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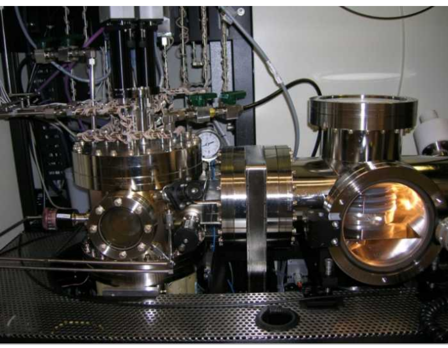

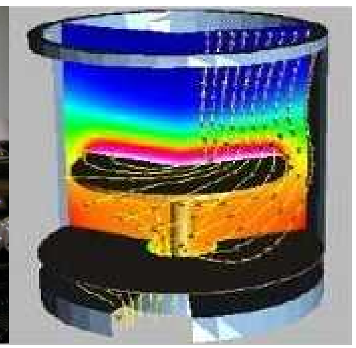

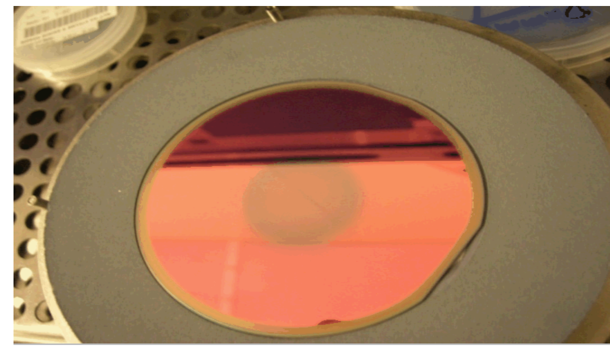

Development of highly doped passivation in the GaInP/GaAs double heterostructure for use in laser cooling

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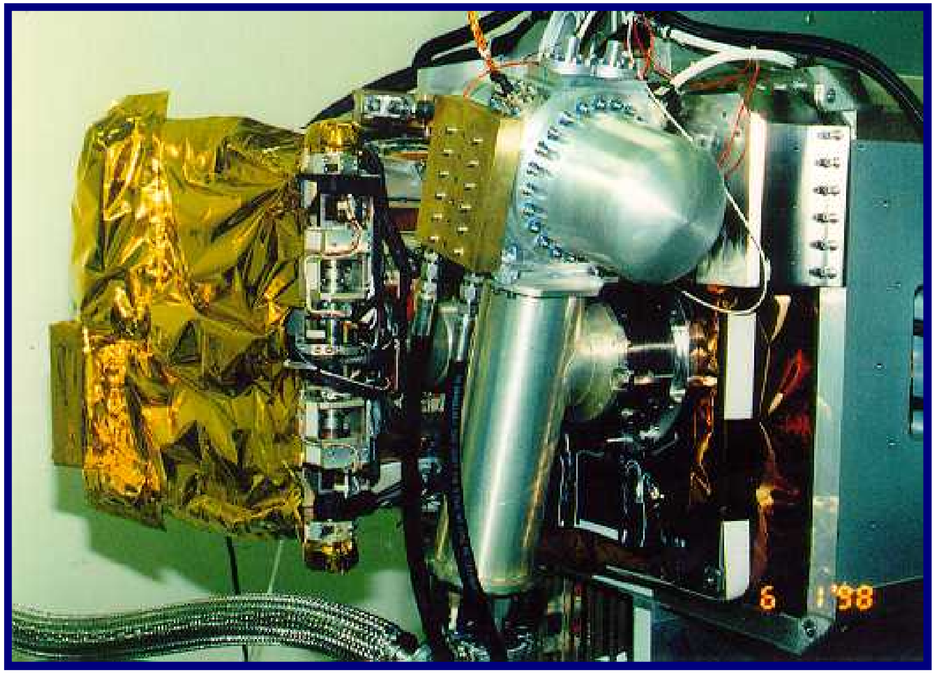
On-orbit cryocoolers – MTI Satellite launched: 3/12/00

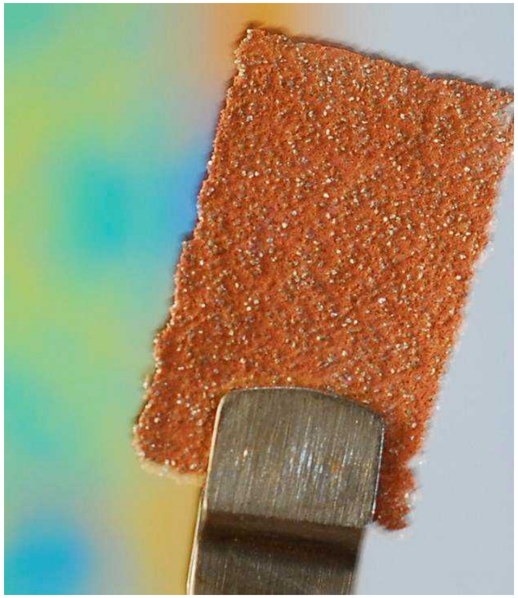
MTI MULTISPECTRAL THERMAL IMAGER

- Capacity 3W @ 65K, closed loop temperature control
- Ran continuously from 11/2000 to 11/2007 (battery anomaly), restarted 2/2008 and running since
- With small adjustments to closed-loop control, has kept FPA very stable @ 75K throughout life



Thermal detector needs

- **Requirement**:
  - Eliminated or reduced cooling requirements, while maintaining or improving HgCdTe-like NETD
- **Possible Approaches:**
  - Uncooled, high-sensitivity IR FPA
  - Reduced cooling requirements
  - Spatially-separated cooling
- **Technologies:**
  - Next-Gen Bolometer technology
  - High-conductivity FPA radiator/substrate
  - Flexible, long-life heatpiping
  - High-efficiency TE cooling
  - Low-vibration, high reliability sterling cooling



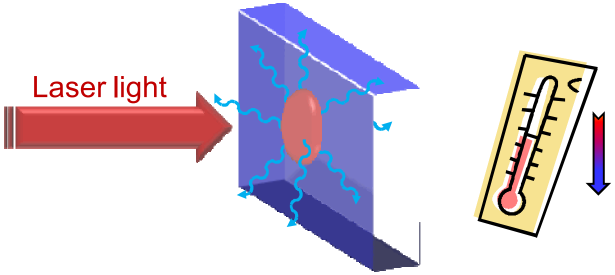
Problem & approach

PROBLEM

- Current on-orbit cryo-coolers use mechanical pumps which can cause vibration and image blur
- Mechanical cryo-coolers require large radiators to remove heat which can increase satellite size and mass
- **Importance** – Development of small, agile coolers that do not interfere with satellite operability is needed

APPROACH

- Optical refrigeration provides a solid state, reliable means of vibrationless cooling

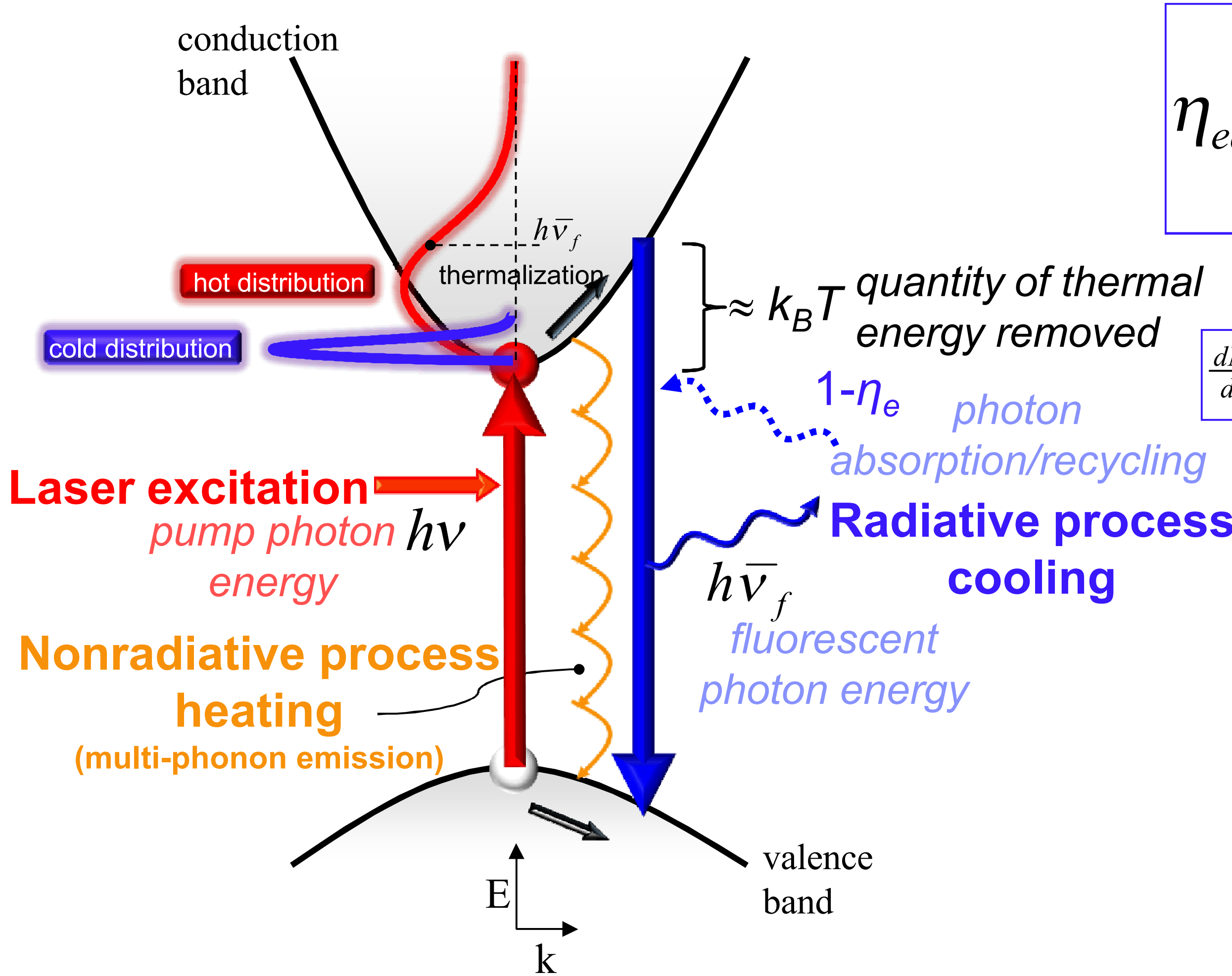


Shining laser light on a material results in bulk cooling through anti-Stokes luminescence.

- Increasing the n-doping in the passivation layer creates a small depletion region around the InGaP/GaAs junction

The cooling cycle in semiconductors

Radiative relaxation must dominate e-h pair recombination for cooling to occur.



External quantum efficiency:

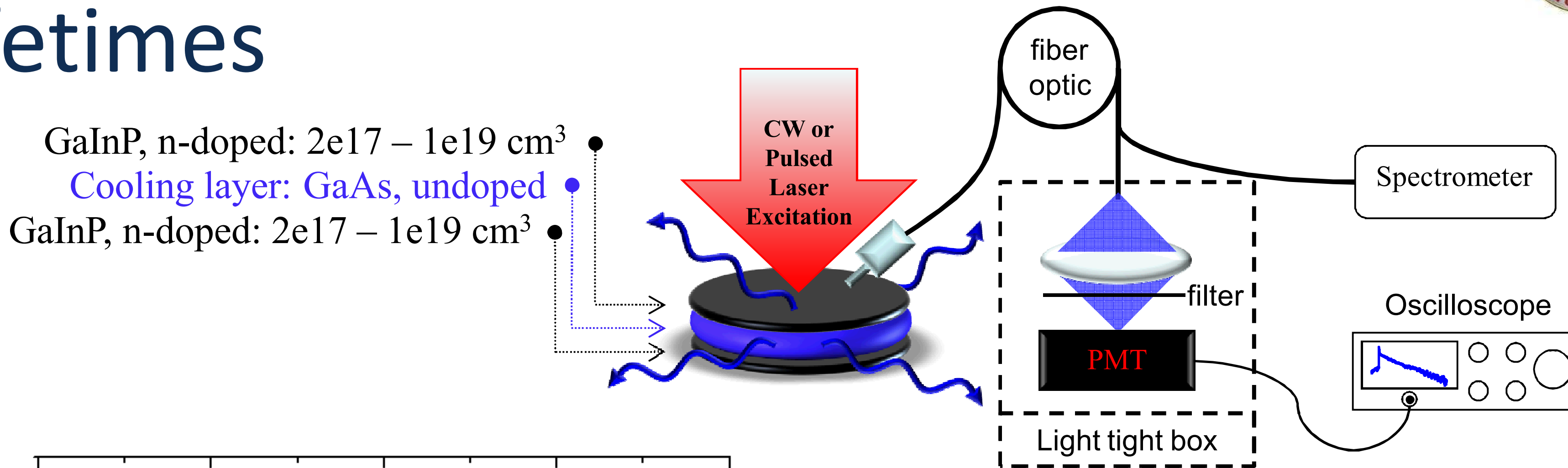
$$\eta_{eqe} = \frac{\eta_e B N^2}{\frac{N}{\tau_{nr}} + \eta_e B N^2 + C N^3}$$

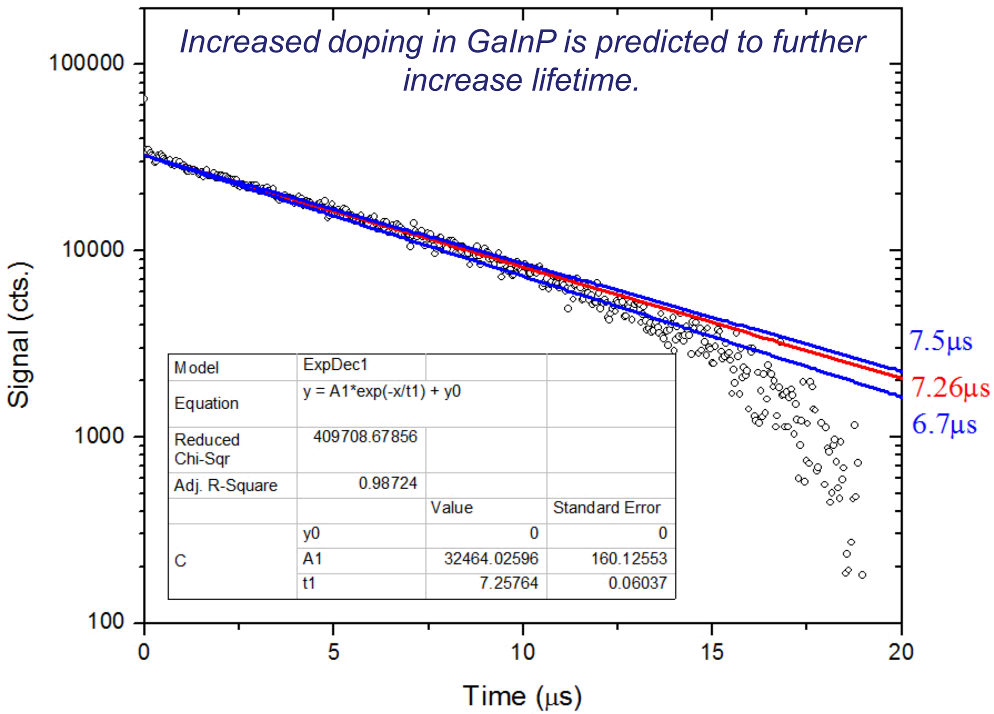
Recombination rate:

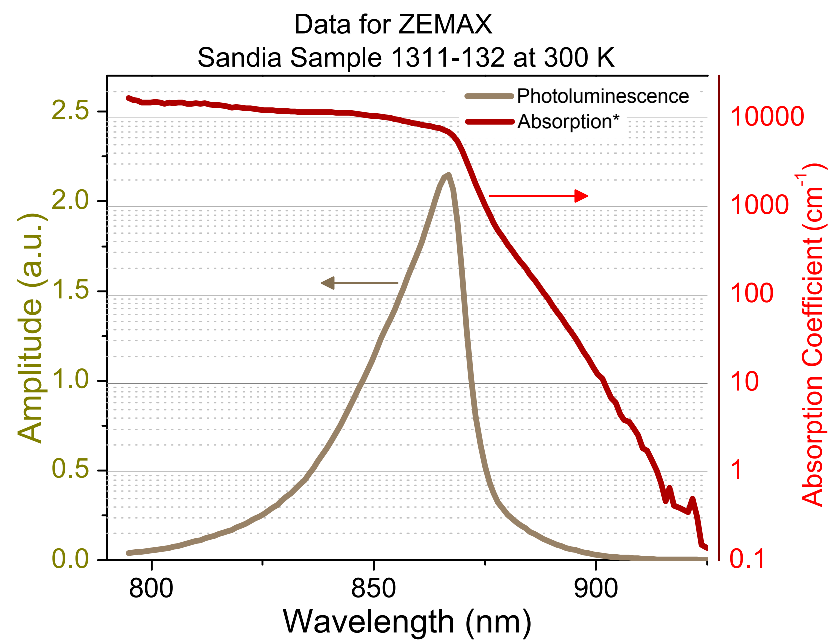
$$\left.\frac{dN}{dt}\right|_{decay} = -N/\tau_{nr} - \eta_e B N^2 - C N^3$$

Best condition for cooling:
Low "*C*"
High "τ_{nr}", "*B*" and "η_e"

Optical characterization shows long lifetimes







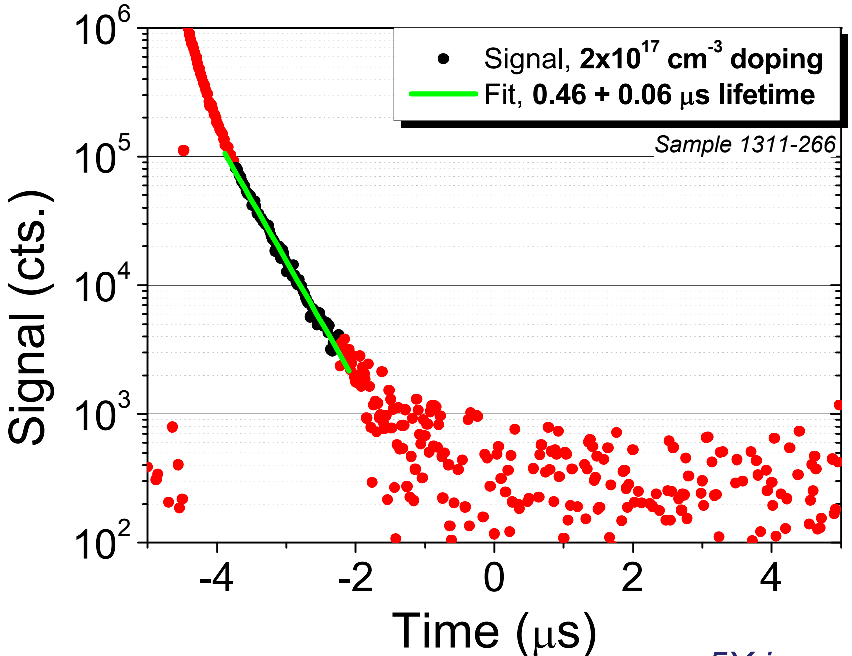
*absorption calculated from PL (van Roosbroeck-Shockley relation)

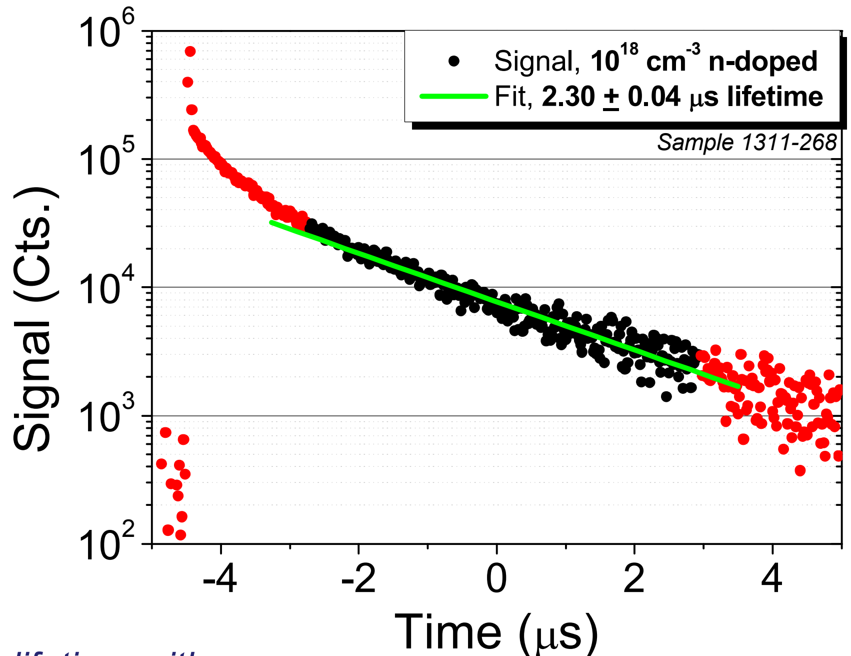
Increased n-doping in the GaInP leads to longer lifetimes

0.5 µm GaInP, n-doped: 2e17 cm^{-3}
1.0 µm GaAs, undoped
0.5 µm GaInP, n-doped: 2e17 cm^{-3}

double heterostructure under test

0.5 µm GaInP, n-doped: 1e18 cm^{-3}
1.0 µm GaAs, undoped
0.5 µm GaInP, n-doped: 1e18 cm^{-3}



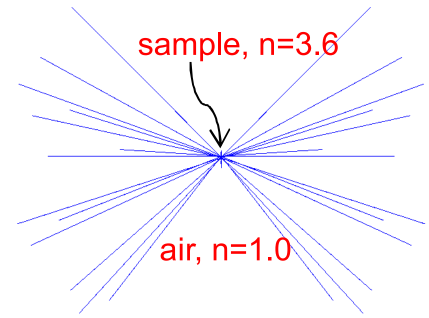


5X increase in lifetime with increased doping in GaInP

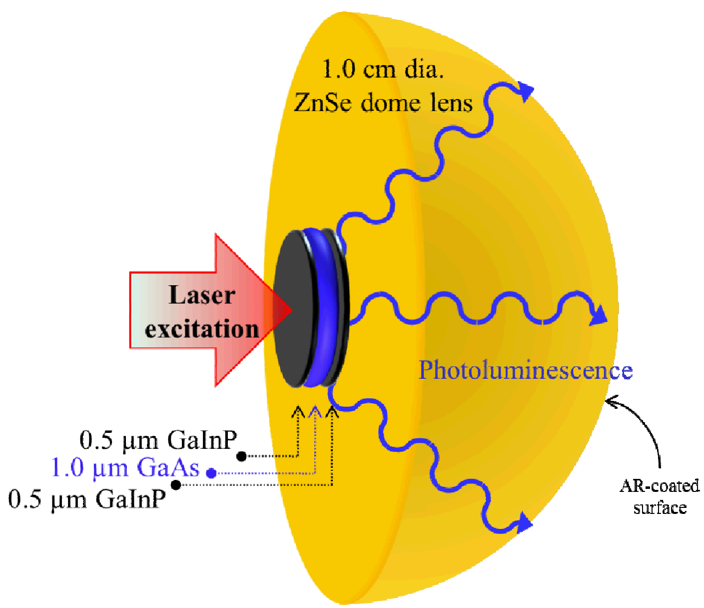
Luminescence extraction simulation

For luminescence to contribute to cooling it must be extracted from the sample to free space.

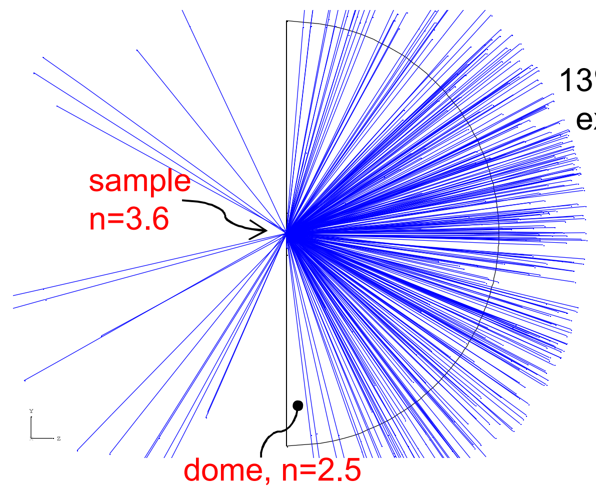
1. *Generated luminescence gets trapped inside the semiconductor due to total internal reflection*



2% of light extracted



Luminescence extraction modeling

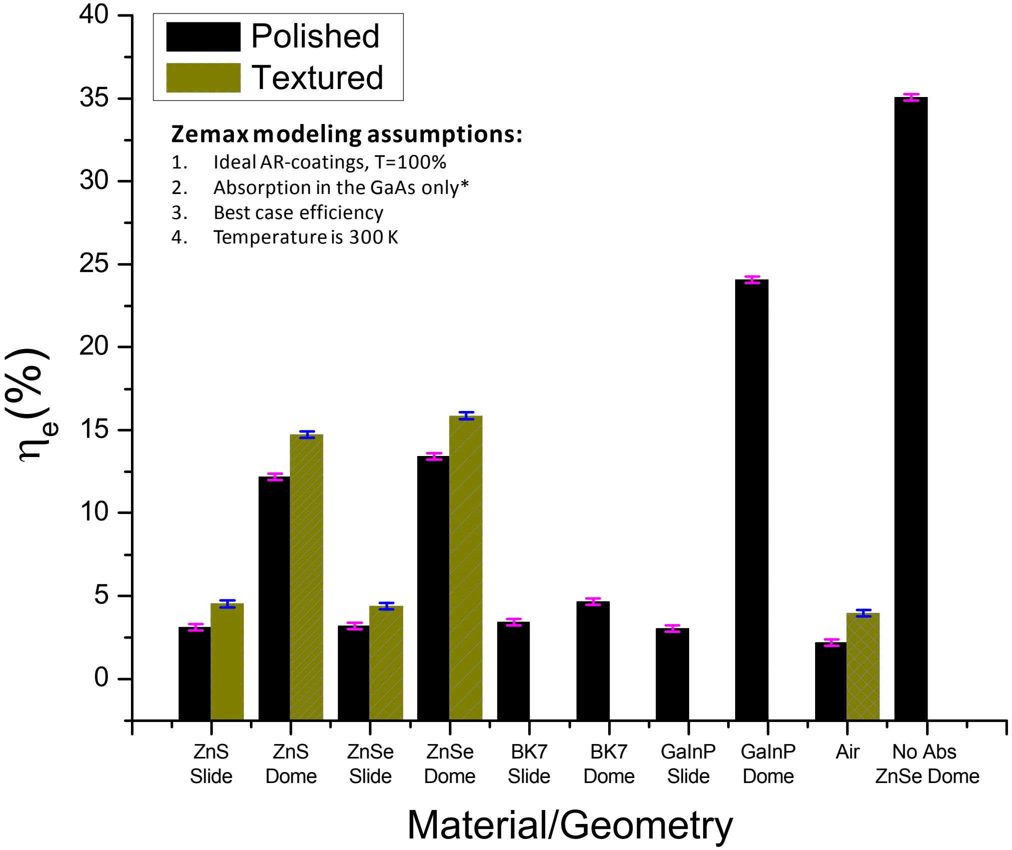


13% of light extracted

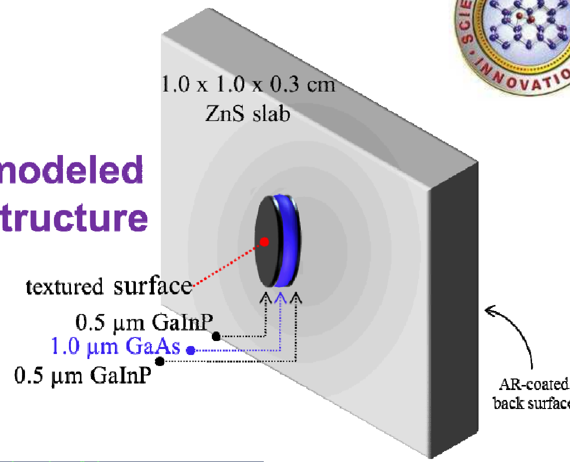
2. *Bonding of the semiconductor to a high index optical element facilitates luminescence extraction*

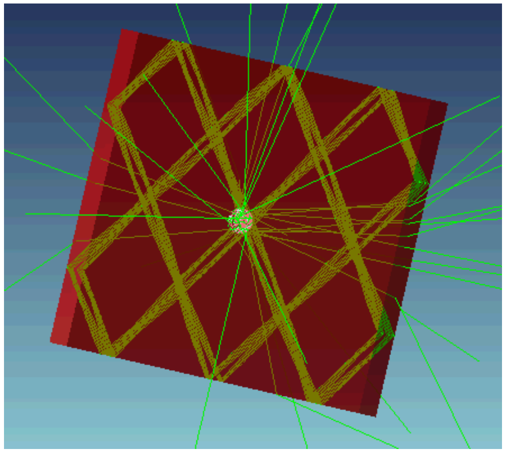
ZEMAX modeling results: geometry and material

Luminescence Extraction Efficiency Results



modeled structure



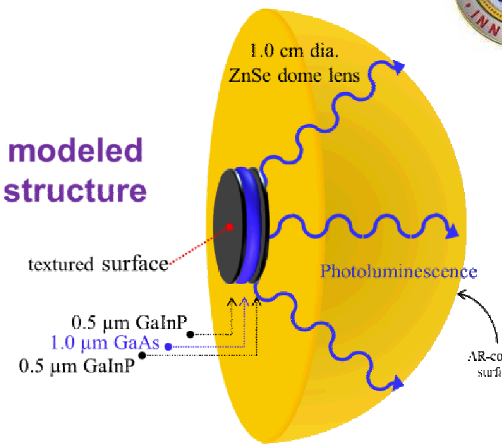


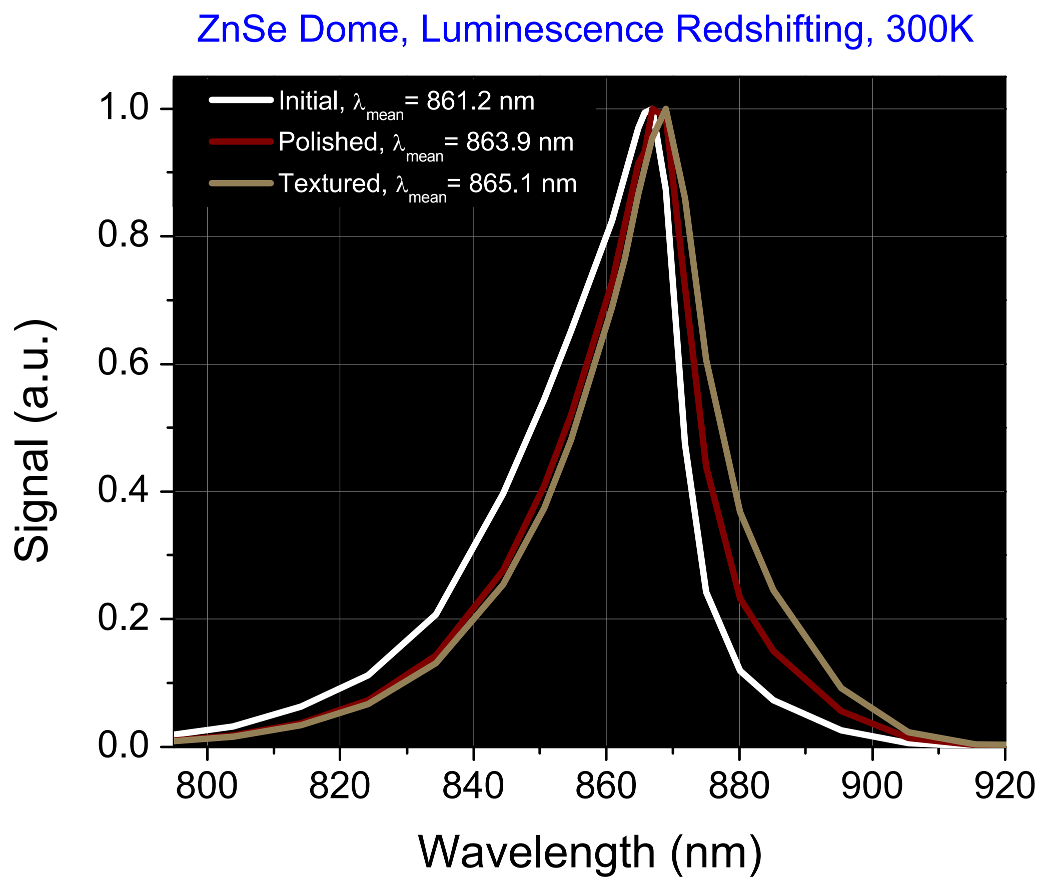
Many rays get trapped in a slide geometry

ZnSe dome lens shows highest extraction efficiency.

Textured/Polished: $$\frac{\eta_e^{texturing}}{\eta_e^{polished}} = \frac{15.9\%}{13.4\%} = 1.19$$

Texturing has the consequence of luminescence red-shifting





Texturing of semiconductor surface results in greater luminescence red-shifting.

Polished: $\frac{h\tilde{\nu}_f - h\nu_f}{k_B T} = 0.19$

Textured: $\frac{h\tilde{\nu}_f - h\nu_f}{k_B T} = 0.27$

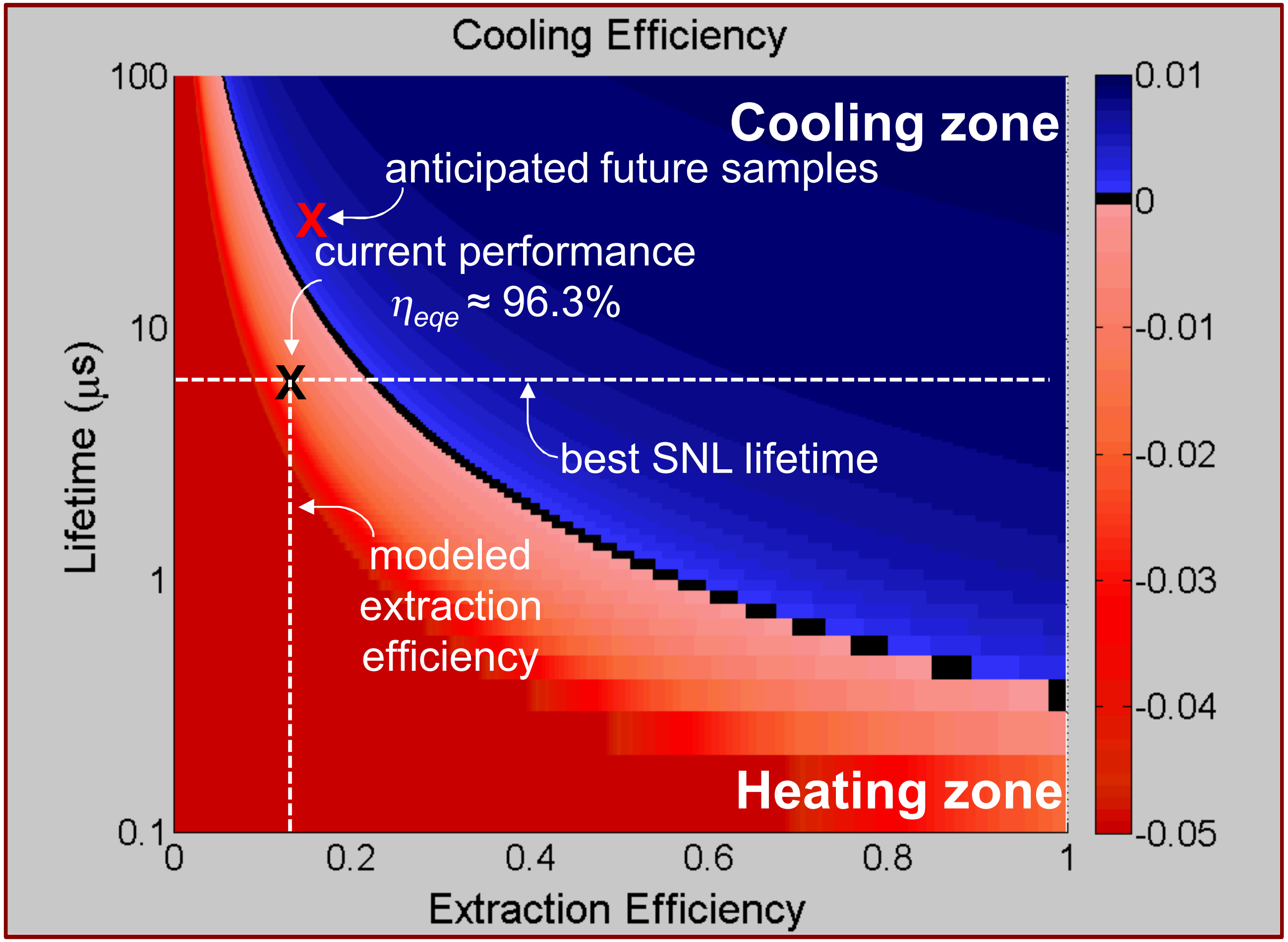
However, the overall cooling power is greater.

$$\frac{\overline{P}_{cool}^{texturing}}{\overline{P}_{cool}^{polished}} = 1.074$$

$$\overline{P}_{cool} = K\eta_e(h\tilde{\nu}_f - h\nu)V \approx K\eta_e(k_B T - \Delta\varepsilon)V$$

$$where \;\; \Delta\varepsilon = h\nu_f - h\tilde{\nu}_f$$

Break-even cooling condition at 300K*



Pumping: 1 $k_B T$ below the mean fluorescent energy

*M. Sheik-Bahae and R. I. Epstein, *Phys. Rev. Lett.*, Vol. 92, No.24, pp. 247403-1 (2004).

Significance

Developed GaInP/GaAs double heterostructures with:

1. High n-doping (≈10^{19} cm^{3}) in the passivating GaInP layer
2. Longer nonradiative lifetimes compared to baseline structures

How:

- Use gas purges between layer growths to create abrupt junctions and prevent dopant bleeding

Next Steps:

1. Fractional heating - external quantum efficiency (EQE) measurements