The Cryogenic operation of $\text{K}_2\text{CsSb}$ photocathode in the DC-SRF photoinjector

XIE Huamu
Peking University
Outline

- Deposition and transportation
- Cryogenic operation in the gun
- Cryogenic performance of $\text{K}_2\text{CsSb}$ photocathode
- Conclusion
Deposition system

- Cold/hot sample holder
- Transport chamber ~10^-8 Pa
- Deposition chamber ~10^-9 Pa
- Cs source chamber
- Sb source chamber
- Quartz crystal monitor
- K source chamber
- Suitcase ~10^-9 Pa
- Transport chamber

Deposition system
The fabrication process of a typical sample (#1) with regular recipe

The fabrication process of a typical sample(#2) with improved recipe
Deposition Recipe
Transport by Suitcase

UHV suitcase

Transport carrier

Pressure (Torr) vs. Duration (Days)

QE (%) vs. Duration (Days)

Pressure (Torr) vs. #20210524 QE

Pressure vs. QE (%)
Outline

- Deposition and transportation
- Cryogenic operation in the gun
- Cryogenic performance of K$_2$CsSb photocathode
- Conclusion
DC-SRF-II First-Stage Beam Test

- Assembled in Jan. 2021
- Cooled down on April 20, 2021
- First-stage beam test from Apr. 29, 2021 to Jul. 21, 2021

2021.4.21
Bunch Charge Test

Average beam current vs macro pulse duration

Experiments on Jun. 22, 2021
Preliminary results

Macro pulse repetition rate 10 Hz, w/o laser shaping

Bunch charge 250 pC
Cathode test in the Gun

QE of photocathode measured in suitcase after extracting from DC-SRF photoinjector

QE of photocathode measured in DC-SRF photoinjector

The manipulator after opening the suitcase
First CW Operation

Rise of photocurrent by 1MHz, 0.65W CW laser irradiation

- 20% Duty factor
  - Q ~ 60 pC

- 50% Duty factor
  - Q ~ 68 pC

- 100% Duty factor
  - Q ~ 80 pC

CW operation

Q ~ 78 pC
Cryogenic performance

Simulation results of temperature distribution

<table>
<thead>
<tr>
<th>position</th>
<th>Valve</th>
<th>cathode</th>
<th>Beam tube</th>
</tr>
</thead>
<tbody>
<tr>
<td>measured/K</td>
<td>35.17</td>
<td>TBD</td>
<td>17.06</td>
</tr>
<tr>
<td>simulation/K</td>
<td>32.53</td>
<td>36</td>
<td>18.64</td>
</tr>
<tr>
<td>error</td>
<td>7.9</td>
<td>9.3</td>
<td></td>
</tr>
</tbody>
</table>
Emittance Measurement

RF phase 36°, S1 current 2.40 A

RF phase 36°, S1 current 2.45 A

RF phase 31°, S1 current 2.40 A

RF phase 26°, S1 current 2.40 A

Normalized rms emittance, 95% particles:
0.4~0.6 mm-mrad @ 22 pC

Experiments on May 29, 2021
Preliminary results
Outline

● Deposition and transportation

● Cryogenic operation in the gun

● Cryogenic performance of K$_2$CsSb photocathode

● Conclusion
Cryogenic performance

![Image of cryogenic equipment with labels: Gas in/outlet, Thermal Couple, and Sample stage.]

[Diagram showing components labeled: Gas in/outlet, Thermal Couple, anode, Sample stage.]
Cryogenic performance

<table>
<thead>
<tr>
<th>Lab</th>
<th>Temp Range</th>
<th>QE@RT (%)</th>
<th>QE Drop</th>
<th>φ@RT (eV)</th>
<th>Δφ (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BNL</td>
<td>300K-166K</td>
<td>10</td>
<td>20%</td>
<td>1.81</td>
<td>0.03</td>
</tr>
<tr>
<td>JLab</td>
<td>275K-77K</td>
<td>11.2</td>
<td>~50%</td>
<td>1.66</td>
<td>0.1</td>
</tr>
<tr>
<td>PKU</td>
<td>300K-95.7K</td>
<td>2.7</td>
<td>~40%</td>
<td>1.90</td>
<td>0.0455</td>
</tr>
<tr>
<td>PKU</td>
<td>300K-36K</td>
<td>4.3</td>
<td>~90%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
To control the QE decay at cryogenic temperature

For lower temperature to measure the QE of photocathode at around 36 K

Heating the photocathode by back illuminating with IR laser.

Lee, H., Bazarov, I., & Cultrera, L. *IPAC’17*
Future work

- The intrinsic emittance of the $\text{K}_2\text{CsSb}$ photocathode at 36 K will be measured in the following beam experiments from the DC-SRF photoinjector.

- Estimated intrinsic emittance at 36 K: $0.1\sim0.2 \text{ mm.mrad/mm}$

- The cryo-photocathode delivered ultra-low emittance electron beam from the DC-SRF photoinjector with ultralow intrinsic emittance photocathode

- We need to find new application of the Cryo-DC/SRF hybrid-gun
1. High QE K$_2$CsSb photocathode with repeatable recipe is fabricated at PKU

2. The K$_2$CsSb photocathode in DC-SRF-II photoinjector delivered required 100-250 pC bunch charge beam

3. The cryogenic K$_2$CsSb photocathode in the gun has the potential to deliver ultralow emittance electron beam for XFEL and UED, for the intrinsic emittance of K$_2$CsSb photocathode at 36 K is very small, which will be measured in next beam experiment.

4. The cryogenic performance of the K$_2$CsSb photocathode has been investigated in a cryogenic sample stage. The spectral response at 90 k and RT are compared, and will be measured at 20-30 K