Testing of Electroluminescent Cooling using Electrical Measurement

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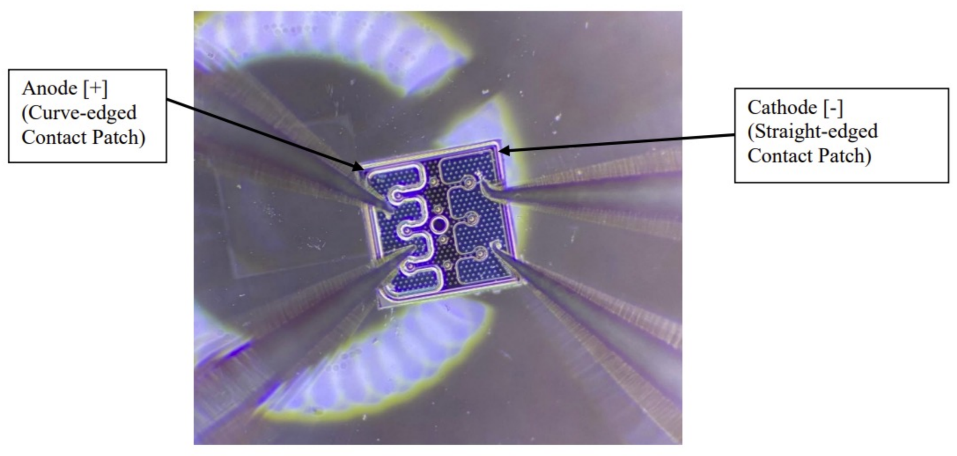
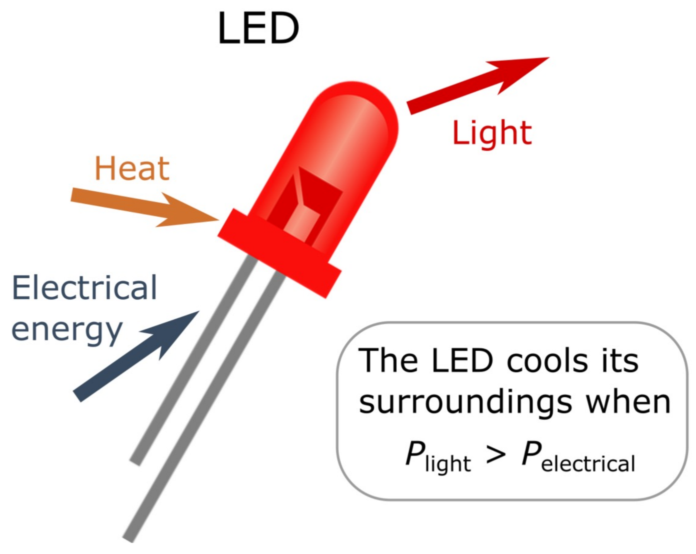
Introduction

Research Status: Electroluminescent cooling leverages highly-efficient modern light-emitting diodes (LEDs) and their ability to convert both electrical and thermal energy into light, providing net cooling to the substrate. Electroluminescent cooling was theoretically introduced about a century ago, but the one existing experiment only indicated ultralow cooling power (~100 picoWatt) with near-zero voltage.
Goal: We aim to test higher power ranges and investigate if a higher cooling rate can be achieved.
Impact: Electroluminescent cooling using a forward-biased LED points to a solid-state refrigerator that is compact, noiseless, vibrationless, and does not require hydrofluorocarbon refrigerants. It has the potential to overcome thermoelectric coolers for cryogenic cooling. It has great potential for cooling circuits and sensors, in both terrestrial and space applications.



GaInN blue LED chip



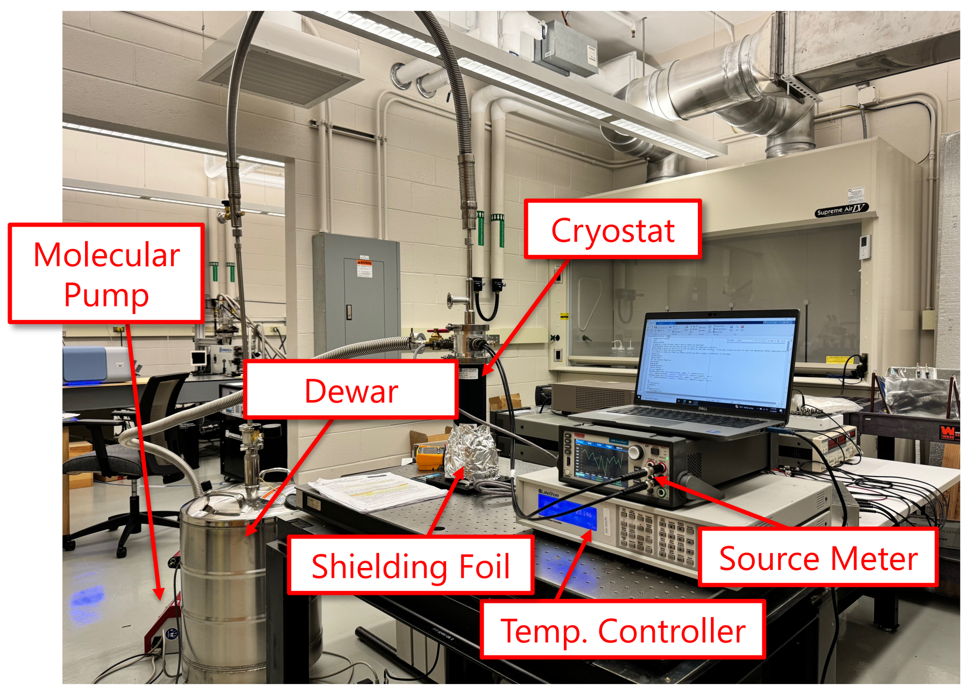
Objectives

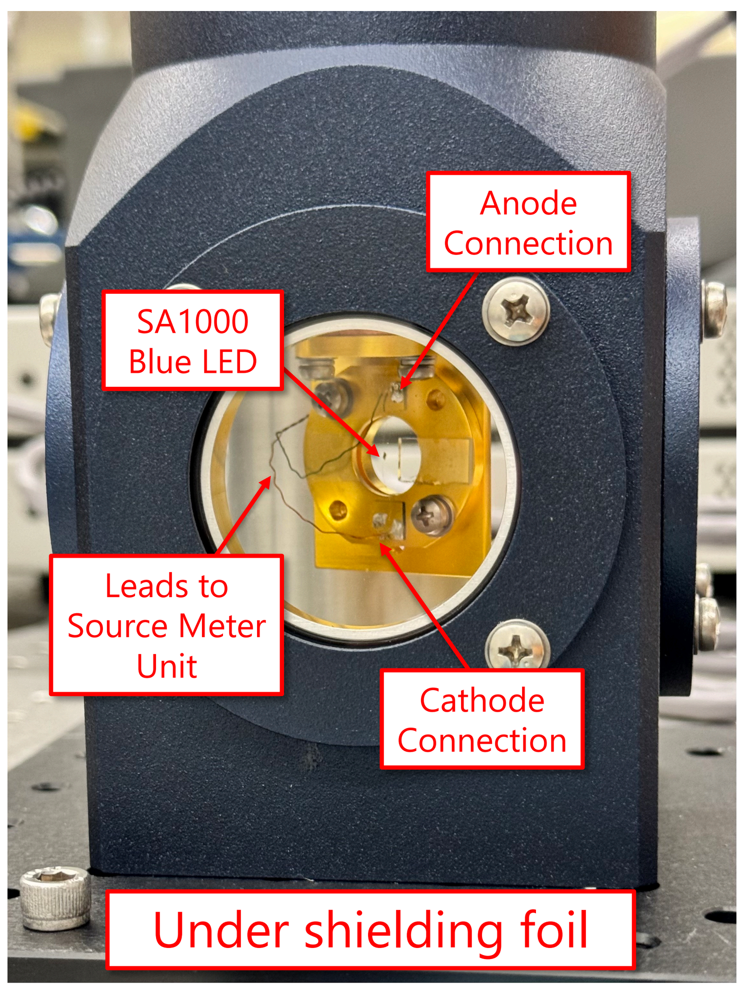
- Investigate the temperature change of the LED by measuring the change of current as a function of time in the presence of applied forward voltage bias.
- Study the dependence of possible cooling performance on voltage, current, and temperature.
- Find the ideal condition for efficient electroluminescent cooling to take place.

Methodology

To create a stable environment for detecting temperature change, all possible environmental factors needed to be eliminated. These factors included heat conduction and convection through air. For our controlled environment, a cryostat (Lakeshore ST-100) was used that provided an evacuated space with controllable temperatures. A turbo-molecular vacuum pump was used to achieve high vacuum of about 10^{-6} Torr. A temperature controller (Lakeshore 340) accurate to 1 millikelvin was used in combination with a 50-liter dewar of liquid nitrogen. Finally, a shielding foil was applied and sealed around the cryostat windows to shield the LED from ambient light. In future testing, optical measurements may be taken that need to isolate the light outputted by the LED.

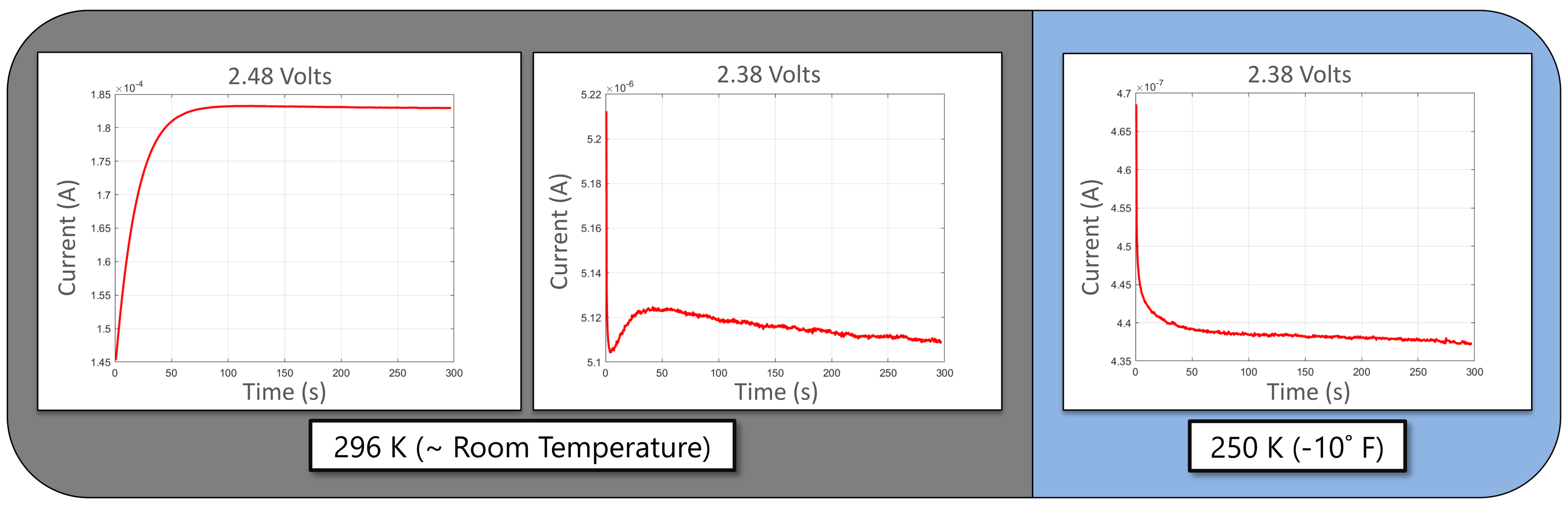
In the electrical measurement, current and voltage of the LED were controlled and monitored using a source measuring unit. All data acquisition was performed via MATLAB through GPIB interface. While measuring either current or voltage, the opposite was controlled to identify trends and determine whether cooling had occurred.





Results / Analysis

For the electrical measurement, voltage was first held constant, and the current was measured. At higher applied voltages (~2.48 Volts), an upward trend in current as a function of time theoretically indicated heating. At lower applied voltages (~2.38 Volts), a downward trend indicated the cooling we were looking for. The cooling done by the LED was relatively greater at a lower ambient temperature (250 Kelvin), however, the magnitude of the current, and thus cooling, was less.

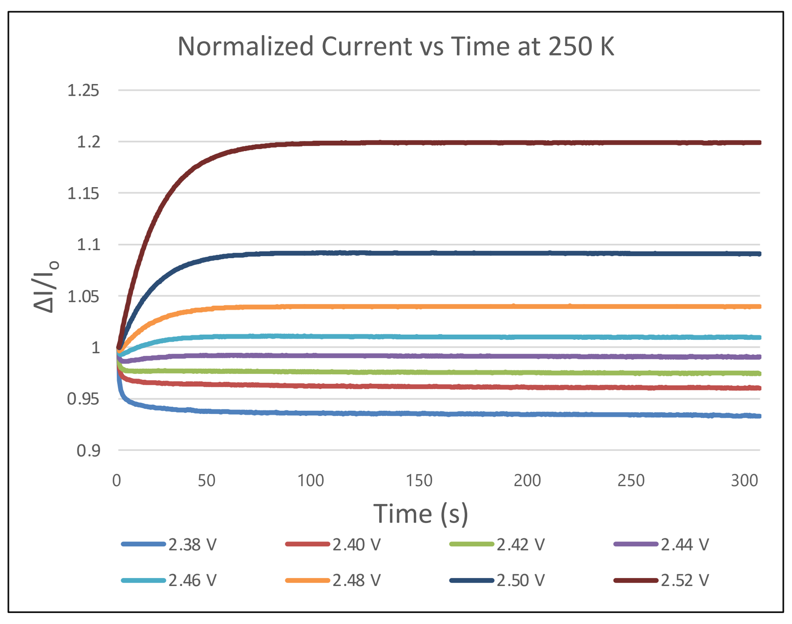


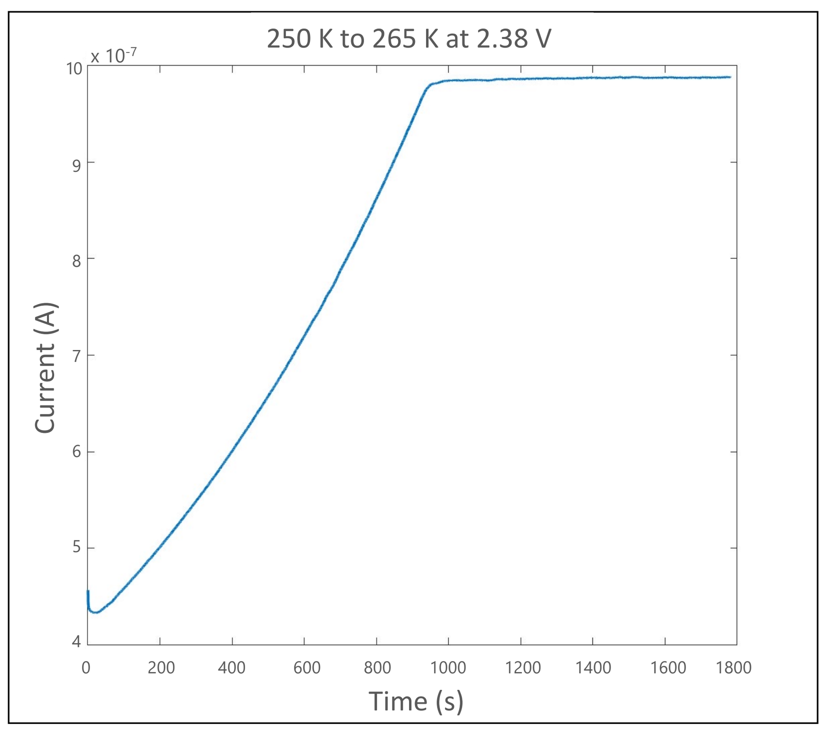
Voltage (V)	Temperature (K)	Starting Current (uA)	Final Current (uA)	Change in Current (%)	Change in Current (uA)
2.48	296	145	183	26.2%	38.00
2.38	296	5.21	5.15	-1.2%	-0.06
2.38	250	0.468	0.437	-6.6%	-0.03

For an LED, at fixed voltage, current increases as temperature increases. We determine temperature change by measuring current.

- At 250 K, current increases when $V \geq 2.44\,V$; current decreases when $V \leq 2.42\,V$.
- Current drops by 7% at $V = 2.38\,V$; current increases by 20% at $V = 2.52\,V$.

It indicates at 250 K, there is heating at $V \geq 2.44\,V$ and cooling at $V \leq 2.42\,V$.
To determine the temperature change, the temperature coefficient of current is calibrated.





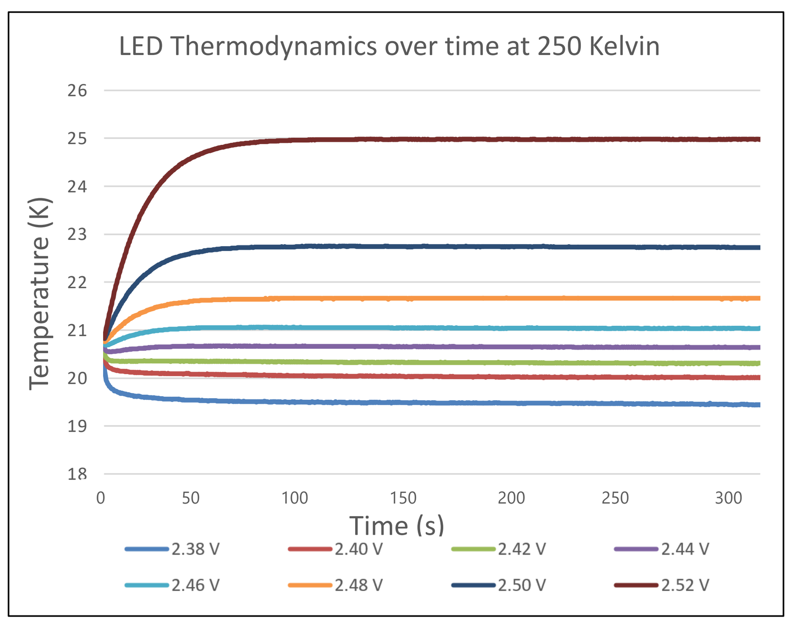
To calibrate the temperature coefficient, the temperature controller was used to ramp up the temperature by 1 K/min over 15 minutes while current was monitored. At 250 K, the temperature coefficient of current is determined as:

$$\alpha \equiv \frac{\Delta I}{I \cdot \Delta T} = 4.1\,\%/K$$

Using the calibrated temperature coefficient of current - α, we determine the temperature changes using $\Delta T = \frac{\Delta I}{I \cdot \alpha}$

- Temperature drops by 1.5 K at $V = 2.38\,V$; temperature increases by 4 K at $V = 2.52\,V$.

It indicates at 250 K, electroluminescent cooling is possible in excess of 1 K for a single LED. For cooling to take place, low voltages ($V \leq 2.42\,V$) should be used.



Future Objectives

- Use independent methods to verify the findings on efficiencies and cooling of the LED.
- Investigate the light output of the LED using a photodetector to study the dependence of the LED efficiency on voltage bias.
- Mount LED on high refractive index hemisphere (e.g., sapphire or ZrO_2) to enhance light extraction from LED, so as to enhance electroluminescent cooling.

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References

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