Photocathodes for SwissFEL

• SwissFEL Introduction
• Photocathode Experience at SwissFEL
• Cs$_2$Te coating (successive, co-evaporation)
• Cs$_3$Sb coating attempts
• Conclusion and perspectives
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SwissFEL

PSI West

PSI East

Hard X-Ray FEL
740 m Long
First Beam End 2016
Aramis

Linear polarization, variable gap, in-vacuum Undulators

First users 2018

Athos

Soft X-ray FEL, variable polarisation

First users 2021

Aramis Main parameters

- Photon energy: 2 – 12.4 keV
- Pulse duration: 20 fs
- e⁻ Energy: 2.1 - 5.8 GeV
- e⁻ Bunch charge: 10-200 pC
- Repetition rate: 100 Hz
SwissFEL RF Photoinjector:
S band, 2.5 Cell; 7 MeV; 100 MV/m; 100 Hz; 10 - 200 pC

Exchangeable cathode plug(*)

(*) CERN design: CLIC Note 303 (1996)
Loadlock chamber behind RF gun

- Loadlock chamber
- Vacuum suitcase

~ 500 N
Vacuum suitcase connected to the load-lock, showing the cathode transfer principle and the storage carrousels.
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Loadlock installed in 2013 at the SITF:

=> Recipe to get reproducible copper $\text{QE}_{\text{Cu}} \sim 10^{-4}$

=> First test of Cs$_2$Te Cathodes: $\text{QE} \sim 10^{-2}$
• 2015: Decision to operate SwissFEL only with Cs$_2$Te

• 2016: Gun + Loadlock moved to SwissFEL
From October 2016 to July 2017: Cathode #32

28.10.2016: QE = 1.3%

04.07.2017: QE ~ 1.3%
\[ \delta_{QE}/QE \sim 15\% \]

Cathode #32: Cs$_2$Te by co-evaporation; very thin layer < 20nm

No QE decay in 10 Months
Why was cathode exchanged?

Electron Beam uniformity issues

⇒ Exchanged cathode on July 21st 2017
⇒ $\text{Cs}_2\text{Te}$ detached at some area (dark spot visible by eye)
From October 2016 to July 2017: Cathode #31

Cathode#31: Cs$_2$Te by successive evaporation; $\sim$ 40nm

24.07.2017:

Averaged QE $\sim$ 0.6 %
Cathode imaging with e-beam on YAG

No defects clearly visible

Courtesy of N. Hiller
Uniformity of Cathode#31

14.07.2017

Stepper motor scan

1 mm

18.08.2017

Uniformity $\delta_{QE}/QE \sim 15\%$

QE scans: 5 pC; $\sigma_{r,\text{laser}} \sim 100$ um
Averaged QE dropped by 40% after 6 Months

or after ~ 15 mC of charge extraction

$P_{cathode} < 1.10^{-9}$ mbar ($1.1e-11$ mbar at the pump)

Influence of Cu substrate?

Lifetime until QE~0.1% > 1 year

Cathode #31 ($Cs_2Te$)

10 Hz; 200 pC

100 MV/m
Cathode emission uniformity

02 Sept. 2017:
Uniformity $\delta_{\text{QE/QE}} \sim 15\%$

Cathode started to develop a QE hole in recent months!

31 Jul. 2018
Uniformity $\delta_{\text{QE/QE}} \sim 10\%$

Cathode #31
Slice emittance / Intrinsic emittance

**Expected Intrinsic emittance**

\[ \varepsilon_{\text{intrinsic,Simple}} = \sigma_{\text{x,laser}} \sqrt{\frac{h\nu - \Phi_{\text{eff}}}{3mc^2}} \]

- \( \sigma_{\text{x,laser}} = 0.148 \text{ mm} \)
- \( \Phi_{\text{Cs}_2\text{Te}} = 3.5 \text{ eV} \)
- \( F = 50 \text{ MV/m} \)
- \( \Phi_{\text{eff}} = 3.23 \text{ eV} \)
- \( h\nu = 4.77 \text{ eV} \)

\[ \varepsilon_{\text{intrinsic}} = 145 \text{ nm.rad} \]

**Measured slice emittance**

Core EmittanceX = 154.3 nm, Projected EmittanceX = 194.83 nm

\[ \sigma_{\text{x,laser}} = 0.148 \text{ mm} \]

\[ \varepsilon_{\text{slice}} = 155 \text{ nm.rad} \]

Charge 200 pC; 300 MeV

Measured slice emittance close to Intrinsic emittance!

~ Copper emittance (Phys. Rev. ST Accel. Beams 18, 043401 (2015))

*Courtesy of E. Prat*
Reducing microbunching gain with $\text{Cs}_2\text{Te}$

**Beam longitudinal phase space after compression**

200 MeV; Factor 6 compression

$\text{Cu photocathode}$

100 pC, ~ 60 A

$\text{Cs}_2\text{Te photocathode}$

200 pC, ~ 120 A

Slower extraction smooths out the longitudinal charge modulation induced by the profile of the illuminating laser.

Results from SITF 2014 - Courtesy of S. Bettoni
Small microbunching gain at SwissFEL

- $\text{Cs}_2\text{Te}$ smooths out the laser profile ripples (more than Cu)
- Microbunching instabilities seems small at SwissFEL

$=>$ Slow cathodes limits microbunching instability gain?

BUT

- LCLS Simulations showed that Microbunching comes from “shot noise” even if laser profile is ideally flat!
- SACLA observed microbunching instabilities with thermionic gun!
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SwissFEL Cathode Preparation system

Microscope camera

Cathode annealing
QE measuring chamber

Linking Chamber

Vacuum Suitcase

Cs2Te Evaporation chamber
Blind deposition:
15nm Te
25 nm Cs
SwissFEL Cathode Preparation system

266nm LED for QE monitoring

Vacuum Suitecase
Cs$_2$Te Deposition

- successive deposition of Te and then Cs
  (recipe from CERN: CERN - CLIC Note 299 – E. Chevallay)

- Coevaporation of Cs and Te
Recipe:
- Cu plug annealed 10 h at 250 deg C
- Co-evaporation while monitoring photocurrent

Difficulty:
- Control of stoichiometry
  (Cs source heats Te source !)
- No independent Cs thickness monitoring

Pressure rises from $10^{-10}$ to $10^{-8}$ mbar
SwissFEL Introduction
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Cs\textsubscript{2}Te coating (successive, co-evaporation)
\textbf{Cs\textsubscript{3}Sb coating attempts}
Conclusion and perspectives
Co-evaporation of Cs and Sb

**Motivation for Cs$_3$Sb:**
- illuminate photocathode with 532 nm
  => Better laser shaping possible
  => Less optics degradation

Cs$_3$Sb compound:

$E_{\text{gap}} = 1.6 \text{ eV}$

$E_{\text{e- affinity}} = 0.45 \text{ eV}$

$\Phi_{\text{eff}} = E_{\text{gap}} + E_{\text{e- affinity}} - E_{\text{schottky}} = 1.7 \text{ eV}$
Evaporation chamber for $\text{Cs}_3\text{Sb}$

- Cs getters (SAES)
- Anode to collect photoelectrons
- Sb shots melted in a Mo Boat
- Mask and holder of the photocathode (can be heated up)
- Quartz microbalance
- RGA to monitor vacuum and Sb, Cs ions.

$P \sim 1.0 \times 10^{-11}$ mbar
Co-Evaporation Cs & Sb

Recipe:
Sb heating power has to be reduced!
Deposition rate Sb: 0.01 – 0.02 Å/s
Deposition rate Cs: 0.1 Å/s
T_{cathode} = 120°C,
Pressure increases to 1.5e-8 mbar
DC illumination with 532nm LED
RGA during co-evaporation

Sb evaporator heats up with Cs evaporator

RGA mass spectrum in the evaporation chamber: Sb and Cs
Total pressure went from 5e-10 mbar to 1.5e-8 mbar
**QE Lifetime of Cs$_3$Sb cathode #27**

Cs$_3$Sb:  
- QE ~ 0.6% at end of deposition (650 nA)  
- QE ~ 0.1% after 1 hour  
- QE ~ 0.001% after 100 hours (w/o illumination)

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**Graphical Representation**

- **Cu$_{27}$ photocurrent**
- **Photocurrent**
- **QE**
- **Time (hours)**

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**Note:**

Lifetime much too short ... for the moment!

QE in gun factor 2 larger due to electric field.
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Conclusion

- Cs$_2$Te experience with SwissFEL user operation rather positive
- Lifetime seems > 1 year with 30 mC/year, 100 MV/m, 5.0*10$^{-10}$ mbar
- Beam quality: slice emittance <300nm; small microbunching instabilities?
- First Cs$_3$Sb coating had acceptable QE (>0.1%) but lifetime much too short

*Perspectives:*

- Photocathodes development with sensitivity to green light
  - Cs$_2$Te with Ge doping to reduce bandgap (532nm)
  - CdTe with Cs activation to reduce electron affinity
Welcome to EWPA 2019!

Dear Colleagues,

It is our pleasure to announce that the European Workshop on Photocathodes for Particle Accelerator Applications (EWPA 2019), will be held at the Paul Scherrer Institut, Switzerland, from September 11 to 13, 2019.

We invite you to participate to this workshop with focus on the recent progress in research and development of photocathodes for accelerator applications. Contributions are welcome from all related topics, including operational experience, preparation, instrumentations, theoretical modelling, industrial applications and novel materials. The scientific programme of the workshop will consist of invited talks and contributed presentations, either in the form of oral presentations or posters.

The workshop will be held from Wednesday noon to Friday noon with the Wednesday afternoon assigned for the poster session and Thursday afternoon for a visit at the SwissFEL facility and the photocathode laboratory as well as the workshop dinner.

Registration and abstract submission will be opened in March 2019.

Scientific Programme Committee
Julius Kühn (HZB)
Thorsten Kamps (HZB)
Tim Noakes (UKRI STFC)
Lee Jones (UKRI STFC)
Rong Xiang (HZDR)
Antonella Lorusso (INFN Lecce)
Christoph Hessler (CERN)
Romain Ganter (PSI)
Background Vacuum

RGA mass spectrum in the evaporation chamber: Sb and Cs after 100 h baking at 250 deg C
Total pressure 9.e-11 mbar - 17.07.2018

- H$_2$
- C
- CH
- CH$_4$
- CO / N$_2$
- CO$_2$
- H$_2$O

Partial pressure (torr)

mass (m/q)
Aramis FEL pulses:

$E_{\text{Photons}}$: max 12.4 keV

Achieved FEL Pulse Energy:
- 570 μJ at 3 keV
- 400 μJ at 6 keV

... still under improvement