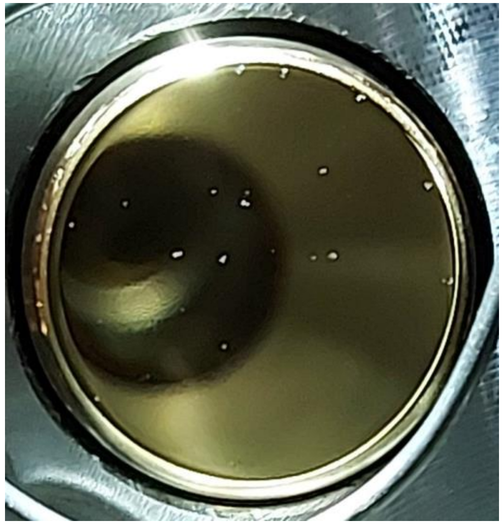
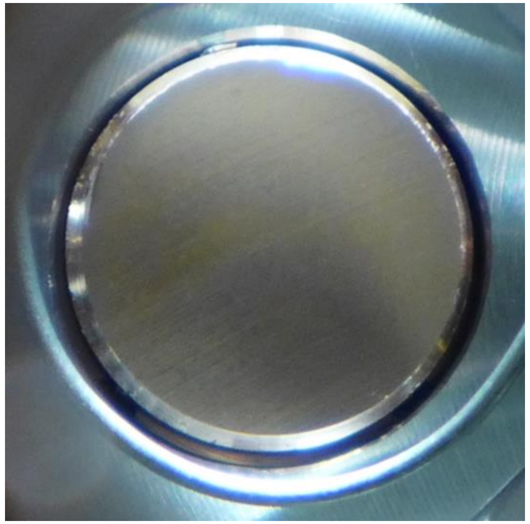
Metal cathode studies in the high gradient RF gun at PITZ

Au cathode



Cu plug



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HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

P³ WORKSHOP 2021
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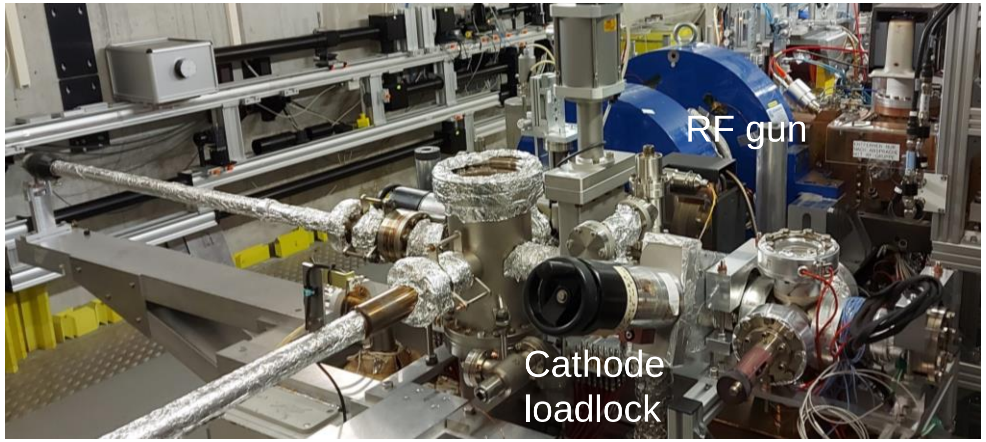
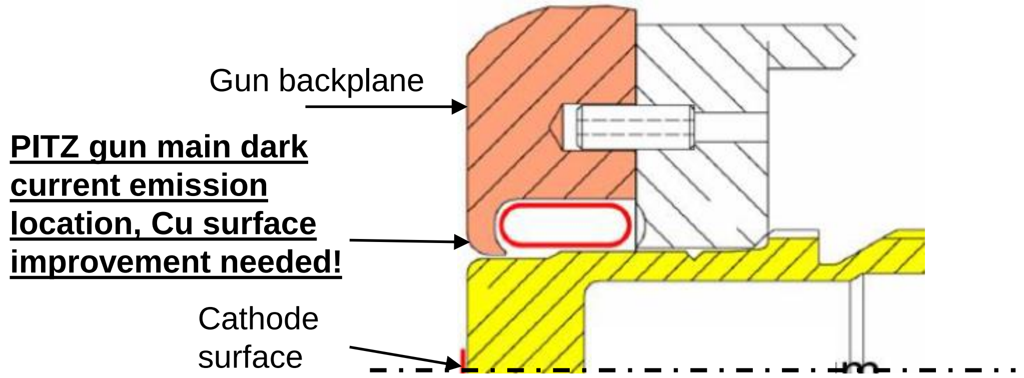
Why metal cathode studies at PITZ?

Thermal emittance and field emission

- Photoinjector test facility at DESY Zeuthen site (PITZ)
  - An ideal test bed for semiconductor and metal cathodes
  - 60 MV/m RF gun with UHV vacuum (~10^{-10} mbar)
  - Cathode load lock system with standard INFN type plugs
  - Comprehensive cathode diagnostics in the beamline
    - QE, QE map, work function, life time
    - Dark current, dark current imaging
    - Thermal emittance, thermal emittance map
    - Cathode response time (<100 fs resolution)



- **Cu** plug → emulate gun backplane field emission
  - Test surface processing **with gun**, expensive
  - Test surface processing **with Cu plugs** + dark current imaging → cheap and fast turn-around

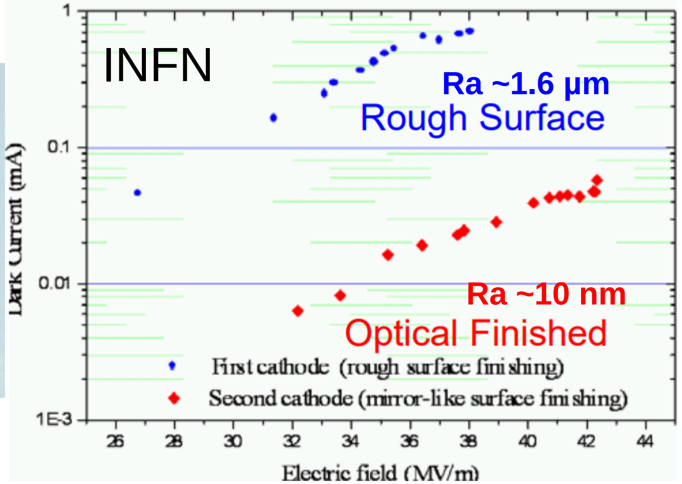


- **Au** cathode → low thermal emittance
  - ~0.5 eV higher work function than Cu and Mo (literature)
  - More robust against vacuum than Cu and Mo
  - Candidate for low charge or low repetition rate guns

Cu surface polishing effect

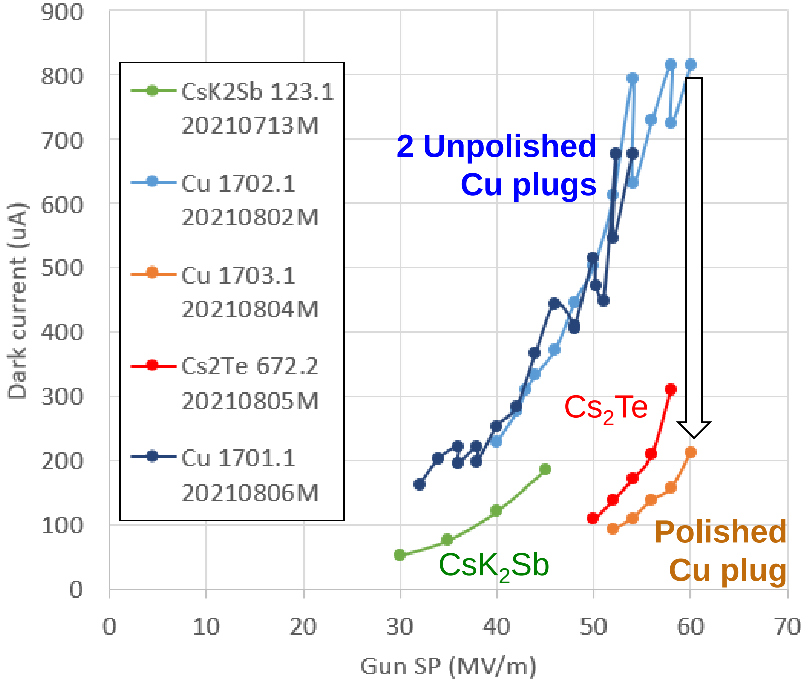
Dark current vs gradient

- Mo plug polishing has helped gun dark current reduction, we want to test its effect on Cu surface

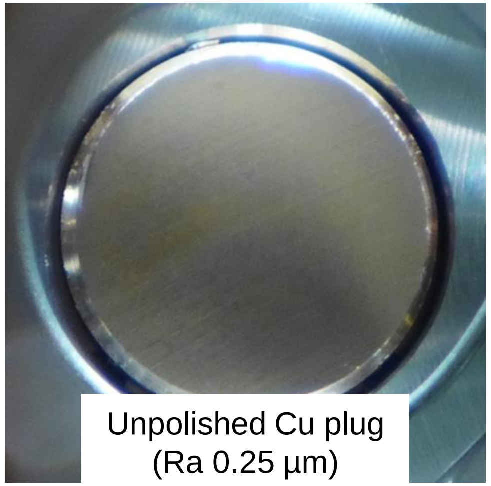


- Unpolished vs polished Cu plugs → how does surface polishing change field emission
  - Three Cu plugs are produced, similar surface quality as gun back plane (Ra **~0.25 µm**)
  - One Cu plug is polished to ca. **~10 nm**
  - All plugs are dry ice cleaned.

Max dark current @~0.8 m from cathode



- All three Cu plugs took >12 hr RF conditioning to 60 MV/m x 60 µs, much more difficult than standard Cs_2Te cathodes (a couple of hrs).
- Polished Cu plug reduced a factor of 4 dark current than unpolished Cu plug @60 MV/m.



Unpolished Cu plug (Ra 0.25 µm)

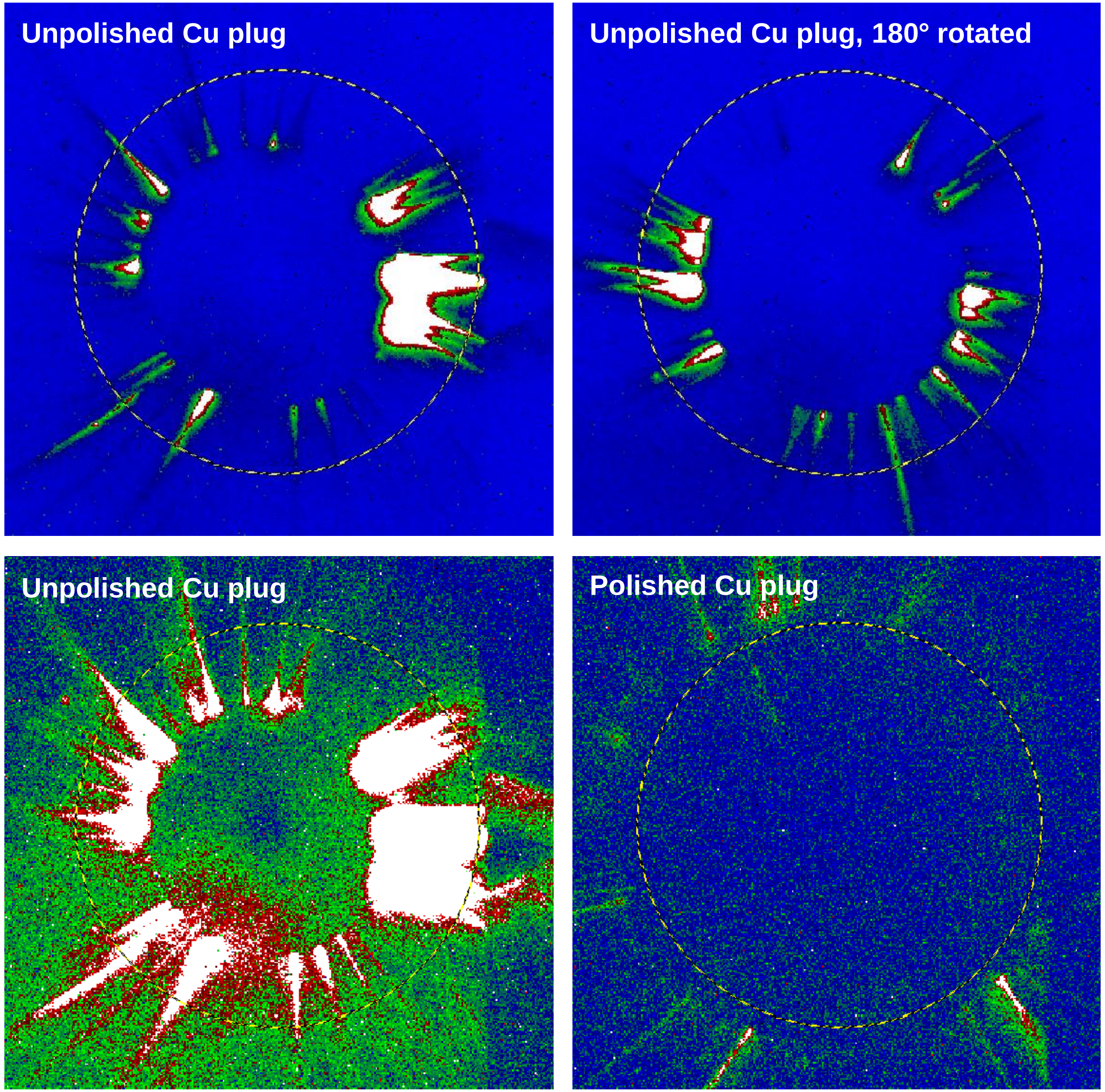
Polished Cu plug (Ra 10 nm)

Cu surface polishing effect

Dark current imaging

- For unpolished Cu plug, strong field emitters are on the plug, proved after plug rotation
- For polished Cu plug, field emitters are from the gun backplane cathode hole area (dash circle is the gap between Cu plug and gun backplane)
- Unpolished vs polished Cu plug
  - Why do the emitters on the unpolished plug locate on a ring (R~5mm on the plug)? Not randomly distributed?
  - In Cu plug center, why no observable difference?
  - Solenoid focusing for max dark current: 500 A for unpolished, 350 A for the polished, why?
    - Plug insertion depth difference → RF focusing change?
    - Emissions came from plug corner?

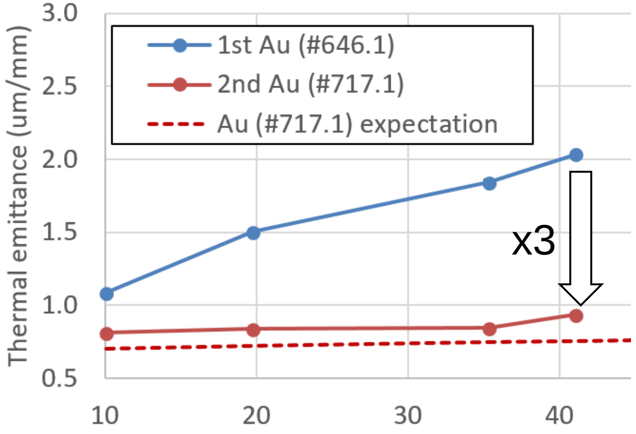
Plugs are removed from the gun for further offline measurements!

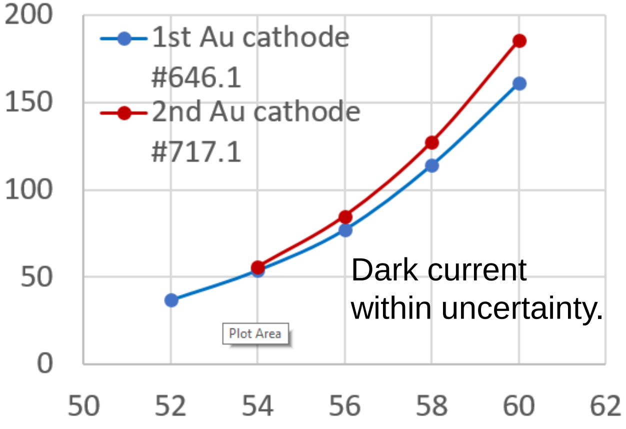


Gold cathode thermal emittance reduction

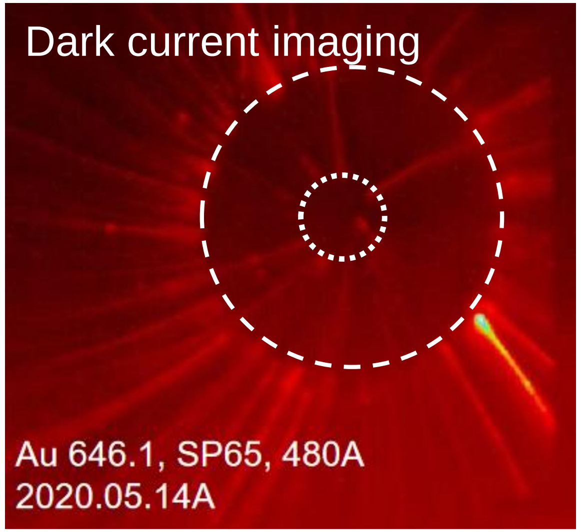
Collaborations between DESY (Sven Lederer) and STFC (Reza Valizadeh)

- Gold cathodes fabricated at STFC by magnetron sputtering
  - 1st try: 5 mm diameter on Mo plug, 100 nm thick
  - 2nd try: full deposition on Mo plug, 150 nm thick
    - Plug temperature during deposition was lower than the 1st try to avoid crystallization
- 2nd cathode improves thermal emittance w.r.t. 1st cathode, with similar dark current and QE (~1×10^{-4})
  - Work function measured to be 4.3~4.2 eV for both cathodes, much lower than literature values
  - Thermal emittance reduced by a factor of ~3 @40 MV/m

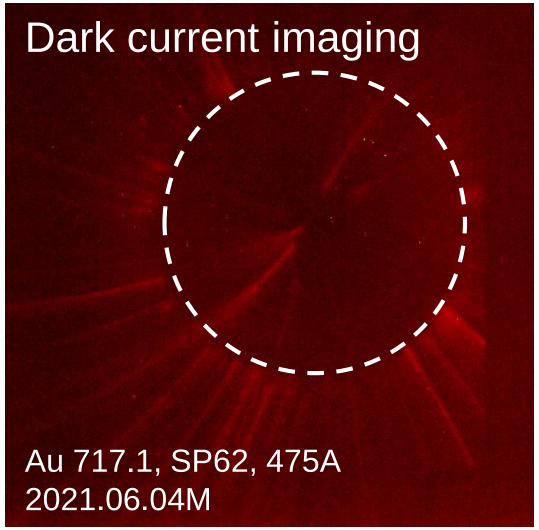




#646.1 (1st)



#717.1 (2nd)



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