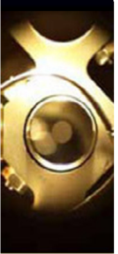
FEL19 –Hamburg, Germany 26-30 August 2019

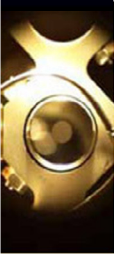
Growing and Characterization of Cs_2Te Photocathodes With Different Thicknesses at INFN LASA

L. Monaco – INFN LASA Milano



Outline

- Overview of INFN LASA photocathode production
- The photocathode growing process
- Analysis during growing: spectral responses and reflectivity
- Analysis after growth: reflectivity, spectral resposes, QE, QE map
- Post analysis: from the QE map to the E_g+E_a map
- First measurements in the PITZ RF Gun

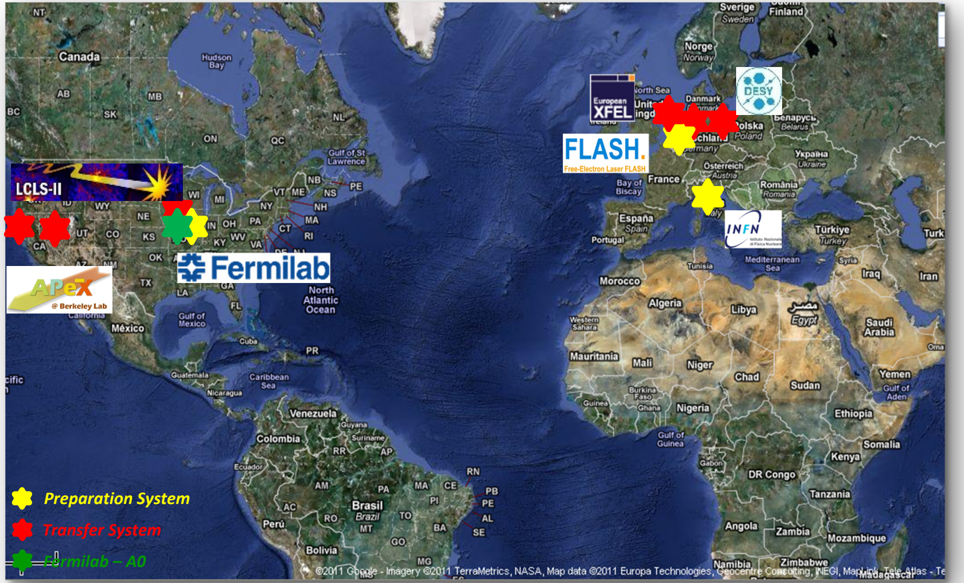


INFN LASA photocathode production status

- Our system is a **“production system”** where we grow photocathodes that satisfy these requests for the operation in photoinjectors:
  - High QE at our reference λ = 254 nm:
    - QE at different wavelenghts to evaluate the QE at the injector laser beam wavelenght
  - Spatial uniform QE on the entire photoemissive film:
    - illumination of the film during growth with a spot size ≥ 5mm to limit non uniformity
    - checked after the production with QE map (also at different wavelenghts)
  - Low dark current during production
    - obtained with optical surface polishing of the Mo substrate
  - Long operative lifetime
    - proved by checking the QE decrease, loss of QE spatial uniformity, darkcurrent in the RF gun
  - Reproducible recipe to have cathodes with symilar characteristics (spectral response, QE, etc.)
    - obtained with the usage of the new multiwavelenghts diagnostic

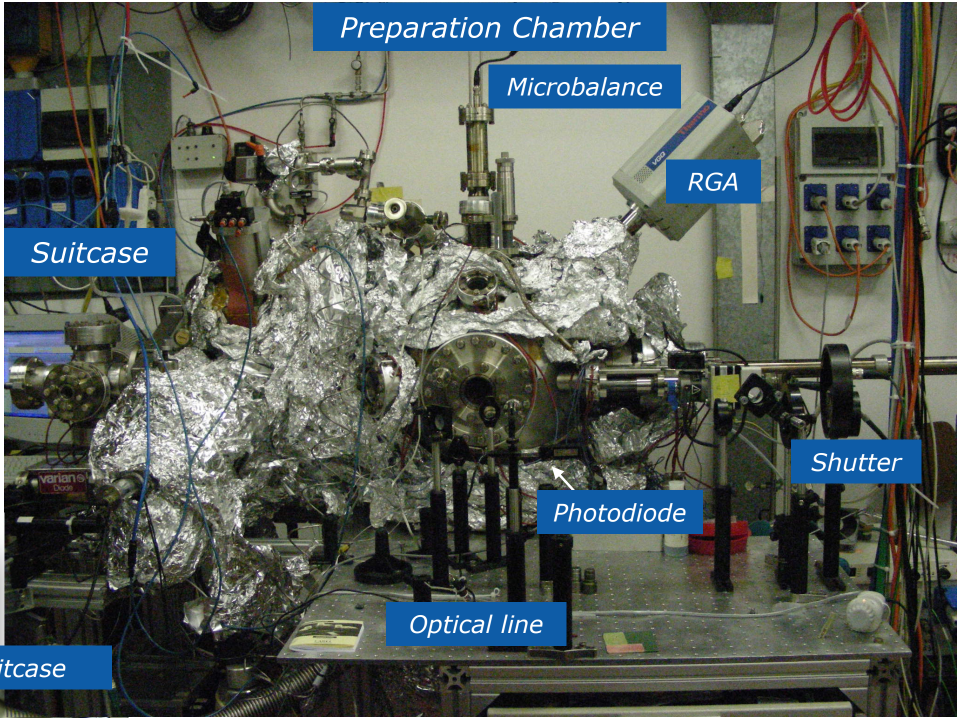
INFN LASA Cs_2Te Photocathodes

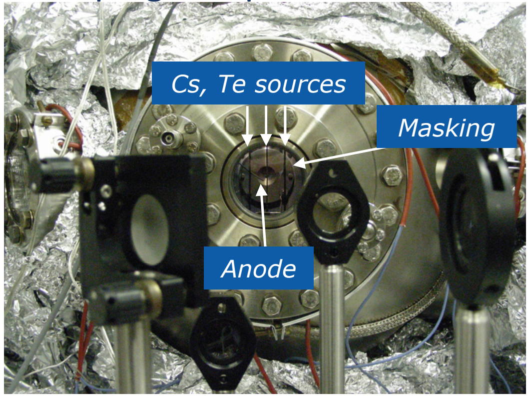
- Since '90s, INFN LASA studied, developed and produced cesium telluride (Cs_2Te) photocathodes used as laser triggered electron sources for the high brightness injectors.
- In 1998, the production started and nowadays we have delivered 150 photocathodes. The operative lifetime in the user facilities (24/7) increased from few months to few years.
  Our photocathode plugs are now a "standard", exchangeable between the different facilities.
- Our photocathodes are used regularly in the injector - RF guns of:
  - **FLASH** (DESY Hamburg)
  - **PITZ** (DESY Zeuthen)
  - **FAST** (Fermilab)
  - **APEX** (Lawrence Berkeley National Lab.)
  - **LCLS-II** (SLAC)
- We have also produced **preparation systems** for **DESY Hamburg** and **FNAL**.
- Moreover, new collaborations are under finalization (i.e. with **SHINE** at Shanghai, China)

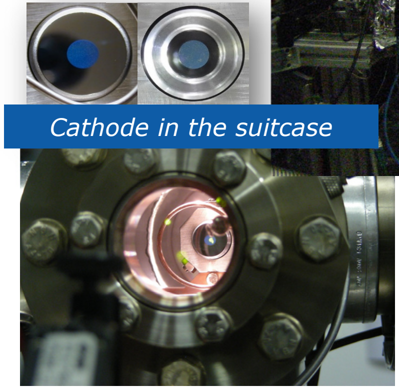


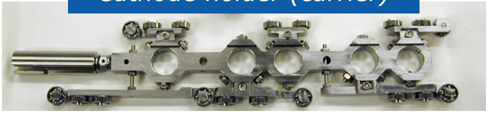
INFN LASA photocathode production: our system

- INFN LASA Photocathode System:
  - Preparation chamber (base pressure 10^{-10} mbar)
  - Transport box «suitcase» (base pressure 10^{-10} mbar)
  - Transfer chamber to RF Gun (base pressure 10^{-10} mbar)
  - Carrier to hold and exchange plugs
- Diagnostic for growing and characterization:
  - Hg-Xe lamp: filters (239 nm ÷ 436 nm), main λ = 254 nm
  - Reflectivity (power meter) and QE (picoammeter)
  - Microbalance for thickness measurement
  - RGA for vacuum quality control
- Masking system: 5 mm (changeable)
- Mo plugs shapes: compatible with all systems



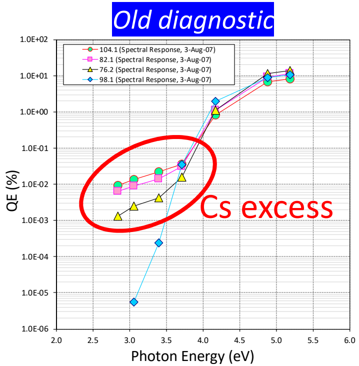


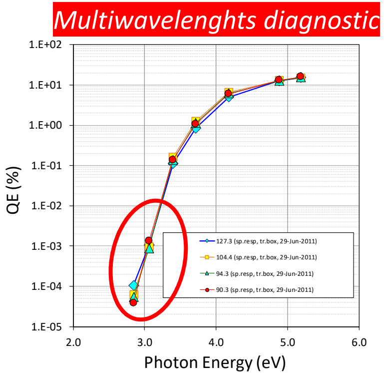


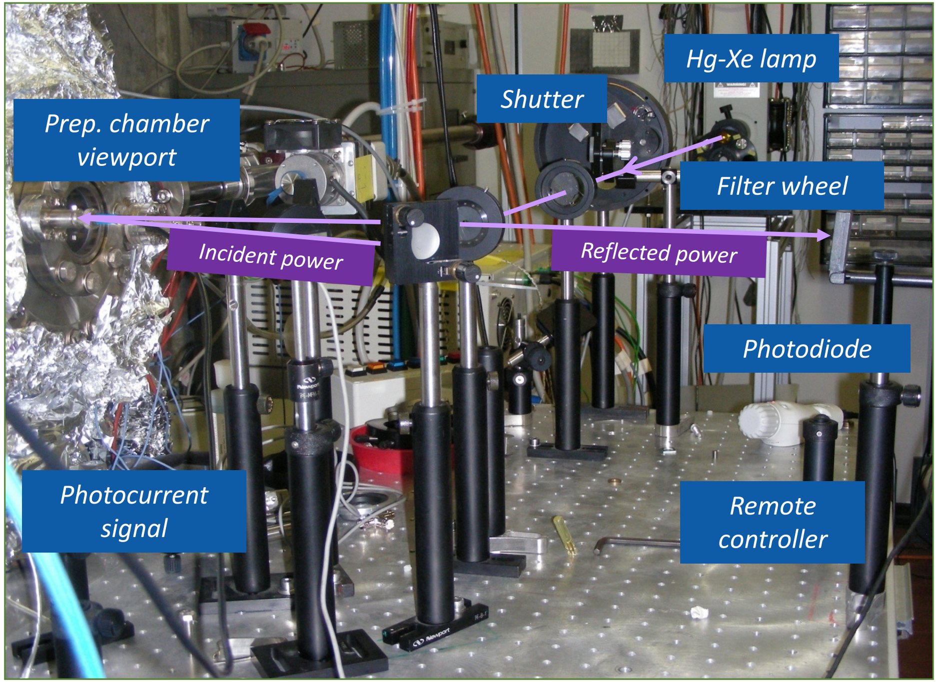


INFN LASA photocathode production: diagnostic

- Since 2009, we introduced a new diagnostic system mainly used for the production phase called “multiwavelenghts diagnostic” obtaining:
  - The optimization of the deposition recipe
    - Better control on the final spectral response (no Cs excess -> lower “low energy” threshold)
    - Improved control of the Te deposition thickness
    - Spectral responses of produced cathodes very similar and reproduceable
    - Higher final QE (at 254 nm)
    - Less consumption of the sources
- Diagnostic at all λs during production





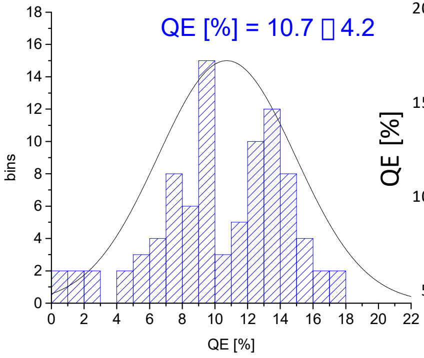


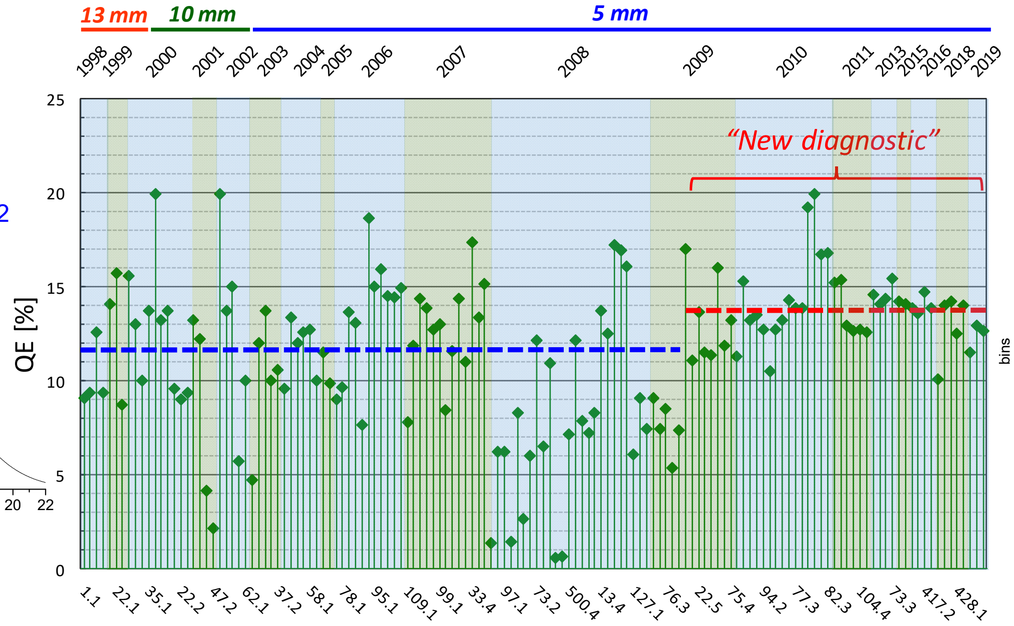
Statistics on produced Cs_2Te photocathodes

- INFN LASA Photocathode Production
  - 150 “standard” Cs_2Te (Te = 10 nm)
  - few at different thicknesses (3 Te = 5 nm and 3 Te = 10 nm films)

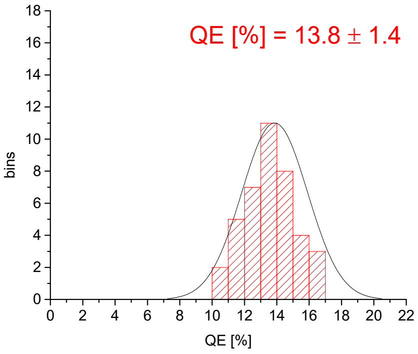
- Average QE (%) @ 254 nm (all films): 11.7 ± 3.9
- Coating ϕ: 13 mm, 10 mm, 5 mm
- “New diagnostic”:
  - *the multiwavelenghts diagnostic*

Old diagnostic





New diagnostic



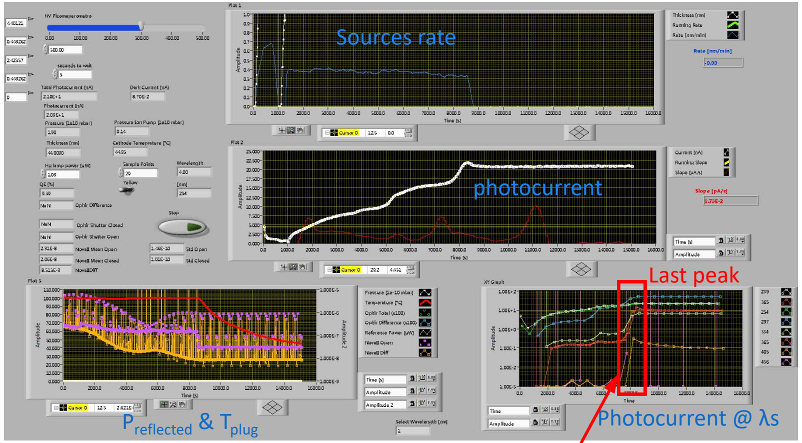
QEs corrected for viewport transparency

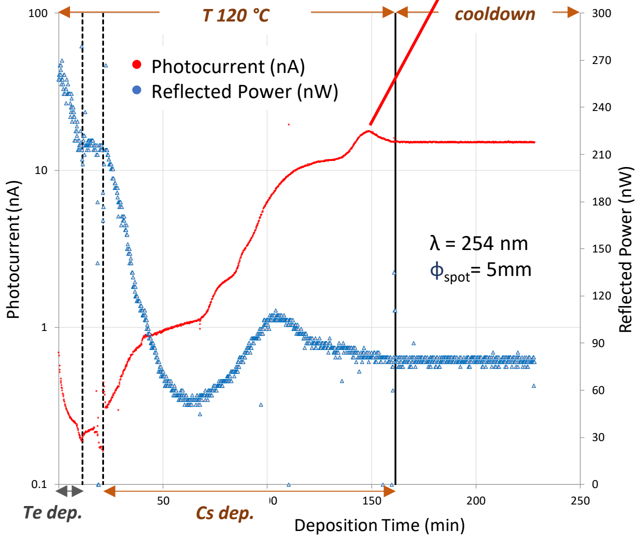
Measurement just after production (transport box, λ=254nm, spot Φ=3mm)

INFN LASA Cs_2Te recipe

- Mo plugs:
  - High purity (99.95%), optically polished ($R_a \approx 10$ nm)
  - Heating cycle from 20 °C -> 450 °C -> 120 °C
- Coating deposition:
  - T = 120 °C
  - Te deposition: 10 nm (1 nm/min)
  - Cs deposition: up to the last QE maximum (1 nm/min)
  - Start cooling down to room temperature
- Photocurrent and Reflected power measurement:
  - Spot @ 254 nm: $\phi \geq 5$ mm, $P_{inc} \sim 1$ µW
  - λ = 239 nm ÷ 436 nm, automatic filter wheel, main λ = 254 nm
- The production of Cs_2Te with different thicknesses is done by changing the deposited Te thickness
  - Standard cathodes: Te = 10 nm
  - Thin cathode: Te = 5 nm
  - Thick cathode: Te = 15 nm

Control panel for the cathode growth





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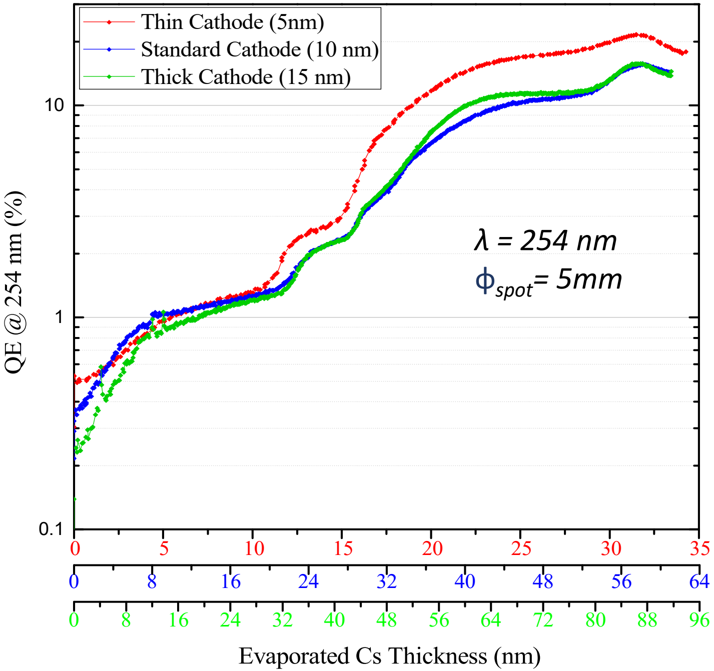
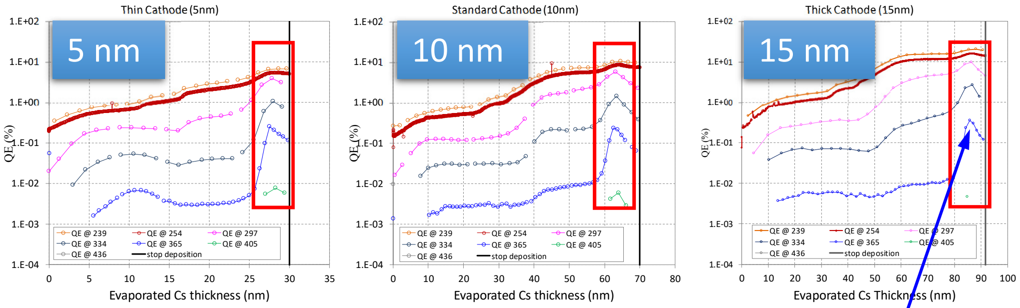
Cathode growth analysis: QE @ λs

- Rescaling the QE grow at 254 nm for different cathode thicknesses w.r.t. the "last peak" thickness, we observe:
  - dependence only on the ratio Te/Cs (about 1 to 6)
  - typical plateaus are visible for the three cathodes and they appear at the same normalized Cs thickness
    - ➢ formation of different Cs_xTe compounds depends on Te/Cs ratio

Cathode	Te (nm)	Cs (nm)
Thin (3 films)	5.1 ± 0.1	33.8 ± 0.5
Standard (26 films)	9.7 ± 0.3	60.4 ± 2.8
Thick (3 films)	15.1 ± 0.2	89.9 ± 3.0

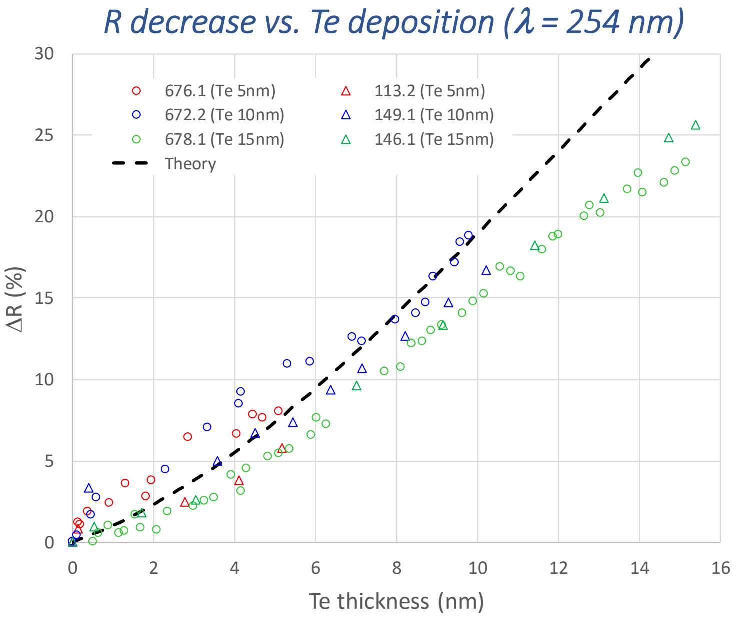


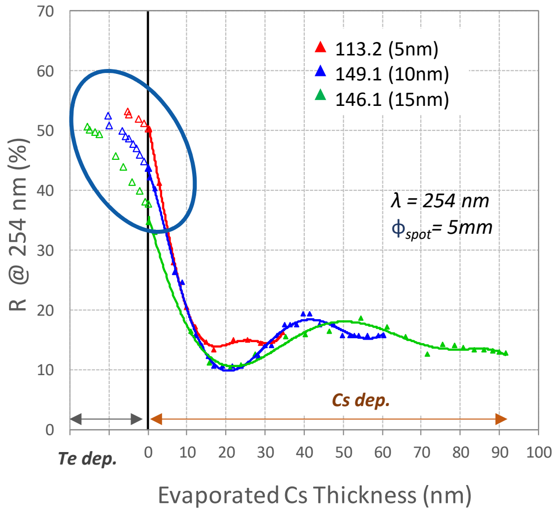


239 nm	254 nm	297 nm	334 nm	365 nm
32%	37%	120%	365%	2000%

- The "last" peak is more evident at longer λs:
  - Better control of the growth process
  - Useful tool for cathode reproducibility (limited Cs excess)

Cathode growth analysis: Te reflectivity @ 254nm

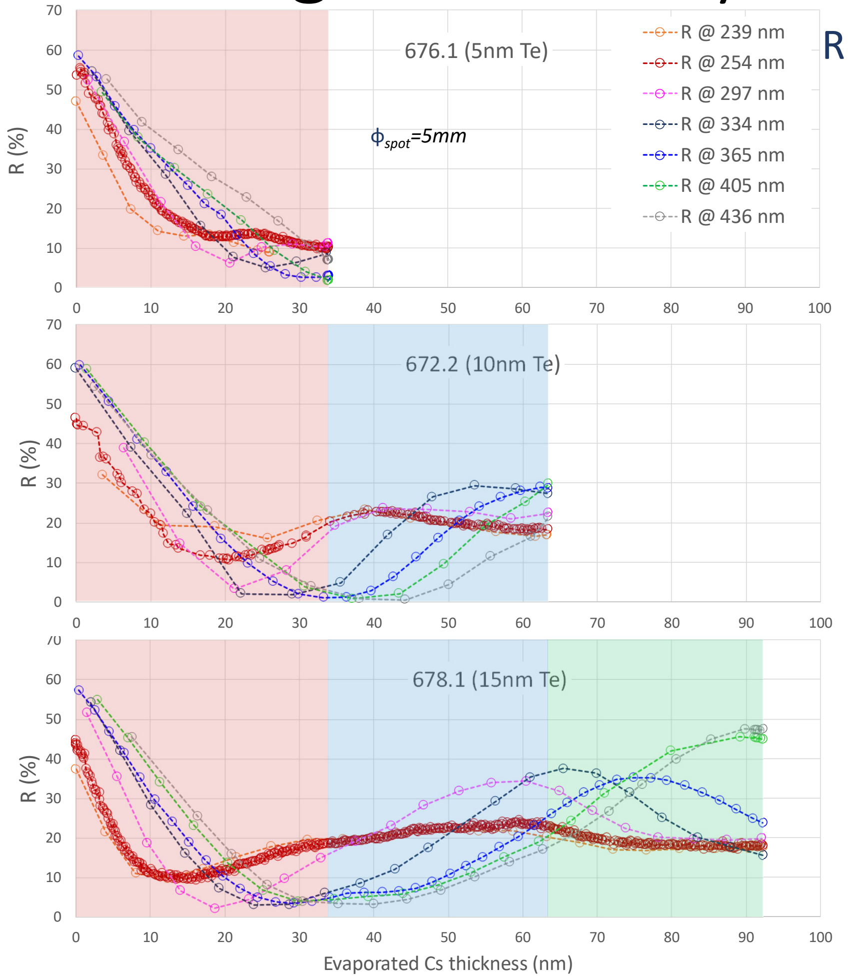




Cathode	Te	ΔR decrease	ΔR theory
Thin (3 films)	5 nm	7.0 ± 0.8%	7.4 %
Standard (26 films)	10 nm	16.8 ± 2.2%	19.1 %
Thick (3 films)	15 nm	27.5 ± 3.0%	31.7 %

- Reflectivity variation during Te deposition (ΔR):
  - Improvement on the evaluation of Te thickness deposited on Mo plug
  - ΔR is also used as indirect control of the plug temperature (too high temperature prevents Te film deposition)
  - Good agreement with theory for 5 and 10 nm of Te

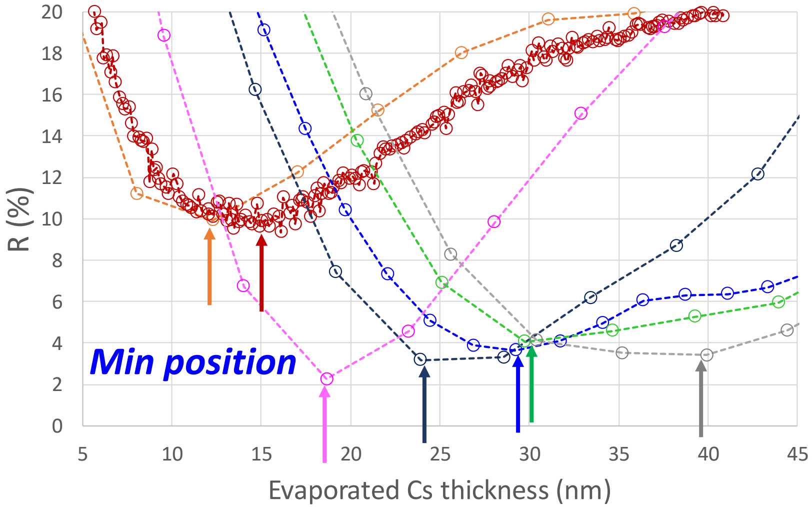
Cathode growth analysis: reflectivity @ λs

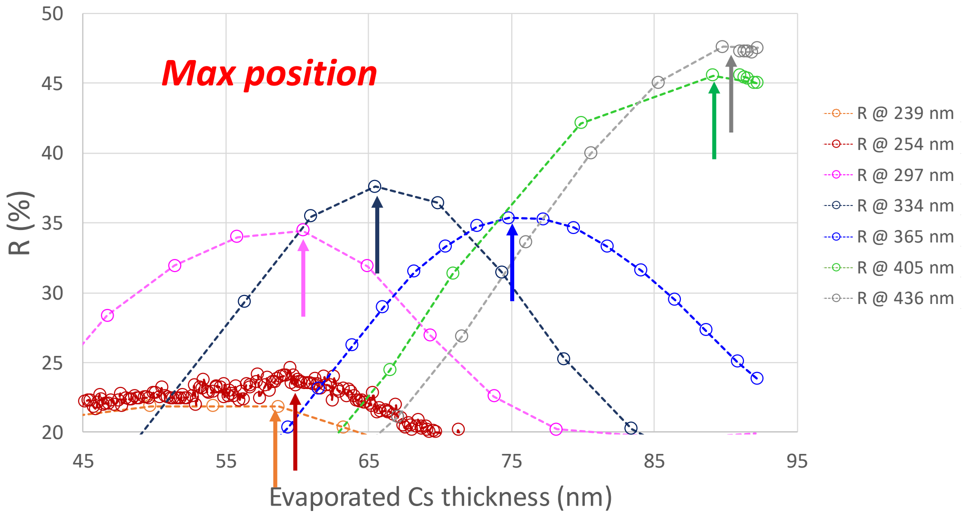


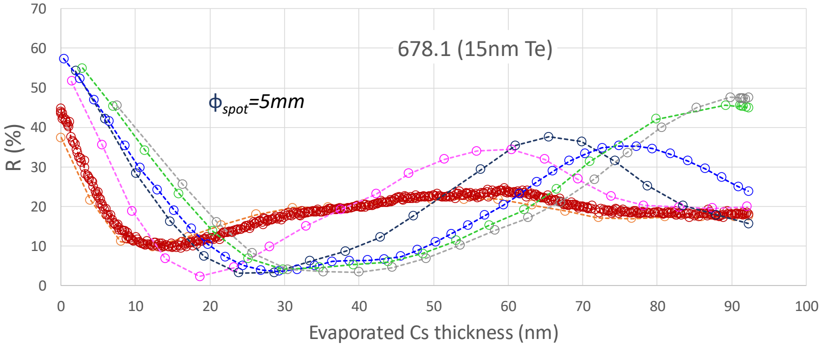
R @ λs (Cs dep):

- Unlike the photoemission data, reflectivity does not depend on the Te/Cs ratio but mainly on the film thickness
- **5 nm**
  - Overall decrease of R at all wavelengths besides shorter one where a first minimum is visible
- **10 nm**
  - R minimum at all wavelengths and also maximum at almost all.
  - Good overlap with “5 nm”
- **15 nm**
  - R minima and maxima for all wavelengths. For shorter wavelengths, an asymptotic value seems to be reached. For longer wavelengths further minima and maxima are still evolving.
  - Good overlap with “10 nm”

Cathode growth analysis: reflectivity @ λs



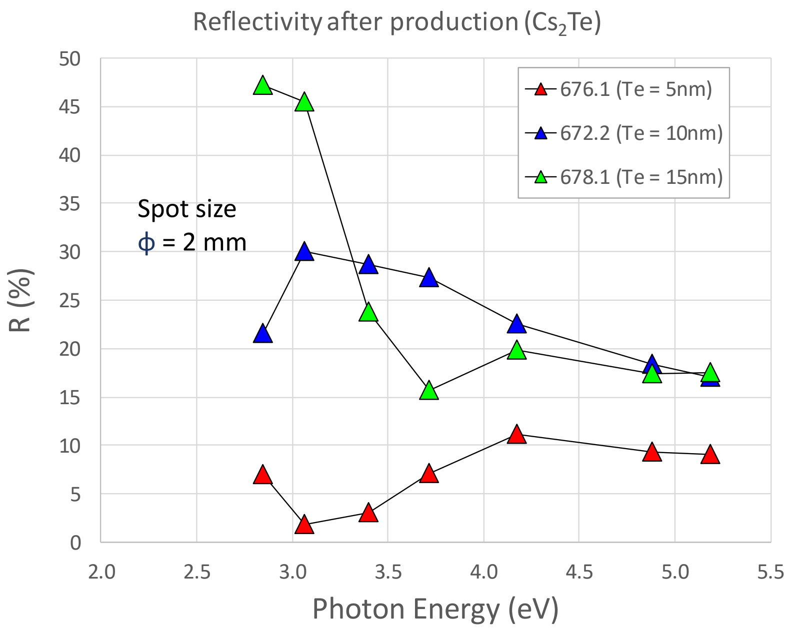




- R @ λs (Cs dep):
  - The reflectivity at all λs has **min**/**max**, whose positions increase (in terms of evaporated Cs thickness) with the increase of the wavelengths

Analysis after production: reflectivity

- After the production, cathodes are moved into the transport box for final diagnostic
  - The reflectivity is measured on the center of the films and on the Mo polished surface measurements with a spot size ϕ = 2mm



R at all λs:

- The final reflectivity, for λ ≤ 297 nm, is the same within few percent.
- At longer wavelengths we measure higher reflectivity for thicker cathode.

Analysis after production: reflectivity

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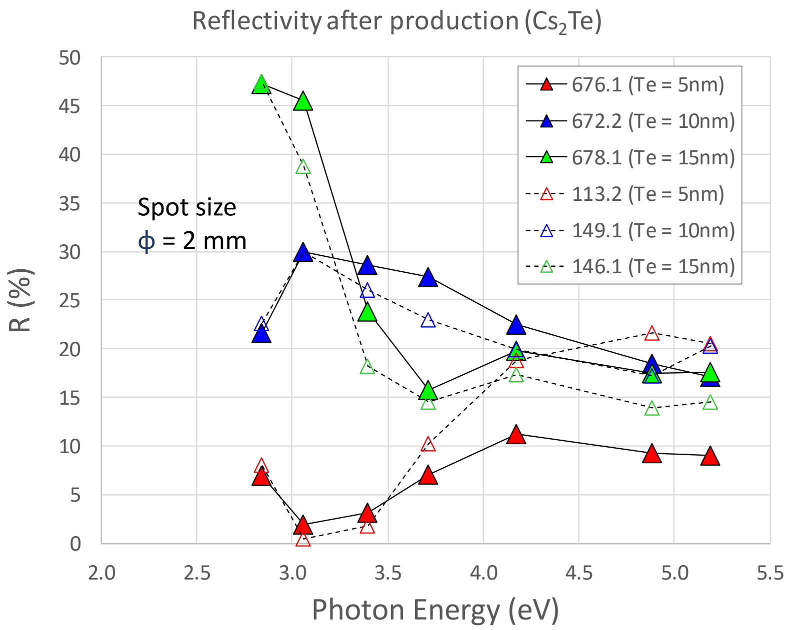

R at all λs:

- The final reflectivity, for λ ≤ 297 nm, is the same within few percent.
- At longer wavelengths we measure higher reflectivity for thicker cathode.

Comparing the new set with the past one:

- Good reproducibility of our recipe
  - Similar behavior at all λs
  - Some differences in value (see R at shorter wavelengths for the thin film)

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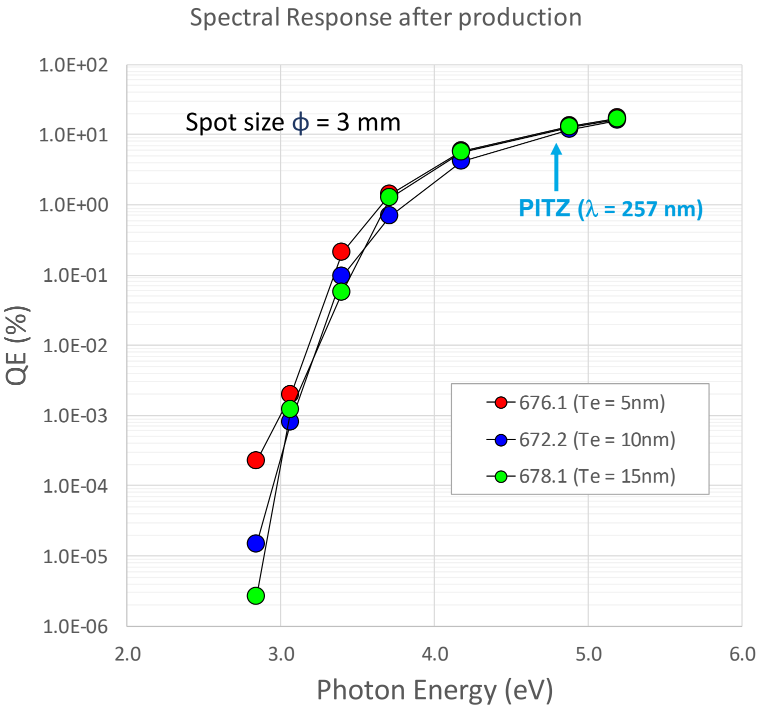
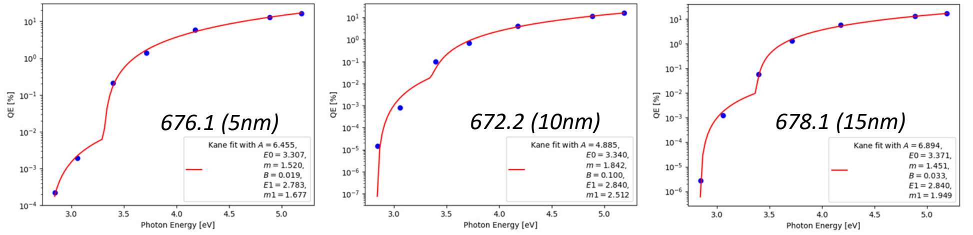
Analysis after production: spectral responses

- The spectral responses are measured (spot size ϕ = 3mm) for the determination of the *energy threshold:* energy gap (E_g) and electro affinity (E_a) -> *"high energy"* and *"low energy"*
- The spectral responses are also used to evaluate the QE at the injector laser wavelength





	676.1 (5 nm)	672.2 (10 nm)	678.1 (15 nm)
$(E_g + E_a)_{high}$	3.31 eV	3.34 eV	3.37 eV
$(E_g + E_a)_{low}$	2.78 eV	2.84 eV	2.84 eV

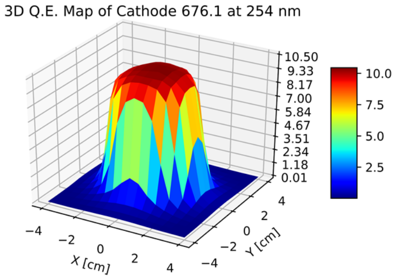
"Kane" model used for the spectral responses fitting

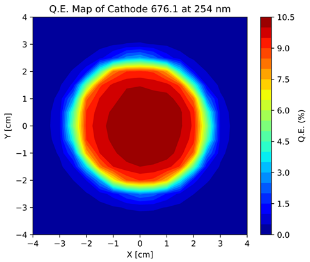
$$QE = A \cdot \left[h\nu - (E_g + E_a)\right]^m + A_1 \cdot \left[h\nu - (E_{g1} + E_{a1})\right]^{m1}$$

- *A* and *A1*: constants
- *m* and *m1*: related to the transition in the material
- E_g and E_a (E_{g1} and E_{a1}): energy gap and electron affinity of the low and the high energy thresholds.

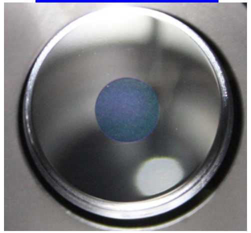
Analysis after production: QE maps @ 254nm

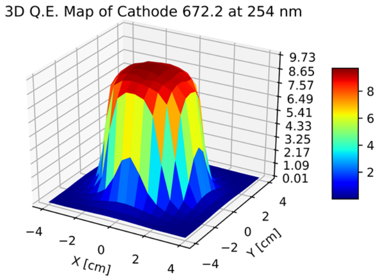
676.1 (5nm)

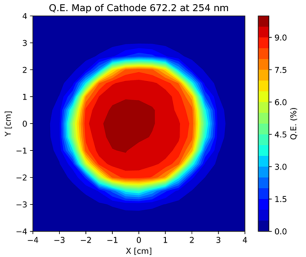




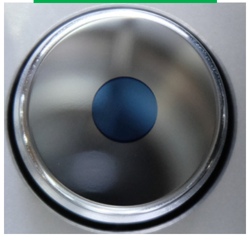
672.2 (10nm)

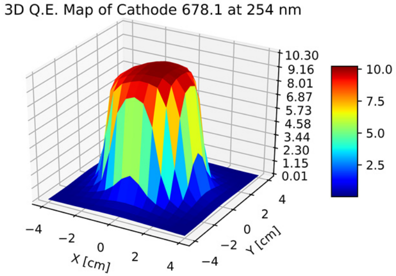


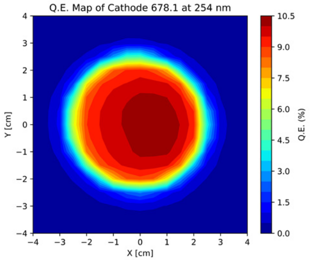




678.1 (15nm)







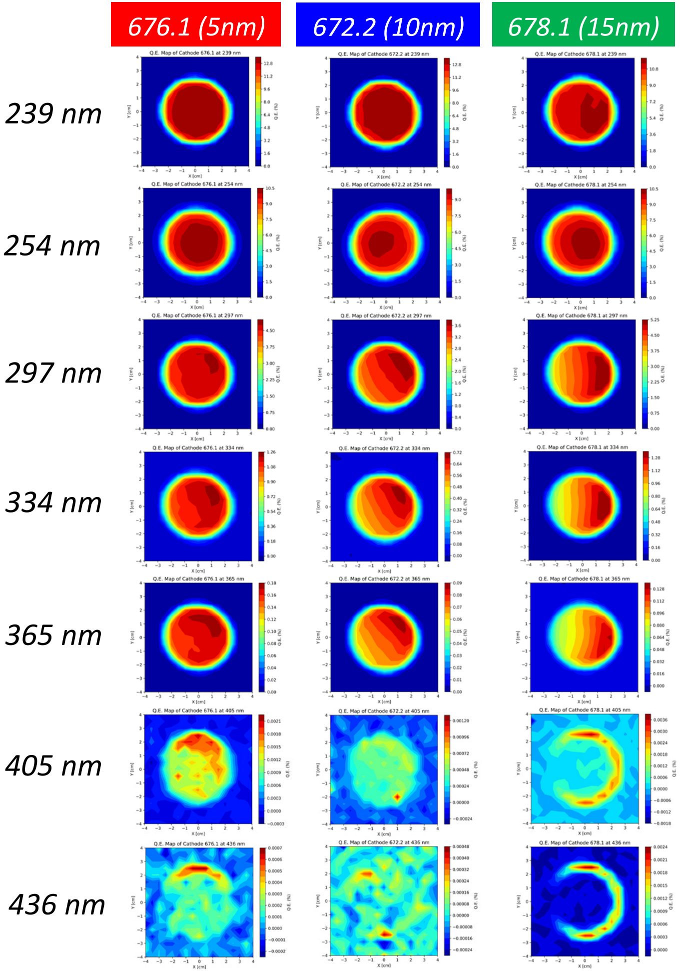
- The QE maps are taken @ 254 nm, to check the spatial uniformity
  - Vapp +500V
  - spot size diameter ϕ ≤ 1 mm
  - step size 0.5 mm
  - range +/- 4 mm

QE uniformity results

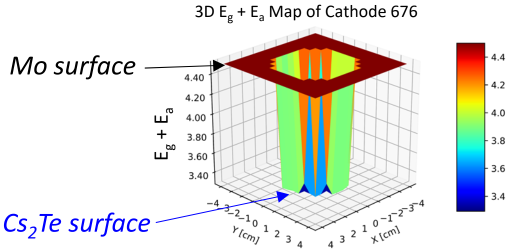
676.1 (5 nm)	672.2 (10 nm)	678.1 (15 nm)
96.0 %	95.9 %	95.5 %

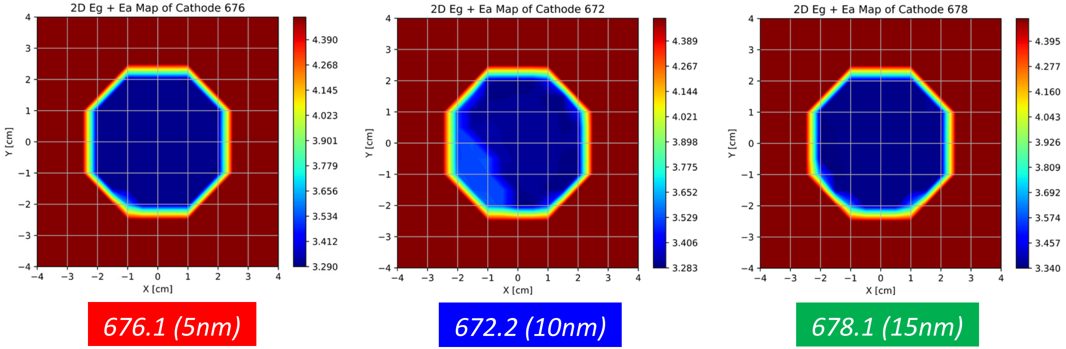
calculated on a ϕ 4.5 mm area

Analysis after production: QE maps at different λs



- The QE maps have been taken also at all wavelengths
- The spectral response analysis applied on the whole map allows getting information about Eg + Ea over the photoemissive surface.
- The Work function of Mo has been set to 4.5 eV





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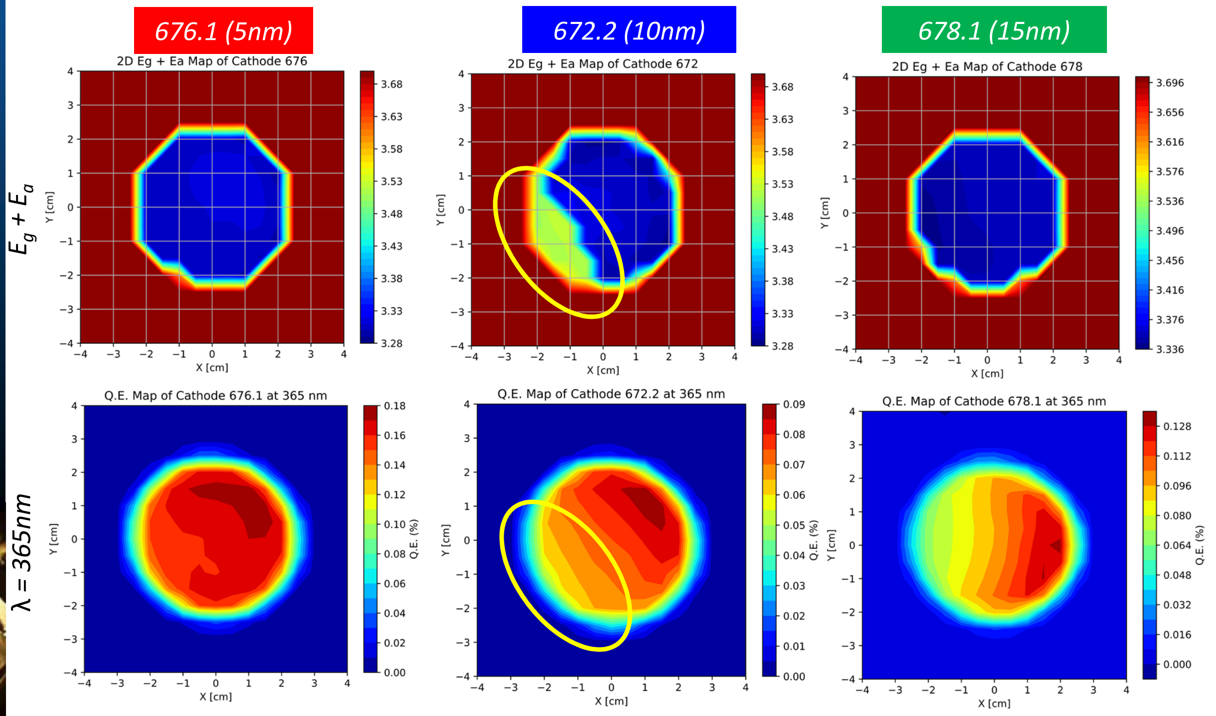
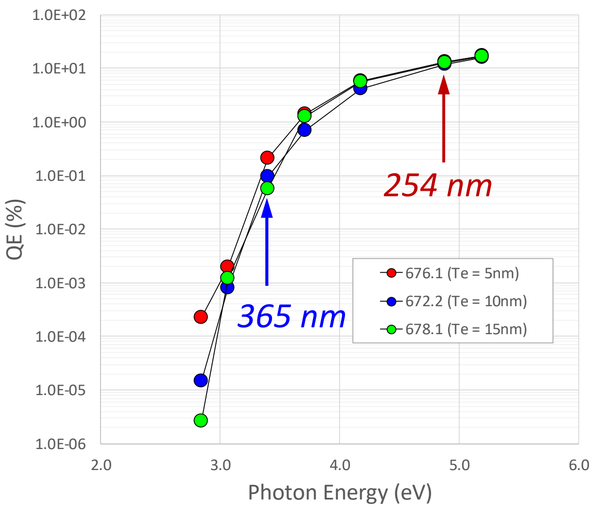
Analysis after production: the E_g+E_a map

Comparison of the E_g+E_a map with the QE map @ 365 nm (more sensitive to variation in E_g+E_a being nearer to the threshold):

- For “10 nm” cathode we have good correlation between low QE and high E_g+E_a





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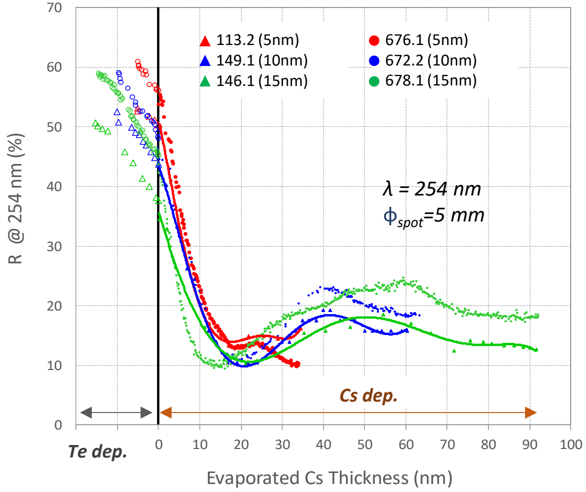
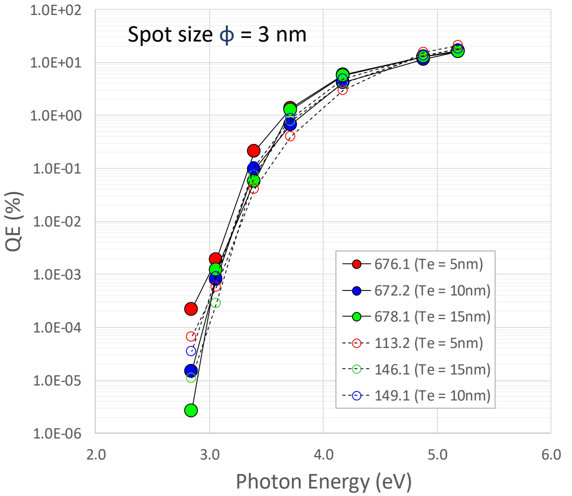
Reproducibility of our recipes

- Besides the standard “10 nm” Te photocathodes, also the photocathodes at “5 nm” and “15 nm” show a good reproducibility.
- R @ 254 nm during Cs deposition show good agreement
- QEs are well reproduced even if the low energy shoulder control needs to be improved.
- Final reflectivity are also well reproduced. The main difference is for “5 nm” at shorter wavelengths.

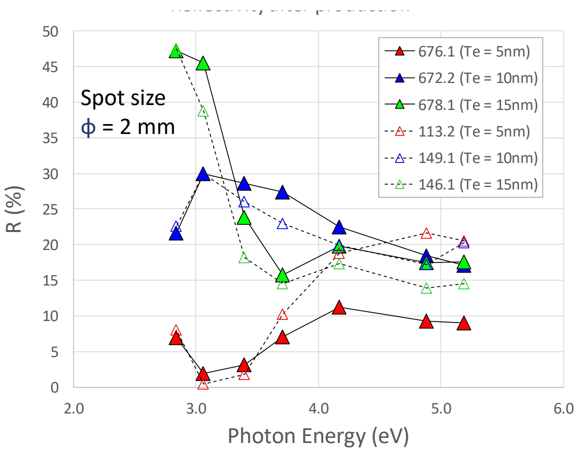
Reflectivity during production

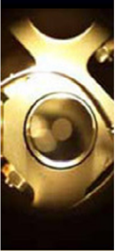


Spectral response after production



Reflectivity after production

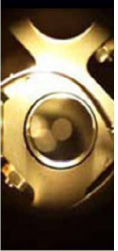




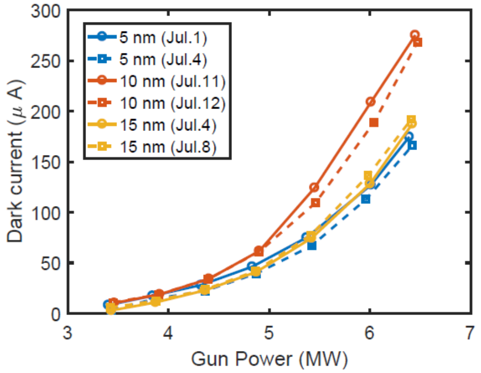
Tests of the three cathodes at PITZ

- Tests of the three new cathodes with different film thickness in a high gradient RF gun have been done at PITZ.
- The testing items include
  - ✓ Dark current
  - ✓ QE vs E
  - ✓ Thermal emittance vs E
  - ✓ QE map and thermal emittance map

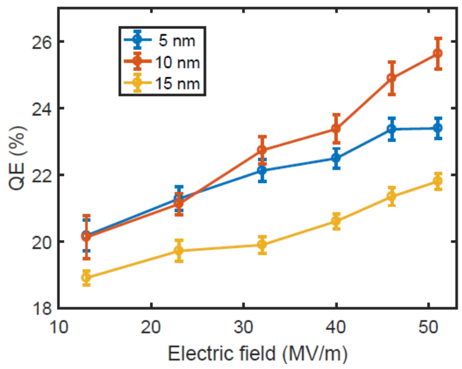
Details can be found in the poster ***WEP062***, Wednesday.



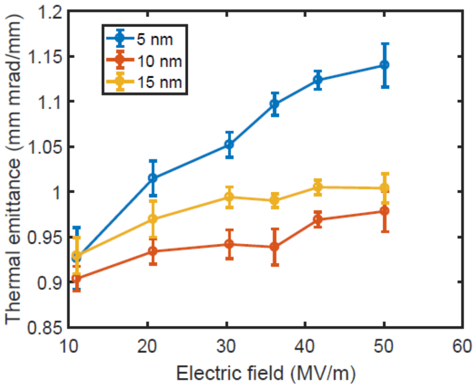
✓ Dark current



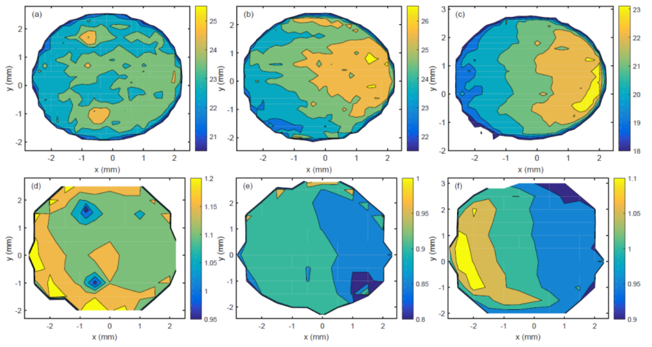
✓ QE vs E



✓ Thermal emittance vs E



✓ QE map (1st row) and thermal emittance map (2nd row)



Conclusion and future perspective

- Three Cs_2Te with different Te thickness have been deposited on INFN plugs
  - QE depends on the Te/Cs ratio
  - Reflectivity depends on film thickness
  - Final QE, QE uniformity (and E_g+E_a) independent from Te thickness
- From test in PITZ RF Gun
  - “5 nm” cathode has higher thermal emittance vs E_{acc}
  - “10 nm” has higher dark current and higher sensitivity to QE increase with E_{acc} (Mo polishing?)
- Future plans:
  - Operative lifetimes vs. thicknesses (at PITZ)
  - Thicker cathodes and more wavelengths to investigate reflectivity and QE measurements
  - Model to obtain the n, k values of Cs_2Te cathodes
  - Explore co-evaporated Cs_2Te with our diagnostic

Thanks to all contributors to this work
and
for your attention!