DEPARTMENT OF MATERIALS SCIENCE & ENGINEERING

(Capstone Expo Assigned) TEAM NUMBER
Anti-Stokes Laser Cooling for Electronics

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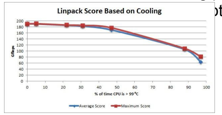
Problem Definition

Modern electronic devices such as CPU's and micro electronics are limited by thermal management challenges that reduce performance, efficiency and lifetime. Conventional cooling methods like air and liquid cooling introduce mechanical vibrations and scaling limitations at small length scales.

Anti-Stokes laser cooling provides a solid state alternative that ... photon up conve...

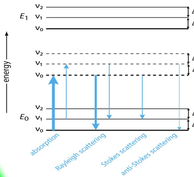


Linpack score, a CPU benchmark used to determine its performance, decreases sharply in hotspot areas above 99°C. By decreasing the heat at the hotspot, the chip can maintain higher speeds and increase overall performance.

However, traditional anti-stokes materials such as Lanthanide-Doped Upconversion Nanoparticles (UCNPs) are expensive and difficult to fabricate. This work explores the use of quantum dots embedded in a perovskite matrix as a low-cost cooling medium.

Anti Stokes Physics

Anti-Stokes Mechanism



When an emitted photon has a higher energy than the absorbed one, the energy difference comes from lattice vibrations (phonons), which produces a cooling effect in t...

$$\eta_c = \frac{\lambda_{pump}}{\lambda_{emit}} - 1$$

Quantum Efficiency

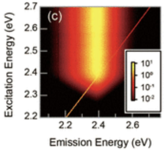
The Quantum Efficiency (QE) is related to how the laser power is transformed

$$QE = \frac{W_{rad}}{W_{rad} + W_{nr}} \approx 1$$

Non radiative decay will convert power into heat which takes away from cooling potential

Cooling Condition

Measured Emission vs excitation intensity plot from primary source. Below the line indicates cooling regime. The plot demonstrates the small range of laser light energies that can be used to achieve cooling.



Design Calculations & Analysis

Cooling Power

PL quantum efficiency and the cooling gain under continuous wave excitation.

$$\eta_{PL} = \frac{1 + \eta_{BX}\beta\tau_X}{1 + \beta\tau_X}$$

β represents the probability of a single QD being excited per unit time, which is assumed to be proportional to the excitation intensity.

Idealized max cooling is (g_{max}=2.1 fW/QD) at 1kW/cm²

$$\mathcal{g} = \beta(\eta_{ext}\langle E_{PL}\rangle - E_{ex})$$

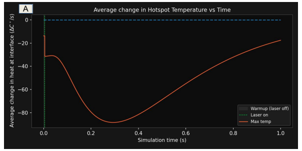
Beyond this optimal excitation density, the system transitions from single exciton recombination removing heat to multiexciton recombination that adds heat defining a strict

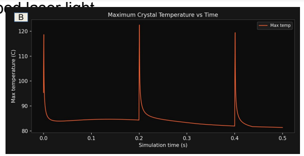
Beer-Lambert Law
For light attenuation

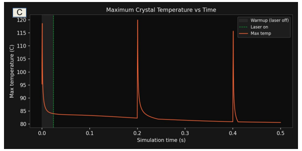
$$I = I_0 e^{-\mu d}$$

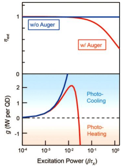
Fick's second law
For heat diffusion

$$\rho c_p \frac{\partial T}{\partial t} - \nabla \cdot (k\nabla T) = \dot{q}_V$$









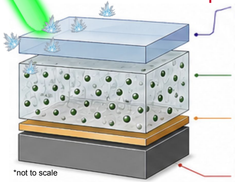
Plot A indicates the rate of temperature change the optical cooler delivers to the chip surface over time. The plot indicates that a saturation of temperature change occurred at about 0.3 seconds before the cooled spot dropped below ambient temperature and heat flowed in from the surrounding.

Plots B and C are for 1 millisecond 800W/cm² hotspot pulses. B is with no laser cooling C is hotspot pulses lined up with cold side saturation time in plot A. A reduction in max temperature by 2-3 °C per hotspot peak which corresponds to a direct chip performance increase.

Design parameters for simulation plots:
2mm active layer
532nm pump wavelength
1% volume fraction of QD
1200W/cm²

Final Design

Macroscopic Structure



Aluminum Oxyfluoride
Optical Gradient (2 µm)

Alumina Perovskite Active Material Matrix (2 mm)

Aluminum
Reflective Backlayer (150 nm)

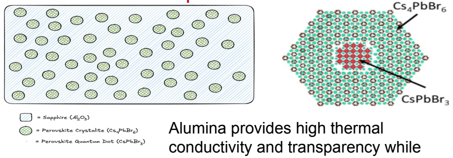
Electronic Component
Heat Source

- Aluminum oxyfluoride used to reduce fresnel losses and increase efficiency via a gradient in refractive index
- Alumina Perovskite matrix is the active material that upconverts the laser light to produce cooling
- Back reflector enhances upward emission and reflects any unabsorbed laser light

Performance Targets

Device Heat Load	800W/cm²
Required active material thickness	2mm
Response Time	<1s
Laser Wavelength	532 nm
Laser power required	~100W
Cooling Efficiency η_c	2.66%
Quantum Efficiency	0.98

Microscopic Structure



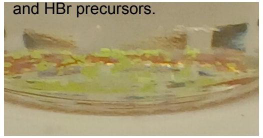
Alumina provides high thermal conductivity and transparency while closely matching the refractive index of the perovskite crystals.

Manufacturing Process

Deposit Al reflective backlayer → Prepare sub-grown Dot-in-Crystal → Combination Cold Sinter and Anneal → Add Optical top layer via sputtered deposition

Prototype & Test Results

Current Progress:
Synthesised the quantum dots within the perovskite matrix from CsBr, PbBr2, and HBr precursors.



Planned Characterization

TEM (Transmission Electron Microscopy)
Examine QD size distribution and dispersion

Raman Spectroscopy
Estimate the quantum efficiency

Photoluminescence spectrum
Confirm emission wavelength and anti-stokes behavior