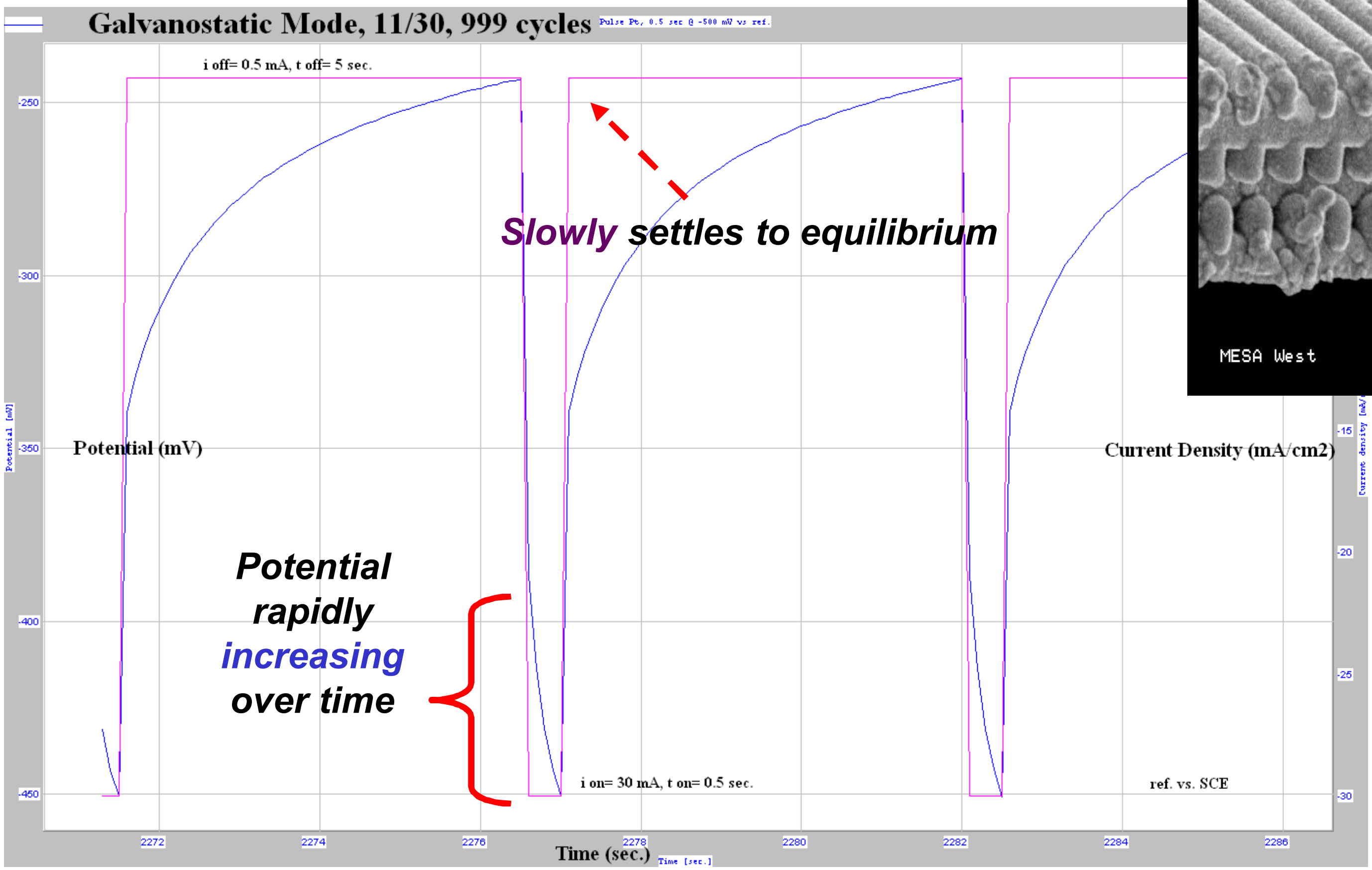
Potentiostatic Deposition:

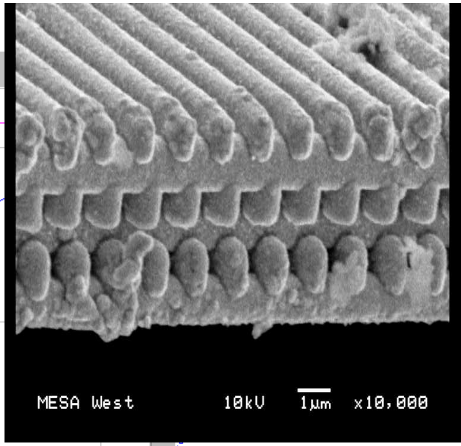
off cycle=OCP, on cycle=-260 mV vs. SCE



Galvanostatic Deposition:

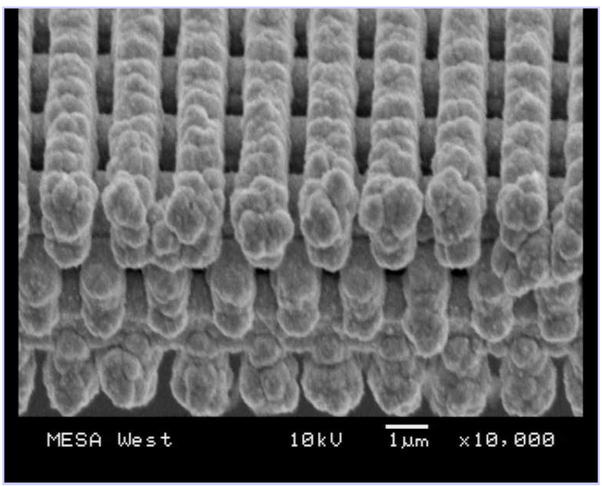
off cycle=0.5 mA/cm2, on cycle=-30 mA/cm2



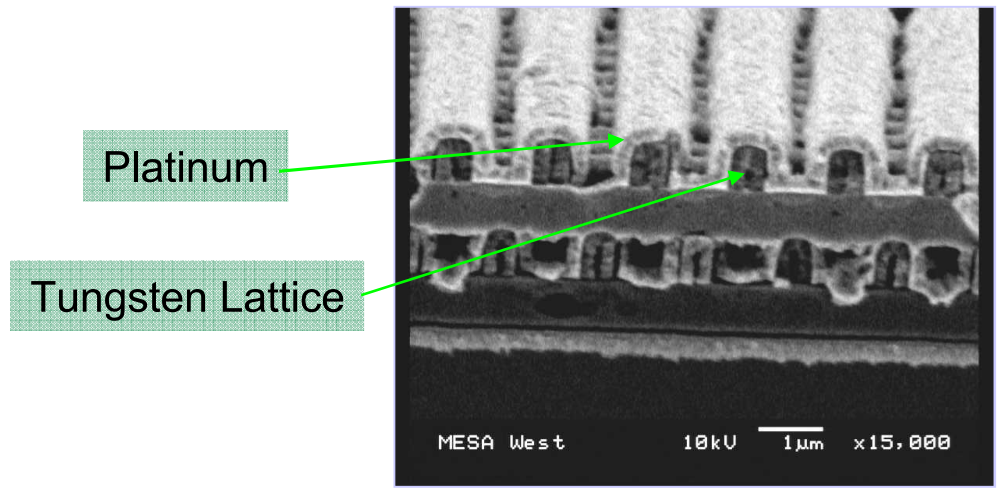


Unsteady state Photonic Crystal Plating to Allow Use at Elevated Temperatures in Air

- **Electrochemical activation of tungsten to allow electroplating of platinum onto a tungsten surface.**
- **This lead to potentiostatic (constant voltage) and galvanostatic (constant current) pulsed deposition of platinum into the lattice stack of a photonic crystal**
  - *Initial goal was to ensure full penetration of platinum into lattice*



Overkill Potentiostatic plating shows good penetration within PC lattice



Cross section of Galvanostatic plating shows good penetration within PC lattice and more uniformity

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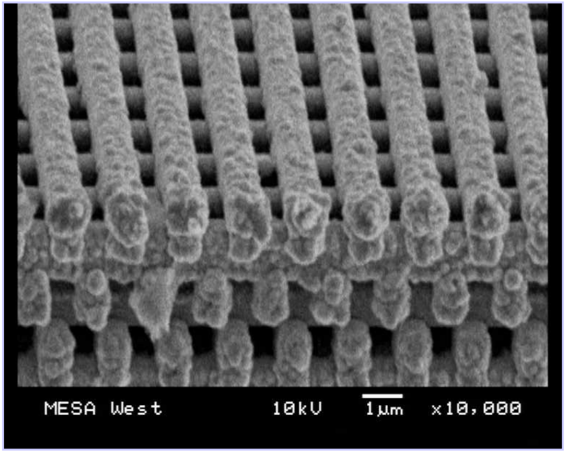
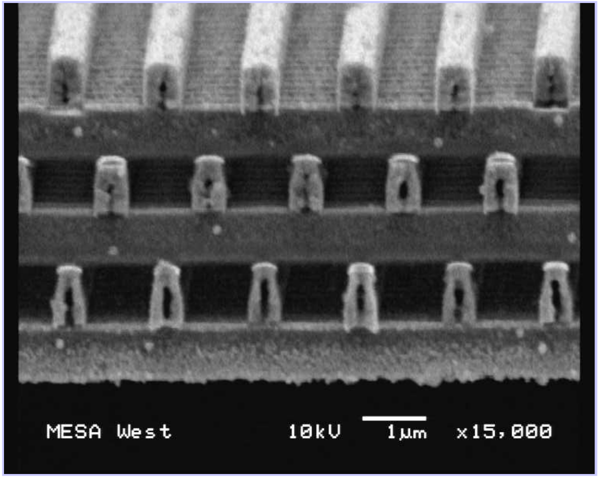
Photonic Crystal Plating to Allow Use at Elevated Temperatures in Air (cont)

- **Filtering the plating solution to 0.2 microns, reducing the pulse cycles to about 100 and reducing the pulse amplitude of the galvanostatic pulse deposition process yielded the desired 20 to 50 nm uniform platinum plating throughout the photonic crystal matrix.**
  - ***Short deposition pulses from 400 to 500 millisecond followed by 3 to 5 second "rest" pulses allowed penetration of Pt ions deep into the lattice center.***



Refined Potentiostatic plating shows consistent penetration within PC lattice, but dendritic bumps



Cross section of Galvanostatic plating shows some penetration within PC lattice and the plating process will be optimized

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Summary and Conclusions

- *Photonic Crystal nanotechnology allows the transformation of waste heat into work.*
- *Photonic Crystal consist of 8 or more layers of nano-scaled beams of tungsten.*
- *Tungsten is extremely difficult to form adhesive electrochemical bonds because of its natural oxides.*
- *Due to layers of nano-scale features of a photonic crystal array, a well developed periodic pulse regime is necessary to allow uniform deposition.*
- *Potentiostatic plating mode allows a constant concentration profile at the working surface, but varies the concentration gradient near the surface.*
- *Galvanostatic plating mode varies the concentration profile at the working surface, but fixes the concentration gradient near the working surface.*