



PhASE 2026 · ORSAY, FRANCE

Overview on Photocathode Research and Development in China

Huamu Xie · Peking University
on behalf of the photocathode research team in China

Photocathodes for Accelerator Science in Europe
21–23 September 2026 · IJCLab

1 SINAP/SARI/ZJLAB

facility evolution, Cs₂Te preparation and in-gun operation

2 Tsinghua University

Cs₂Te and K₂CsSb photocathode deposition systems

3 Dalian Advanced Light Source

Cs₂Te preparation, reproducible fabrication, storage lifetime and DALS gun operation

4 Wuhan University

Cs₂Te photocathode deposition system (ultimate pressure 1.54×10^{-9} Pa)

5 China Academy of Engineering Physics

K₂CsSb deposition system; time-of-flight MTE measurement chamber

6 Institute of High Energy Physics

High-voltage DC gun; superlattice GaAs for high polarization

7 Chongqing University

Cs-Te / Cs-O-Te activation of GaAs photocathode

8 East China University of Technology

Nanophotonic GaAs NEA photocathodes: : nanostructured emitting surfaces; metasurface and Fabry–Pérot designs with flat emitting surfaces

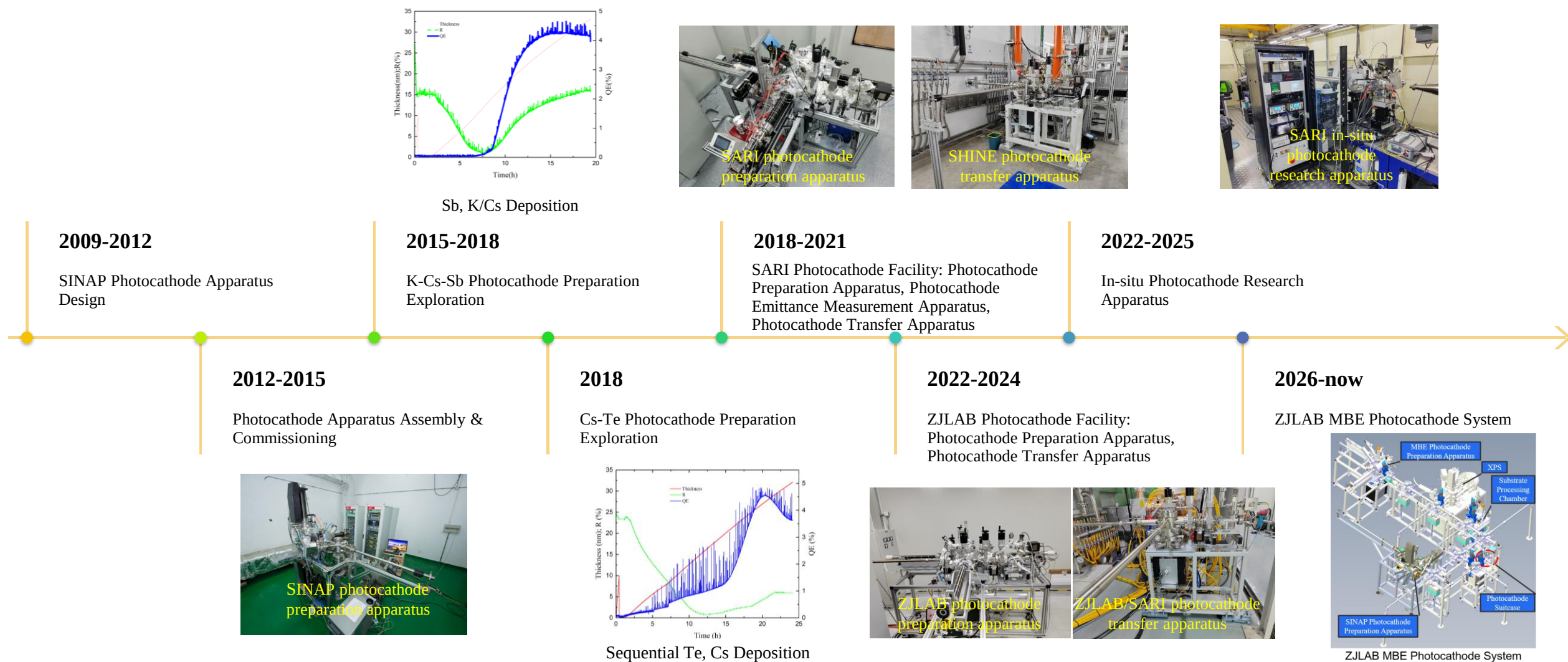
9 Westlake University

Coherent secondary photoemission from SrTiO₃; four-step model for quantum materials

10 Peking University

K-rich K₂CsSb in a cryogenic DC-SRF gun; high QE & ultralow MTE; cryogenic free-drift MTE platform

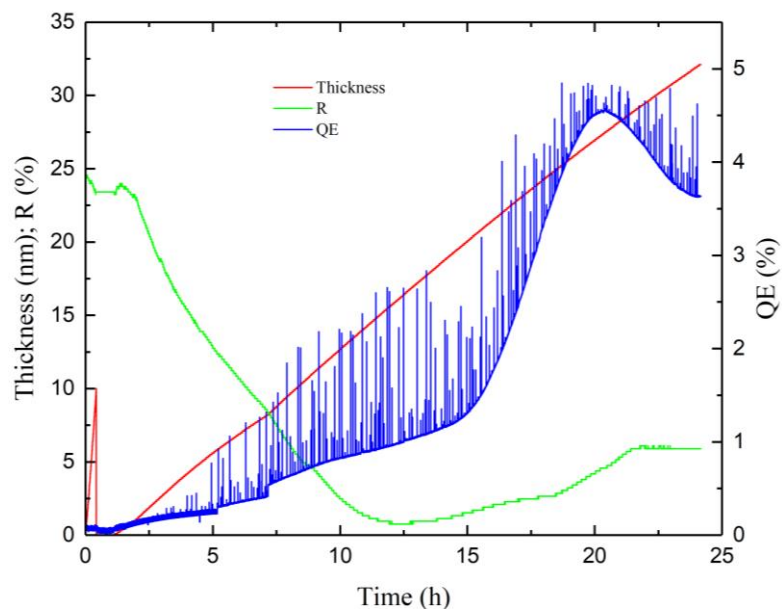
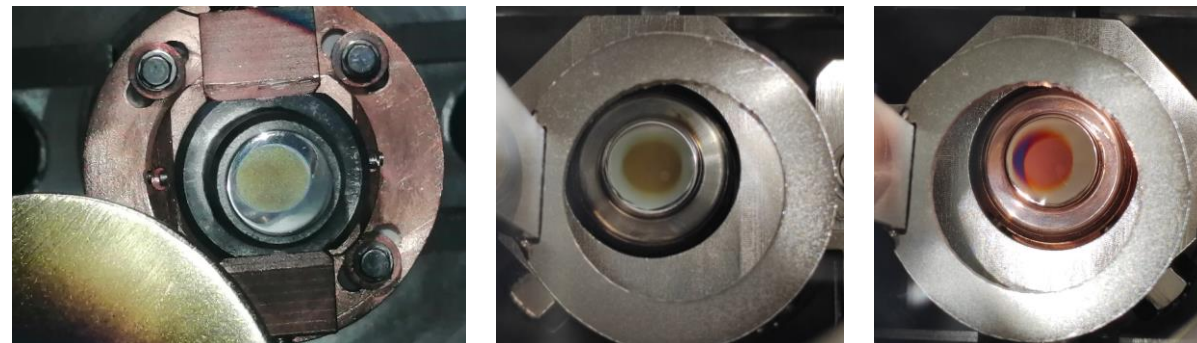
Evolution of Photocathode Facilities and Related Research in SINAP/SARI/ZJLAB Team



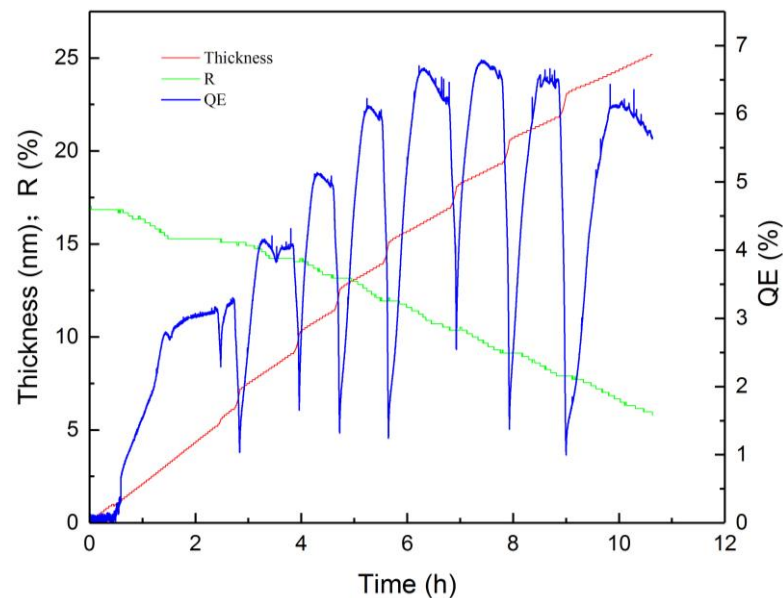
Courtesy of LI Xudong

■ Cs₂Te Photocathode Preparation

- Sequential Te, Cs Deposition
- Intermittent Te, Continuous Cs Deposition
- Te, Cs Co-evaporation

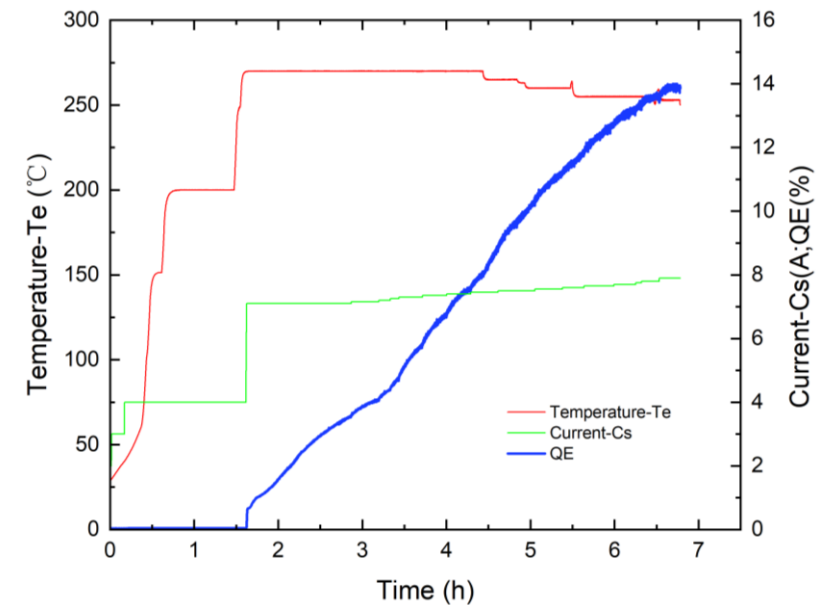


Sequential Te, Cs Deposition



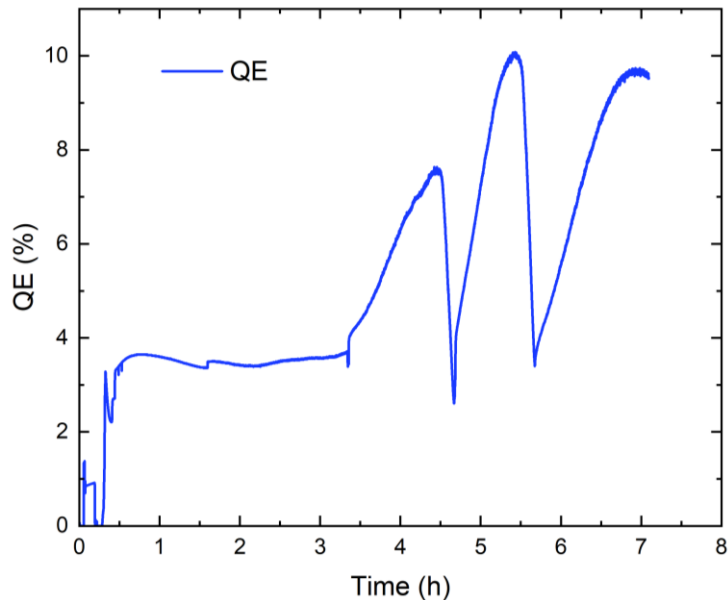
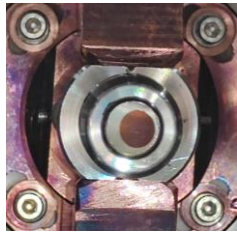
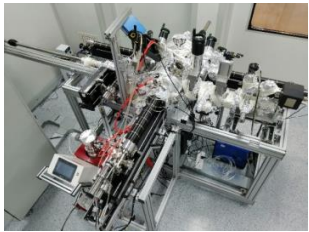
Intermittent Te, Continuous
Cs Deposition

Courtesy of LI Xudong

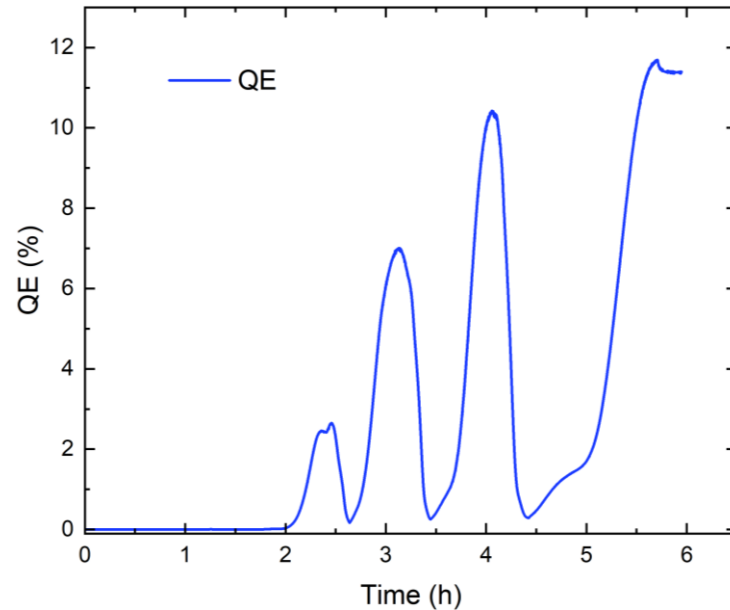
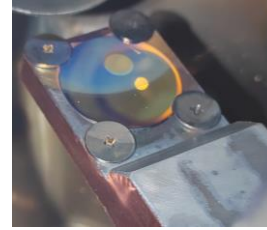


Te, Cs Co-evaporation

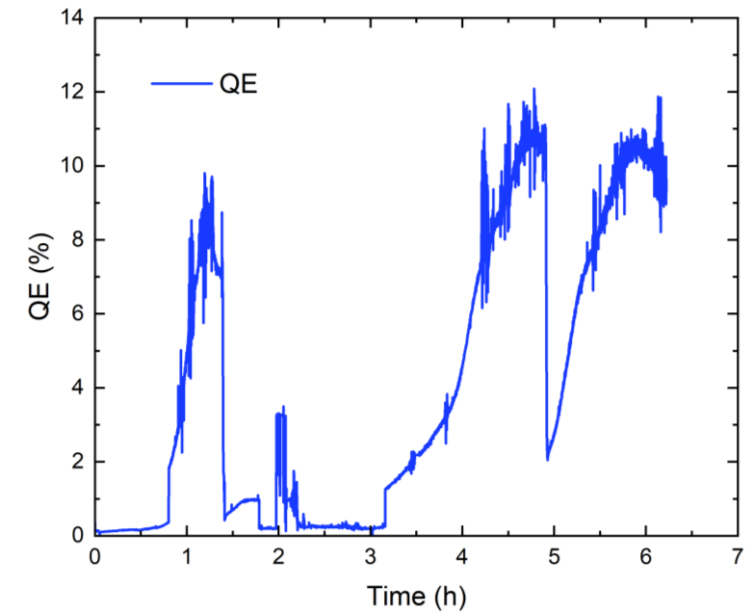
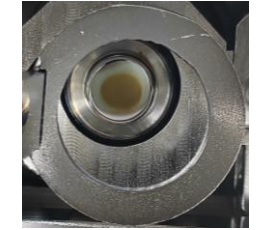
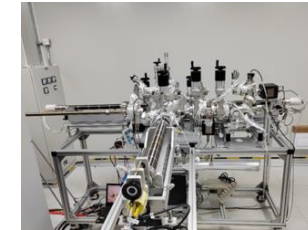
▣ Cs₂Te photocathode preparation by intermittent Te and continuous Cs deposition on different apparatus



SARI photocathode preparation apparatus



SARI in-situ photocathode research apparatus



ZJLAB photocathode preparation apparatus

Courtesy of LI Xudong

▣ Cs₂Te photocathode operation @SHINE photocathode VHF electron gun

▣ Support commissioning of SHINE electron gun, injector, Linac and undulator commissioning



1 Dec 2023

- Mo plug(Ra~50nm): 36.5nm(Not over-inserted)
- QE=7.5%@255nm(Preparation chamber)
- QE=10%@257.5nm(Electron gun)
- Objective:
- SHINE VHF Gun Commissioning



14 Jan 2014

- Mo plug(no polishing): 36.5mm(Not over-inserted)
- QE=10%@255nm(Preparation chamber)
- QE=12.5%@257.5nm(Electron gun)
- Objective:
- Cs₂Te Photocathode Dark Lifetime (SHINE VHF Gun)
- Dark current: up to 5 μ A



25 Sep 2024

- SS plug(Ra~10nm): 37mm(0.5mm over-inserted)
- QE=11%@255nm(Preparation chamber)
- QE=7.5%@257.5nm(Electron gun)
- Objective:
- SHINE Injector Commissioning
- Gun dark current: abrupt rise 20 nA $\rightarrow$ 400 nA (during commissioning)



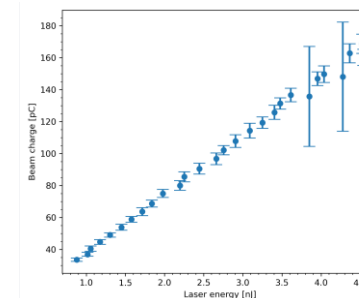
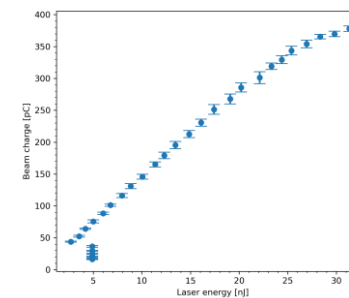
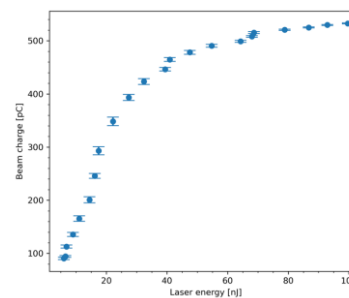
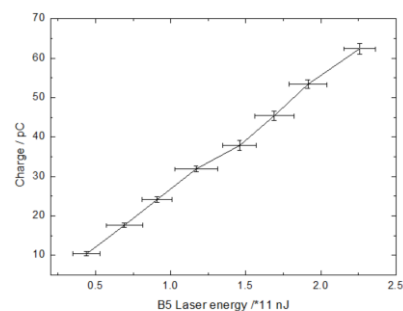
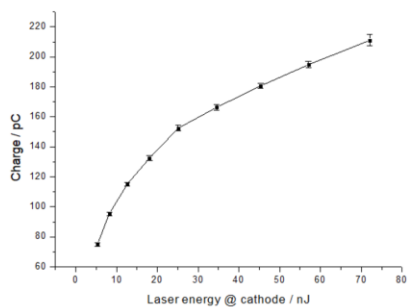
25 Nov 2024

- Mo plug(Ra~15nm): 37mm(0.5mm over-inserted)
- QE=18%@255nm(Preparation chamber)
- QE=7.5%@257.5nm(Electron gun)
- Objective:
- SHINE Injector Commissioning
- Gun dark current: < 2 nA



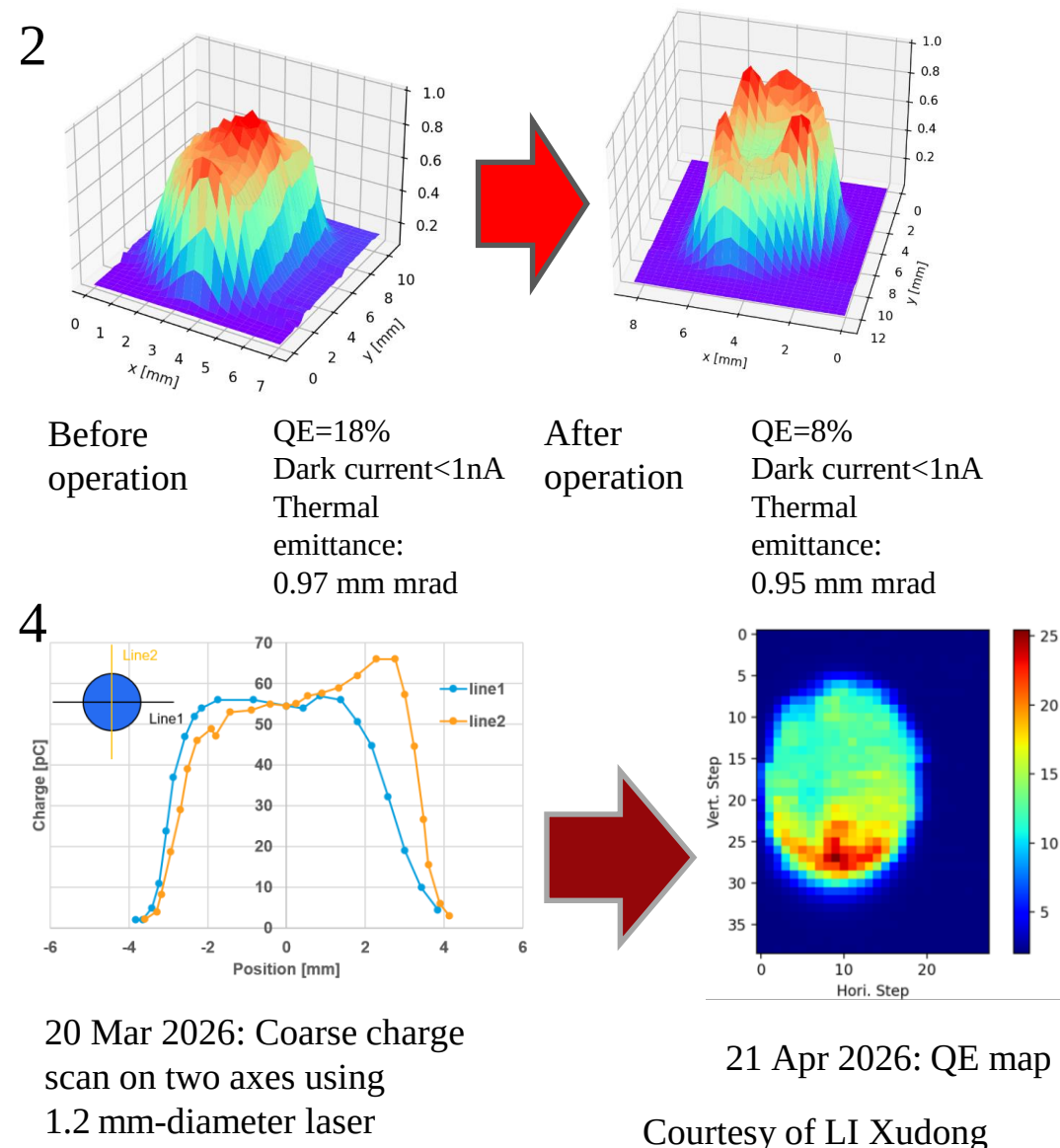
25 Jun 2025

- Mo plug(Ra~15nm): 37mm(0.5mm over-inserted)
- QE=5%@255nm(Preparation chamber)
- QE=18%@257.5nm(Electron gun)
- Objective:
- Linac and undulator commissioning
- dark current: < 2 nA (25 Jun 2025) $\rightarrow$ < 3 nA (26 Jun 2026)

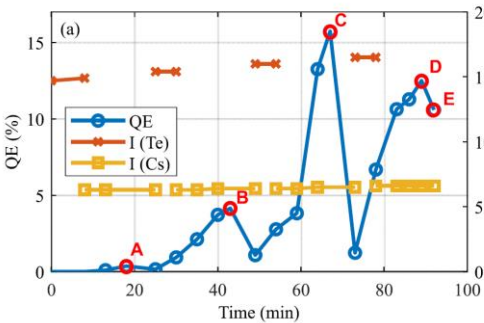
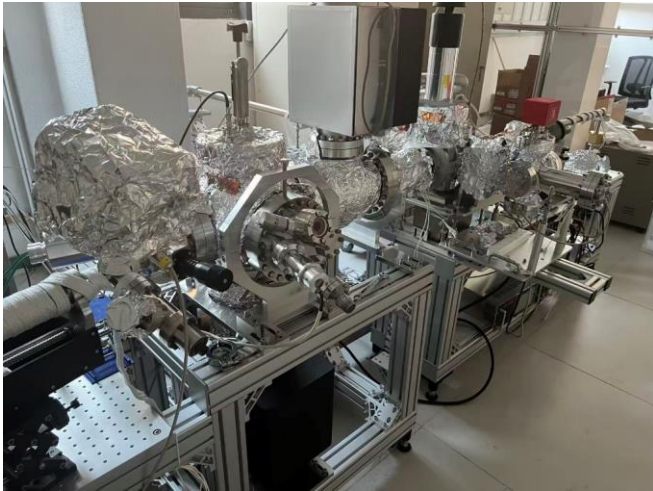


▣ Cs₂Te photocathode operation @ZJLAB/SARI
photocathode VHF electron gun

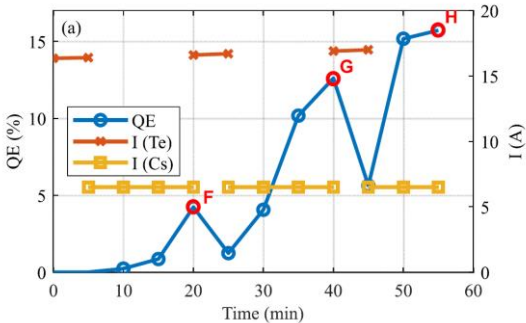
	Time	Current	QE@257nm
1	2024.12.27-2025.01.06	0.1mA	16%→5%
2	2025.03.22-2025.03.29	1mA	18%→8%
3	2025.12.09-2025.12.18	0.45mA	5.8%→1.34%
4	2026.03.21-2026.04.21	0.5mA/1mA	13.1%→10.7%



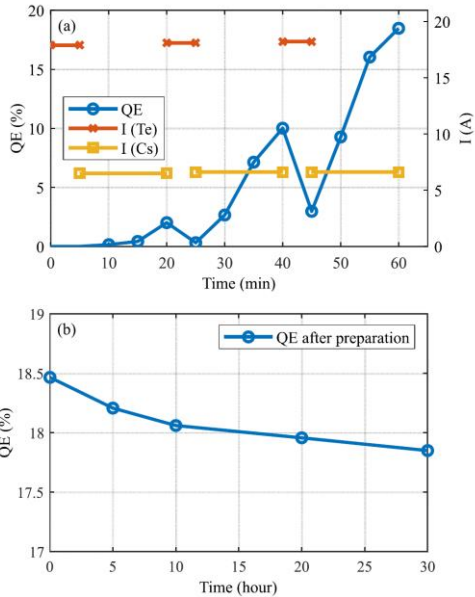
THU: Cs₂Te photocathode deposition



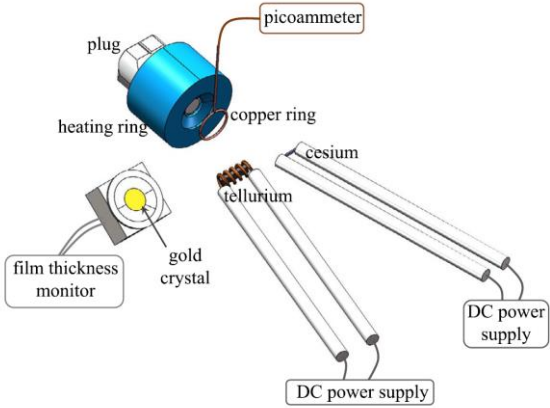
Four-layer deposition experimental



Three-layer deposition experimental



The maximum quantum efficiency is 18.5%, and the 1/e lifetime fit is greater than 760 hours



Internal structure diagram of the preparation chamber

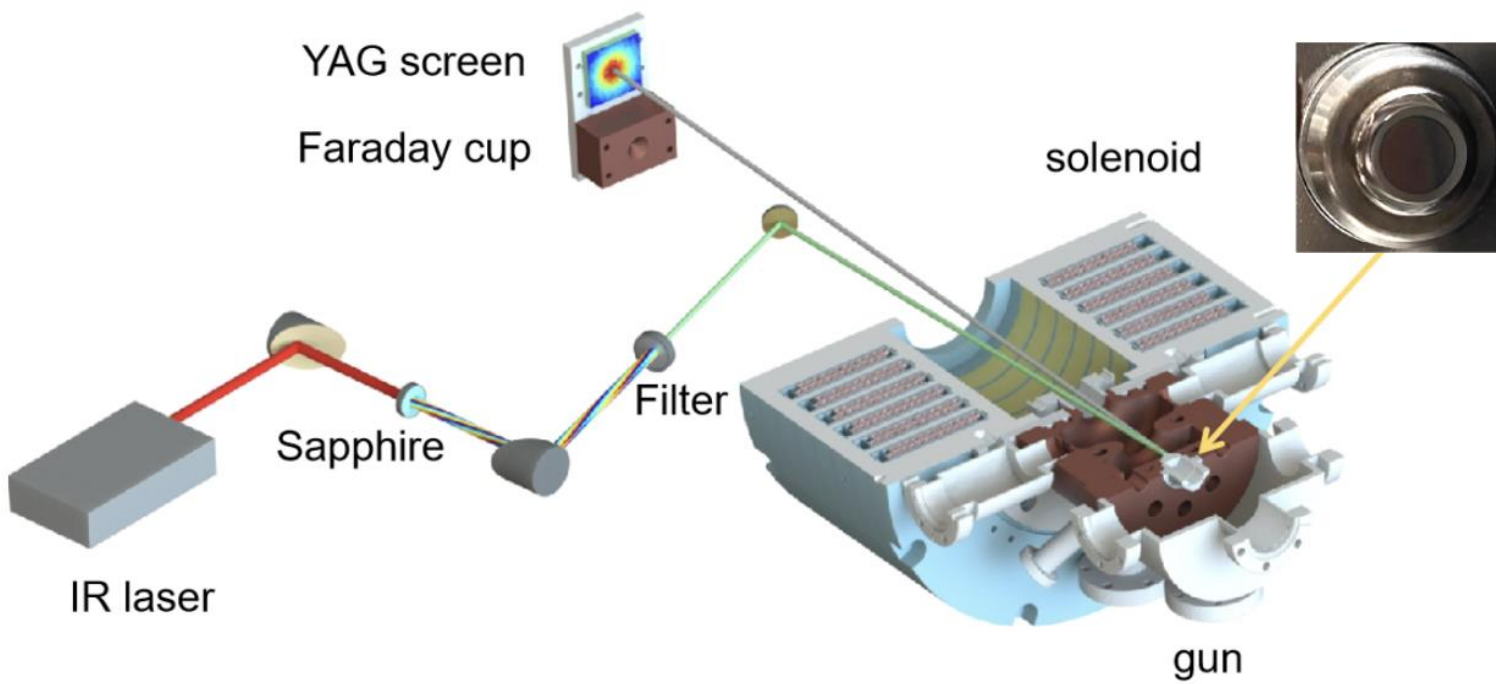
Point	Te thickness (nm)	Cs ₂ Te thickness (nm)	Ratio	QE
A	5.6	22.1	0.253	0.4%
B	11.2	46.2	0.242	4.1%
C	16.6	81.2	0.204	15.7%
D	22.0	111.6	0.197	12.5%
E	22.0	121.2	0.182	10.6%
F	5.5	27.5	0.201	4.2%
G	11.0	57.6	0.191	12.6%
H	17.0	85.4	0.199	15.7%

The optimal ratio of the thickness of tellurium to the relative thickness of cesium tellurate is approximately 0.2

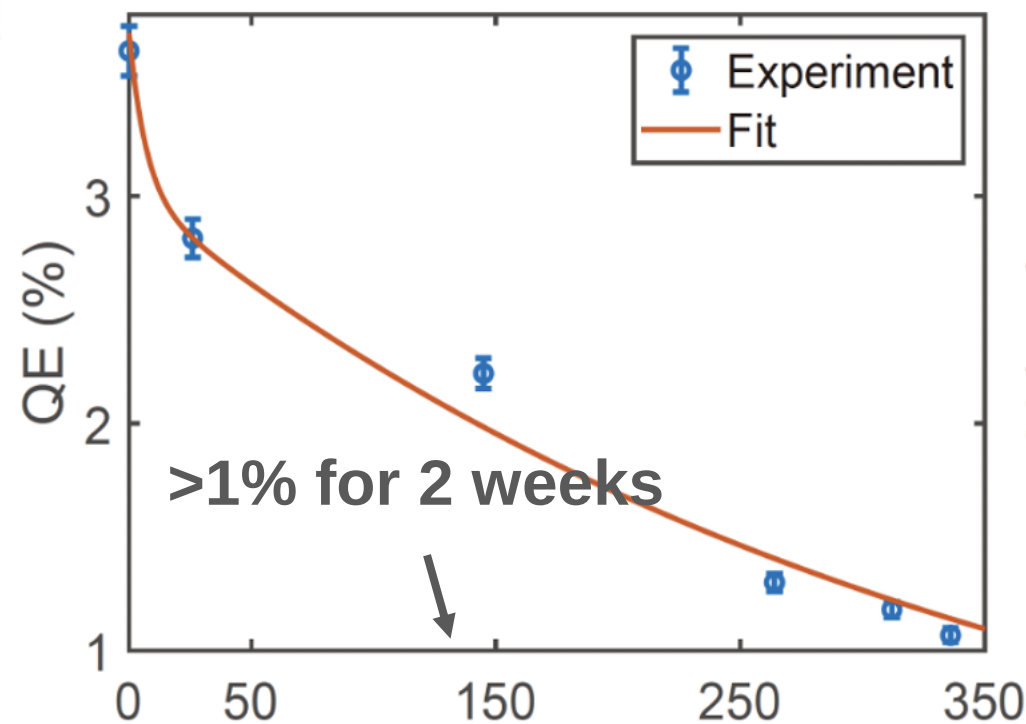
layer	Te thickness (nm)	Cs ₂ Te thickness (nm)	QE
4	23.0	115.3	11.7%
4	22.6	106.8	12.4%
4	16.5	83.8	14.5%
3	16.0	79.6	15.6%
3	15.8	77.4	15.2%
3	17.0	85.6	17.1%
3	16.5	83.0	18.5%

The results of the subsequent several experiments

- THU: K_2CsSb photocathode deposition



K_2CsSb in ultrahigh-vacuum S-band gun @ 100 MV/m



- K_2CsSb first time survived and characterized at ~ 100 MV/m

- Measured QE and MTE at different laser wavelength, P. Huang et al., to be submitted

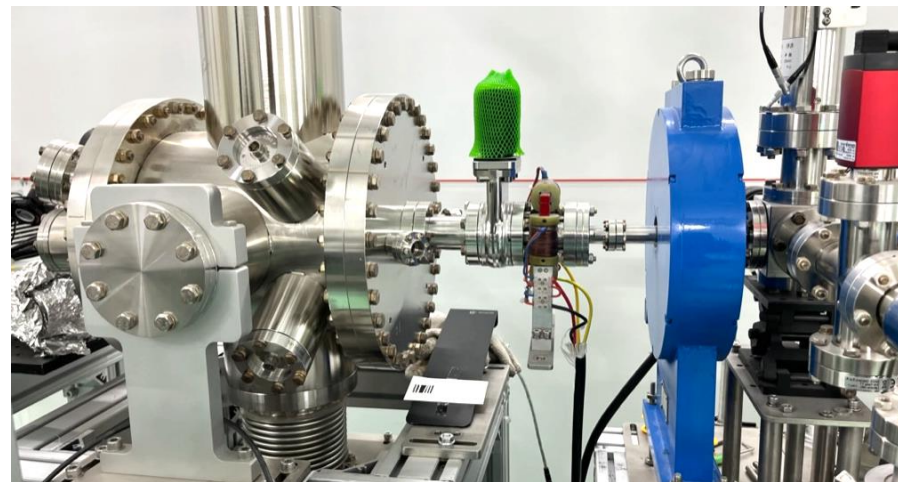
- Potential benefits for FEL and others, P. Huang, NIMA 1051, 168251 (2023)

- THU: Photocathode R&D infrastructure at Tsinghua

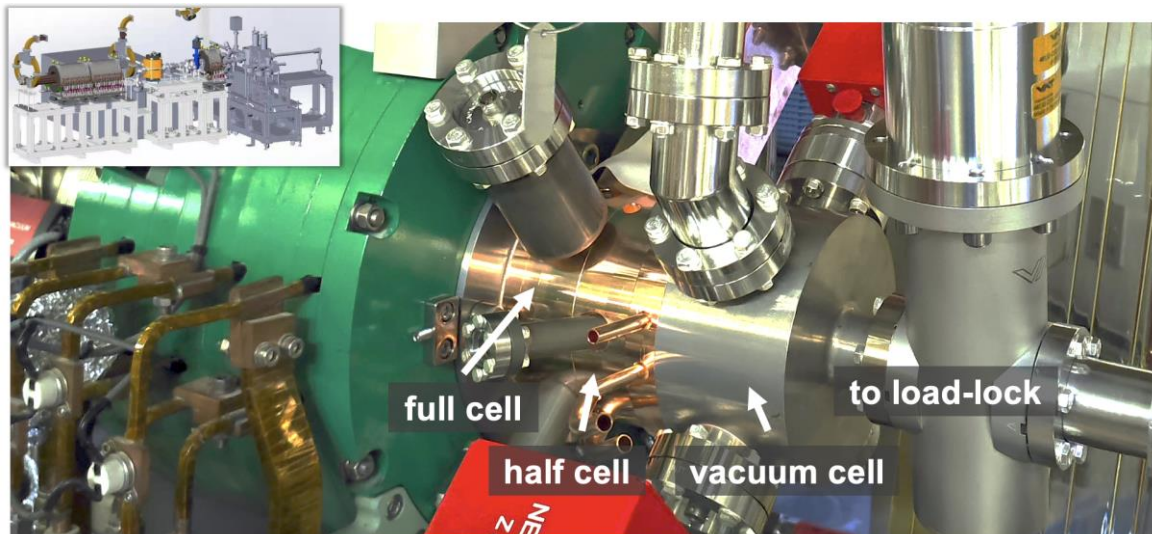
Photocathode preparation system



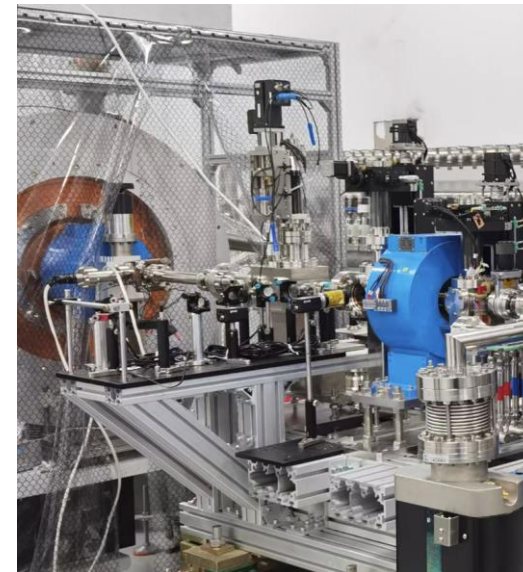
200 keV DC gun, 7.5 MV/m



Ultrahigh vacuum S-band gun up to 100 MV/m



VHF gun, CW, ~30 MV/m

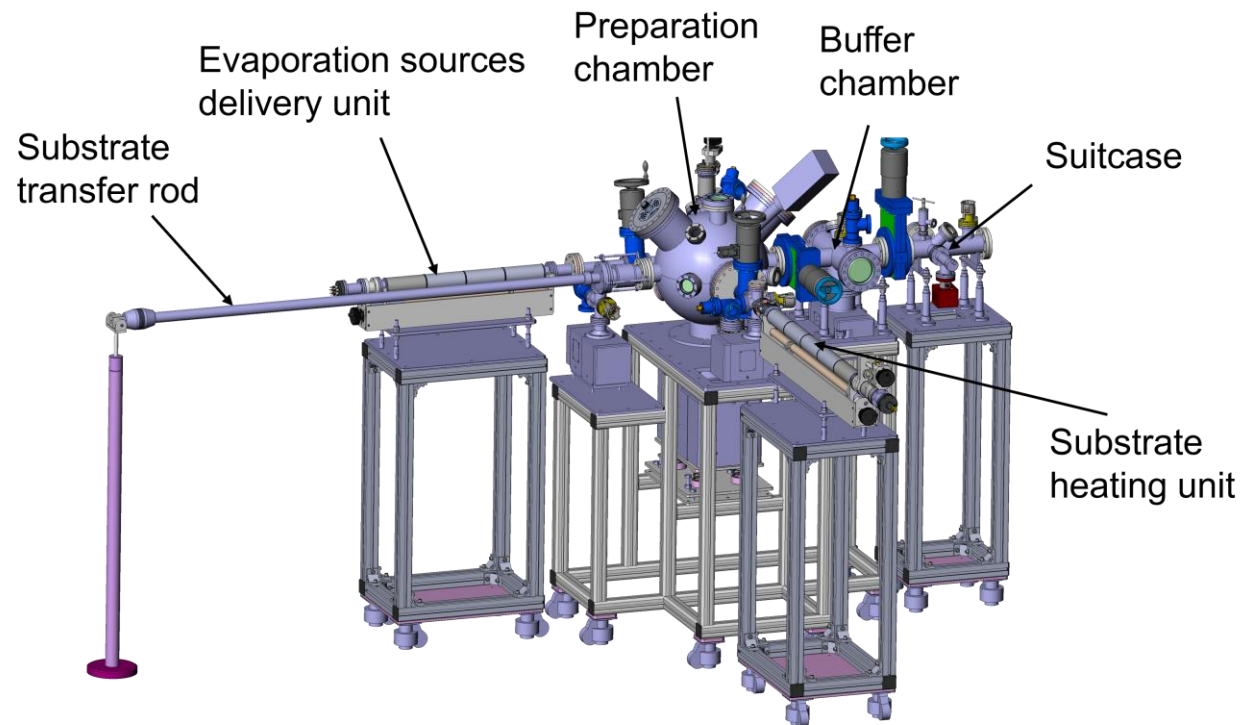


Courtesy of LI Renkai

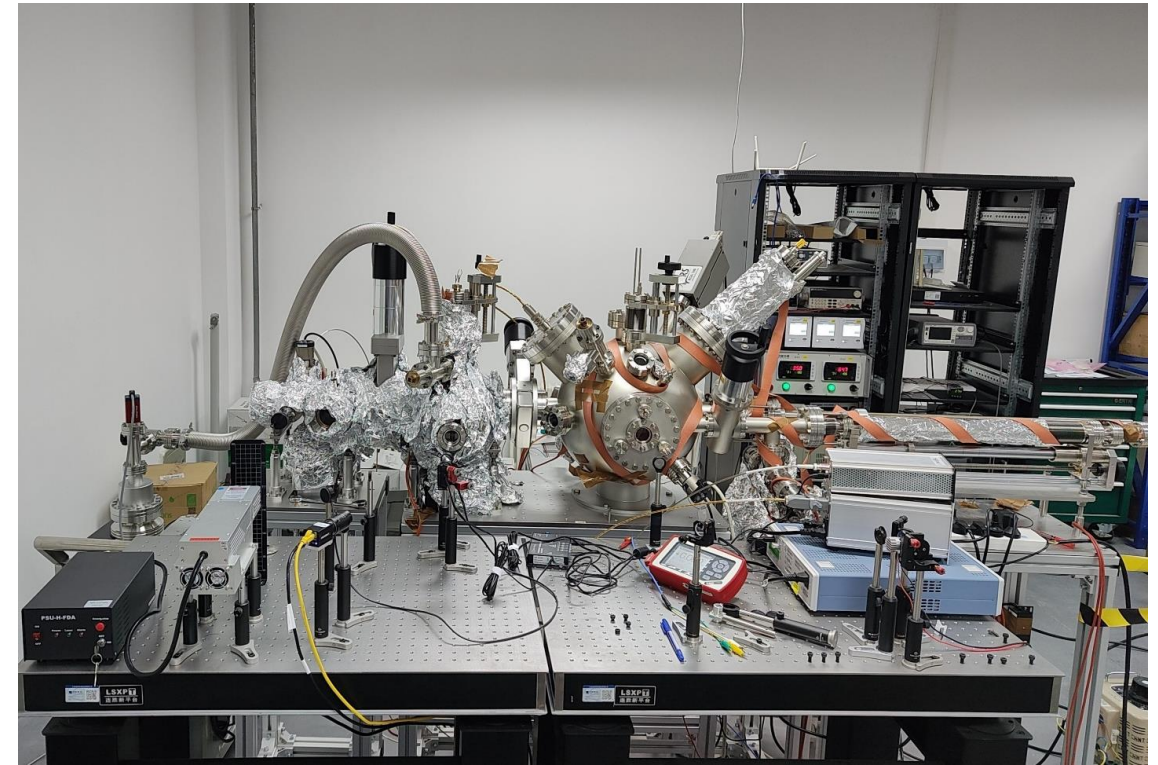
● DALS: Cs₂Te photocathode preparation system

A LASA-inspired UHV system has been established for reproducible Cs₂Te growth, storage and transfer to guns.

Commissioned in 2022 · base pressure 3×10^{-9} Pa · integrated evaporation, heating, buffer and storage&transfer chambers



System layout: substrate transfer, Te/Cs sources, preparation, buffer and storage chambers



Installed preparation system and in-lab commissioning setup

● DALS: Reproducible Cs₂Te fabrication and storage lifetime

The process reproducibly delivers high-QE Cs₂Te cathodes at 255 nm, with long-term stability under UHV storage.

15+ cathodes

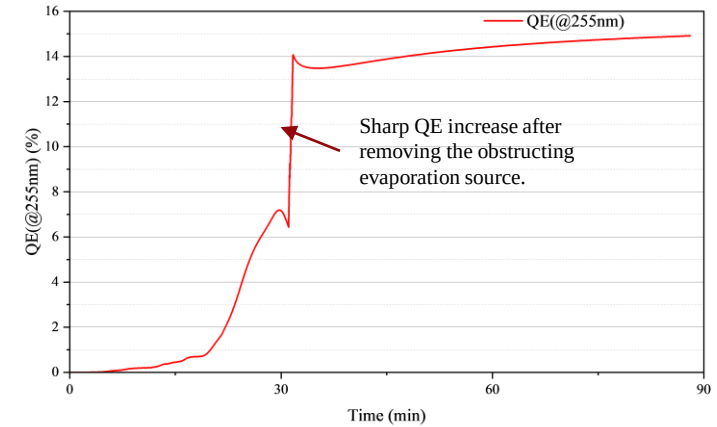
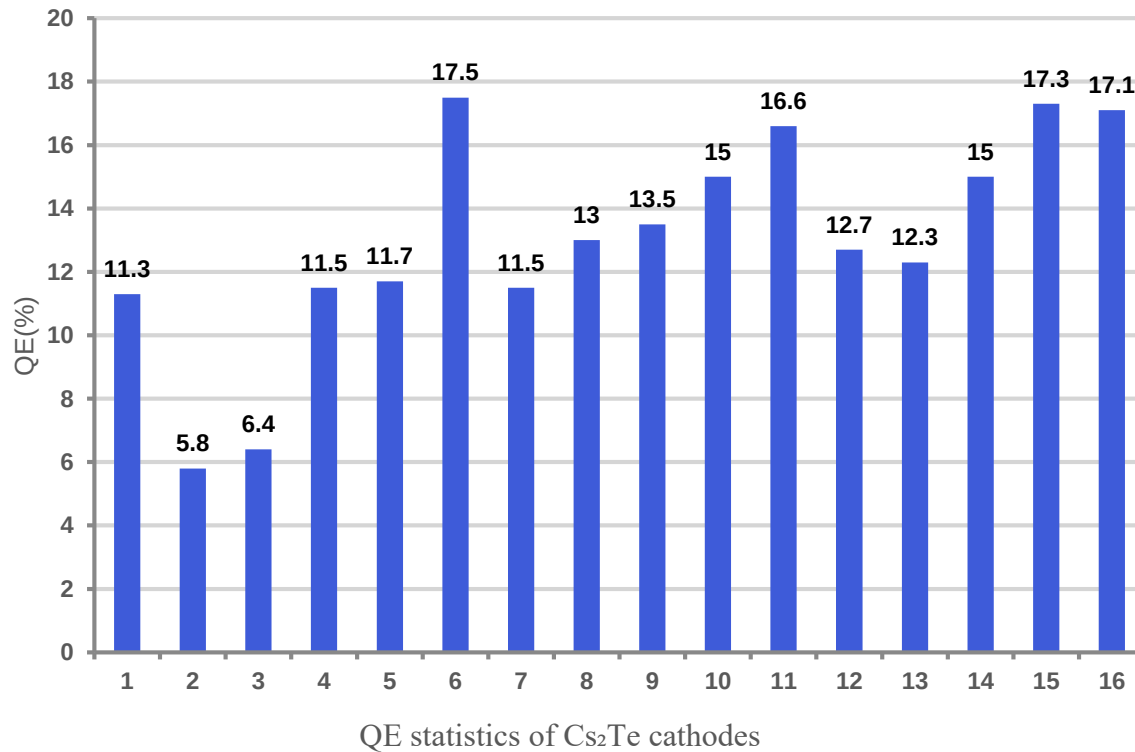
fabricated and characterized

≈13% average QE

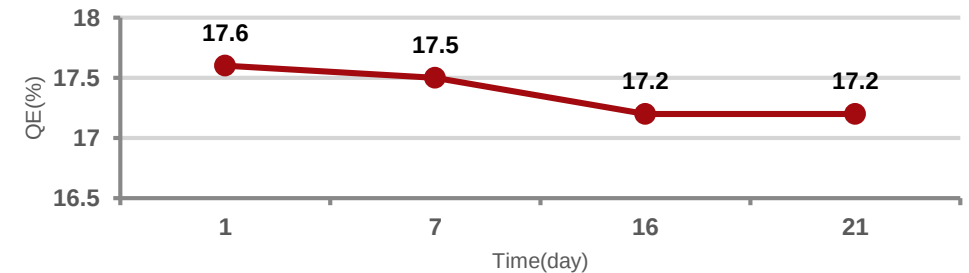
@255 nm across the present batch

>300 days

UHV storage lifetime



Typical QE evolution during Cs deposition



Representative short-term storage stability

Courtesy of YANG Jiayue

● DALS:Operational Cs₂Te photocathodes in DALS guns

Prepared Cs₂Te cathodes have transitioned from fabrication to beam delivery in both DC and VHF guns.

22.9% initial QE

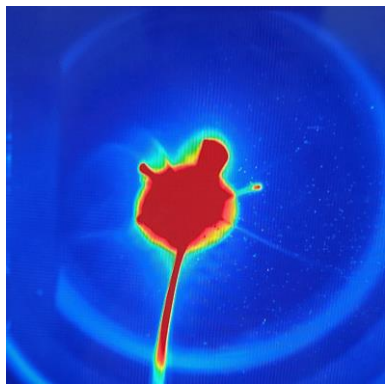
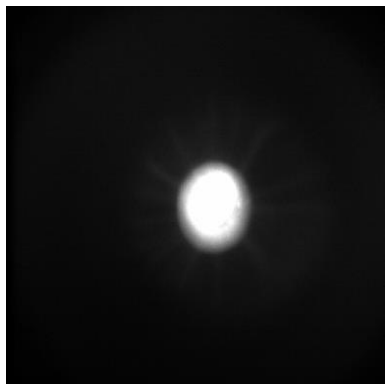
VHF gun cathode, Mar. 2025

2 nC @ 10 kHz

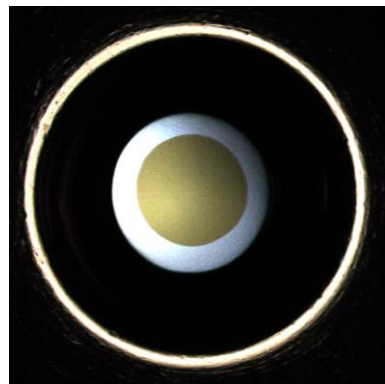
maximum demonstrated bunch charge

>10 C extracted

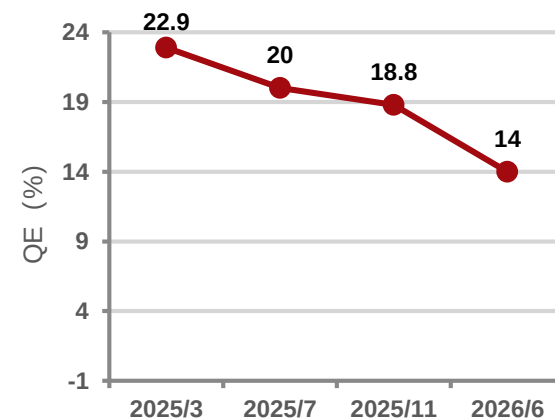
QE remains ≈14% after >1 year



First beam: 330 kV DC gun (left) and 750 kV VHF gun (right).



Cs₂Te cathode installed in VHF gun



QE retention during VHF-gun operation

Operational timeline:

- First DC-gun operation in Jun. 2023.
- VHF-gun operation since Mar. 2025.
- Current work focuses on correlating QE degradation with total extracted charge, vacuum history, and laser exposure.

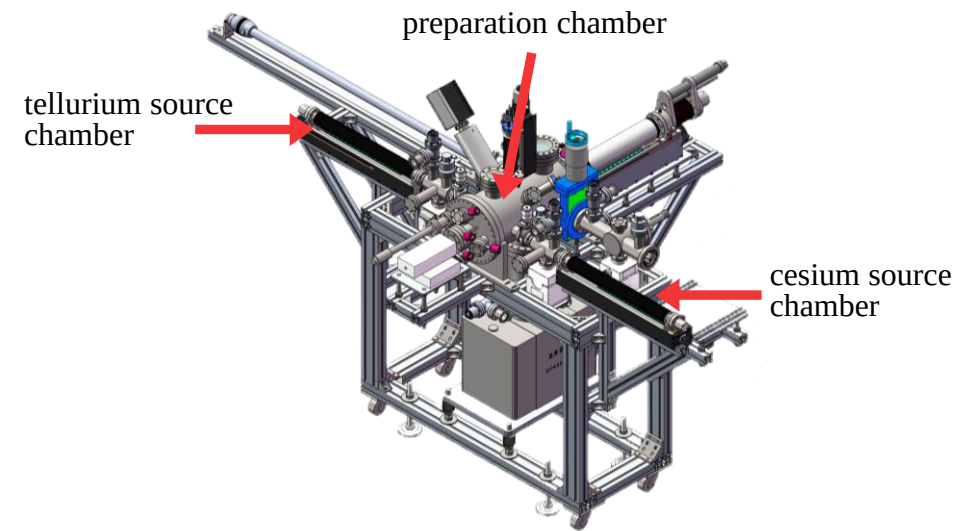
VHF gun



Superconducting injector of DALS

Courtesy of YANG Jiayue¹³

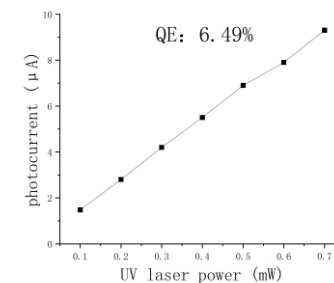
● WHU:Cs₂Te photocathode deposition system



schematic



photograph of the setup

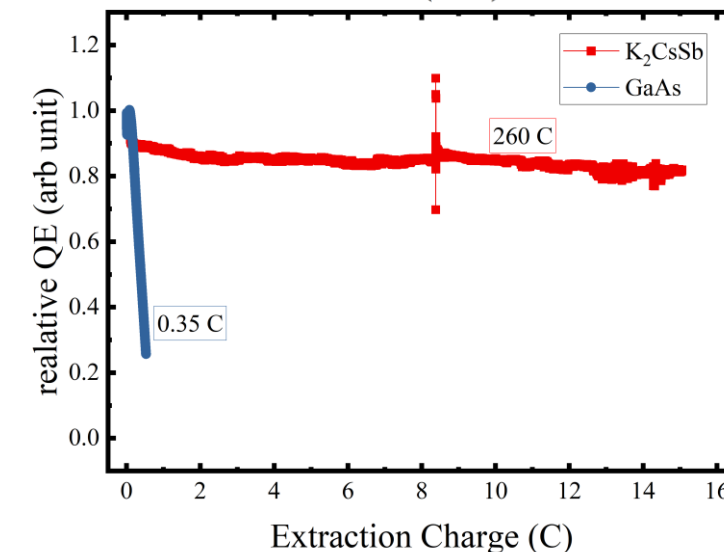
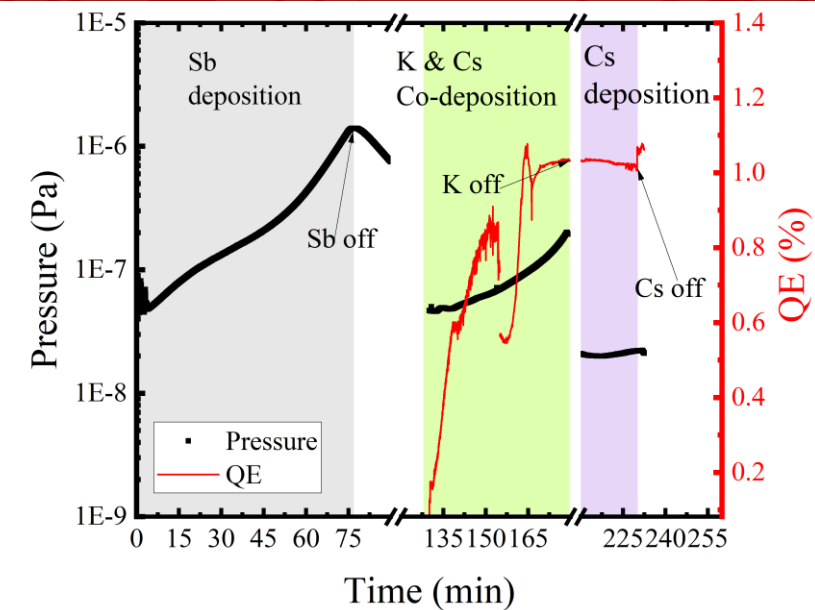
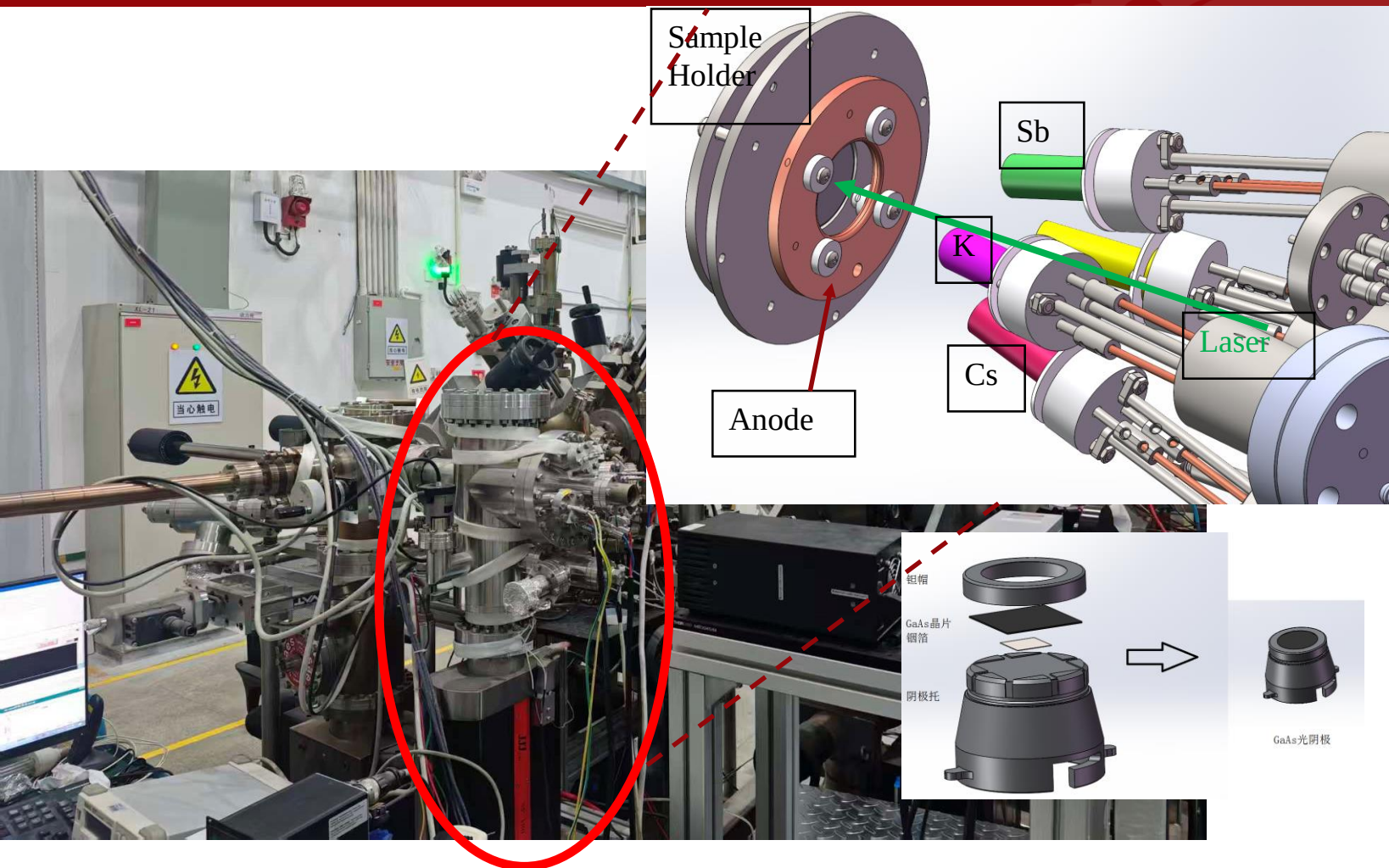


test preparation of Cs₂Te

Features:

- ultimate pressure 1.54×10^{-9} Pa of the preparation chamber;
- compatible with three evaporation source chambers (only two equipped), enabling the preparation of bialkali photocathodes;

● CAEP:K₂CsSb photocathode deposition system



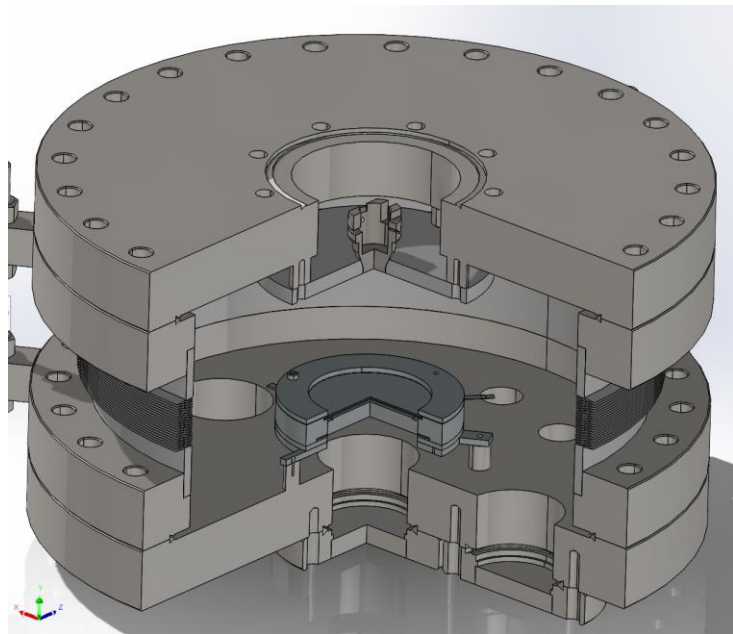
- ▶ Bialkali deposition chamber integrated with GaAs chamber
- ▶ K, Cs effusion cell
- ▶ Co-evaporation on GaAs substrate

Courtesy of XIAO Dexin

K₂CsSb sample exhibits a charge lifetime of 260 C under 50 μ A extraction

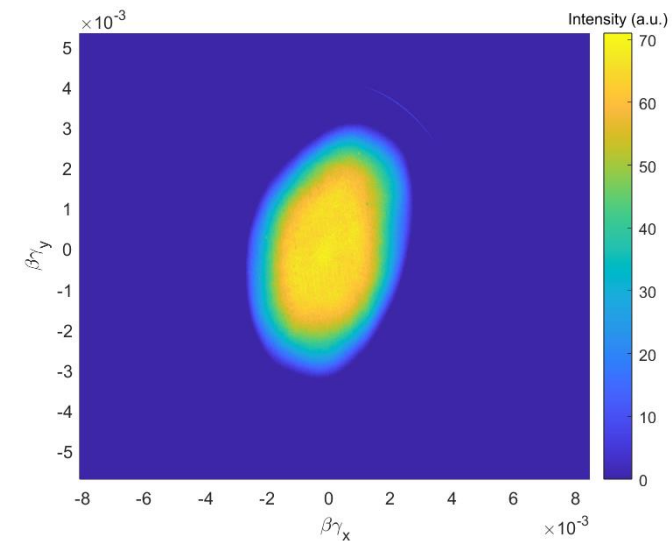
● CAEP:MTE measurement chamber

- ▶ MTE measurement chamber based on Time of Flight method
- ▶ Elimination of the grid and direct use of the MCP entrance as the anode to avoid electric-field distortion
- ▶ The intrinsic emittance measured for Cs₂Te was 1.02 μm/mm, consistent with published results.

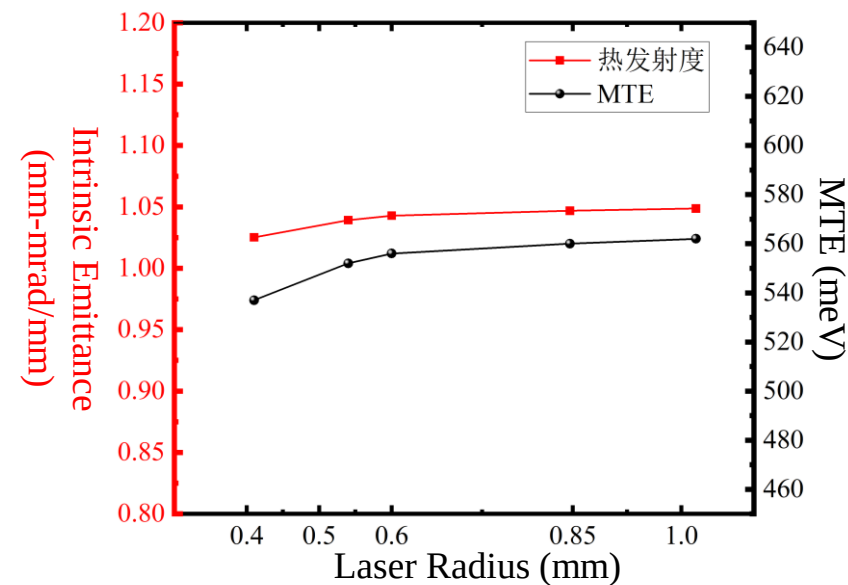


MTE measurement chamber.
Left: 3D Model, Right: photograph

Courtesy of XIAO Dexin



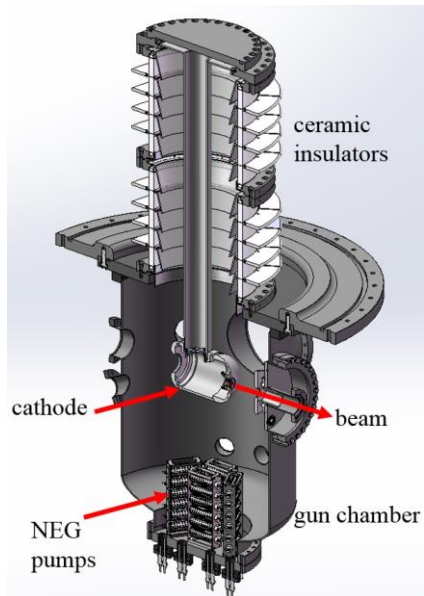
electron momentum spectrum of Cs₂Te



Intrinsic Emittance measurement results

A photocathode DC-Gun for high average current R&D at IHEP

- A photocathode DC high-voltage electron gun has been constructed at IHEP
- Achieved stable operation of 400kV DC high voltage
- An electron beam with an average current $>5\text{mA}$ was obtained using GaAs photocathodes
- The photocathode system now is currently being upgraded (from GaAs to K_2CsSb)



A photocathode DC-Gun



A GaAs photocathode system



A K_2CsSb photocathode system

High polarization electron source R&D at IHEP

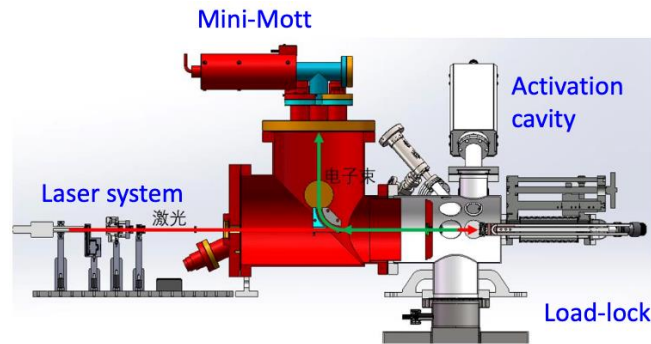
Domestic R&D on Superlattice GaAs photocathode (**Goal: polarization $\geq 85\%$, QE $\geq 0.8\%$**)

- In collaboration with a domestic company Acken Optoelectronics Ltd. @ Suzhou
- First test samples produced through a MBE system in June 2025
- A platform for SL photocathode performance test now under construction (activation, QE, polarization)
- A SL GaAs wafer has been cut, and a quarter had been delivered to JGU Mainz (Valery. Tyukin)

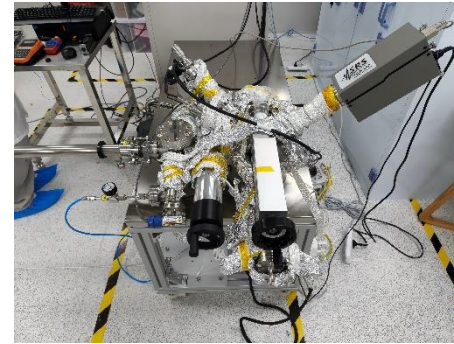
GaAs	5 nm	$p=5 \times 10^{19} \text{ cm}^{-3}$
GaAs/GaAsP SL	$(4/3 \text{ nm}) \times 14$	$p=5 \times 10^{17} \text{ cm}^{-3}$
GaAsP _{0.35}	2750 nm	$p=5 \times 10^{18} \text{ cm}^{-3}$
Graded GaAsP _x ($x = 0 \sim 0.35$)	5000 nm	$p=5 \times 10^{18} \text{ cm}^{-3}$
GaAs buffer	200 nm	$p=2 \times 10^{18} \text{ cm}^{-3}$
p-GaAs substrate ($p > 10^{18} \text{ cm}^{-3}$)		



SL GaAs layer structure and produced wafers



A platform for SL photocathode performance test



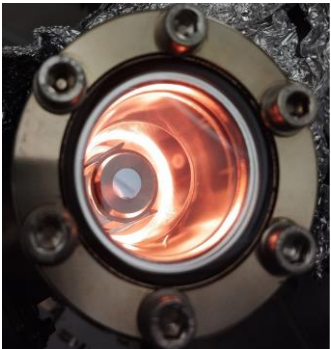
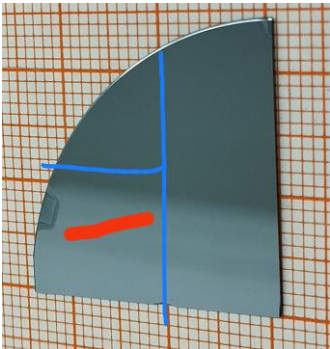
V. Tyukin (JGU Mainz) sliced the SL wafer @ Acken

High polarization electron source R&D at IHEP

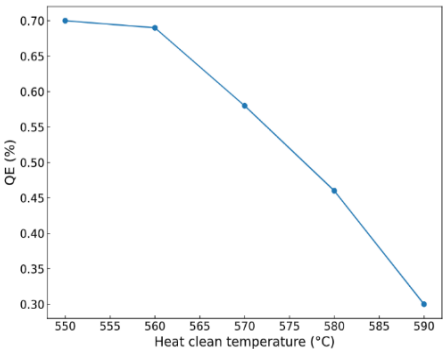
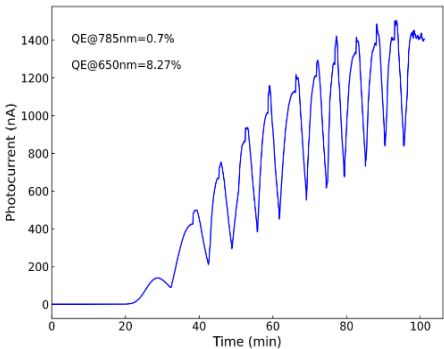
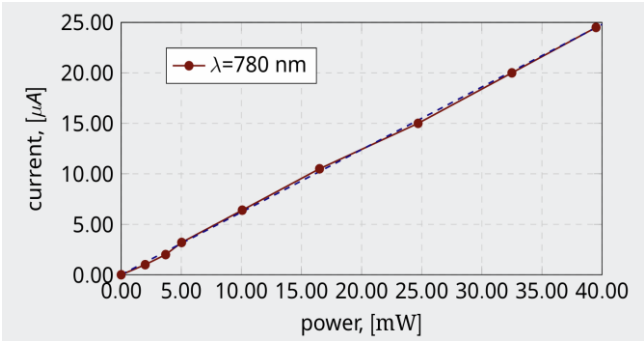
Performance test of Superlattice GaAs photocathode

- Activation experiment and performance test of the SL GaAs had been carried out in 2026
- Preliminary performance tests show promising results and the second batch of samples have been completed growth
- Beam polarization measurement results will be used for our Mott polarimeter calibration in future

Parameter	Valery Tyukin @ JGU Mainz	Wei Liu @ Chongqing University
Beam polarization	80%~82%, slightly higher or comparable to SVT SL wafer	—
Activation method	Yo-Yo method, Cs + NF ₃	Yo-Yo method, Cs + O ₂
Quantum efficiency	0.1% @ 780 nm	0.7% @ 785 nm



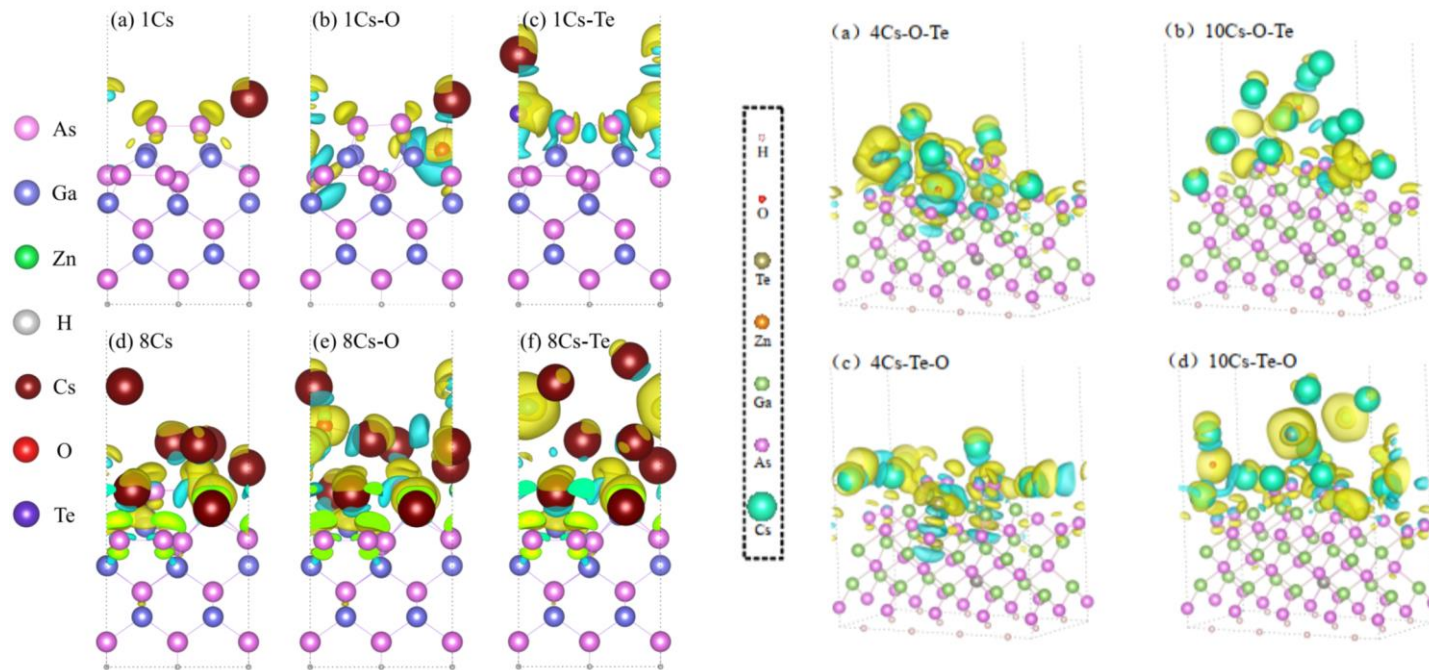
SL GaAs photocathode test at JGU Mainz



SL GaAs photocathode test at Chongqing University

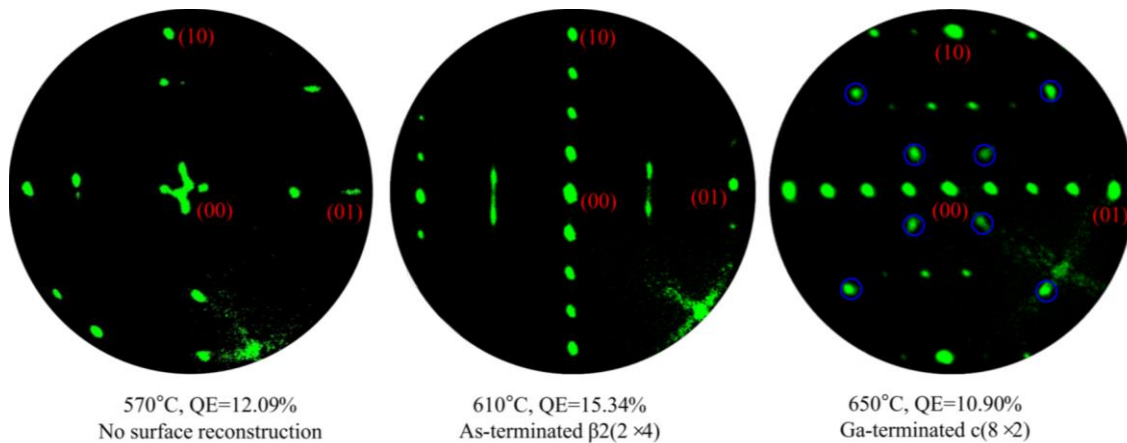
Courtesy of LI Xiaoping

Charge-density-difference distributions

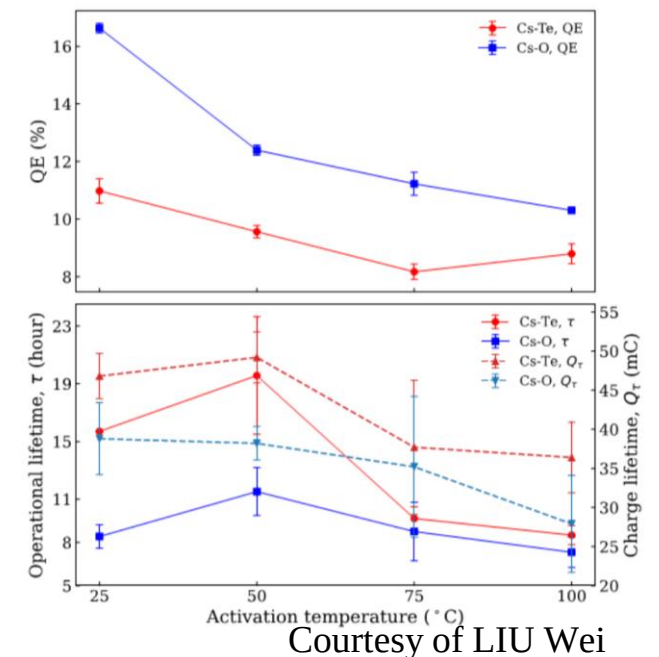
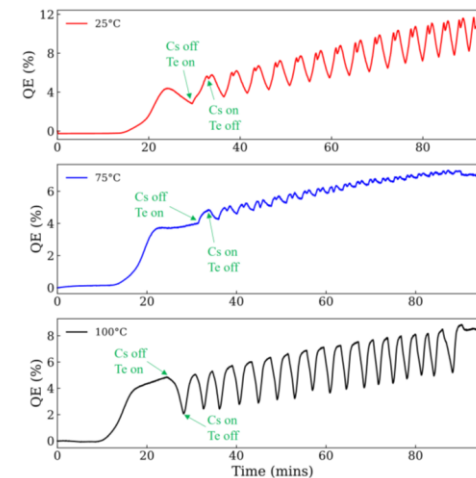


▢ Cs-Te activation: higher lifetime but lower QE than Cs-O activation

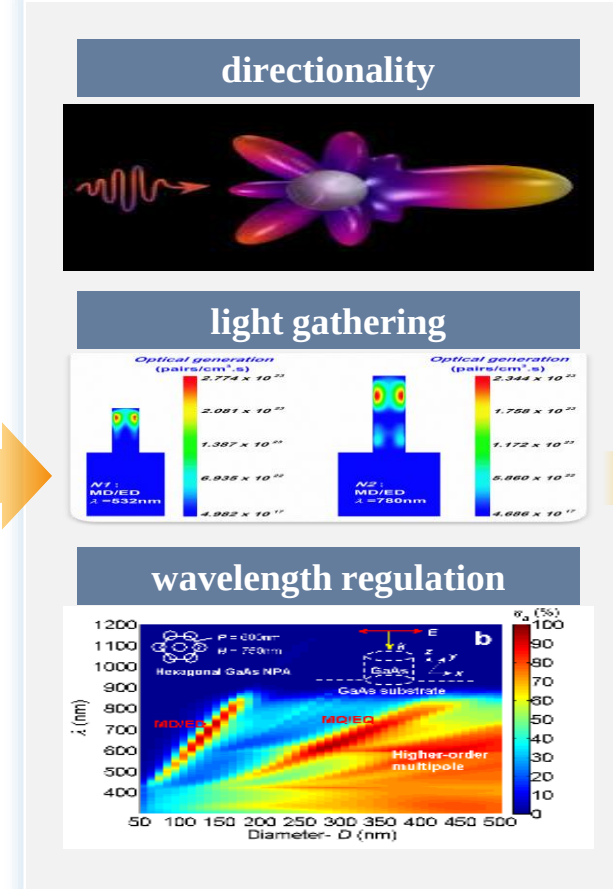
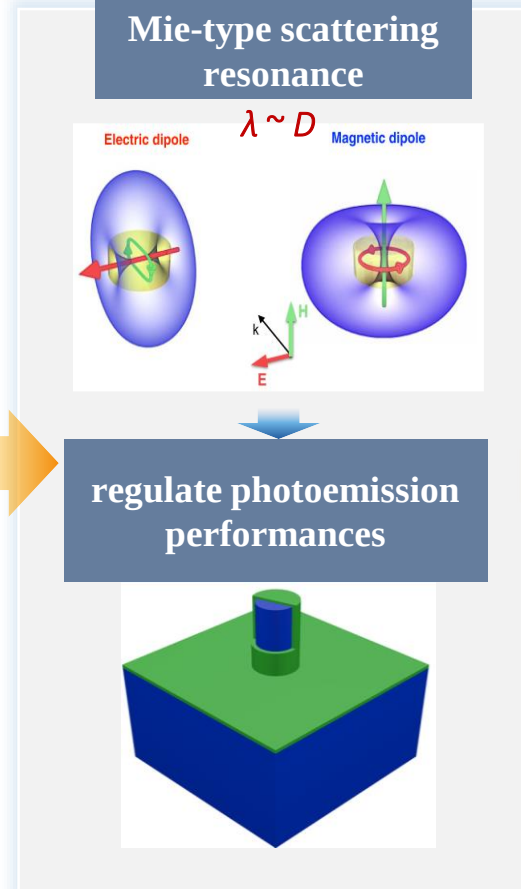
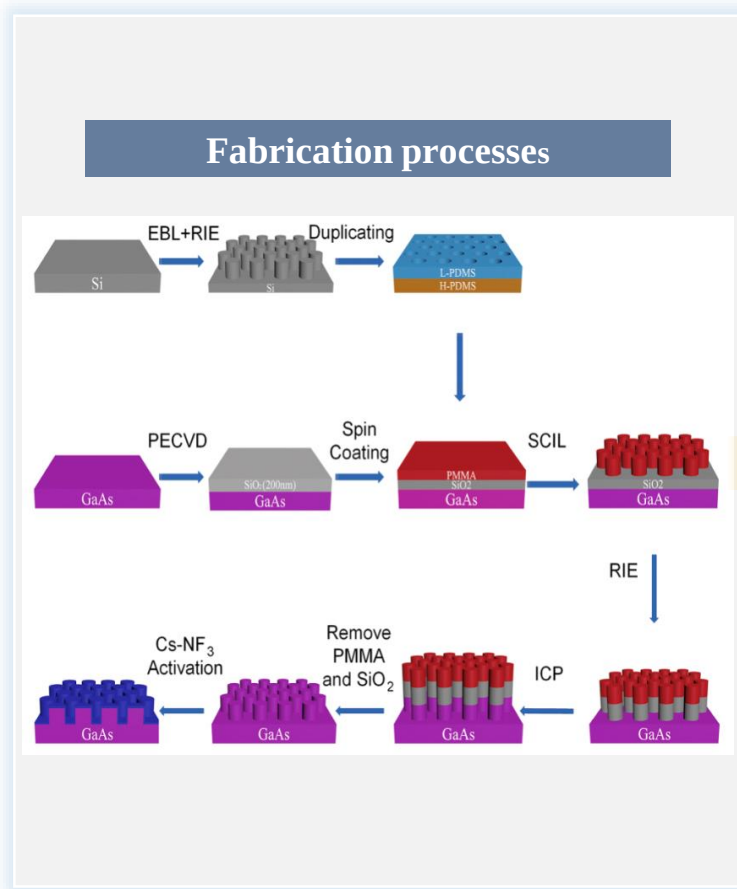
▢ Cs-O-Te/Cs-Te-O activation: higher QE and lifetime than Cs-Te activation (on study)



LEED pattern for GaAs(100) surface



● ECUT: Nanophotonic GaAs NEA photocathode (PC) with the nanostructured emitting surface



Reflection	<10%
Absorption	>90%
QE	3.5 times
response	ps
waveband	All
lifetime	10 times

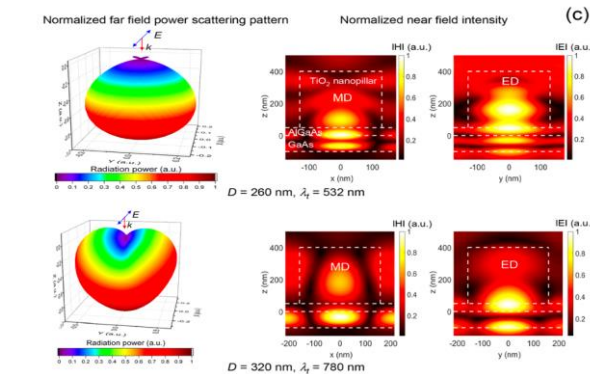
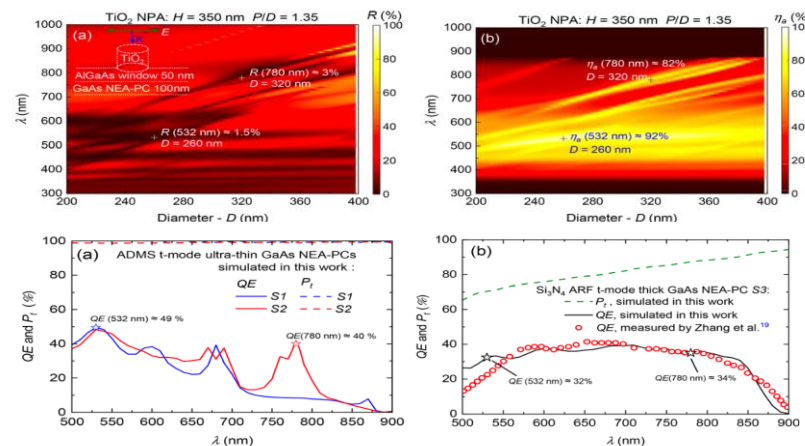
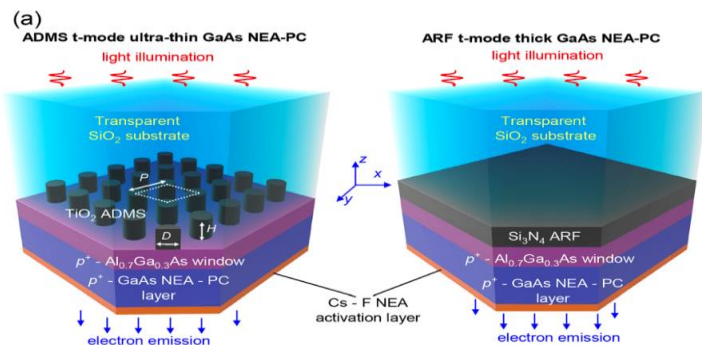
[1] Phys. Rev. Appl. 2019, 12: 064002

[2] Jpn. J. Appl. Phys. 2019, 58, 010908

[3] Applied Physics A-Materials Science & Processing 2016, 122, 1003

ECUT: Advanced optical structure for the GaAs NEA PC with the flat emitting surface

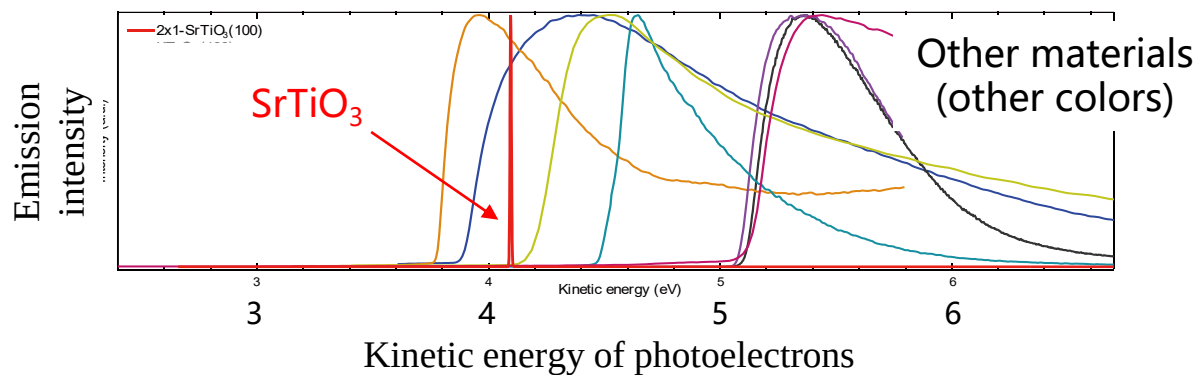
Metasurface PC with transmission-mode



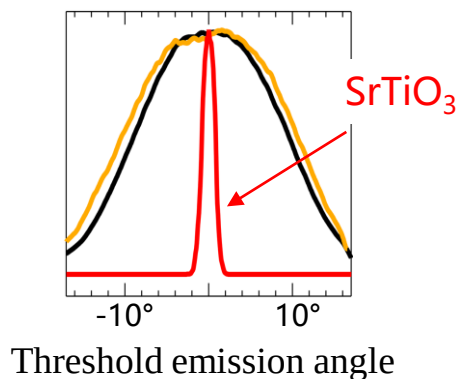
Exceptional initial beam coherence

Photoemission spectrum
(low kinetic energy region)

High monochromaticity



High collimation

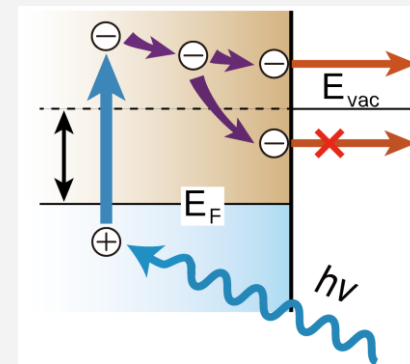


Incompatible with current theory

Current theory for photocathode

Incoherent process

Many-body, excited state, non-equilibrium dynamics



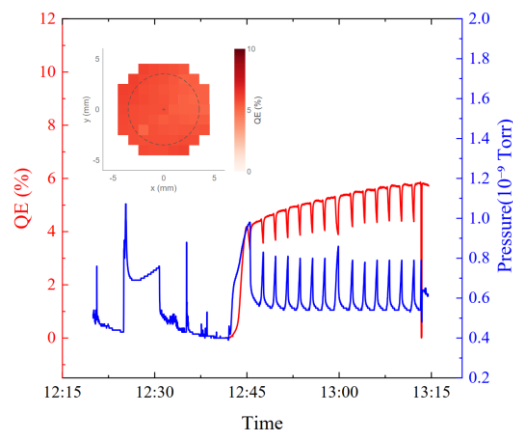
Photoexcitation
Transport
Escape

- Disruptive performance; may drive paradigm shifts in photocathode R&D.
- Need for a new theoretical framework of photoemission.

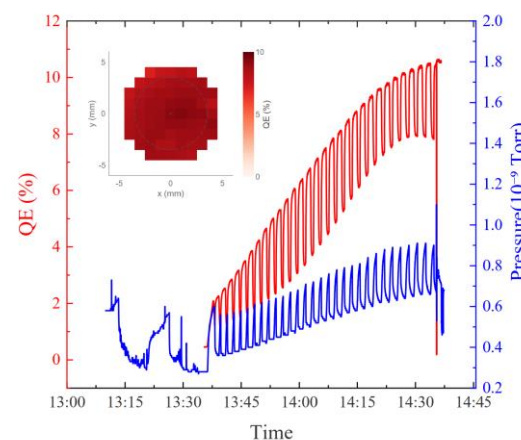
PKU: K-rich K_2CsSb growth in a cryogenic DC-SRF gun

Cryogenic cooling lowers MTE but typically costs QE → **PKU strategy: change the growth recipe, not just cooling**

Conventional K deposition



K-rich deposition



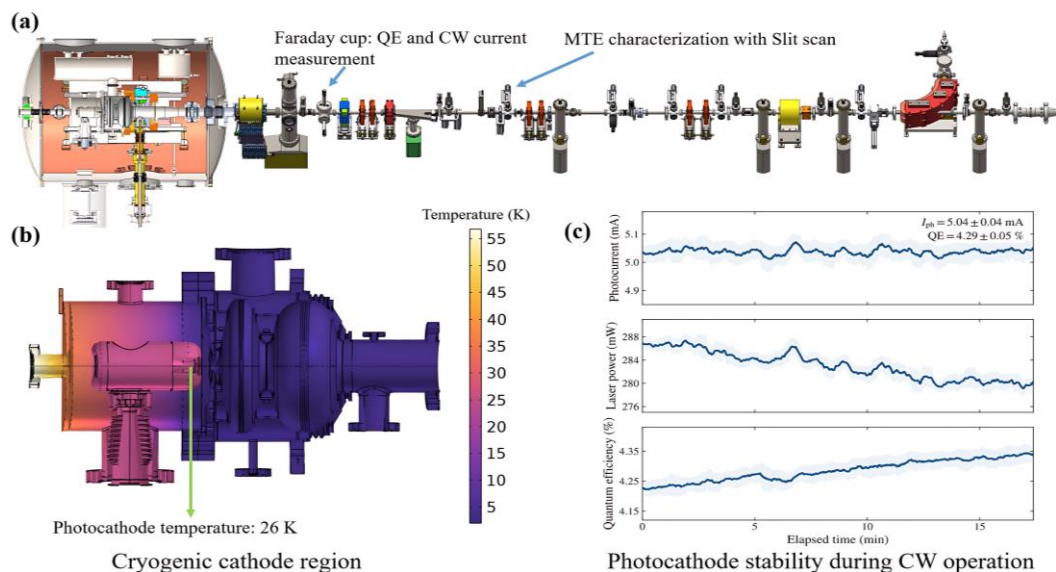
Key difference

Extended K deposition improves film stoichiometry and **carrier transport**.

K-rich K–Cs–Sb/Mo;

as-prepared QE = 8–10%, Max QE: 9.47%, mean QE: 8.64%, uniformity: 94.74% over a 7-mm-diameter area.

"The growth recipe, not cooling alone, controls cryogenic QE retention."



Conditions

DC-SRF Gun

CW gun

Cathode ~26 K

LHe-conduction cooled

81.25 MHz rep. rate

high-average-current env.

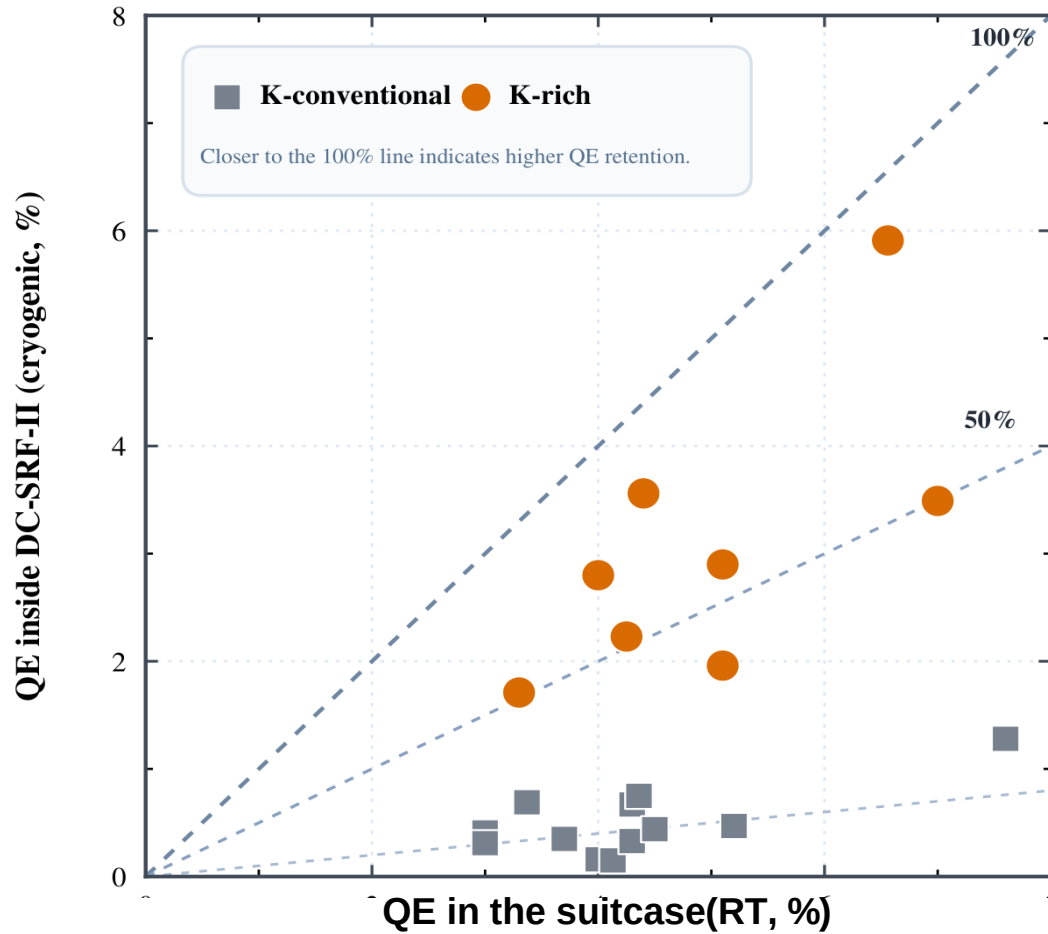
In-situ measurement

QE, MTE, CW current in-gun

<https://arxiv.org/abs/2609.18137> To be submitted

● PKU: High QE & ultralow MTE in CW gun operation

High QE retention after cooling

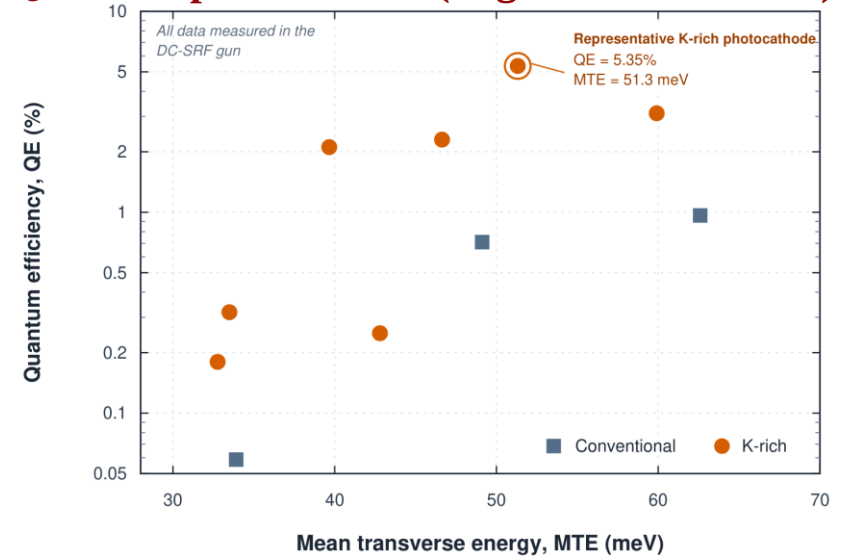


K-rich cathodes retain markedly higher QE at cryogenic temperature

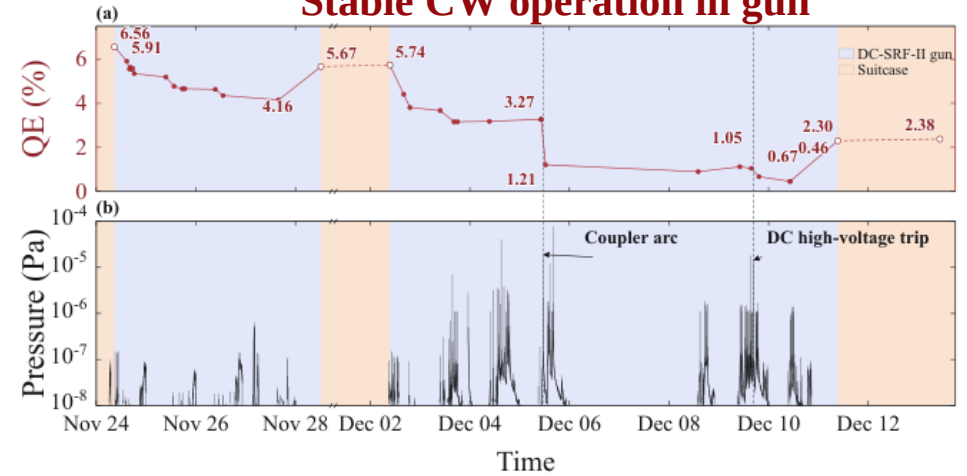
5.35% QE · >5× higher

51.3 meV_{MTE} · >65% reduction

QE-MTE performance (in gun measurement)



Stable CW operation in gun



~20-day operation history with pressure monitoring

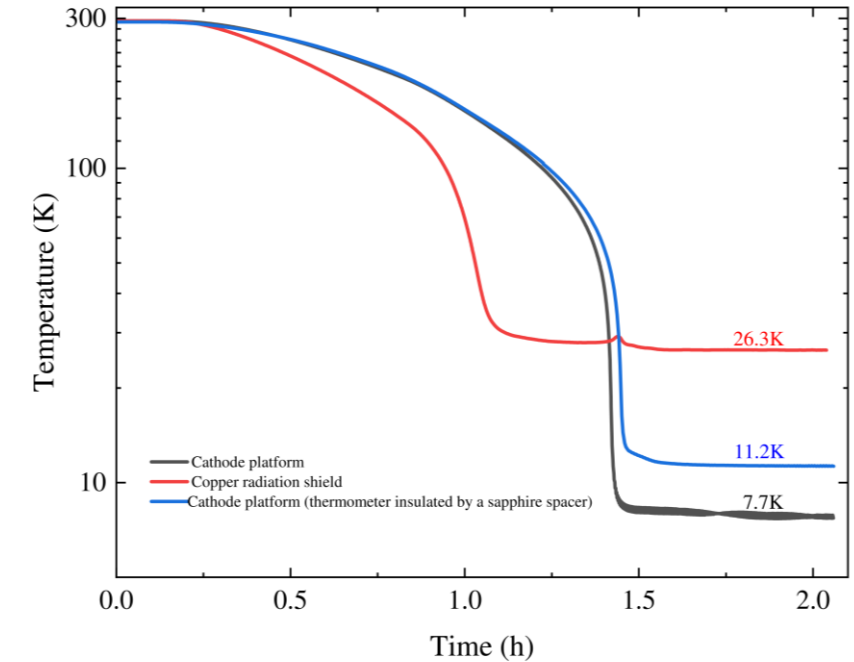
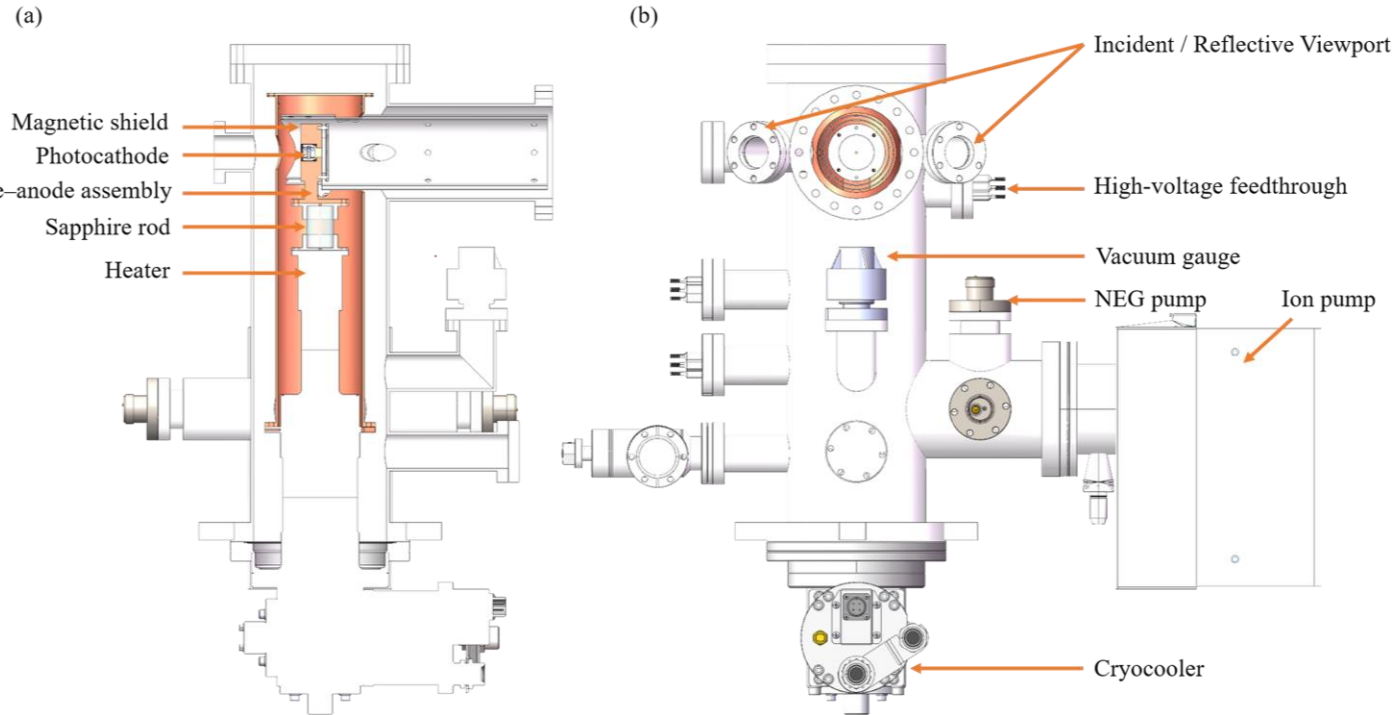
<https://arxiv.org/abs/2609.18137>

To be submitted

K-rich growth raises QE without elevating MTE.

PKU: Cryogenic free-drift MTE platform: design and 10 K commissioning

Resolve transverse distribution of low-MTE photocathodes from RT to the 10 K regime. **Stable cryogenic operation demonstrated**



Planar cathode-mesh free-drift geometry

Up to 8 kV extraction design

UHV cathode transfer & pumping

Two-stage cryocooling + magnetic shielding

7.7 K cathode platform

~1.5 h to stable operation

5×10^{-9} Pa commissioning pressure

The platform combines cryogenic operation, UHV, small residual magnetic field, and 2D electron imaging for temperature-dependent MTE studies.

01 A distributed national capability

ZJLAB/SARI, THU, IHEP, DCLS, CAEP, ECUT and PKU now cover cathode growth, activation, UHV transfer, beam operation and dedicated MTE or polarization measurements.

02 Cs₂Te leads operational deployment

SHINE and DALS have moved Cs₂Te into DC and VHF gun service. The reported results include 10–20% initial QE, storage beyond 300 days, nC-class bunches and multi-coulomb extraction.

03 K₂CsSb targets visible-light and CW operation

THU, CAEP and PKU report gun-compatible growth and lifetime studies. PKU combines 5.35% QE with 51.3 meV MTE during cryogenic in-gun measurements.

04 Polarized and nanostructured GaAs are emerging

Domestic superlattice growth and testing has reached 80–82% polarization in an external test. ECUT is exploring optical structures that improve absorption while controlling response time and MTE.

SHARED PRIORITIES Reproducibility across growth systems · lifetime mapped against extracted charge and vacuum history · cross-laboratory benchmark protocols

Xudong Li, SARI/ZJlab

Xiaoping Li, Institute of high energy physics(IHEP)

Renkai Li, Tsinghua University (THU)

Wei Liu, Chongqing University (CQU)

Jiayue Yang, Dalian lightsource (DALIS)

Dexin Xiao, Yonglong Zhao, China academy of engineering physics (CAEP)

Ruihua He, Westlake University

Yuancun Nie, Wuhan University(WHU)

Xincun Peng, East China University of Technology(ECUT)

Huamu Xie

hmxie@pku.edu.cn

Thanks for your attention!



北京大学
PEKING UNIVERSITY

射频超导实验室
SRF LABORATORY

陈佳洱