IRCM Requirements for Mid-Infrared Semiconductor Lasers

Workshop on 6.1Å III-V Semiconductors
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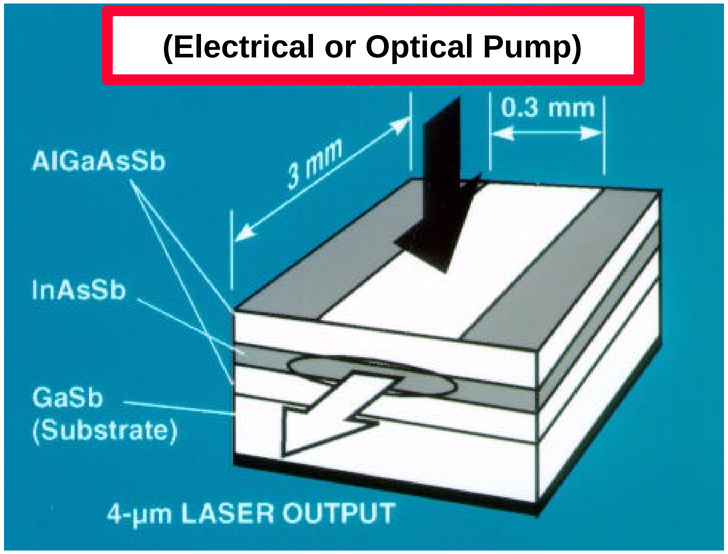
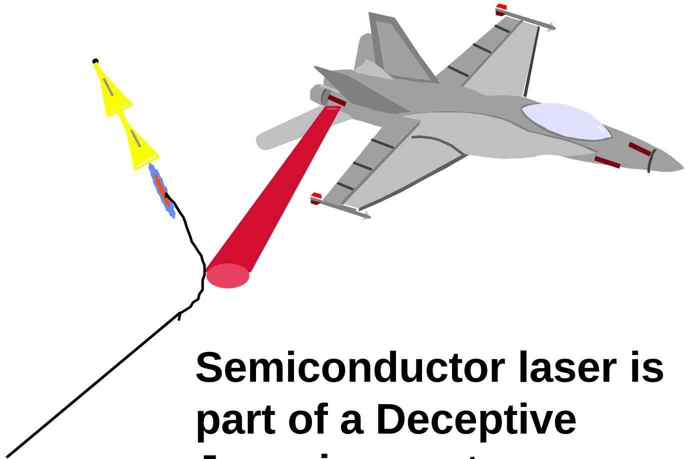
Why Semiconductor Lasers for IRCM?

– **Advantages**

- Extremely simple design
- Robust, monolithic cavity
- No nonlinear optics
- Easy, direct modulation
- Small, lightweight, efficient
- Mass producible, cheap





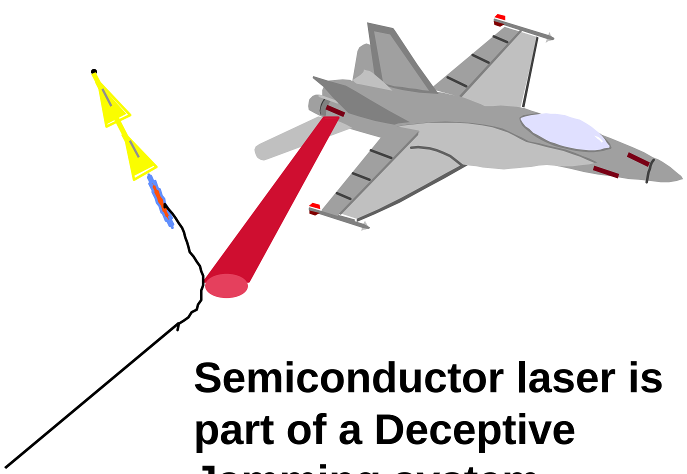
Semiconductor laser is part of a Deceptive Jamming system.

– **Disadvantages**

- Not fully demonstrated for IRCM
- Cooling required (size, weight)
- Low power
- Poor beam quality

IRCM Techniques

- **Decoys (flares)**
- **Deceptive Jamming (Watt-class lasers)**
- **Damage/Destroy (>Watt-class lasers)**



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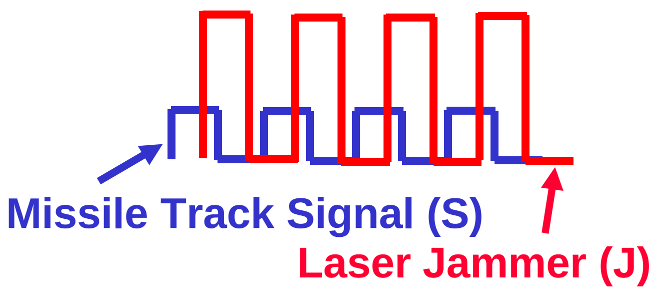
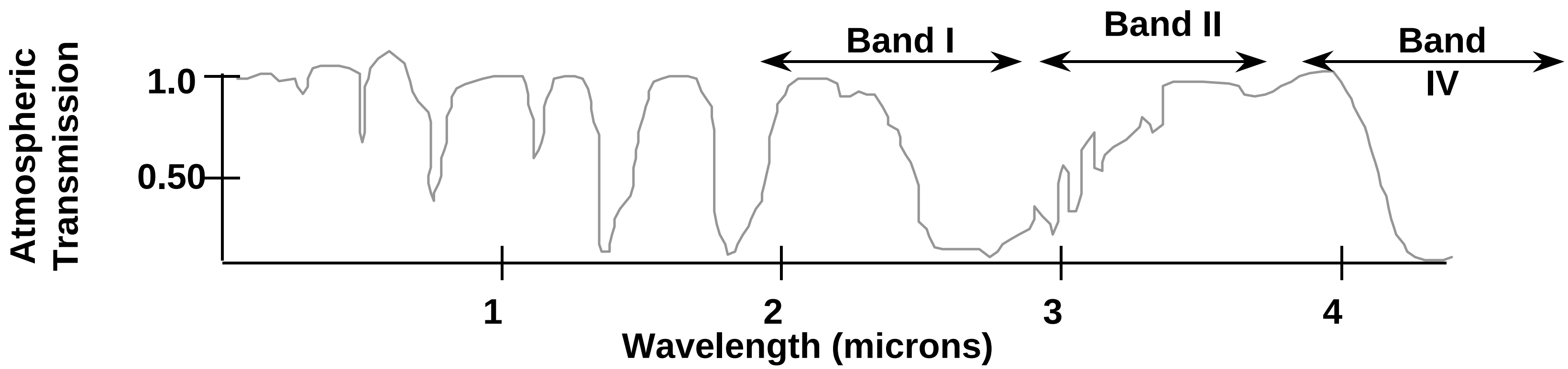


IRCM Wavelengths



- Band IV is the most important (but not the only) band
- Multi-band sources of light are the ideal

IRCM Laser Requirement

System Design Choice		Laser Specification
Missile Types	→	$\lambda_{1..n}$, **Pulse Width, PRF**
J/S Ratio & Range	→	**Radiant Intensity (W/str)**
Pointer Accuracy	→	**Minimum Divergence**
Aperture Size	→	**Brightness (W/cm^2/str)**
Operating Time	→	**Cooler Size**
Max Size/Weight	→	**Operating Temperature**

Typical DoD Design

Variable	Design Value
Wavelength	Bands I, II, IV
Pulse Width	50-500 μsec
PRF	~ kHz
Duty Cycle	25%
Peak Power	~2 Watts
Etendue	60 mm•mrad
Operating Time	15 sec ON, 45 sec OFF
Initial Cool-Down Time	3.5 minutes
Weight	40 pounds
Size	1 ft^3

A Joint Program

Advanced Multiband Infrared Countermeasures Laser Source Solution (DTO WE.43.08)

[redacted]

POC: AFRL/Directed Energy
Amount: $11M over 3 years
Schedule: FY98-00

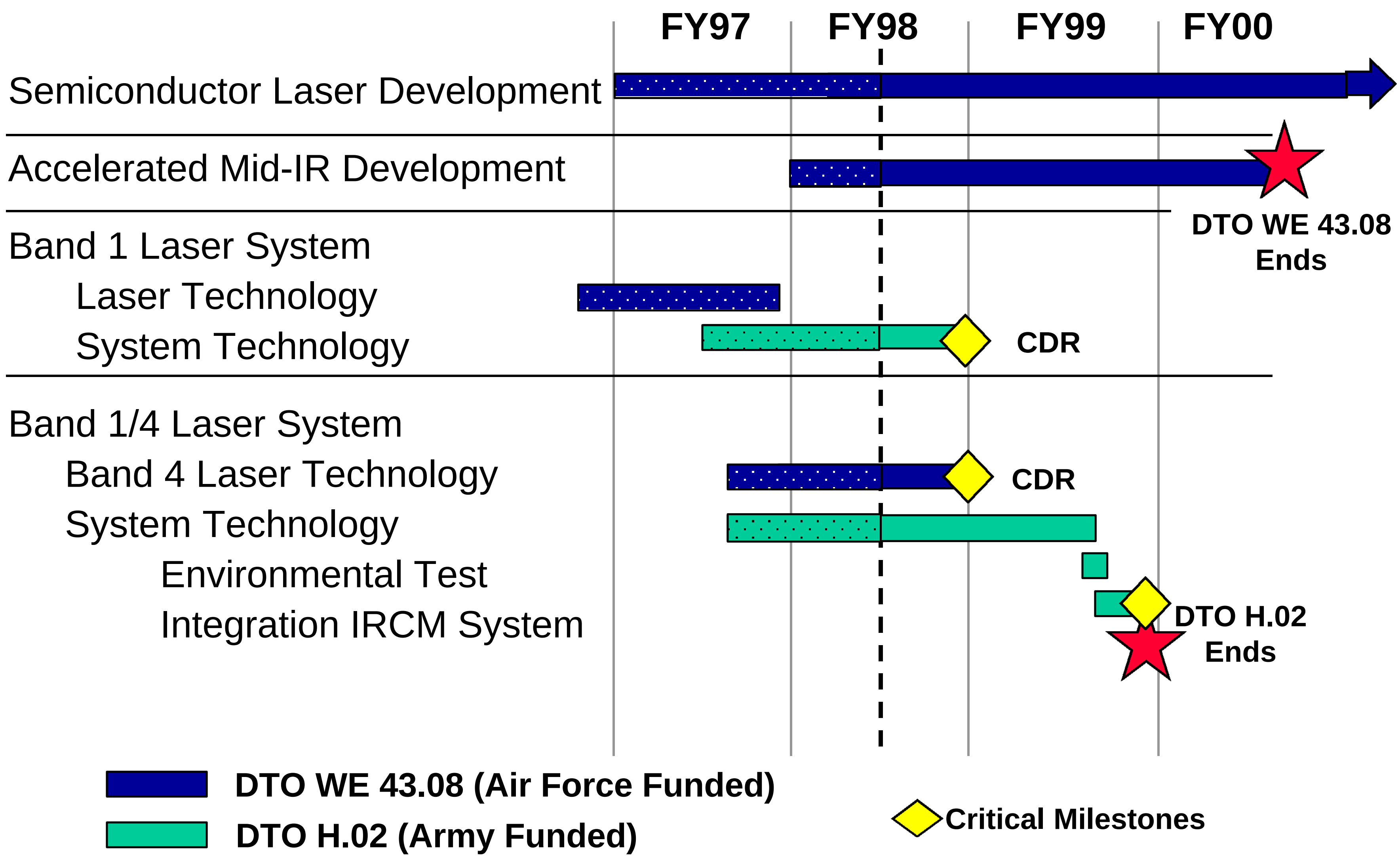
- Objective: Accelerate Mid-Infrared semiconductor laser technology

POC: Army CECOM/NVES
Amount: $15.7M over 3 years
Schedule: FY97-99

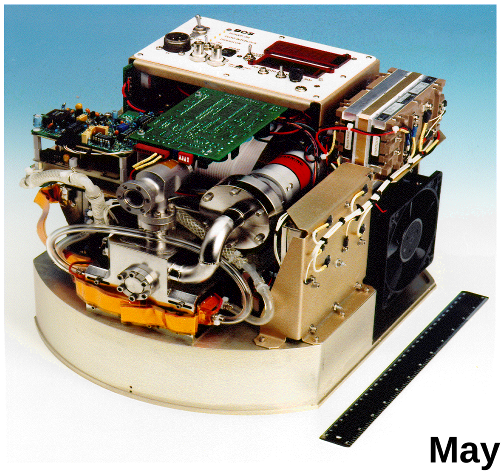
- Objective: Explore advanced laser-based IRCM Systems

Army is investing over $1.8M into semiconductor laser system/packaging issues

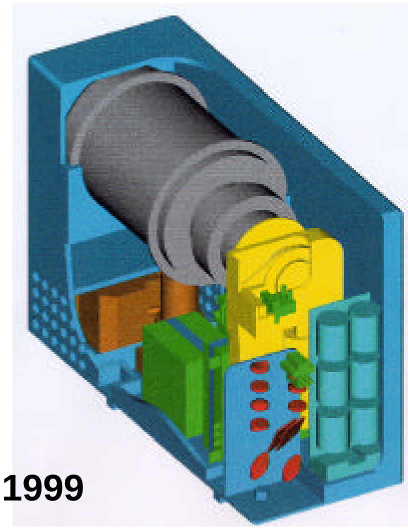
Semiconductor Laser Roadmap



Semiconductor Laser Prototypes



May 1996



July 1999

US/UK Package		Army DTO H02
4 µm only	**Wavelength**	2 µm and 4 µm
1 ft^3	**Volume**	1 ft^3
1 Watt	**Power (Peak)**	2 Watts
50 pounds	**Weight**	40 pounds
60 min	**Initial Cool-down Time**	3.5 min
None	**Interface**	Micro-gimbal and fiber

Semiconductor Laser IRCM Systems

- **Design trade-off space has some room:**

Cool down time:	**3.5 minutes**	**10 minutes**
Weight:	**40 lbs.**	**60 lbs.**
Volume:	**1 ft^3**	**1.5 ft^3**
Prime Power:	**400 Watts**	**800 Watts**
Laser Aperture:	**<1 cm**	**<2 cm**

2 Watts Pk/(0.5 W ave.) → 6 Watts Pk/(1.5 W ave.)

- **Estimated Cost:**
  - **- Single Prototype: $1.5M**
  - **- Production Engineering: $1.8M (includes reliability & environmental testing)**
  - **- 8 to 10 “Beta” Units: $0.4 M each**
  - **- 50 to 100 Production Units: $0.15M each**

Laser Technology Thrusts

Band 4 Lasers

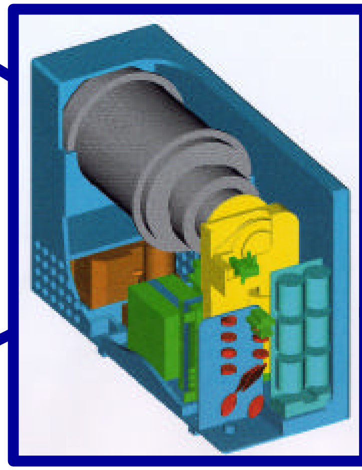
- **Increase Operating Temperature**

70 Kelvin ⟶ >200 Kelvin

High Brightness Lasers

- **Improve Beam Quality**

>20xD.L. ⟶ <5xD.L.



Band 4 Lasers

- **Develop compact diodes**

Opto-pump ⟶ Electrical-pump

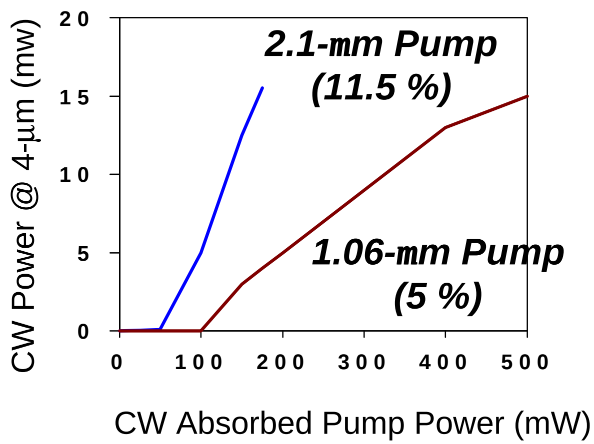
Band 1 lasers

- **Incoherent Arrays**
- **Microlens Technology**

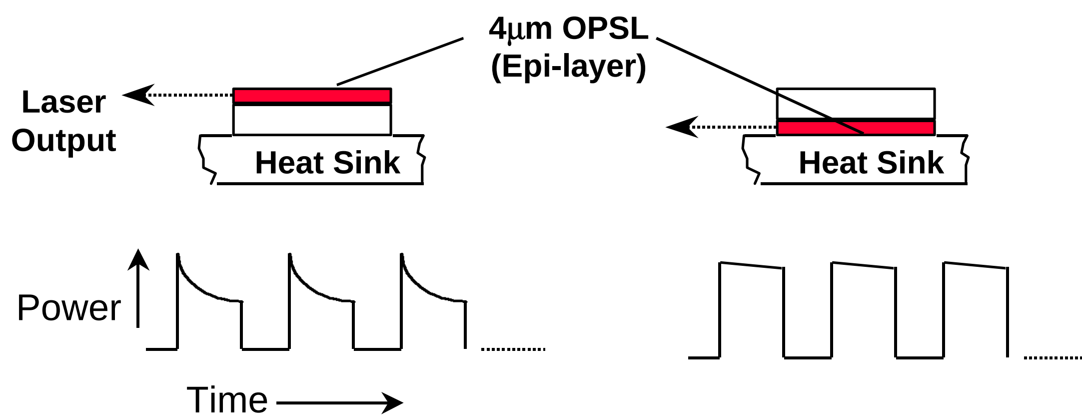
Single Emitter ⟶ Arrays

Approaches to Increasing Operating Temperature

Approach #1: Optically pump at 2 µm

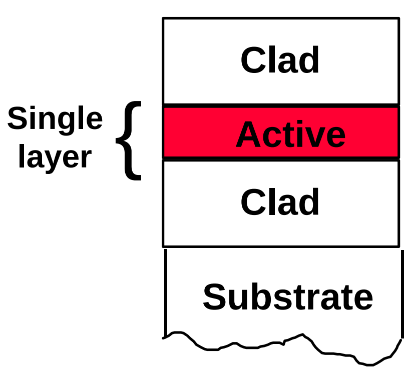


Approach #2: Mount laser epitaxial side down



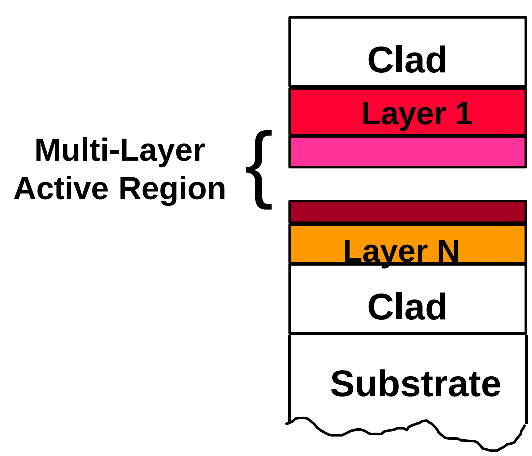
Approach #3: Bandgap Engineering

"Traditional" Semiconductor Laser



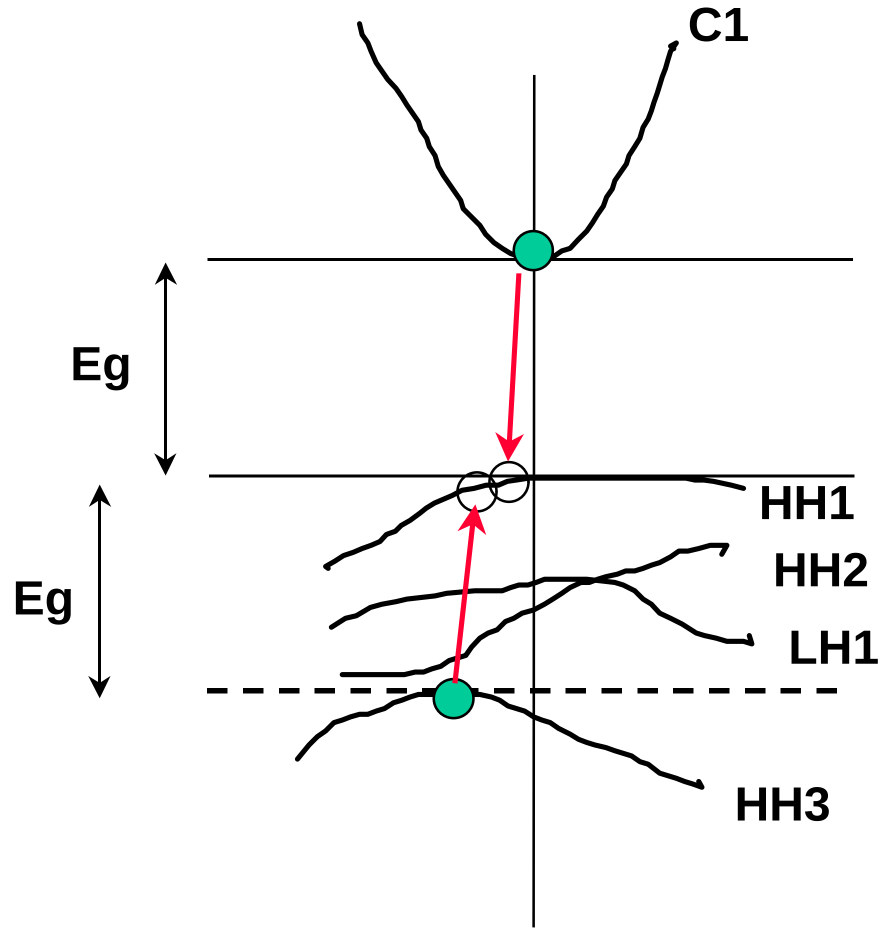
- **More Heat**
- **Less Light**

Bandgap Engineered Laser



- **More Light**
- **Less Heat**

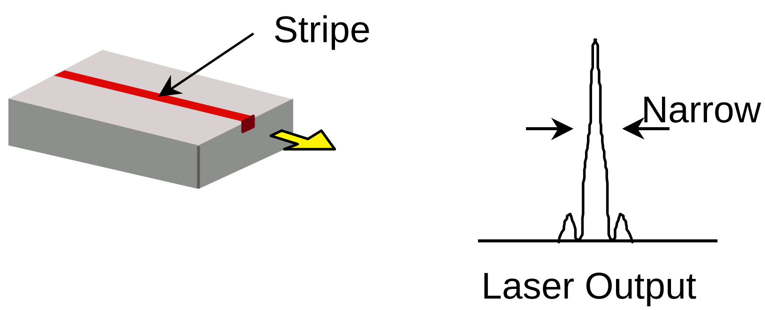
Non-Radiative Losses (Heating)



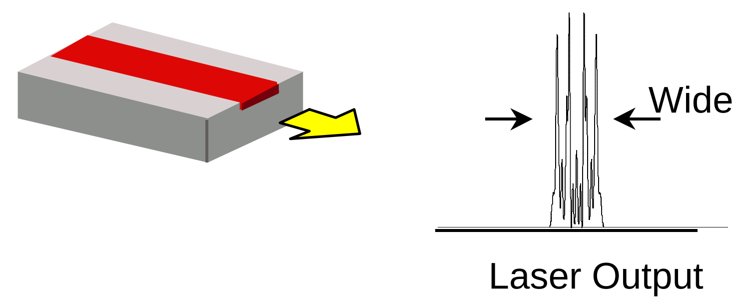
Problem
When hole states are spaced by Eg (resonant with bandgap), electrons give their energy to heat, not light

Solution
1. Engineer materials to avoid resonance
2. Avoid lasing with holes (intraband laser)

High Brightness Lasers
(Improving Beam Quality)

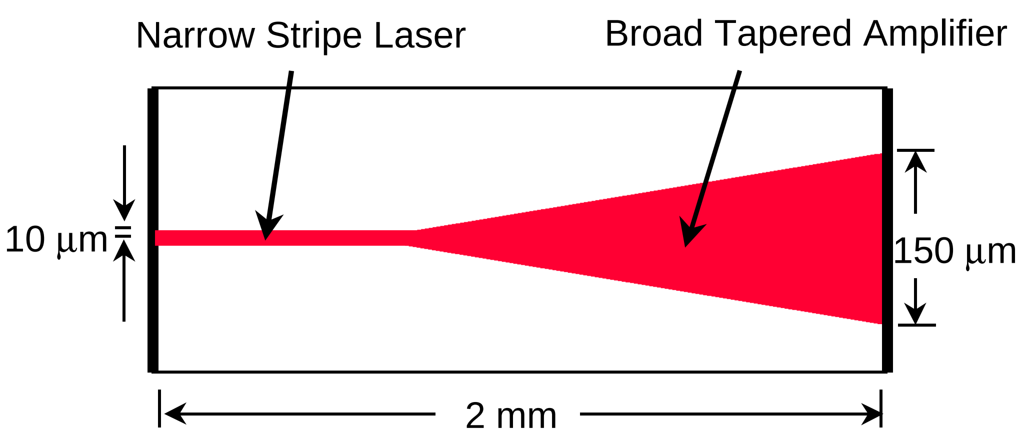


Narrow Stripe Concept
- Limited to Low Power
- Good Beam Quality (< 5xD.L.)



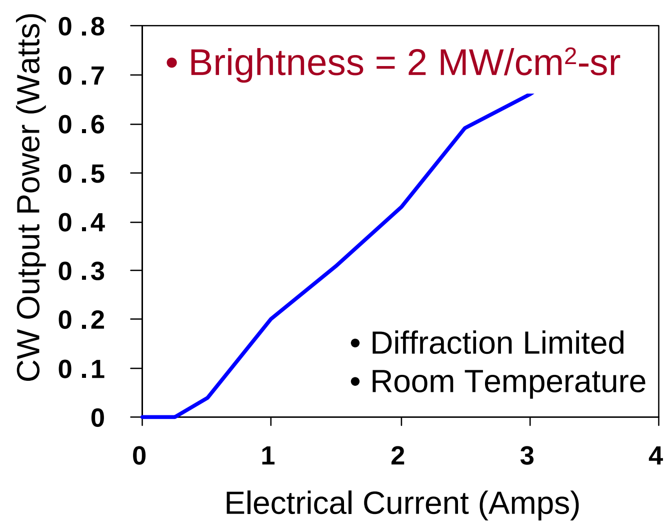
Wide Stripe Concept
- High Power Capability
- Poor Beam Quality (~20xD.L.)

Tapered Laser Concept

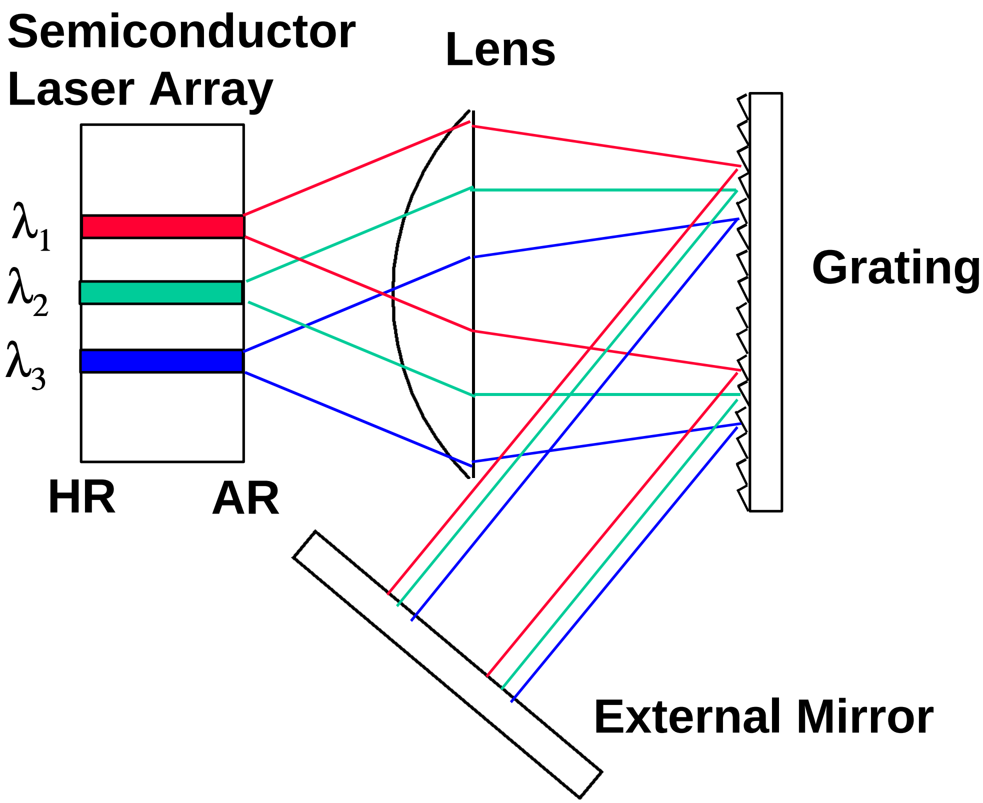


(Top View)

Results from 2.1 µm Single Emitter



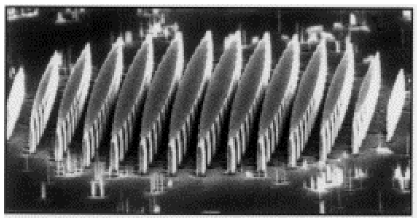
Improving Laser Array Brightness



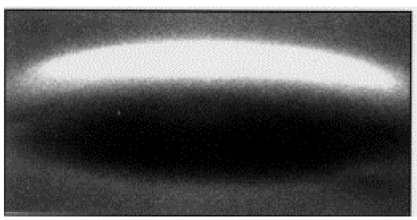
Wavelength overlap increases total radiance (brightness).
Does not increase <u>spectral</u> radiance.
IRCM is a broad band laser application; this approach works!

GaP Microlens Technology

Etched Preform

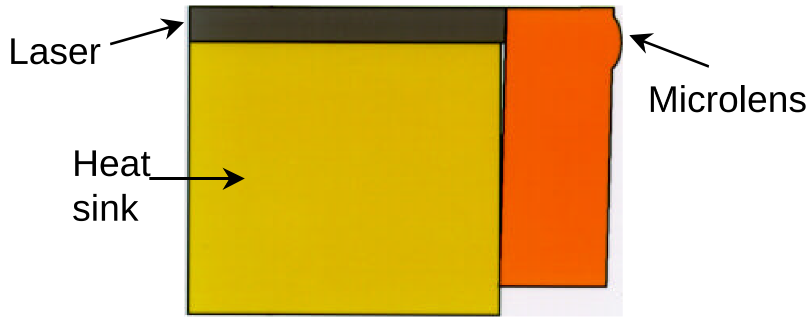


Smoothed Lens

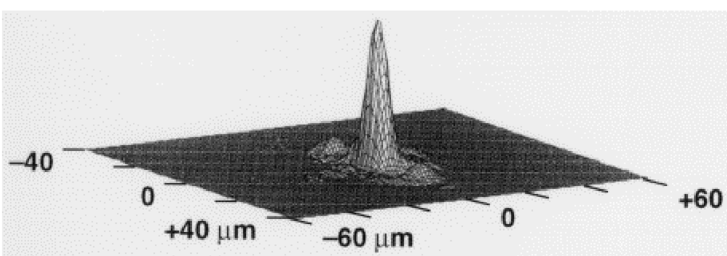


150 µm

Microlens integrated with laser chip



Intensity Profile through Lens



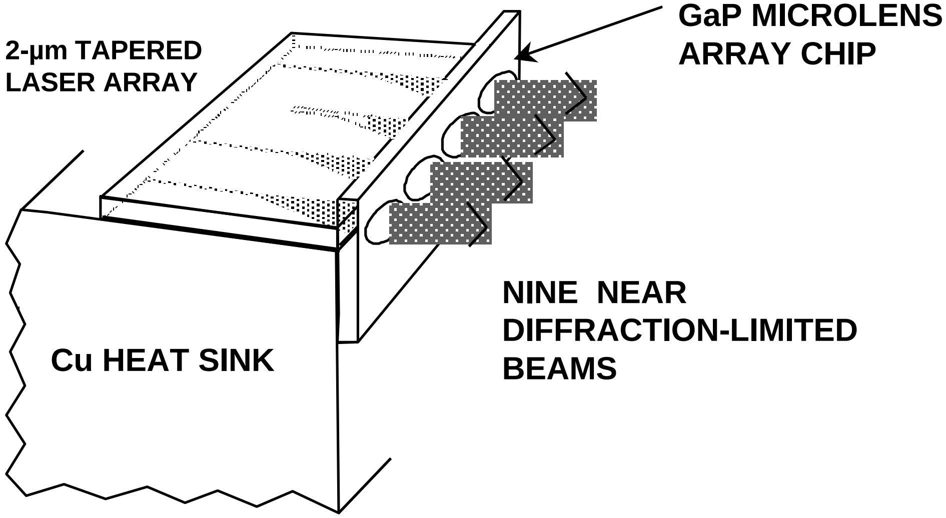
(>67% into single mode fiber)

Microlens Technology

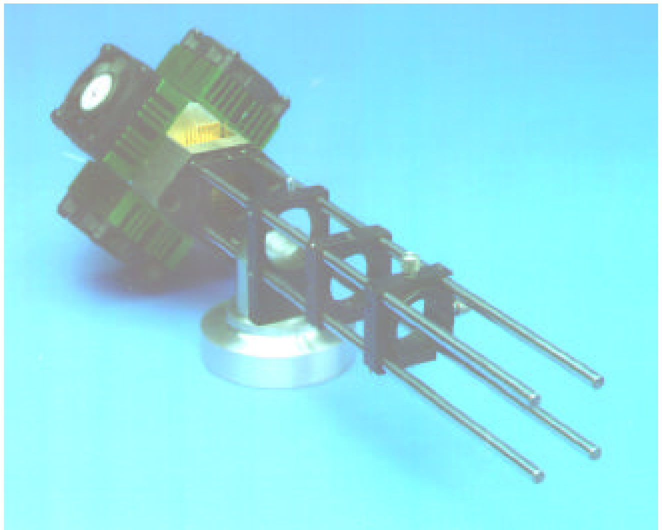
- **Wide wavelength range (0.7 to 5 µm)**
- **High collection efficiency**
- **Custom designed to match laser array**
- **High alignment tolerance**
- **Can either collimate or focus**

IRCM Band 1 Diode Laser Prototype

9 Element Array with Integrated Microlens



Deliver to Army/CECOM



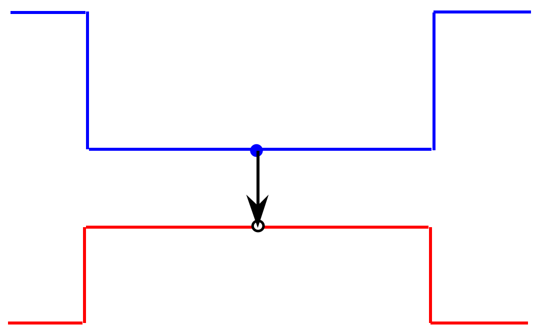
Current Status

- 1.4 Watts peak from 8 elements
- 2.1 µm wavelength
- 6 mrad divergence from <1 cm^2 aperture
- Reliability issues being worked

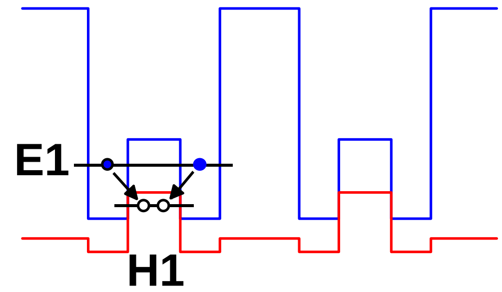
- Can easily replace existing IR lamps used in ATIRCM & DIRCM
- Band 1 Laser applicable to ground vehicle IRCM protection

Mid-IR Laser Structures

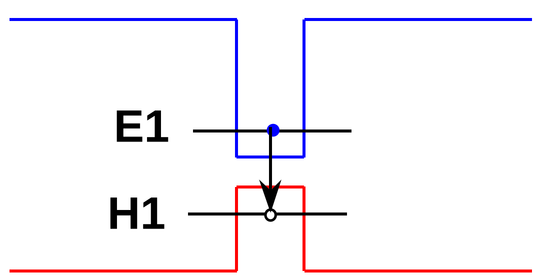
Double Heterostructure Laser



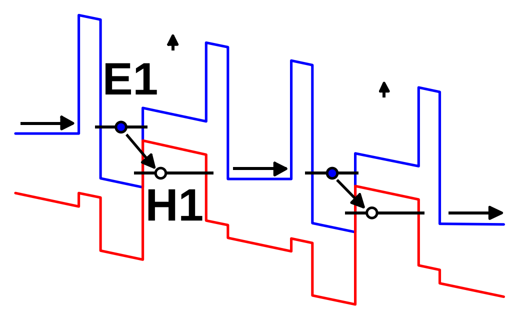
Type-II W Laser



Type-I Quantum Well Laser

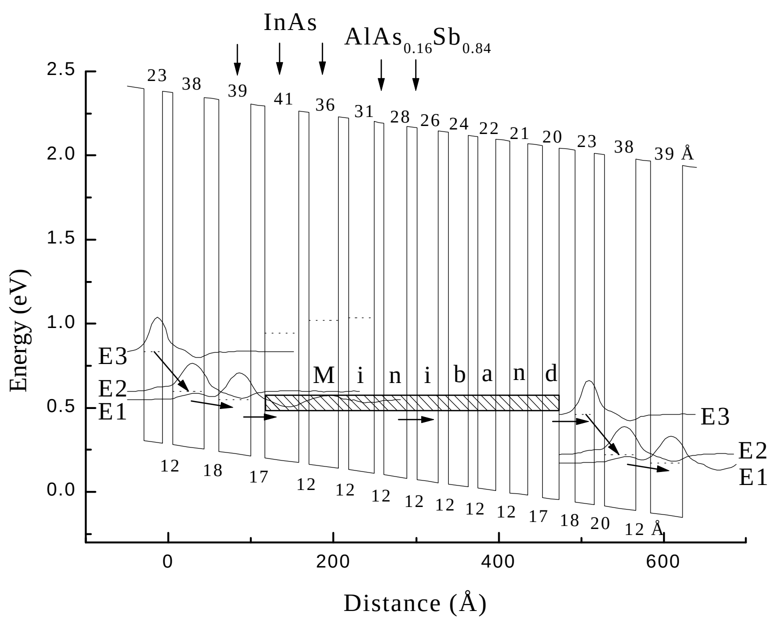


Interband Cascade Laser

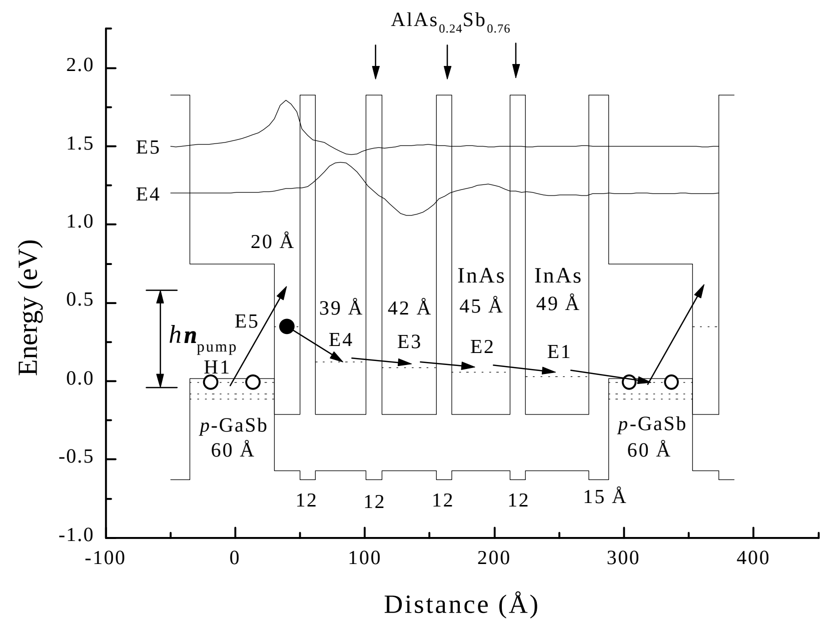


Novel Mid-IR Laser Concepts (NRL)

Antimonide-based Quantum Cascade Laser



Quantum "Fountain" Laser (Optically Pumped)



Calculations indicate lower thresholds for AQCL, low non-radiative losses for QFL.

Summary

- **IRCM view of semiconductor lasers: new kid on block with LOTS of potential**
- **Key technical goals: brightness and high temperature operation**
- **Strengths: lots of novel ideas, strong community collaboration**
- **Weakness: short window of opportunity (October 1997-October 2000)**