Superconducting Photocathodes

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Cathode Options for SCRF Injector

- Use the niobium wall as a cathode

  Simple, but low Nb QE limits current

  J. Smedley, T. Rao, and Q. Zhao, J. Applied Physics **98**, 043111 2005

- Use an RF choke-joint to allow non-SC cathodes

  Enables use of Cs_2Te (and others)

  D.Janssen et al., Nucl. Instr. And Meth. In Phys. Res. A445 (2000) 408-412.

- Coat Nb in cathode region with another superconductor, with better QE

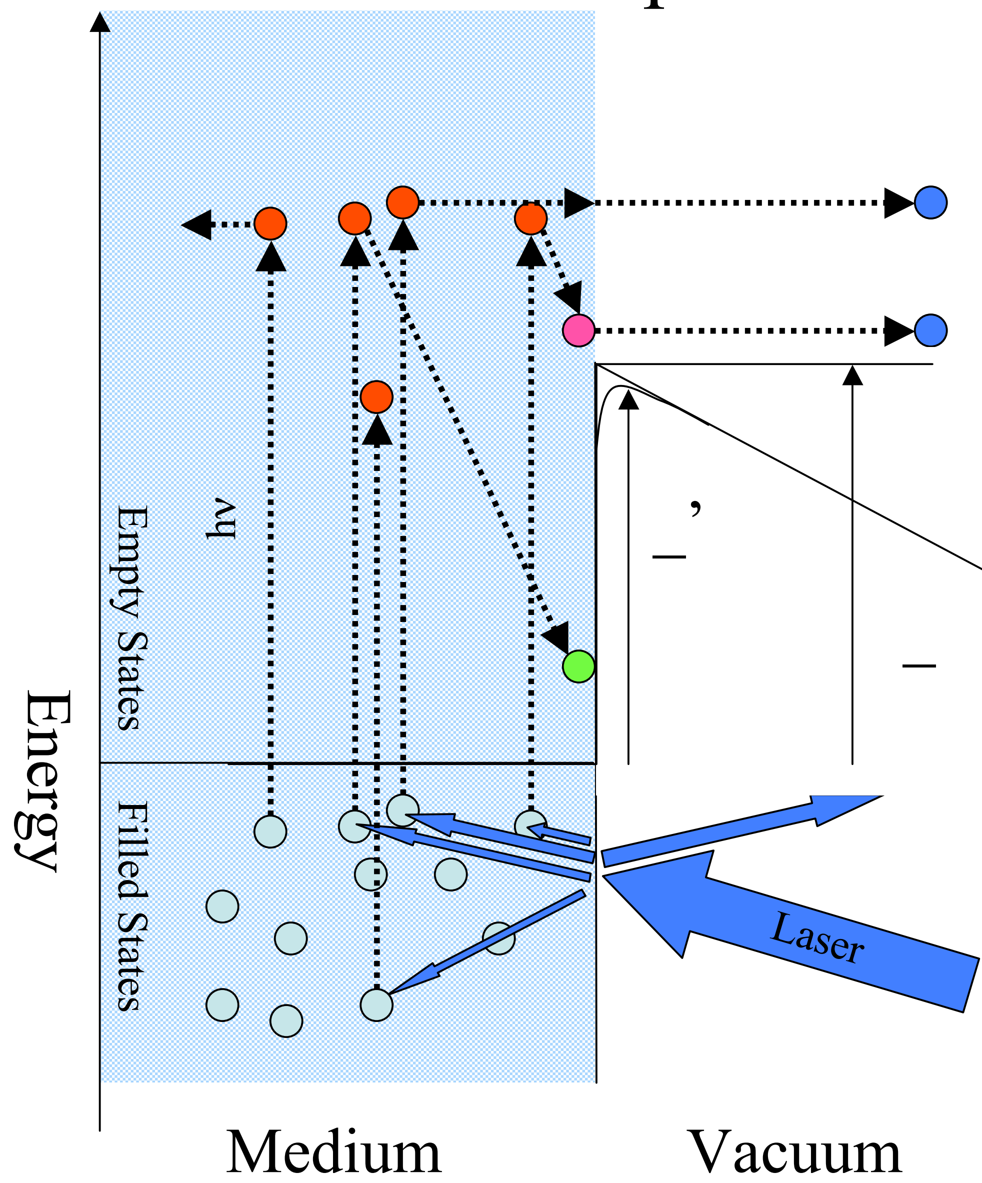
Comparison of Pb & Nb

Lead	Niobium
Type I Superconductor	Type II Superconductor
Used in Ion Accelerators	Many Accelerator Applications
Critical Magnetic Field*: 80mT	Critical Magnetic Fields*: 160mT, 300mT
Maximum Gradient*: ~17MV/m	Maximum Gradient *: >60MV/m
Critical Temperature: 7.9K	Critical Temperature: 9.2K
Photoelectric Work Function: 3.95eV	Photoelectric Work Function: 4.3eV

* Values for 2K, 1.3 GHz

From: Basic Principles of RF Superconductivity and Superconducting Cavities, Peter Schmuser

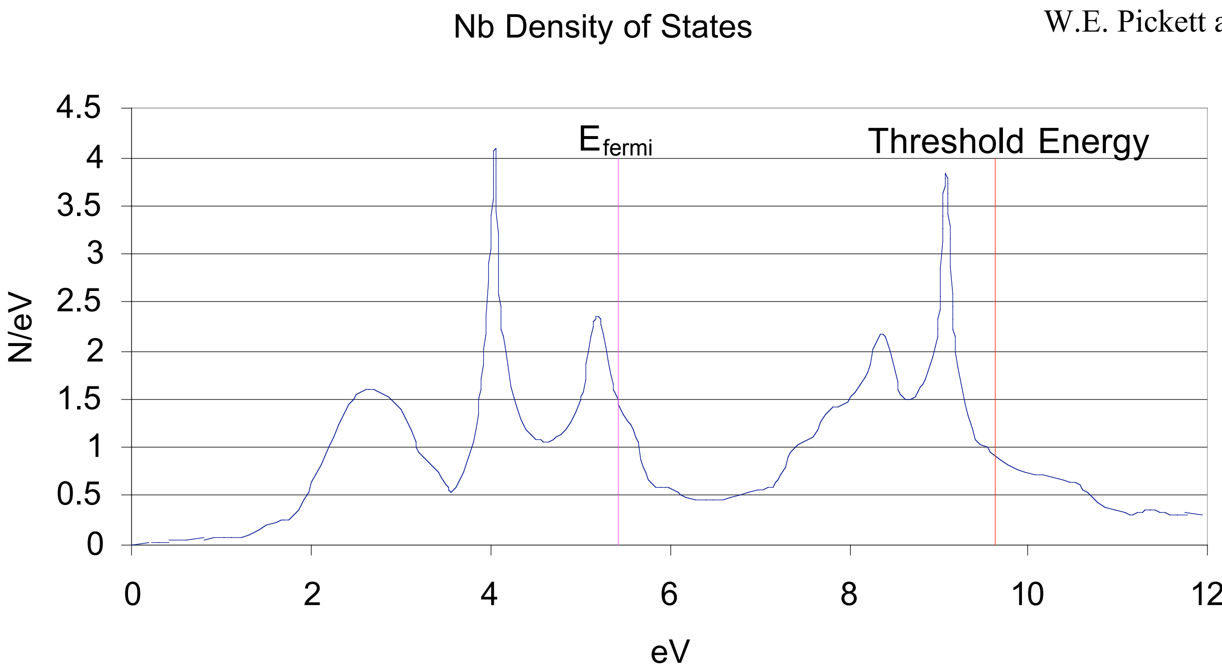
Three Step Model of Photoemission



1) Excitation of e⁻ in metal
   - Reflection
   - Absorption of light
   - Energy distribution of excited e⁻
2) Transit to the Surface
   - e⁻-e⁻ scattering
   - Direction of travel
3) Escape surface
   - Overcome Workfunction
   - Reduction of Φ due to applied field (Schottky Effect)

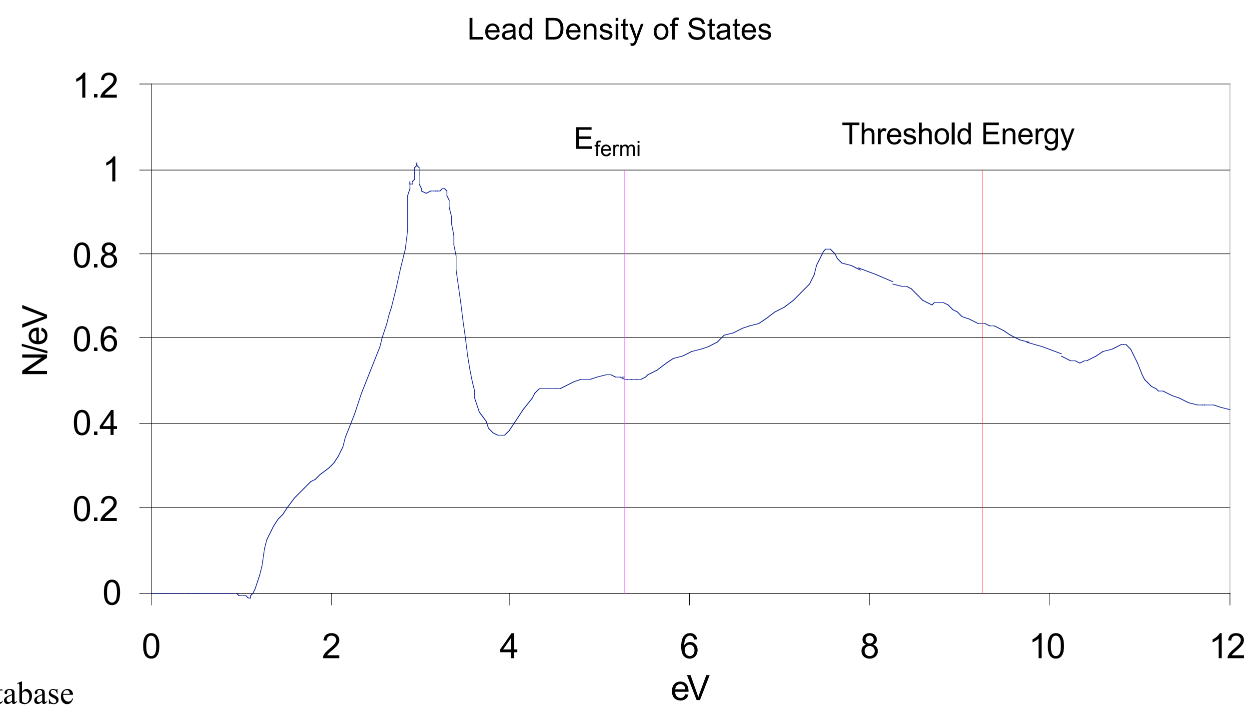
Integrate product of probabilities over all electron energies capable of escape to obtain Quantum Efficiency

W.E. Pickett and P.B. Allen; Phy. Letters **48A**, 91 (1974)



Density of States for Nb

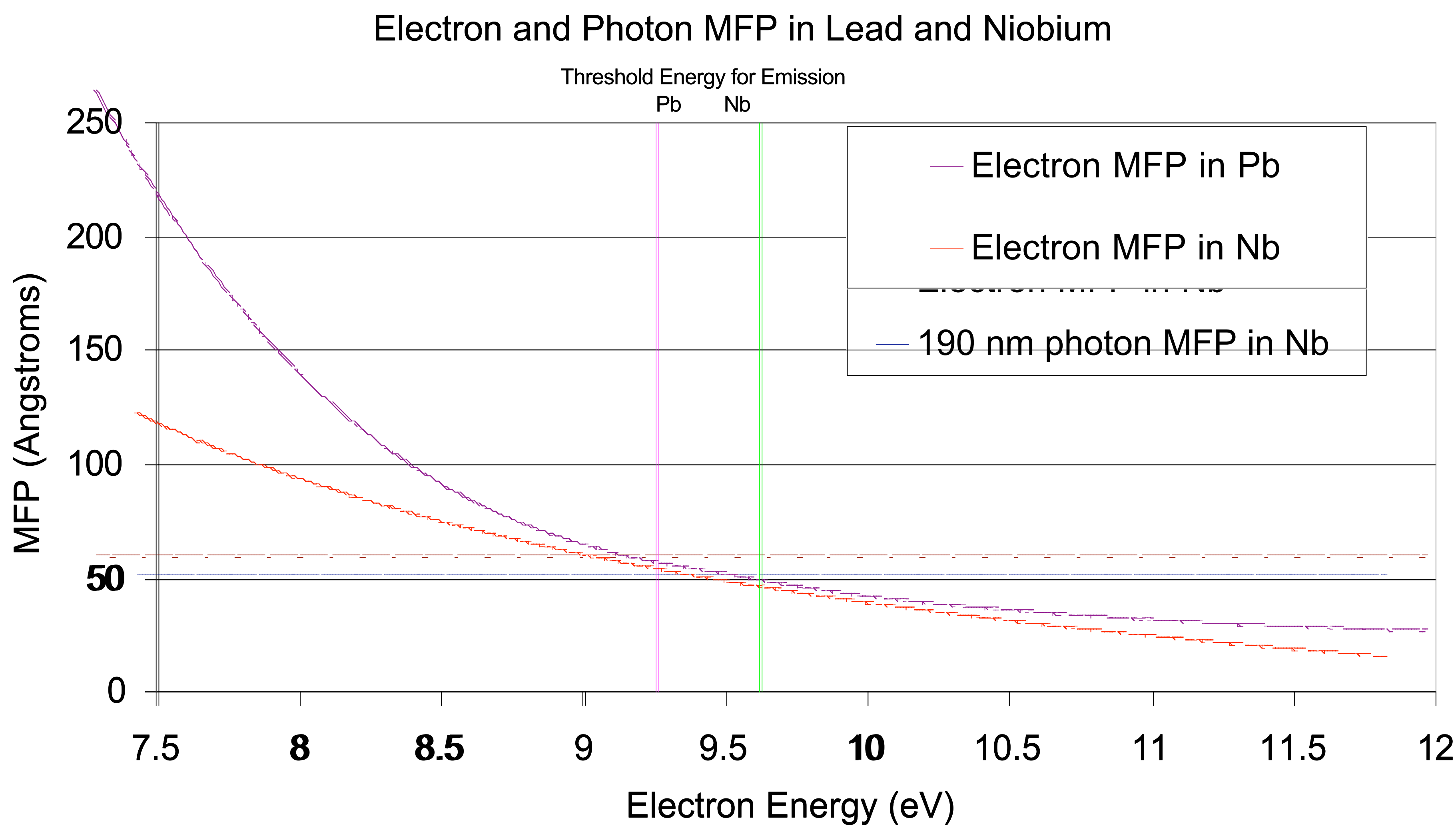
Large number of empty conduction band states promotes unproductive absorption

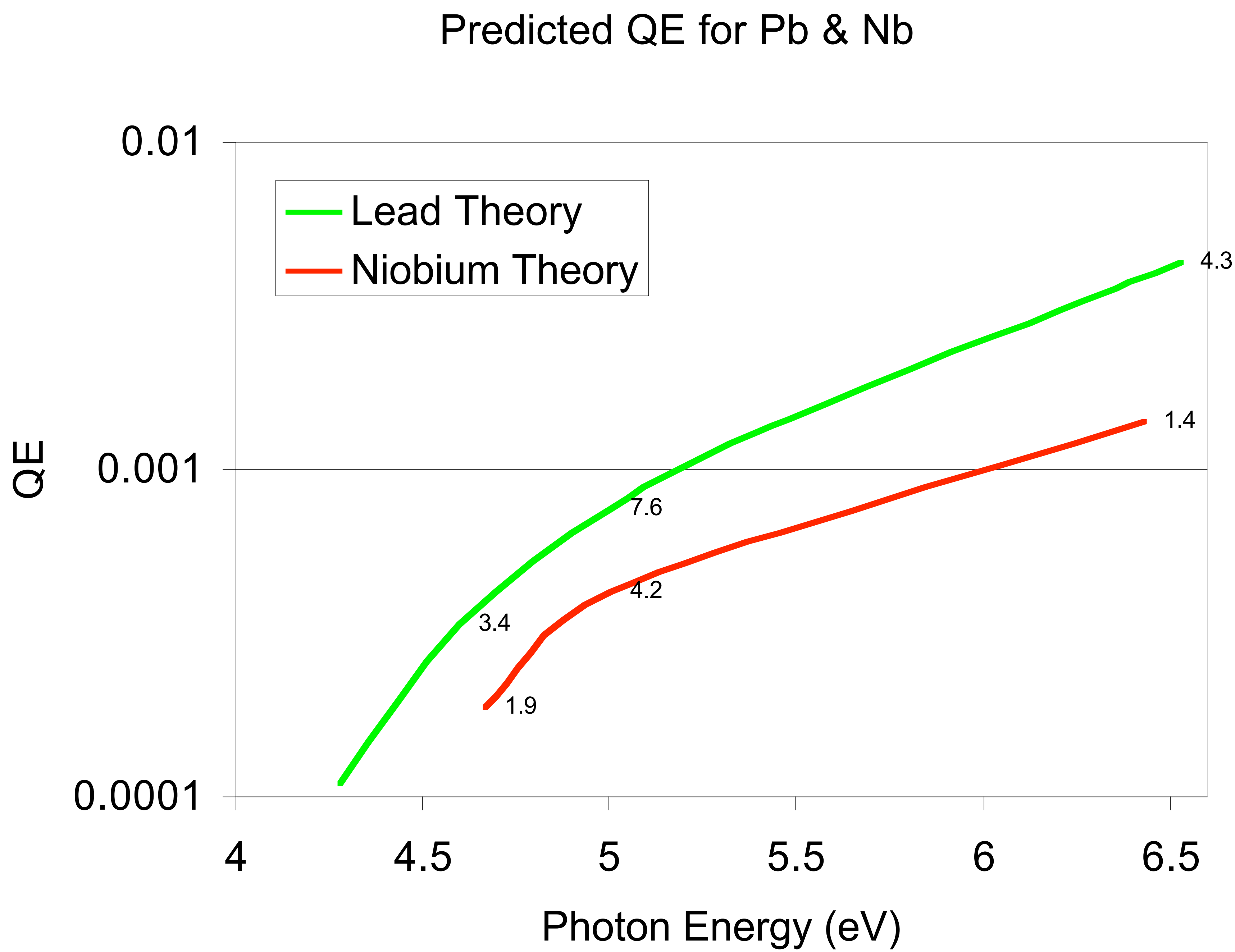


Density of States for Lead

Lack of states below 1 eV limits unproductive absorption at higher photon energies

NRL Electronic Structures Database


Electron and Photon MFP in Lead and Niobium
Threshold Energy for Emission
Pb
Nb
Electron MFP in Pb
Electron MFP in Nb
190 nm photon MFP in Nb
MFP (Angstroms)
250
200
150
100
50
0
7.5
8
8.5
9
9.5
10
10.5
11
11.5
12
Electron Energy (eV)


Predicted QE for Pb & Nb
Lead Theory
Niobium Theory
QE
0.01
0.001
0.0001
4
4.5
5
5.5
6
6.5
Photon Energy (eV)
4.3
7.6
3.4
1.4
4.2
1.9

QE Measurements

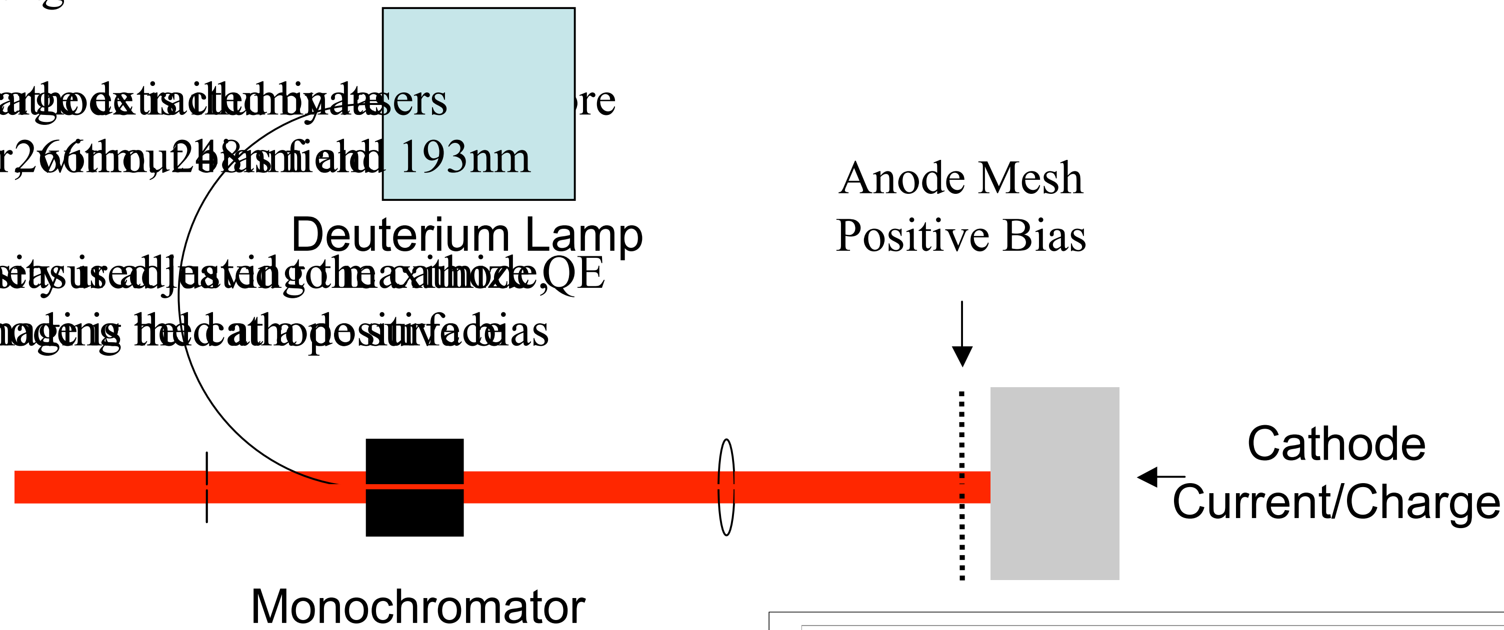
Original System

Measure charge extracted by lasers operating at 266nm, 248nm and 193nm

Charge density is adjusted to maximize QE without damaging the cathode surface

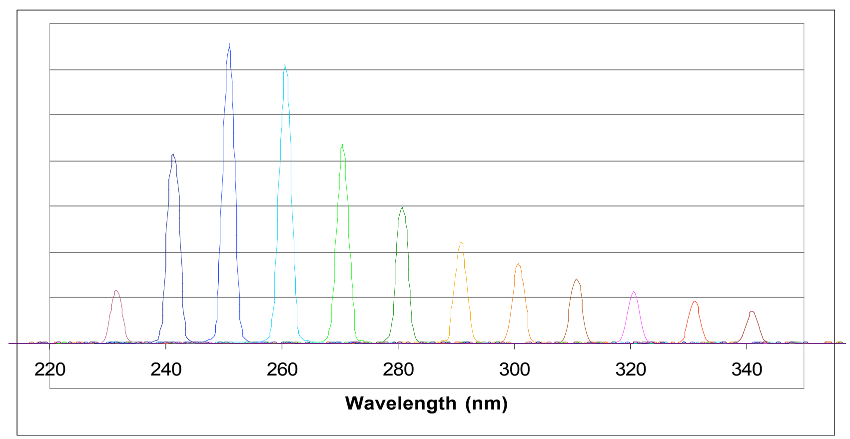
Laser Cleaning

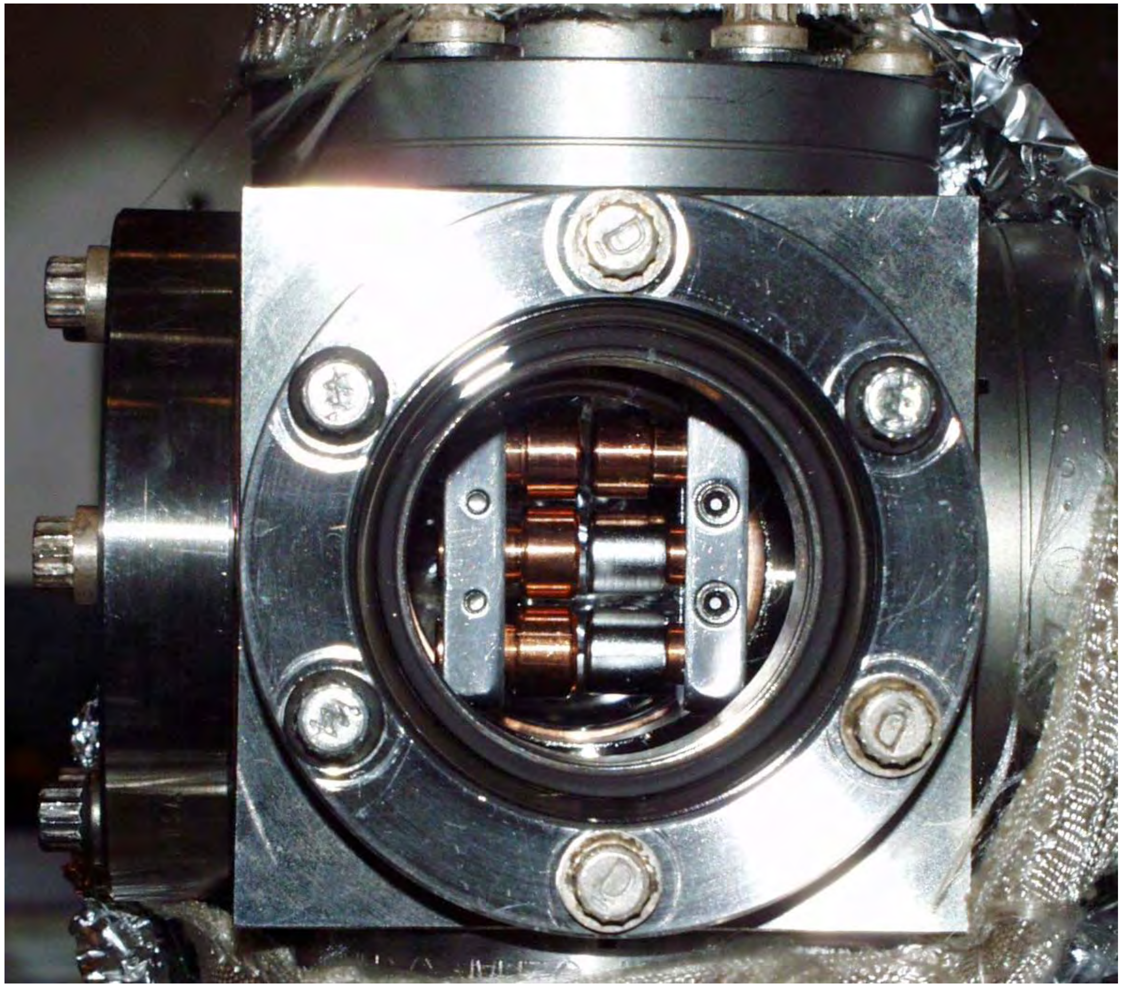
Surface of cathode is cleaned by ...re intense laser, without an field



Advantages of Lamp Source

- QE can be measured at any wavelength
- Material workfunction can be established
- Measurement source does not affect QE



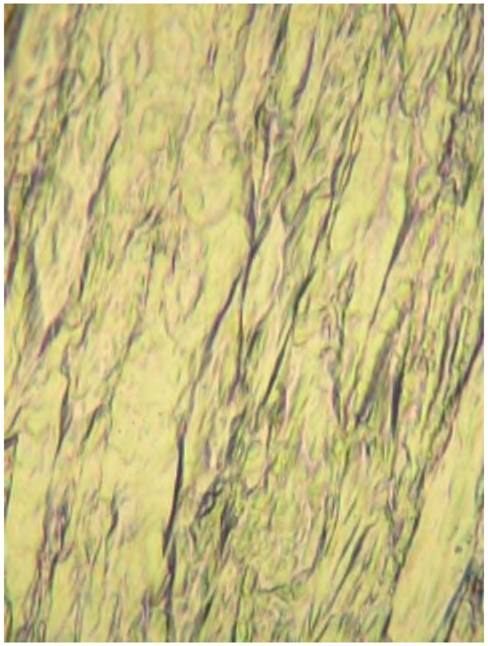


Cathode Preparation - Niobium

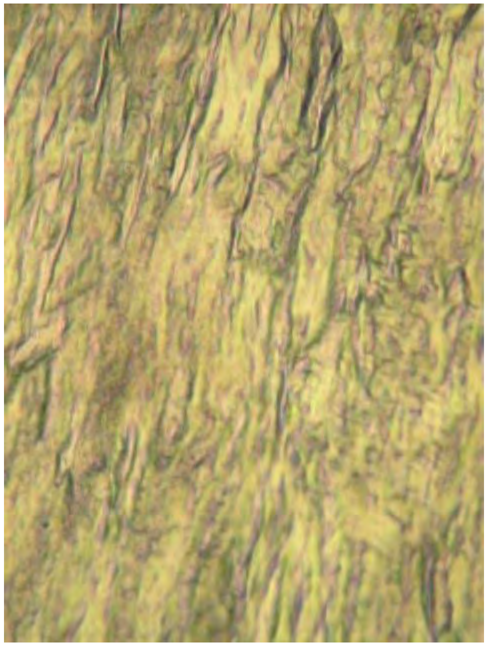
- Amorphous, RRR 250 Nb Cathodes
- Three surface preparations:
  - Mechanical polish (with diamond slurry)
  - Electropolishing
  - Buffered chemical polish
- In situ laser cleaning
  - Nd:YAG 4th harmonic (266 nm), 12 ps pulse, ~0.2 mJ/mm^2
  - KrF Excimer (248 nm), 12 ns pulse, ~2 mJ/mm^2

Nb Surface Finish

Buffered Chemical Polish

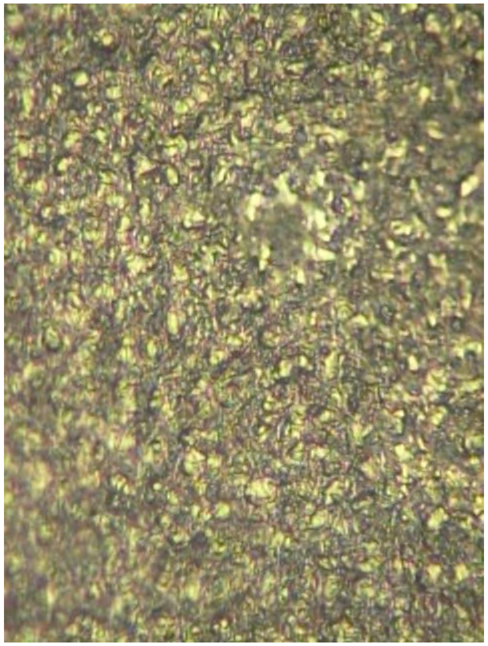


no laser cleaning



0.25 mJ/mm^2

12 ps Nd:YAG (266 nm)

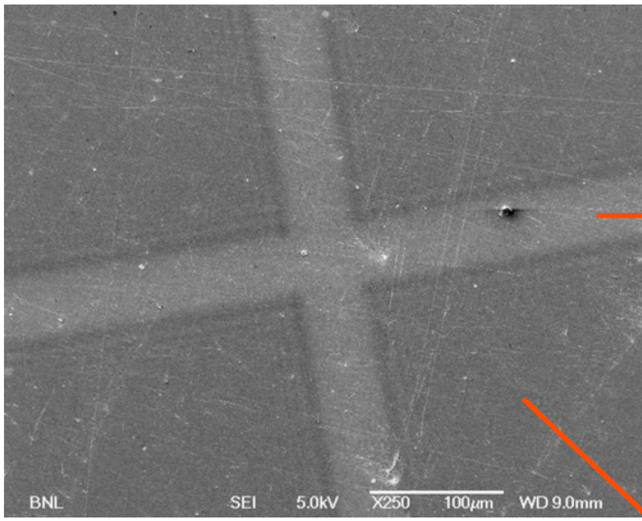


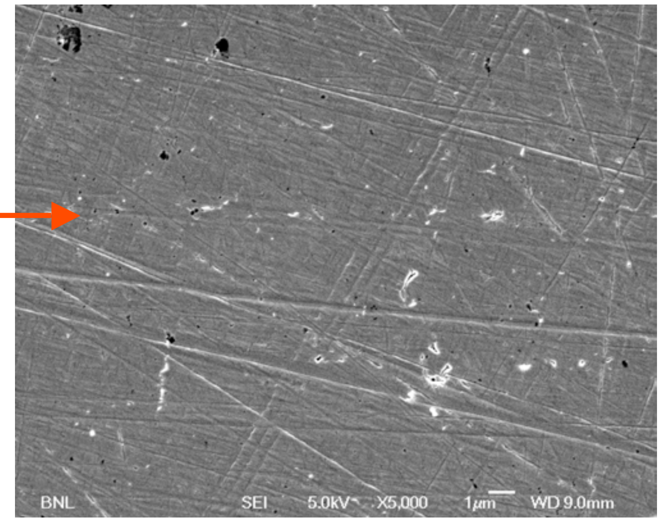
0.67 mJ/mm^2

12 ps Nd:YAG (266nm)

20 μm

Nb Surface Finish



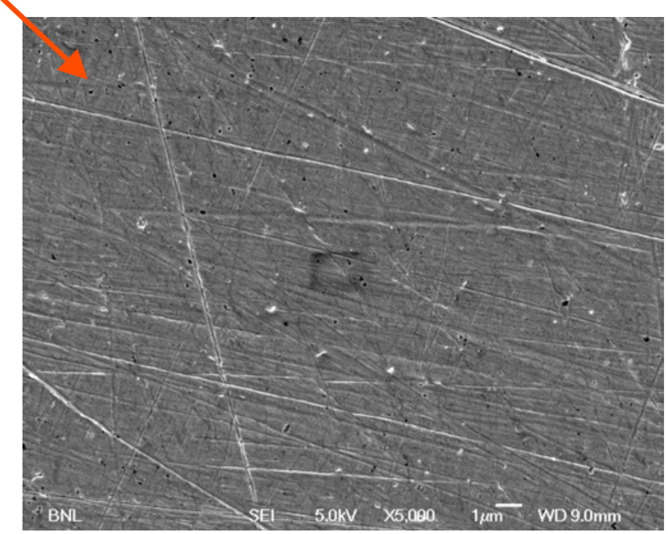


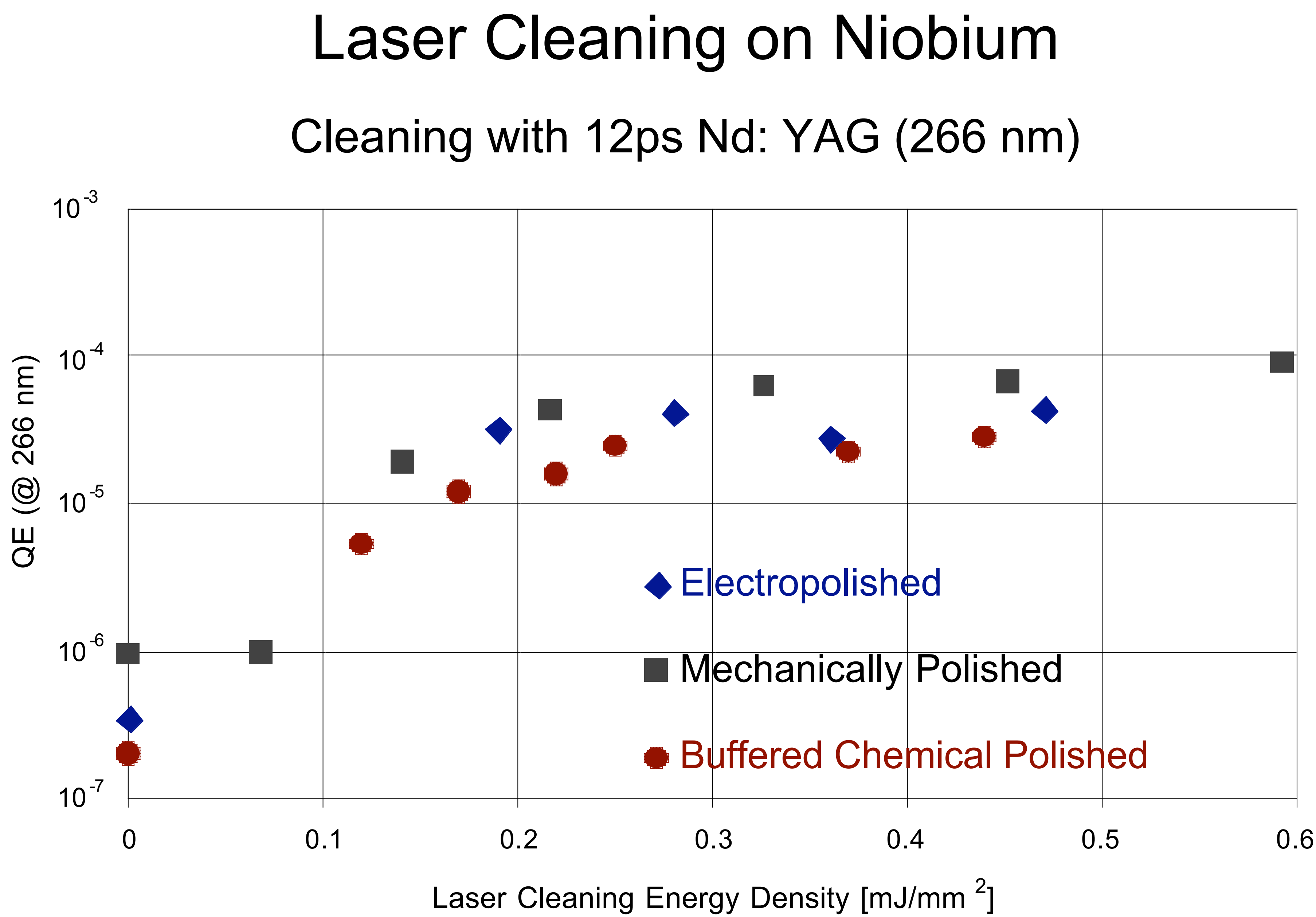
Mechanical Polish

Laser Cleaned

2.5 mJ/mm^2

12 ns KrF (248 nm)



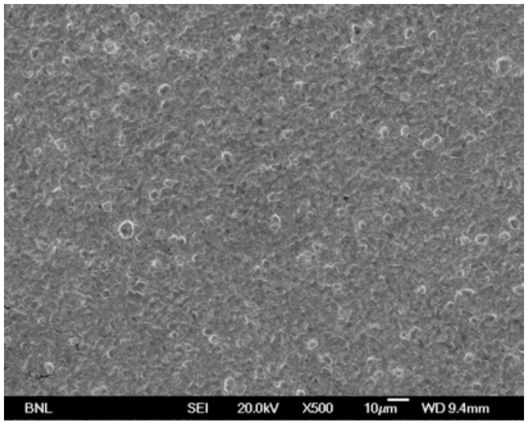

Laser Cleaning on Niobium
Cleaning with 12ps Nd: YAG (266 nm)
QE (@ 266 nm)
10^-3
10^-4
10^-5
10^-6
10^-7
0
0.1
0.2
0.3
0.4
0.5
0.6
Laser Cleaning Energy Density [mJ/mm 2]
Electropolished
Mechanically Polished
Buffered Chemical Polished

Cathode Preparation - Lead

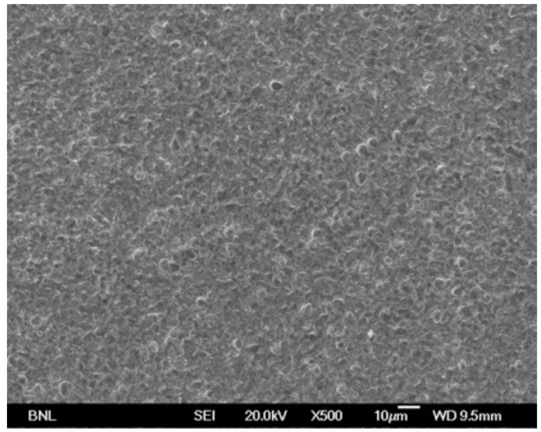
- Nb Cathodes used as substrate
- Four deposition methods:
  - Electroplating
  - Vacuum deposition (evaporation)
  - Sputtering
  - Vacuum Arc deposition
- Solid lead, mechanically polished
- In situ laser cleaning
  - KrF Excimer (248 nm), 12 ns pulse, ~0.2 mJ/mm^2

Lead Surface Finish and Damage Threshold

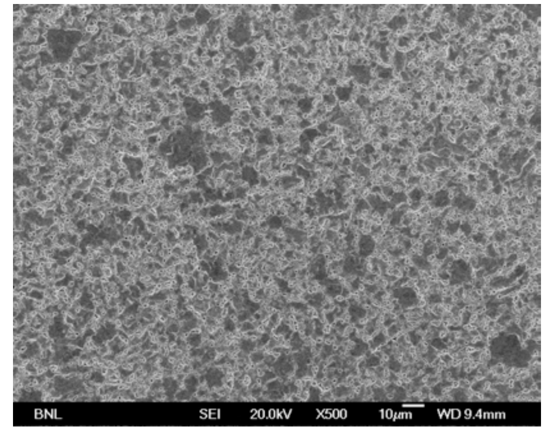
Electroplated Lead



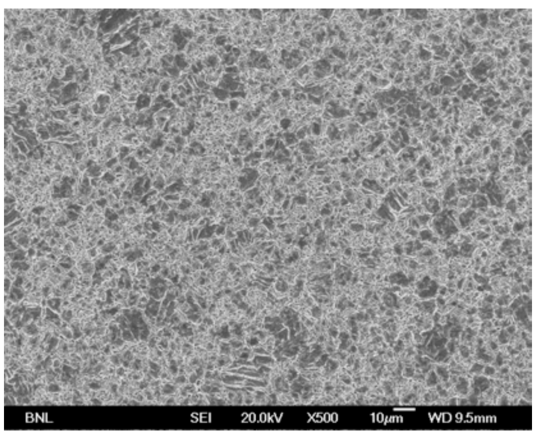
Prior to Laser Cleaning



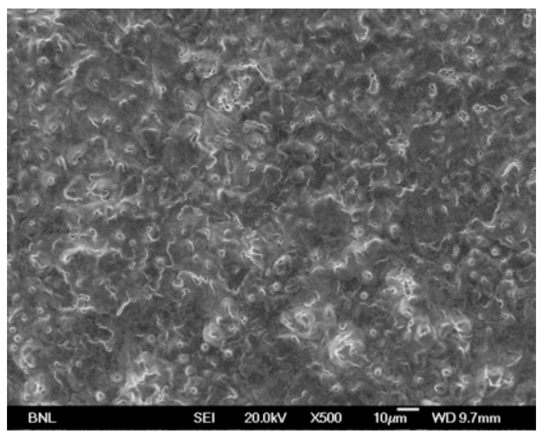
0.11 mJ/mm^2



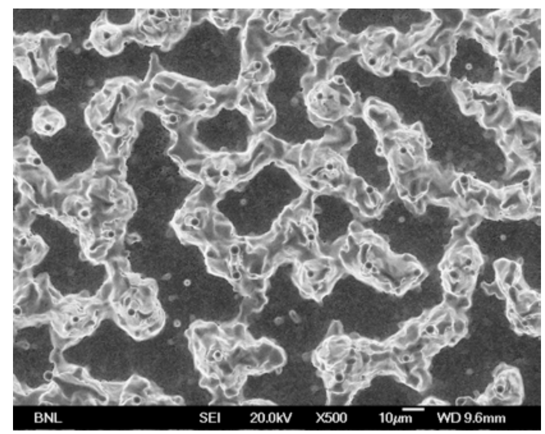
0.26 mJ/mm^2



0.52 mJ/mm^2



1.1 mJ/mm^2

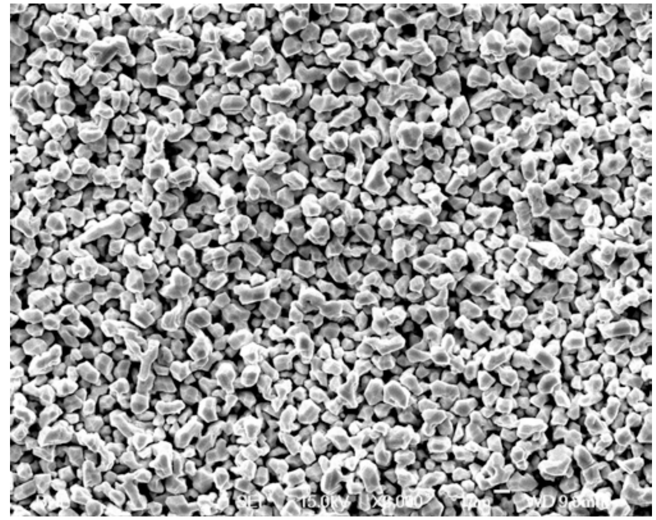


1.8 mJ/mm^2

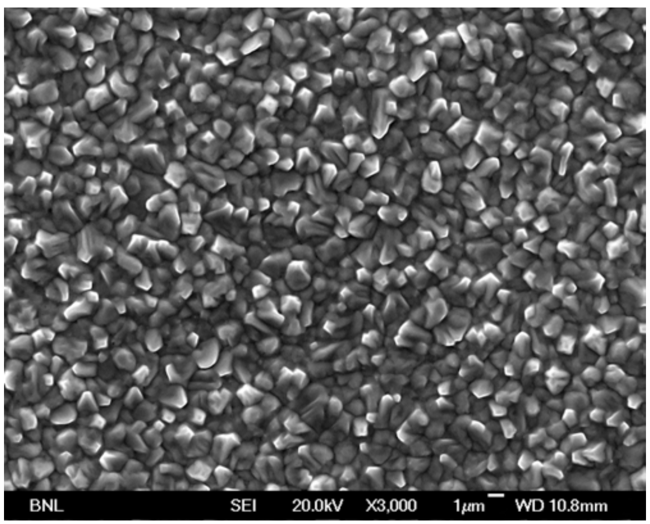
Surface Uniformity

Arc Deposited

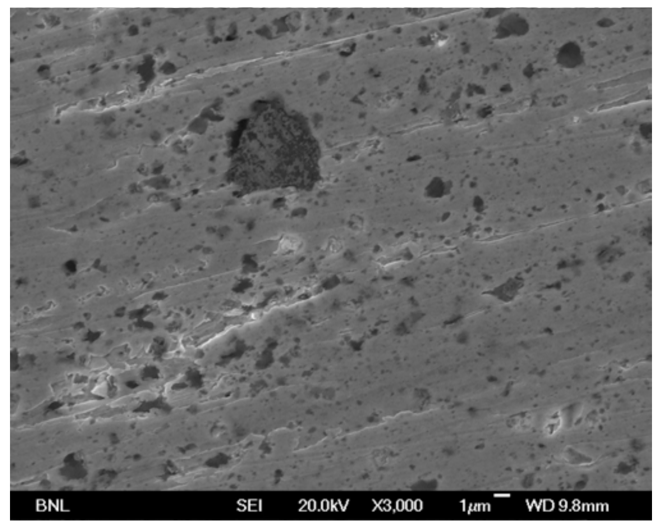
Sputtered



Vacuum Deposited



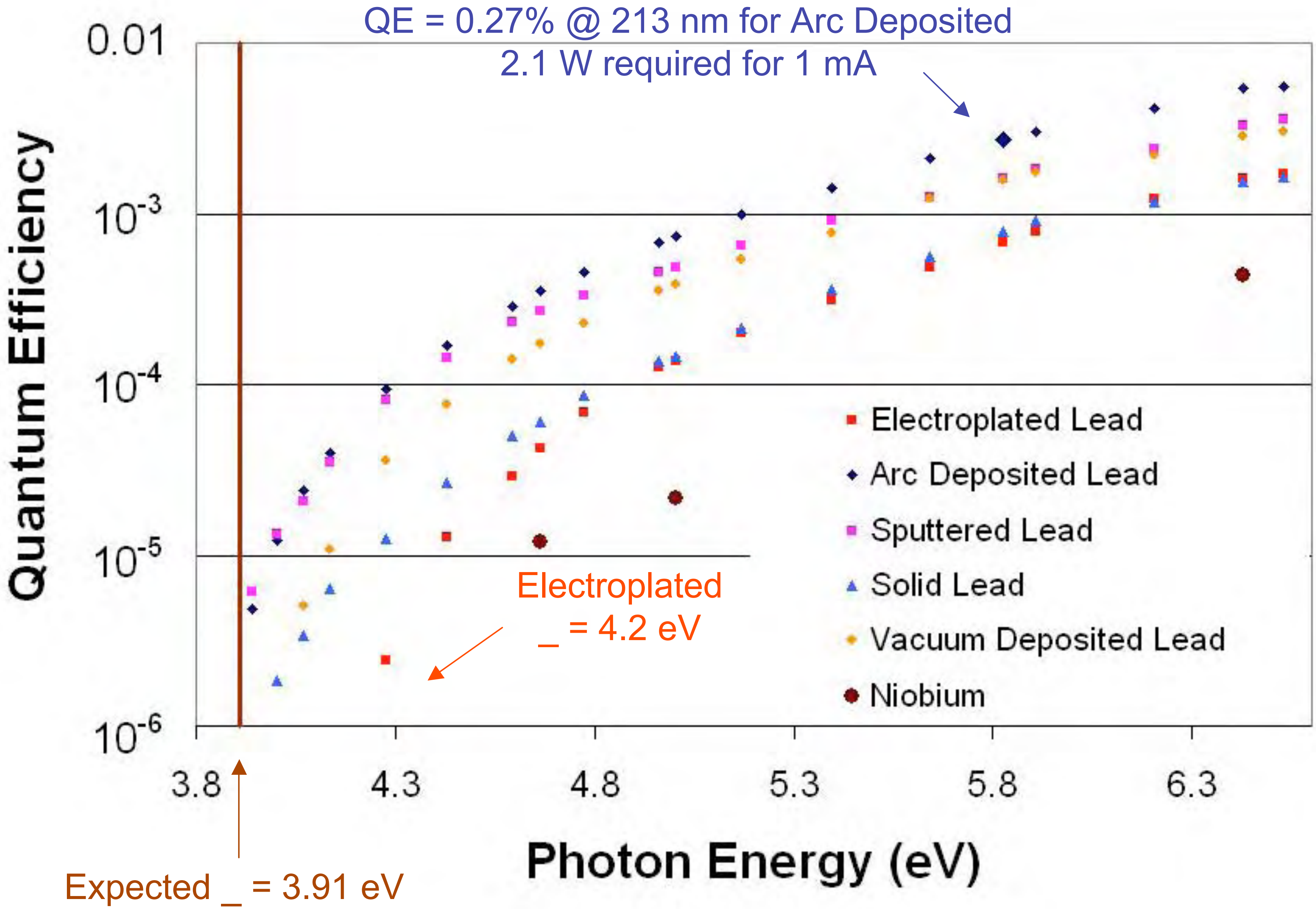
Solid

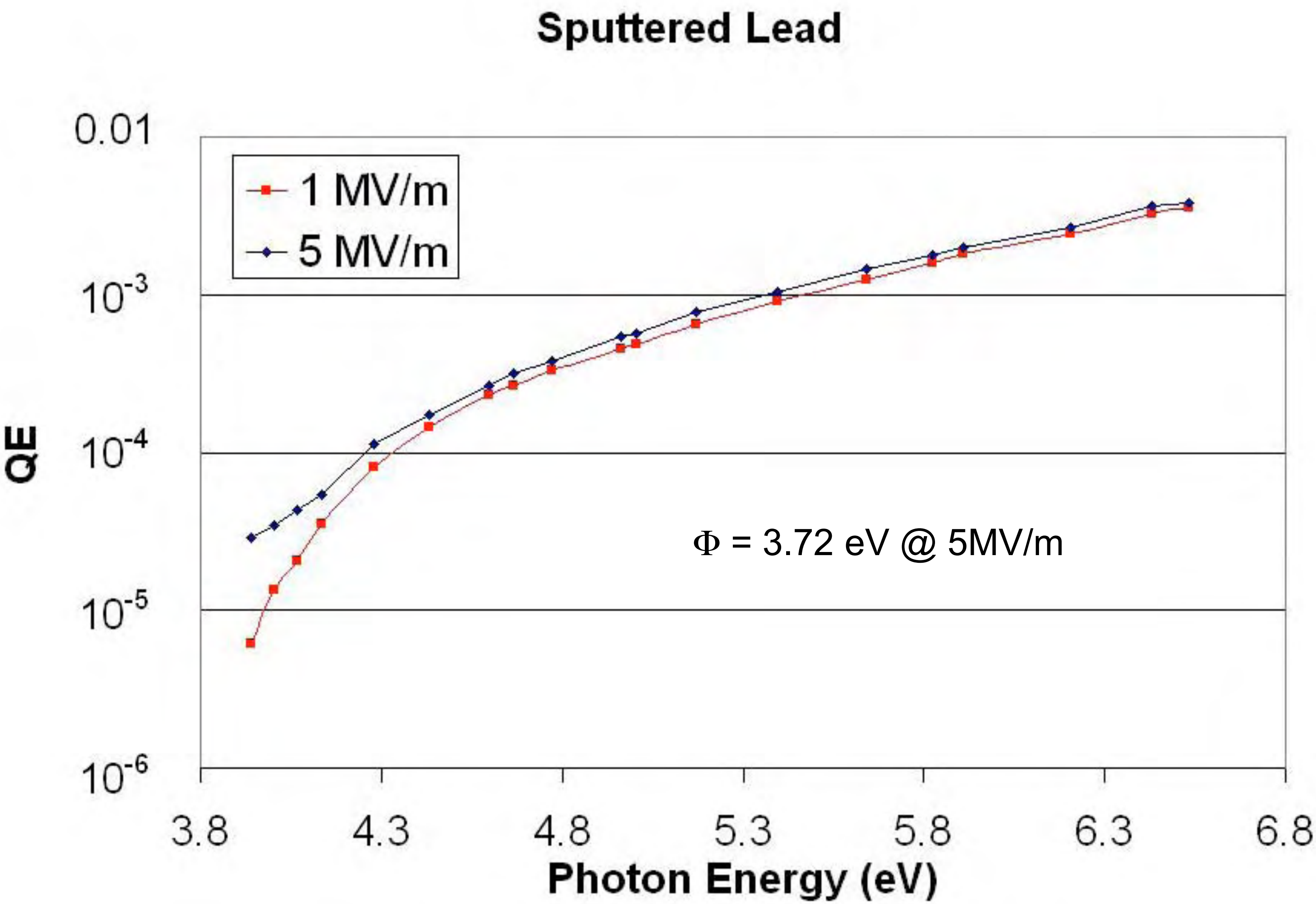


10 _m

All cathodes laser cleaned with 0.2 mJ/mm^2 of 248nm light

Photoemission Results





Sputtered Lead
1 MV/m
5 MV/m
QE
0.01
10^{-3}
10^{-4}
10^{-5}
10^{-6}
Φ = 3.72 eV @ 5MV/m
3.8
4.3
4.8
5.3
5.8
6.3
6.8
Photon Energy (eV)

Cold Temperature QE

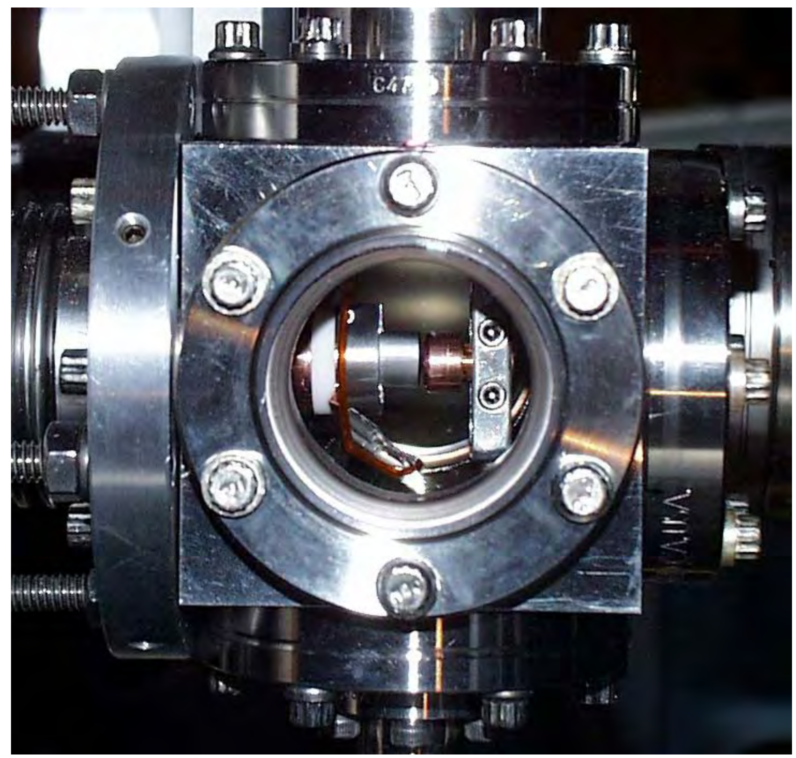
Previous measurements made at room temperature

How will lead behave at cryogenic temperatures?

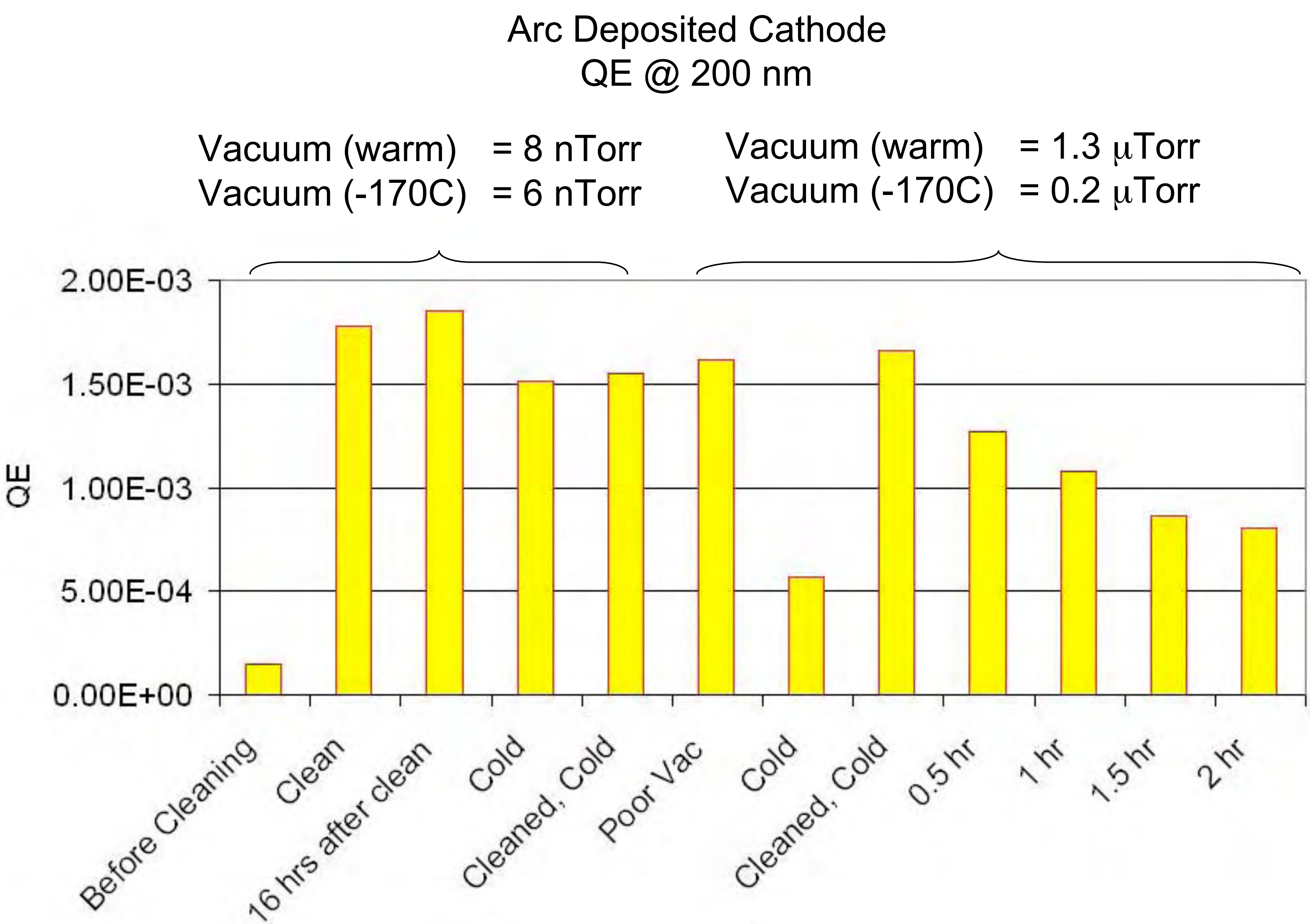
To find out, we mounted the cathode on a LN_2 cooled vacuum cold finger, capable of reaching -170 C

Electroplated and Arc Deposited

Structurally, the lead coatings were unaffected by multiple warm/cold cycles



Effect of Temperature and Vacuum on QE



Summary

- Niobium, although a great superconductor, is a relatively poor photocathode
- For moderate average currents, SC lead plating the cathode may be an attractive alternative to niobium
- QE_{266nm}=0.035%, QE_{213nm}=0.27%, QE_{190nm}=0.55%
- Cold temperature operation is not a problem, as long as vacuum is good
- For higher average currents, an RF choke assembly can be used to accommodate high-QE cathodes