RELIABILITY EXPERIMENTS OF A HIGH CURRENT DENSITY PHOTOCATHODE FOR HIGH-POWER TERAHERTZ DEVICES

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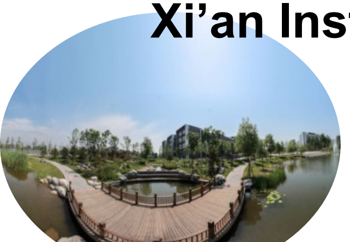

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Motivations

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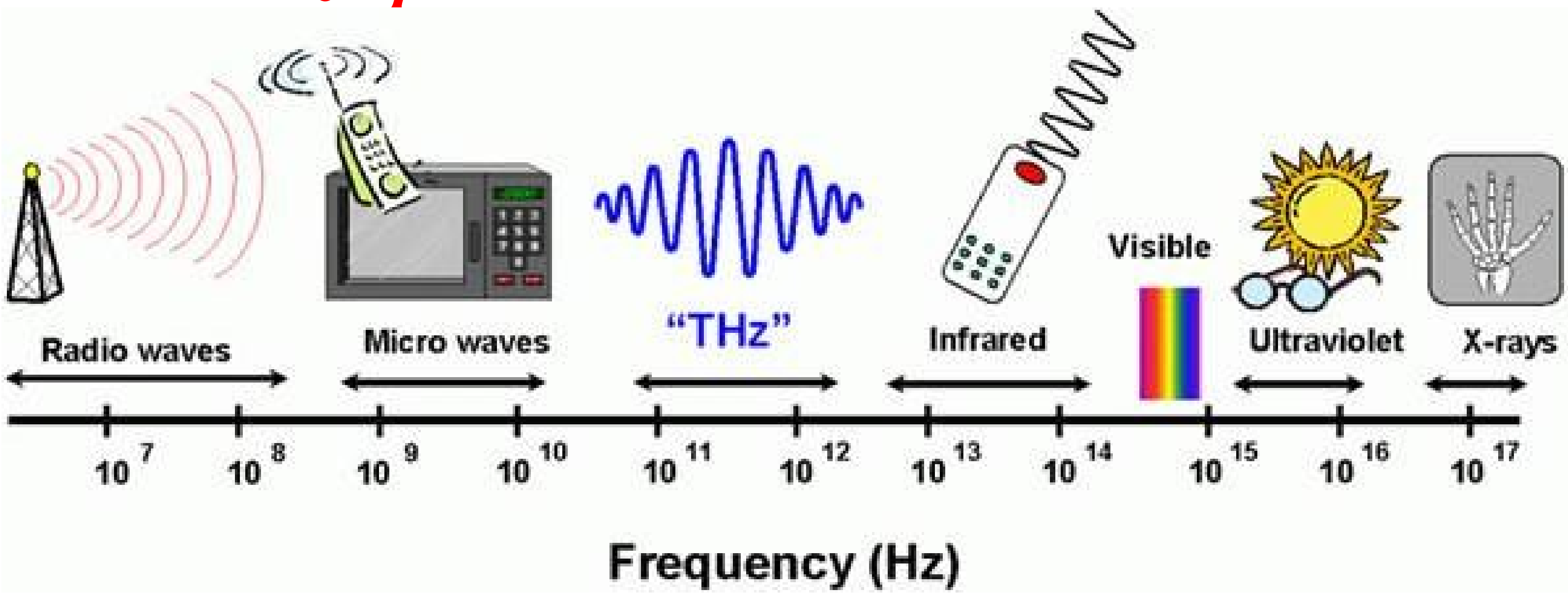
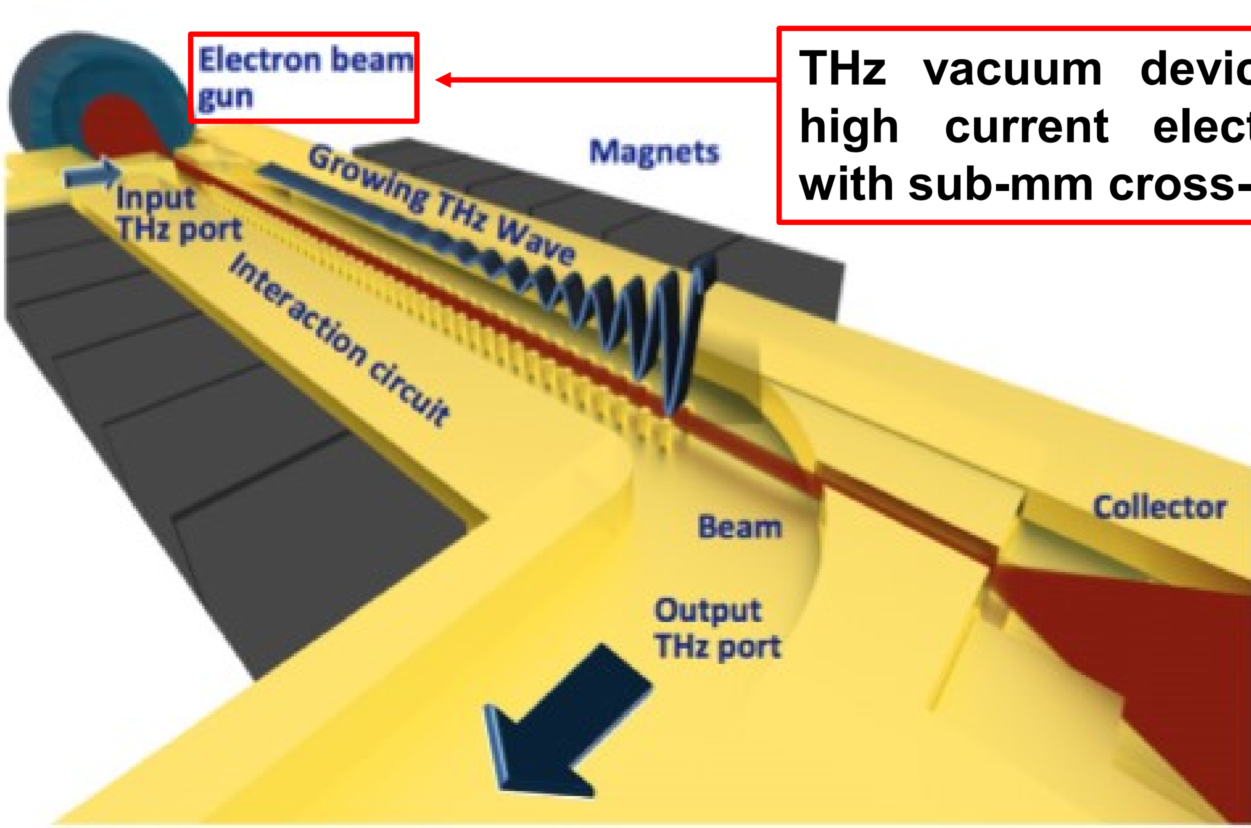
Terahertz Spectrum



- ❑ **Non-ionizing**
- ❑ **Better resolution compared to microwave**
- ❑ **Better penetration depth compared to infrared ray**

Currently, Vacuum devices are still the only practical device for many high-power applications

Motivations



THz vacuum devices demand high current electron beams with sub-mm cross-sections

When the frequency evolved from kHz to THz, the transverse circuit dimensions of Vacuum electronic devices will typically need to be less than the free space wavelength i.e. sub-mm.

S S Dhillon etc. The 2017 terahertz science and technology roadmap[J]. Journal of Physics D Applied Physics A Europhysics Journal, 2017.

THz Vacuum Photomixer

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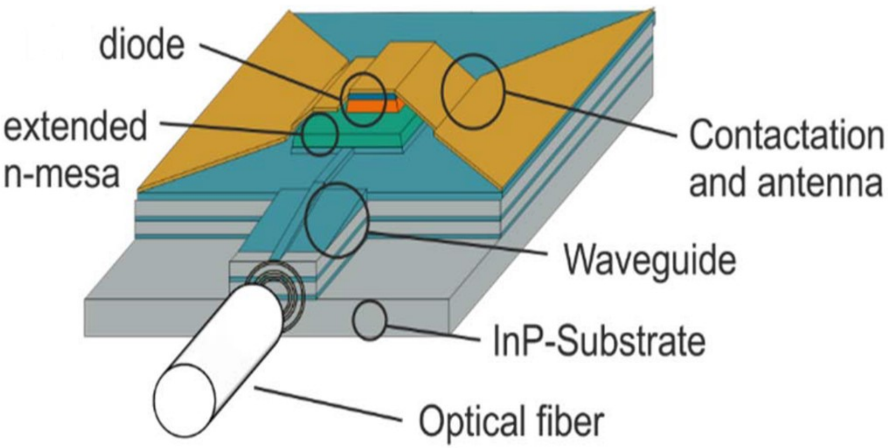
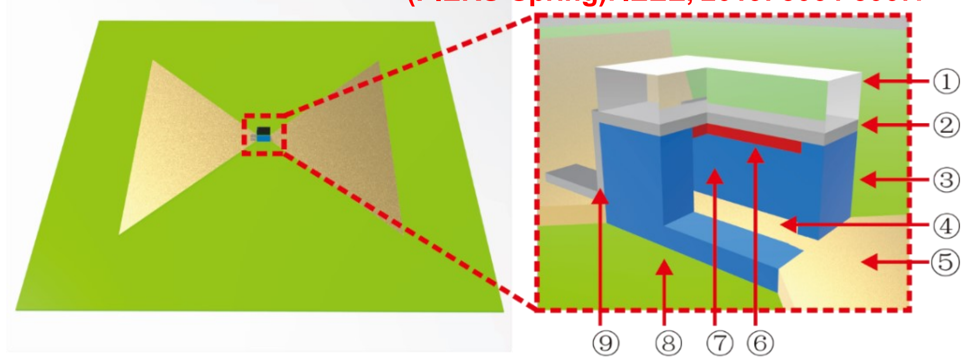
Replacing the solid-state high-speed diode based THz source with a vacuum diode using ultrafast photocathode

IRMMW-THz, 2018, pp. 1–2.



(PIERS-Spring). IEEE, 2019: 3064-3067.



①Photocathode substrate
②Electric contact
③Dielectric channel wall
④Diode anode
⑤Antenna electrode
⑥Diode photocathode
⑦Vacuum channel
⑧Antenna substrate
⑨Electrode contact

THz emitter based on PIN photodiode contacted by a bowtie antenna

THz emitter based on Vacuum photodiode contacted by a bowtie antenna

High Power Terahertz Source Based on Planar Antenna Integrated Vacuum Photodiode

Photocathode options

Metal photocathode

- Has a short response time
- QE is relatively low (on the order of 10^{-5} to 10^{-4})
- Their work function is also high (>4eV), which could only be excited by ultraviolet photons

Negative electron affinity (NEA) photocathodes

- High QE
- Response time is typically a few picoseconds

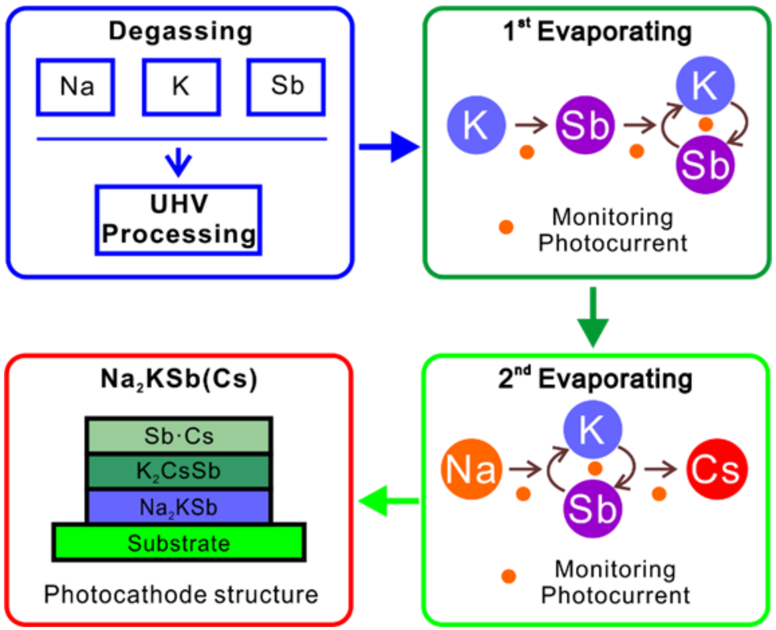
Positive electron affinity (PEA) photocathodes

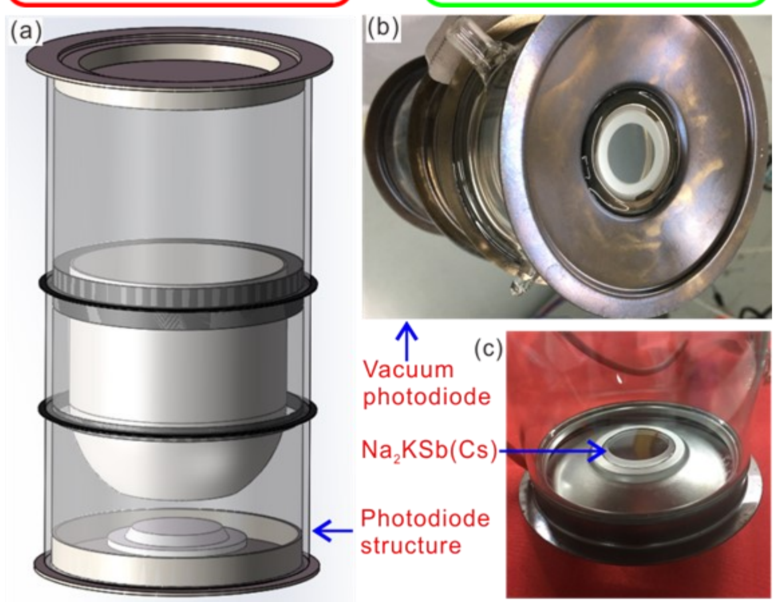
- Low esponse time
- Cs_3Sb, CsK_2Sb, Cs_2Te, and $Na_2KSb(Cs)$ photocathodes are the main choices of PEA materials.

Response time, quantum efficiency, and laser spectrums are interrelated and mutually restricted. Because of this, we need to determine **the tradeoff** among these three factors.

Multi-alkali photocathodes are a suitable option.

Photocathode Fabrication





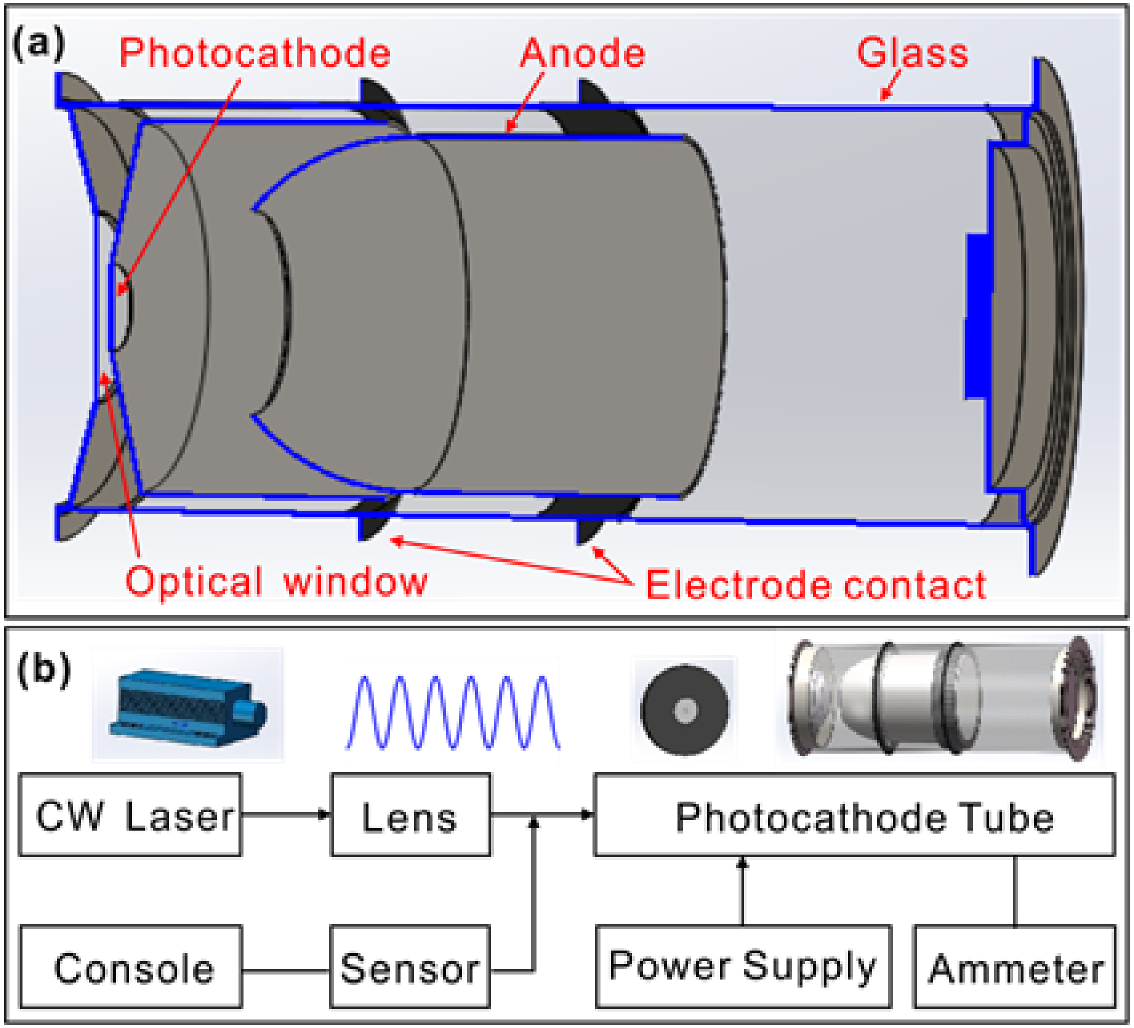
The evolution of the composition of the $Na_2KSb(Cs)$ cathode with time can be simply separated as three phases:

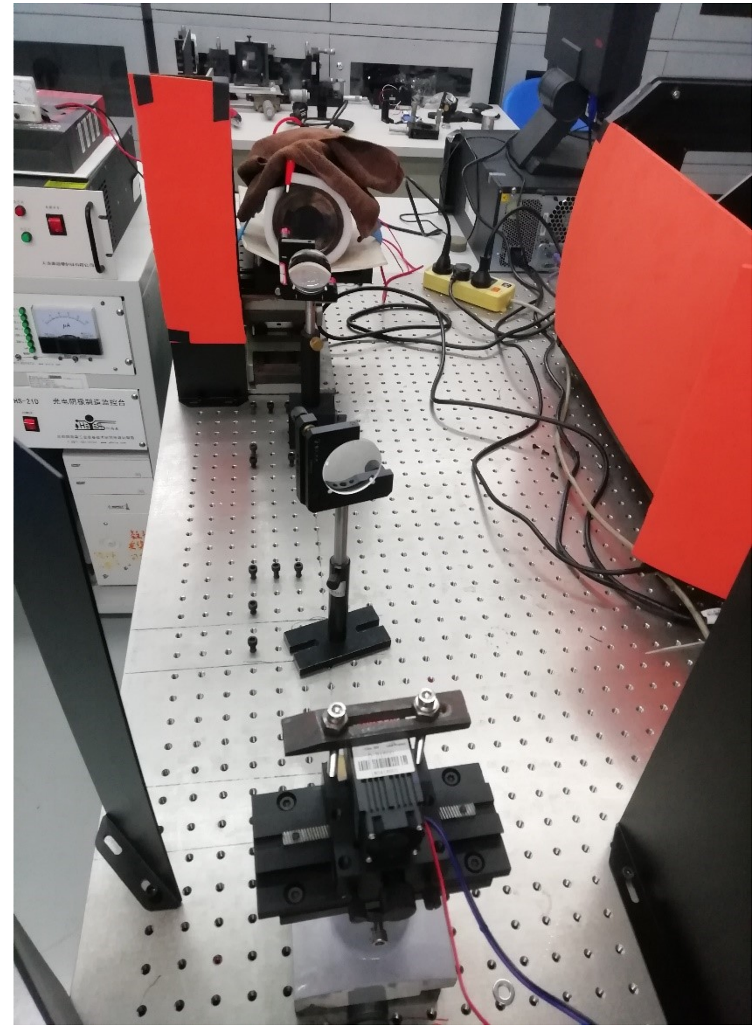
(1) evaporate K and Sb, the K-Sb film is established;
(2) evaporate the excess of Na to form the Na-K-Sb film;
(3) optimize the evaporate of K、Na、Sb to form a transparent Na_2KSb film
(4) evaporate Cs and Sb to grow the surface emission film.

Two main differences:

- ☐ **Electrical thin film contact**
- ☐ **Diamond substrate**

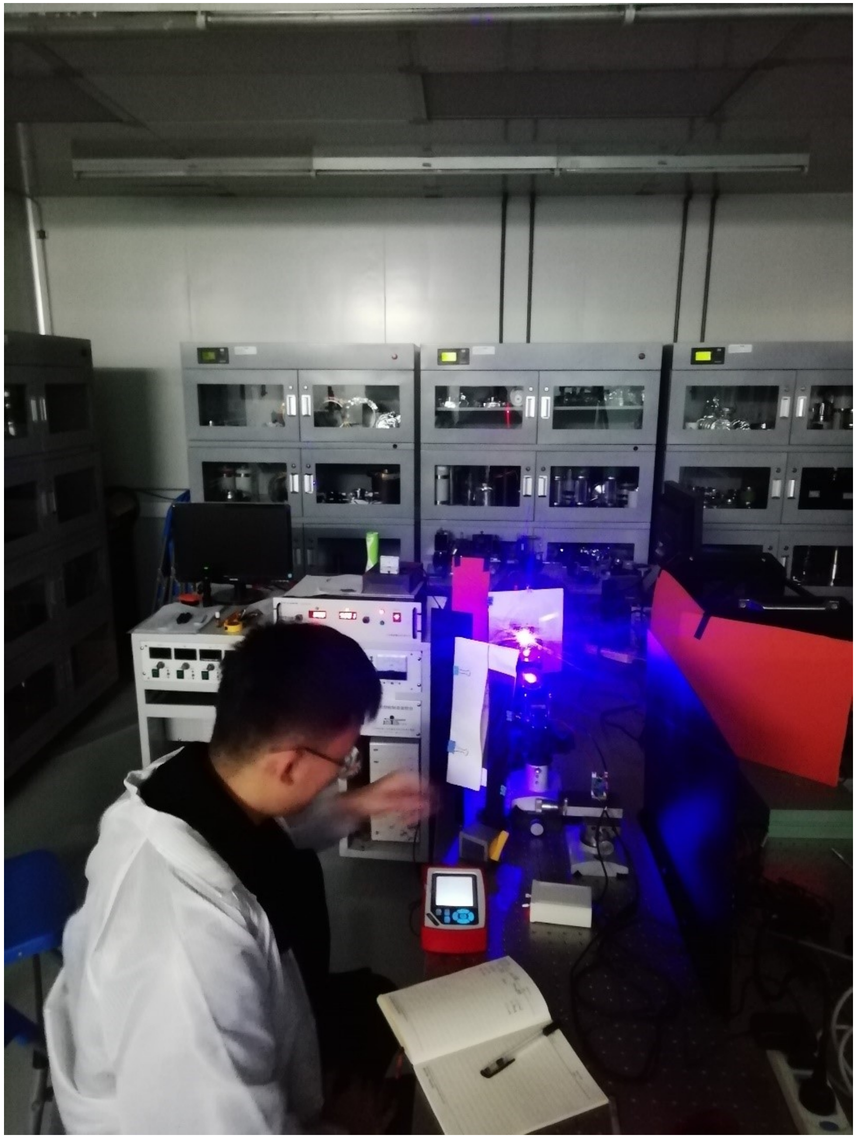
Experiment setup

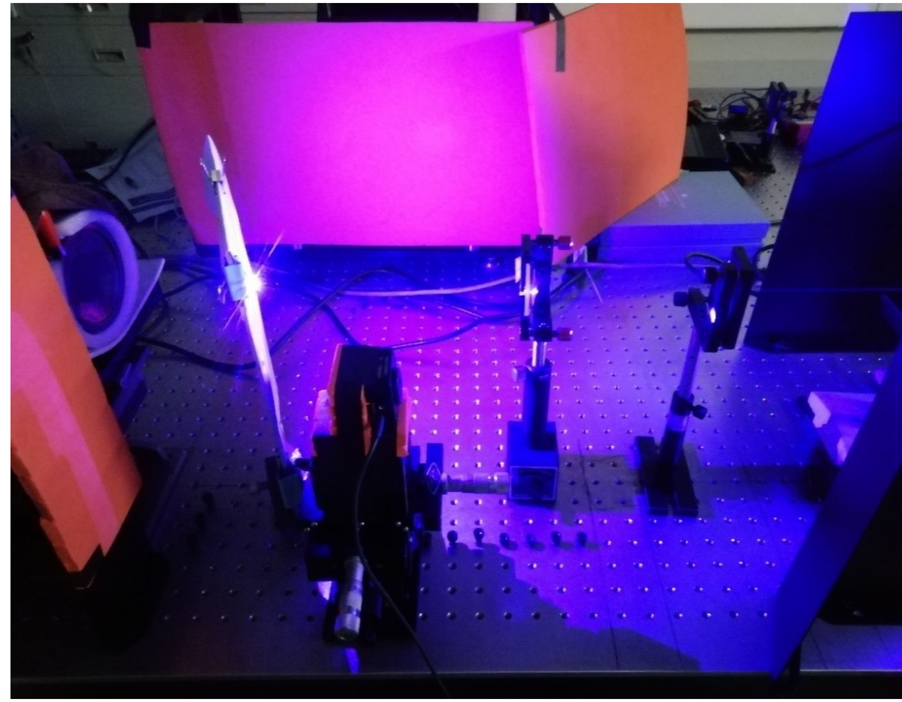




The performance of the photocathode was characterized by measuring the anode current as a function of laser power and interval time.

Experiment setup





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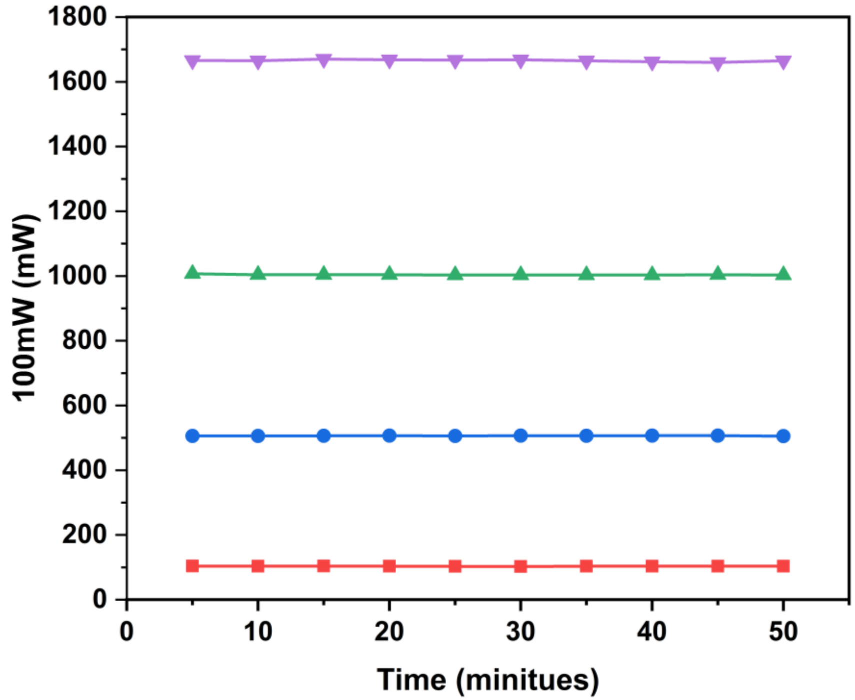
Laser power

The laser power and optical power meter sensor are setup for cross-checks.



Laser power monitoring at 100 mW, 500 mW, 1000 mW, 1600 mW.

The results show that the standard deviation of the four sets of data are 0.43, 0.59,1.22, and 2.95 respectively, which indicates that the **laser output is remarkably stable.**

Current Comparison

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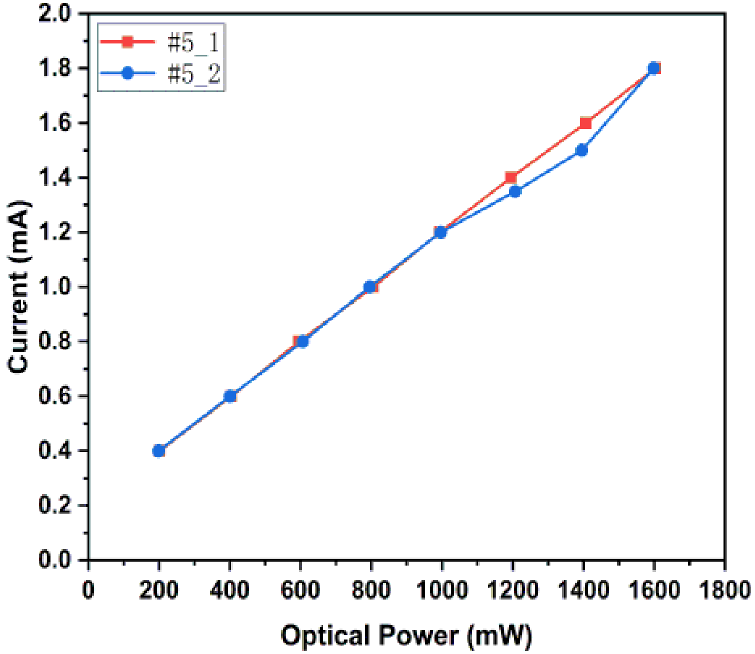
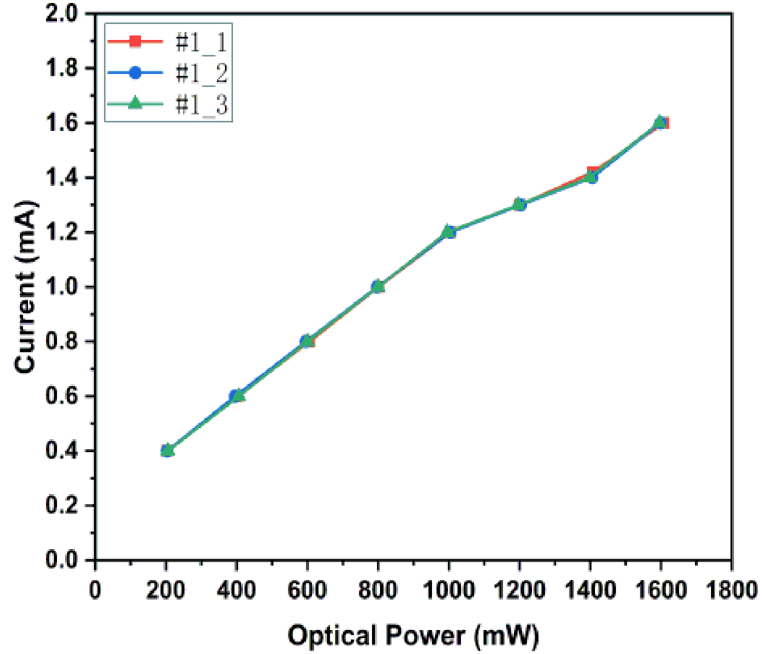
Plots of the current monitored at different laser power unpublished



(a) between five-minute interval

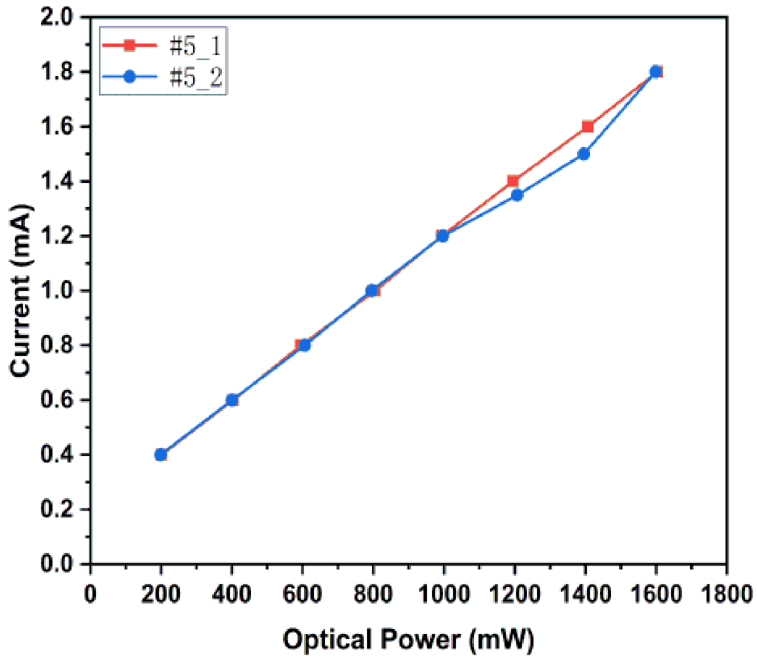


(b) between one-minute interval.

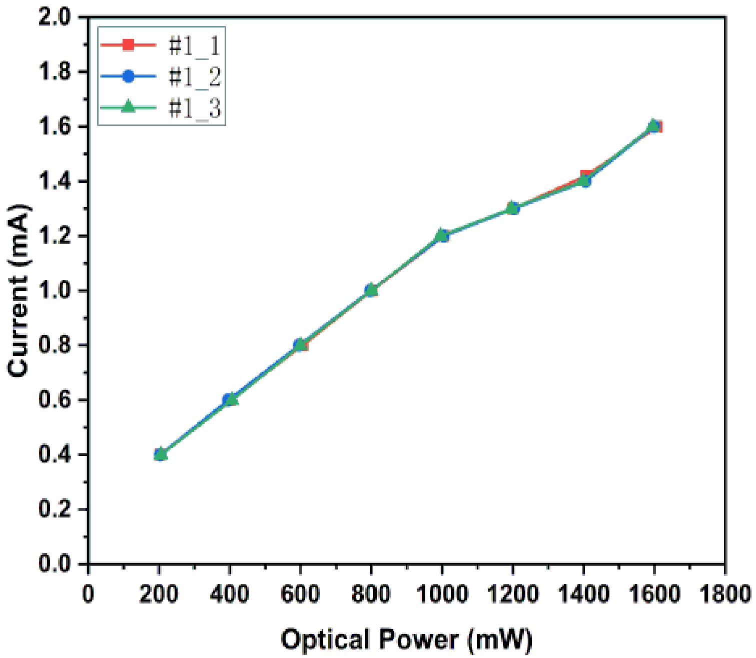
Compared with Fig. (b), the lines in Fig. (a) have **higher linearity**. The only two deviating points may be caused by reading error from the passive ammeter.

Power Comparison

Plots of the current monitored at different laser power **unpublished**



(a) between five-minute interval



(b) between one-minute interval.

The plots in Fig. (b) deviation from Fig. (a) after 1000 mW indicated that the **heat dissipation may affect** the performance of the photocathode.

Stability of emission

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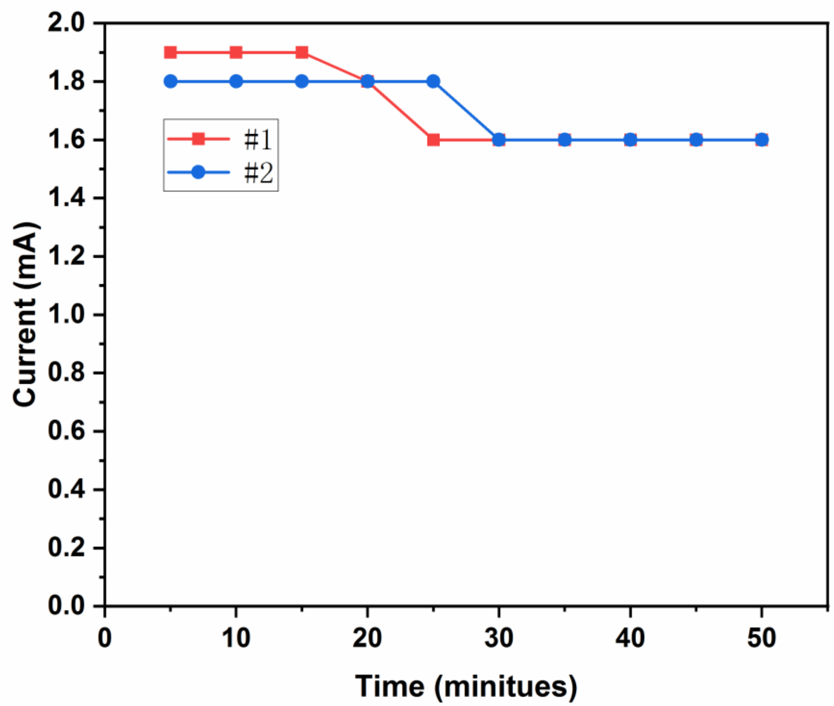
Plots of the current monitored between five-minute interval at 1600 mW

unpublished

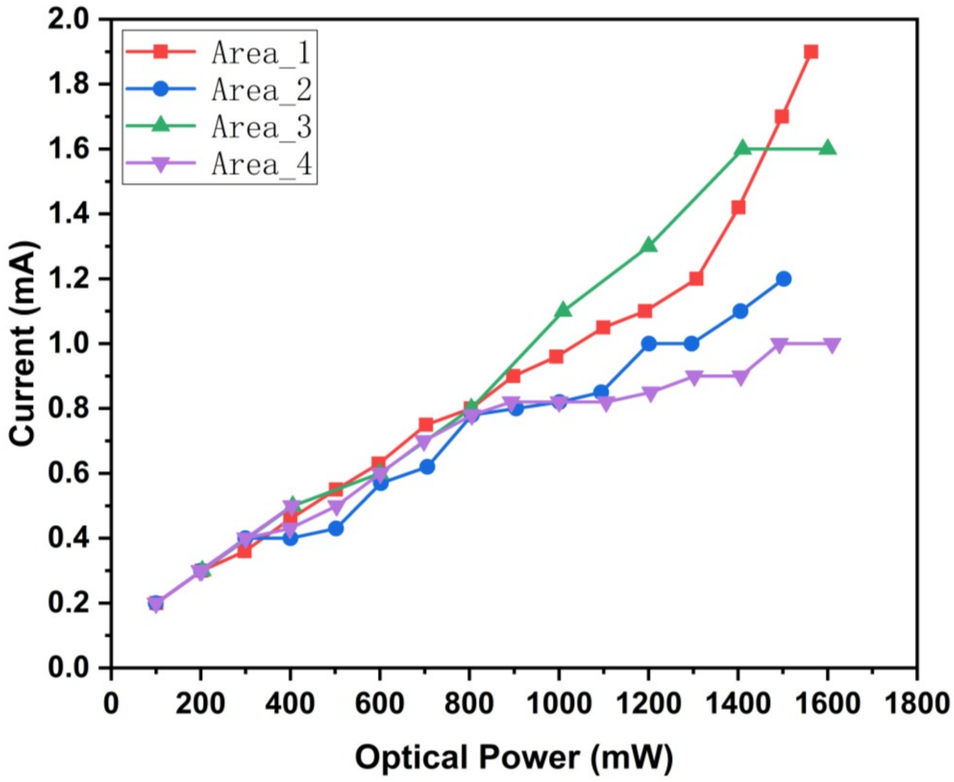


The observed current decay suggested that long operating times may require the photocathode to **be cooled at high current density levels**.

Non-uniformity emission

Plots of the current monitored at different laser power and different areas between one-minute interval.

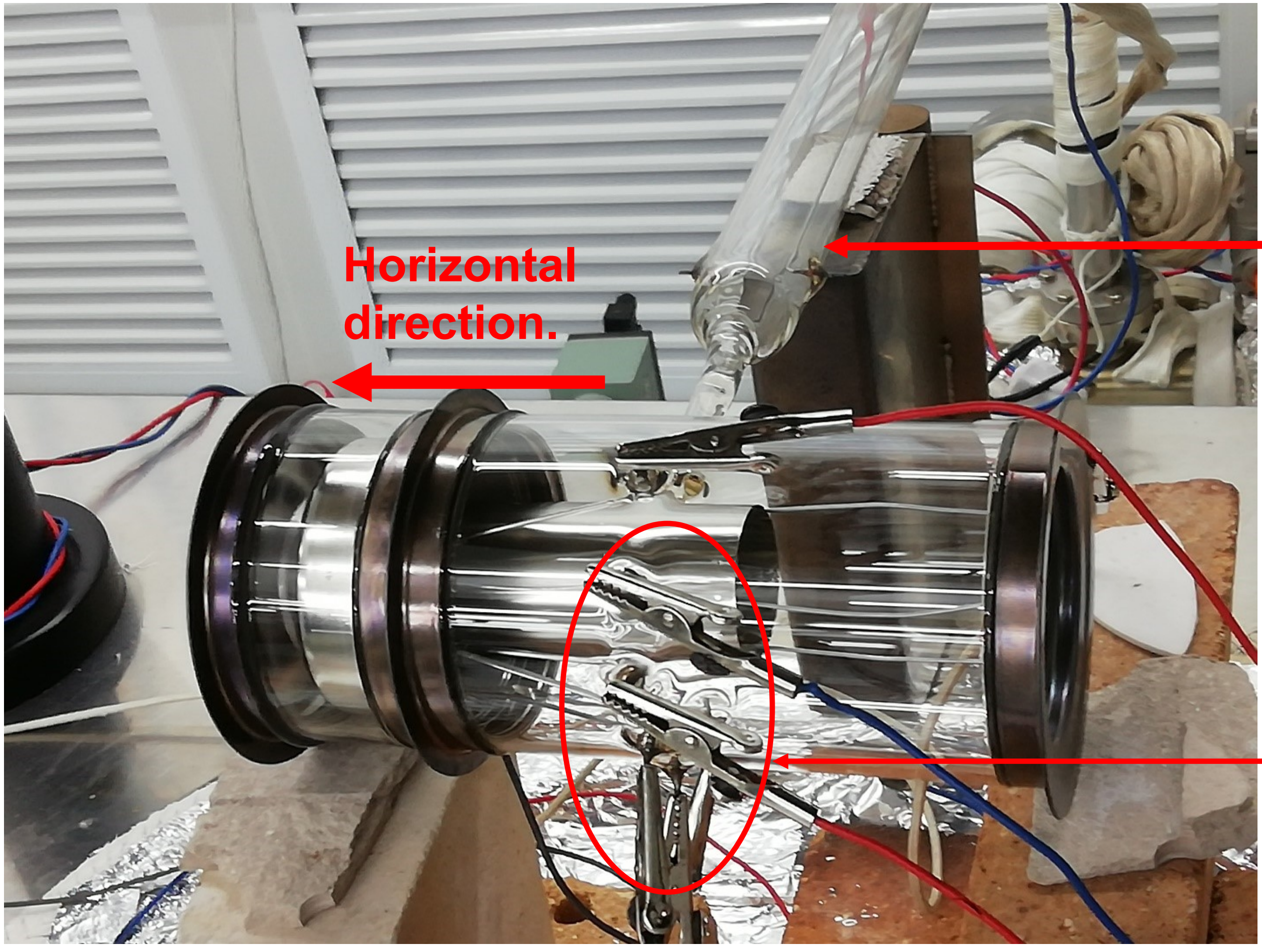
unpublished



It can be clearly seen that the emission current performances are **very different** especially when the laser power is above 800 mW.

Non-uniformity emission

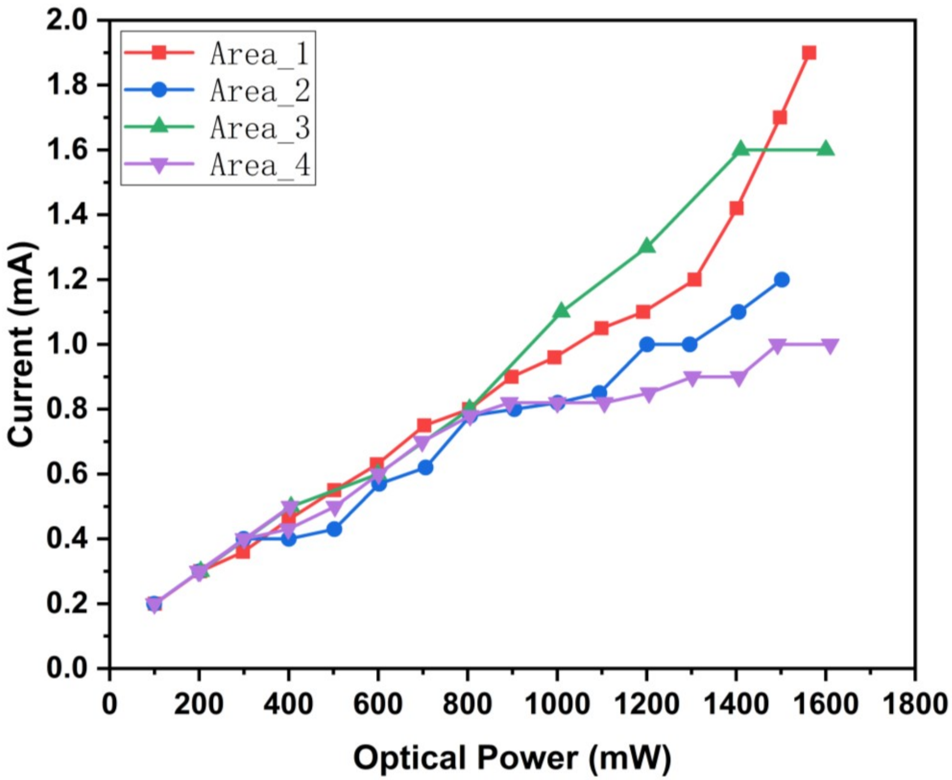
unpublished



This non-uniformity of electron emission from different areas may be caused by **fabrication technology.**

Non-uniformity emission

unpublished



The current characteristics in Area_3 and Area_4 are exhibiting a saturation behavior at higher optical power

Area_1 is exhibiting a current enhancement. The tendency of the line which depict the current of Area_2 is not clear.

The enhancement of current may be attributed to the conductive current caused by a built-in electric field between the emission area and its adjacent areas.

Summary and Future Work

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Summary

- We have developed a high current density photocathode and experimentally validated the repeatability, stability of the photocathode at different laser power;

- The multi-alkali photocathode has the potential candidate to provide high current density, small cross-section electron beams with long lifetimes and lower cathode temperatures for practical use in THz traveling-wave tube and extended interaction klystron electron source. .

Future work

- The non-uniformity emission performance of $Na_2KSb(Cs)$ photocathode has inspired us to further optimize the cathode fabrication technology and package design.

- Efforts are underway, and more detailed experiment results will be reported later.

THANK YOU