Photoemission Properties of LaB_6 and CeB_6 Under Various Temperature and Incident Photon Energy Conditions

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Outline

- Background
- Research object
- Experimental setup
- Results and Discussion
- Summary

Requirement for photocathodes

High QE | Long lifetime | Low cost

Material that satisfy ALL of these requirements has not been found yet.

Comparison of photocathode characteristics.

Properties	Semiconductor (GaAs with Cs layer)	Metal compound (LaB_6 (100) ※2,3)
Quantum Efficiency (room temperature)	> 10 % (with 3.5 eV laser)	< 0.1% (with 3.5 eV laser)
Work function	≤1.4 eV	2.66 eV
Lifetime	$< 20h@10^{-9}$ Torr	$10^3 h@10^{-9}$ Torr

※1 K.Uhchida et al. , IPAC (2014) MOPRI032
※2 S. Garrbe, phys. stat. sol. (a) 2, 497 (1970)
※3 M.Boussoukaya et al, Nucl. Instr. Meth. Phys. Res. A 264 (1988) 131-134
※4 D. Satoh et al., PASJ (2013) 540-543

Previous researches

To improve property of photocathode materials, In previous researches:

Lifetime improvement of Semiconductor.

- GaAs※1:
  Deposition of $Cs - Te$ film on the surface.
  → Lifetime improvement with keeping the QE high is intended.

QE improvement of thermionic cathode materials.

- LaB_6※2:
  By heating, cathode surface is cleaned and it prevents the QE drop.
  → Temperature dependence of QE has also been observed.
- Iridium – Cerium compound:
  With new methods, new compound Ir_5Ce※3 has been developed for photocathode.
  → High QE(0.27%@266nm), long lifetime (>>1000h, LaB_6) and lower vacuum requirement ($\sim 10^{-8}$ Torr) accomplished.

※1 K.Uhchida et al. , IPAC (2014) MOPRI032
※5 M. Asakawa et al., Nucl. Instr. Meth. Phys. Res. A 331 (1993) 302-306
※4 D. Satoh et al., PASJ (2013) 540-543

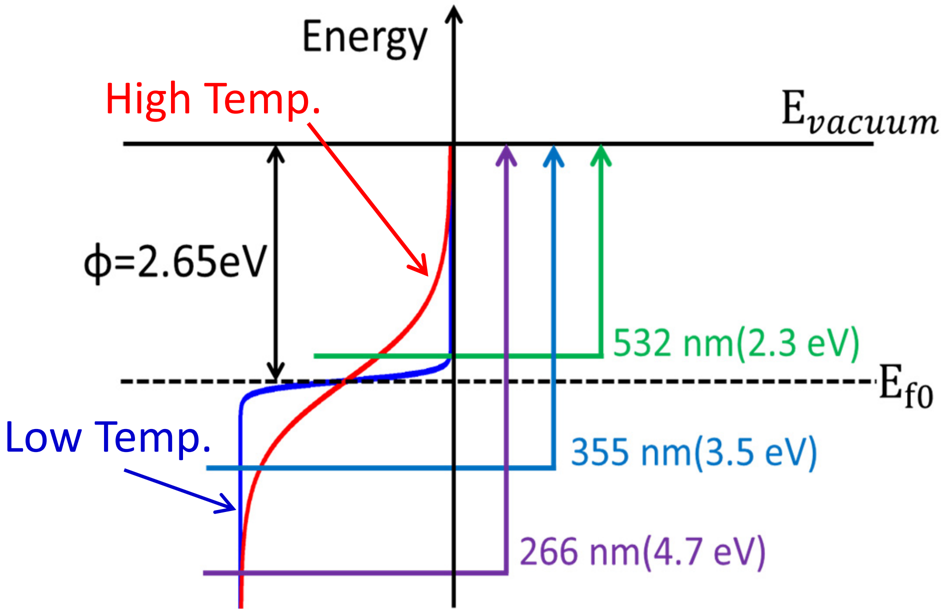
Approach for photocathode improvement

Metal hexaboride thermionic cathode have low work function and long lifetime
→ Preferable thermionic cathode materials for photocathode use.

Additional electron excitation by heating the cathode is assumable to be one of the ways to *improve the QE of them*

- ✓ Number of electrons which can be extracted by a given wavelength of laser will increase.
- ✓ Thermally excited electrons can be extracted by *laser with lower photon energy than the work function*.

Initial energy distribution in LaB_6 cathode



Objective

Acquire a basic knowledge on:

The photoemission properties of metal hexaboride materials

over various **laser wavelength** **and** **temperature**

and feasibility of QE improvement by

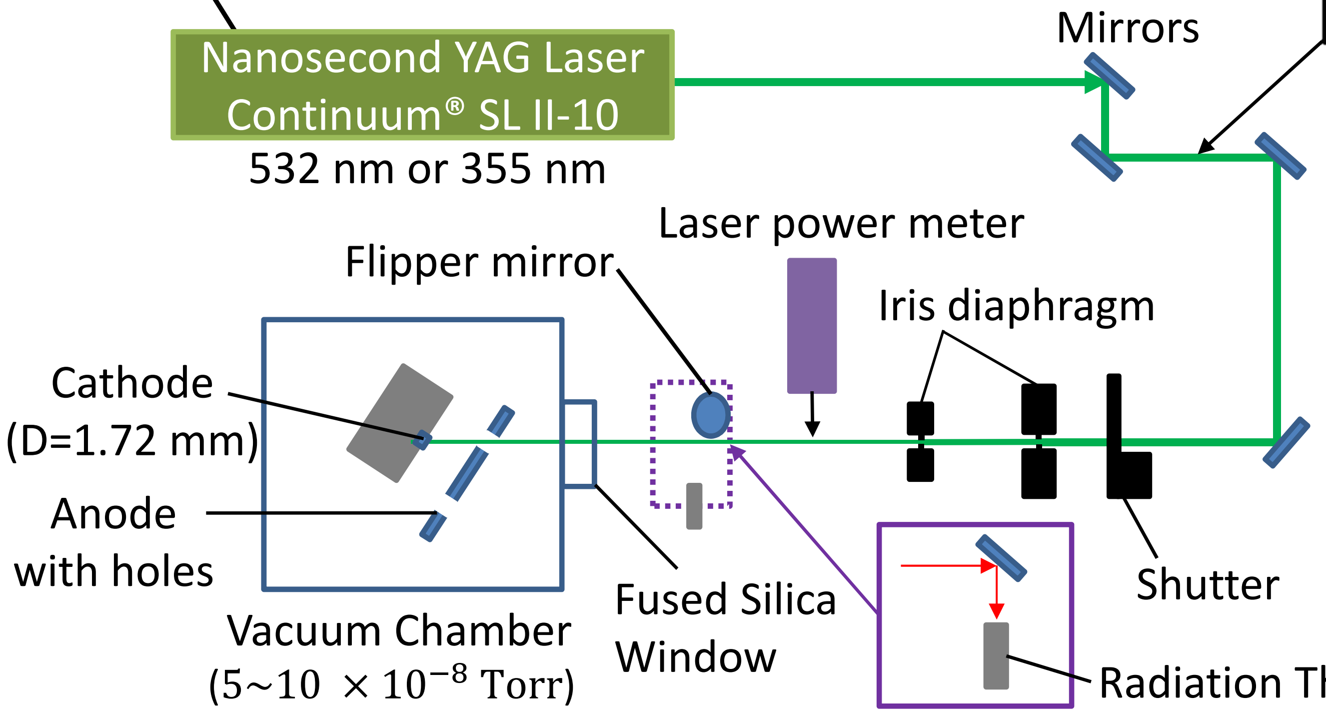
Assistance of Thermal Excitation

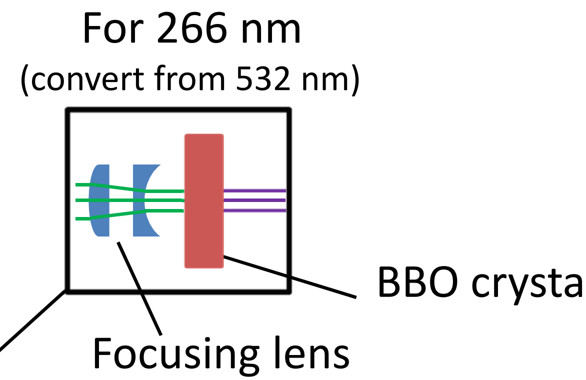
for further applications.

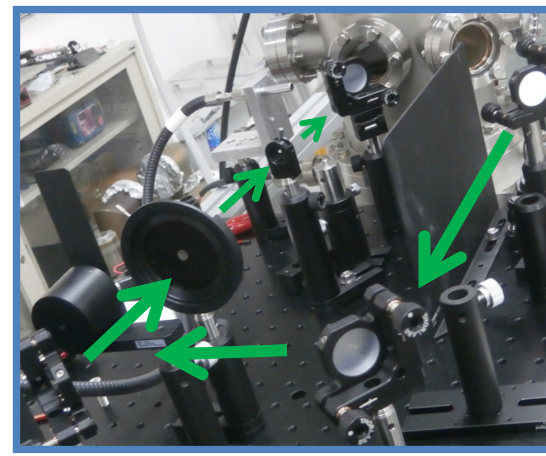
LaB_6 and CeB_6 are used as photocathodes with 266, 355, 532 nm lasers under wide range of temperature.

Experimental setup

Repetition Rate(Hz)	2
Pulse width (ns)	4-6



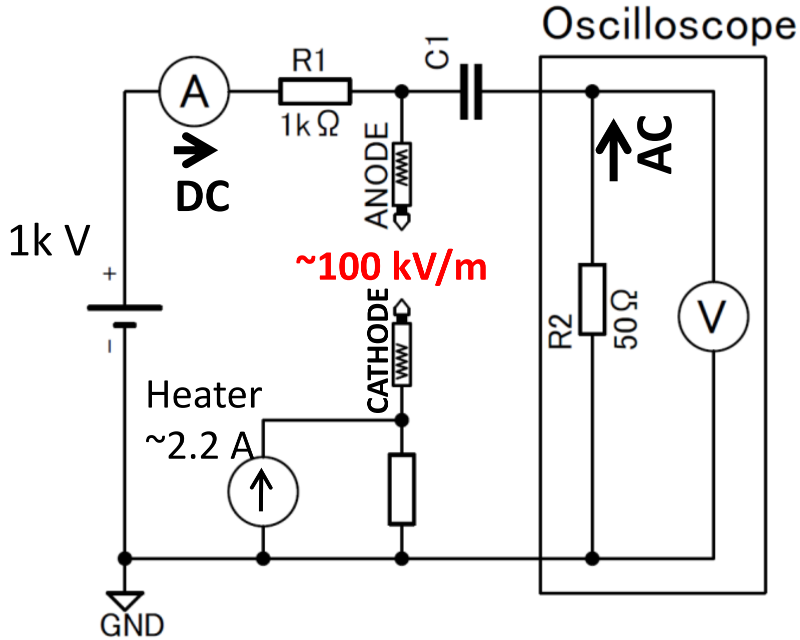




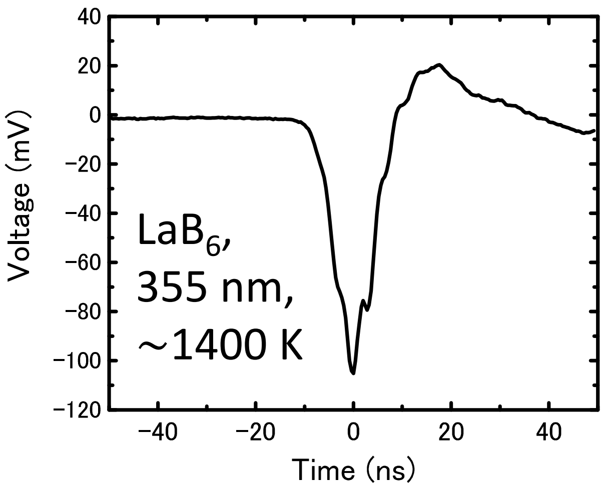
Current Measurement

- ✓ Heating the thermionic cathode cause DC current.
- ✓ It is required to distinguish DC thermionic current and Pulsed photoemission current .

Equivalent Circuit



Typical Waveform



Photoemission pulse current is measured by oscilloscope with AC coupling.

Definition of QE in this study

With our experimental setup, it is difficult to discuss the absolute value of QE:

- Laser didn't perfectly overlap on the cathode
- Polarization of laser was not measured and controlled.
- Calibration of measurement system has not been done precisely.

→ For relative QE comparison, we used:

$$\eta = \frac{number\ of\ electrons\ detected}{number\ of\ incident\ photons}$$

that resembles to the external quantum efficiency.

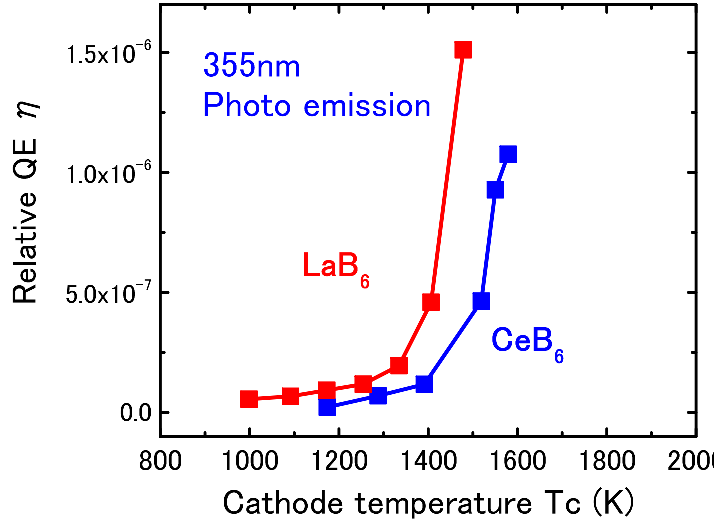
Calculations were done by

$$\eta = \frac{C/e}{P_L/E_P}$$

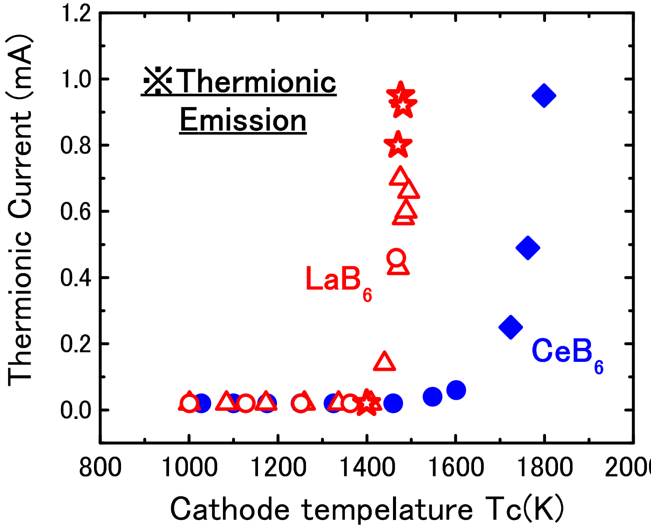
C: $Photoemission\ charge$ [C]
e: elementary charge [C]
P_L: Laser Power [J]
E_P: Photon Energy [J]

Comparison between LaB_6 and CeB_6

Relative QE comparison @355nm.



Thermal emission current comparison.



- LaB_6 has better performance than CeB_6 as photocathode with thermal excitation.
- Difference: Richardson constant.
  → LaB_6 has larger number of electrons which are thermally excited, at the same Tc.
- Life time comparison is required for further application of those materials for accelerator.

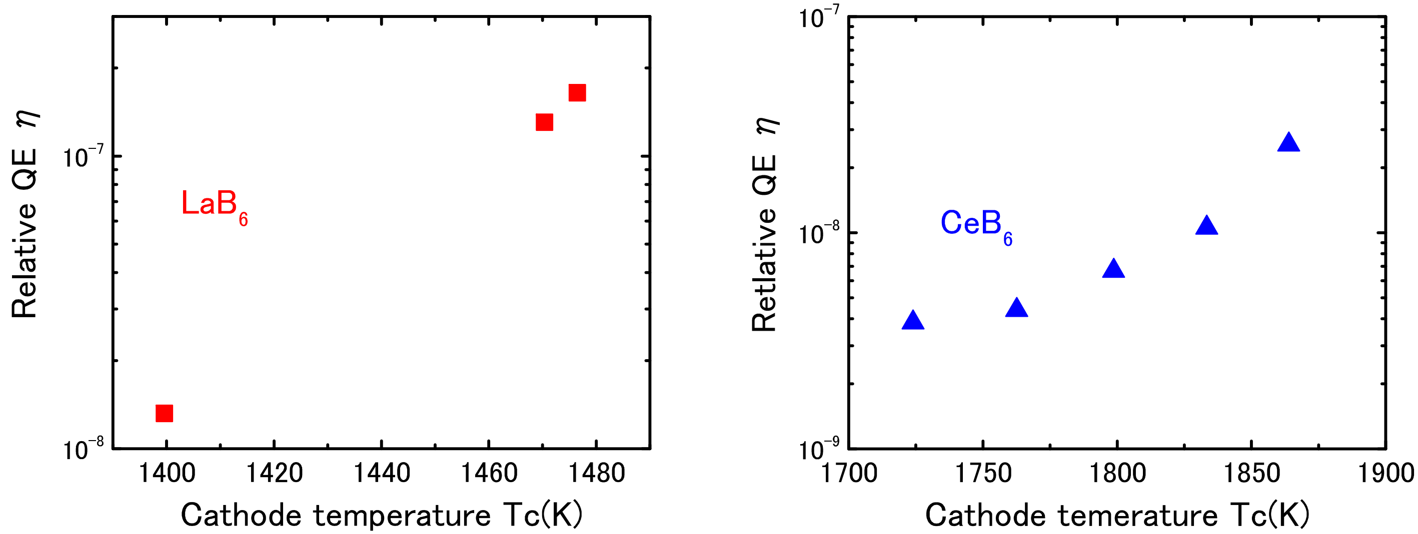
Properties for LaB6 and CeB6.※6

Properties	LaB_6	CeB_6
Work function(eV)	2.66	2.59
Richardson constant ($A/cm^2/K^2$)	29	3.6

※6 J.M. Lafferty, J. Appl. Phys. 22, 299 (1951) 299-309

Feasibility test of photoelectron emission by 532 nm laser ($2.3\ \mathrm{eV} < \phi\ 2.65\ eV$)

Tendency of Photo electron emission of the two materials



- ✓ Measurable photoemission current appeared at higher temperature.
- ✓ About one order of magnitude of QE improvement observed by heating up the cathode for both the materials.

→ With the assistance of thermal excitation, photoelectron emission by 532 nm laser ($2.3\ \mathrm{eV} < \phi\ 2.65\ eV$) is feasible.

$$\eta = \frac{number\ of\ electrons\ detected}{number\ of\ incident\ photons}$$

Photoemission by laser with photon energy < ϕ

One possible reason for photoemission by laser under ϕ is multi photon excitation.

$\text{Prob}_2. \propto \text{Pulse energy}^2$

$\text{Prob}_2.$: Probability of 2 photon excitation.

It has linear dependence.

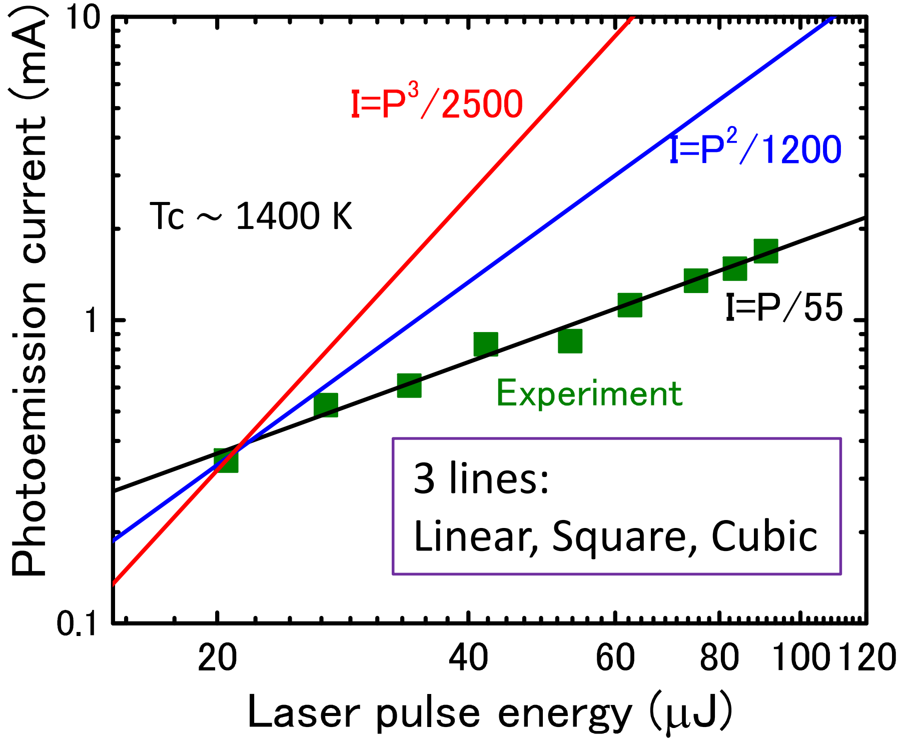
↓

<u>Single photon excitation</u>

with the assistance of thermal excitation

<u>is dominant.</u>

Laser pulse energy dependence of photoemission from CeB_6 @532 nm

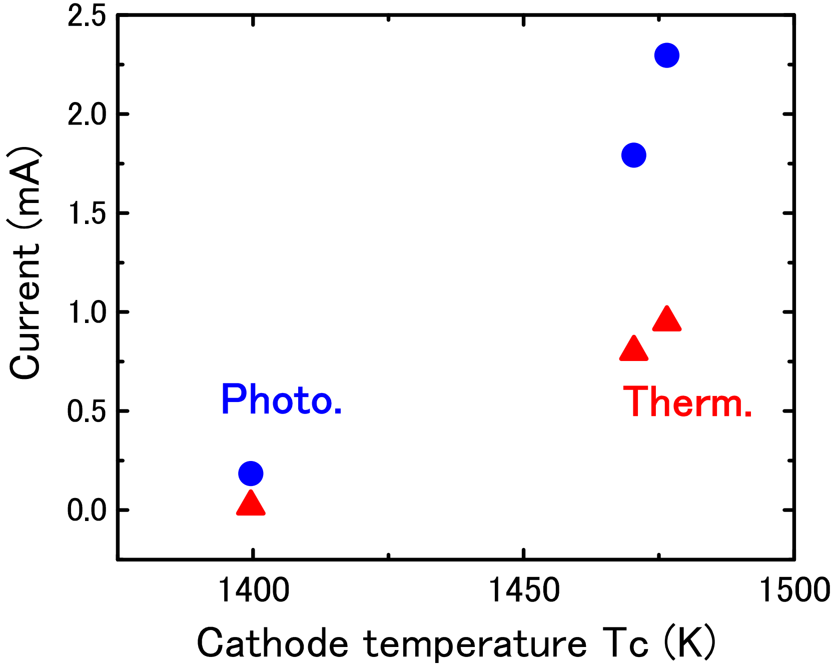


For practical use

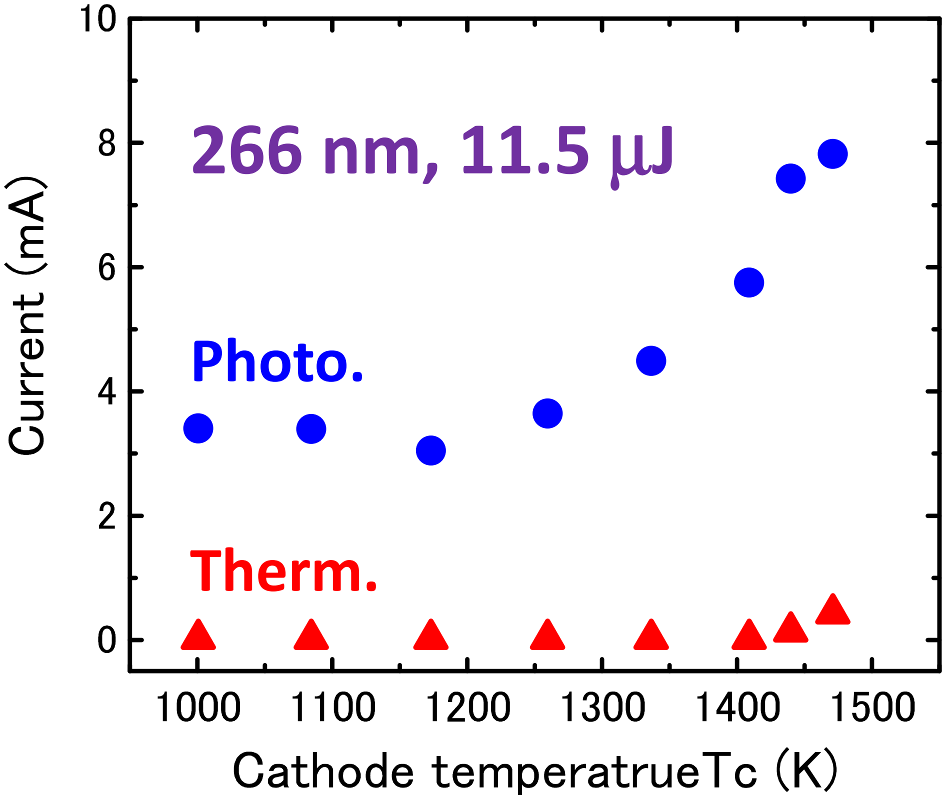
Assistance of thermal excitation is effective but:
Thermionic emission current is not negligible at higher temperature.
Practical condition for applications:
✓ High photoemission current with negligible thermionic current.

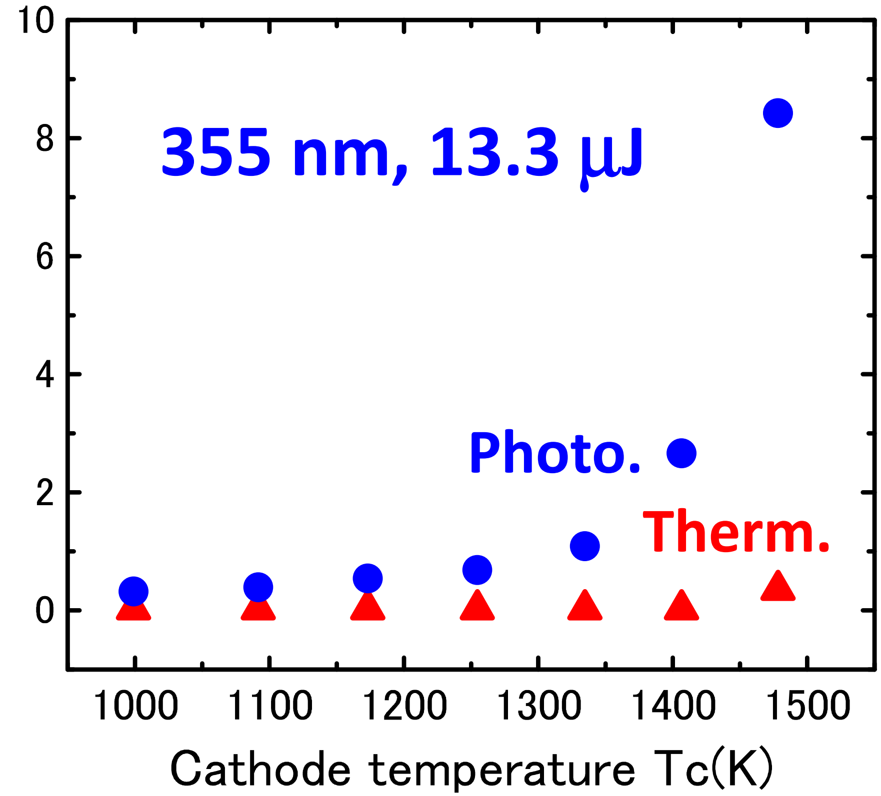
✓ QE measurement under more higher temperature
are required
for evaluating the availability of LaB_6 photocathode with 532 nm laser incidence.

Photo/Thermal emission current comparison of LaB_6 @32.5μJ, 532 nm.



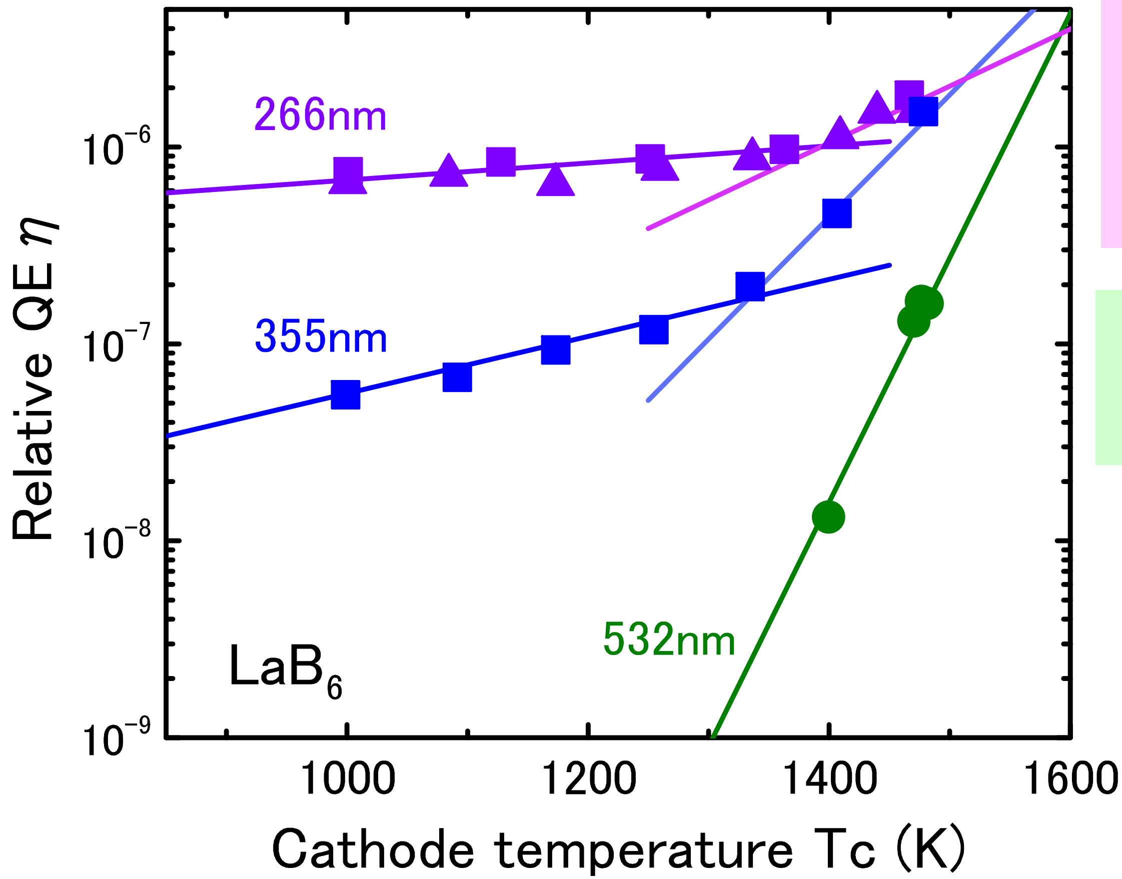
Temperature Dependence of Photoemission Current from LaB_6 for Higher Photon Energy Case





- Photoemission currents depends on the cathode temperature.
- QE improvement effect is larger for 355 nm case than that for 266 nm.

Comparison of Photoelectron Yields of **LaB_6** under Various Temperature and Photon Energy



Effect of QE Improvement by Thermal Excitation
266 nm < 355 nm < 532 nm

Quantum Efficiency
532 nm < 355 nm < 266 nm

Thermal excitation can contribute to increase the quantum efficiency.
For some applications, dark current due to thermionic emission must be considered.

$$\eta = \frac{number\ of\ electrons\ detected}{number\ of\ incident\ photons}$$

Summary

- The photoemission properties of LaB_6 and CeB_6 were compared.
- LaB_6 has higher photoemission than CeB_6 at the same heating temperature.
- Photoemission with 3 different incident laser wavelengths (266, 355, 532nm) under various temperature was examined .
- Longer wavelength had stronger dependence of QE on temperature.
- With increasing photon energy, lower the dependence on cathode temperature was observed.
- Further research about the comparison of photoemission and thermionic emission current is required for real applications.

References

※1 K.Uhchida et al. , IPAC (2014) MOPRI032

※2 S. Garrbe, phys. stat. sol. (a) 2, 497 (1970)

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