Electronically-Steerable, Coherent Laser Arrays

REALLY Small, Lightweight, High Power Lasers for DoD Applications

MTO Symposium
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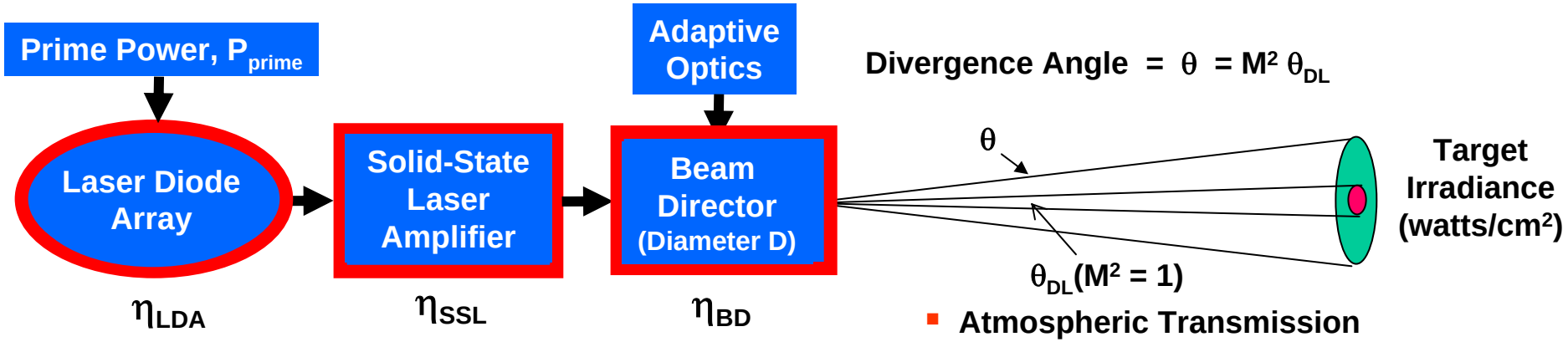
Diode-Pumped, Solid-State Laser Systems



- Atmospheric Transmission
  - Turbulence (including aero-optics)
  - Absorption (molecular/aerosol)

- **Power Delivery Efficiency** $\sim \frac{\eta_{LDA}\,\eta_{SSL}\,\eta_{BD}}{M^4}$

- **Challenges**
  - Power Scaling
  - Efficiency
  - Beam Quality
  - Size and Weight
  - Lifetime/Reliability
  - Electronically-steered, Conformal, Adaptive, Optical Phased Arrays

Technologies:

- Electronically-Steered, Optical Phased Arrays driven by:
  - Fiber Laser Amplifiers (APPLE)

  or directly by:
  - Coherent Laser Diode Arrays (COCHISE)

Challenge: Electronically-Steered 100 kW Laser System at 2 kg per kilowatt

APPLE Laser Beam Directors

Adaptive Photonic Phase-Locked Elements

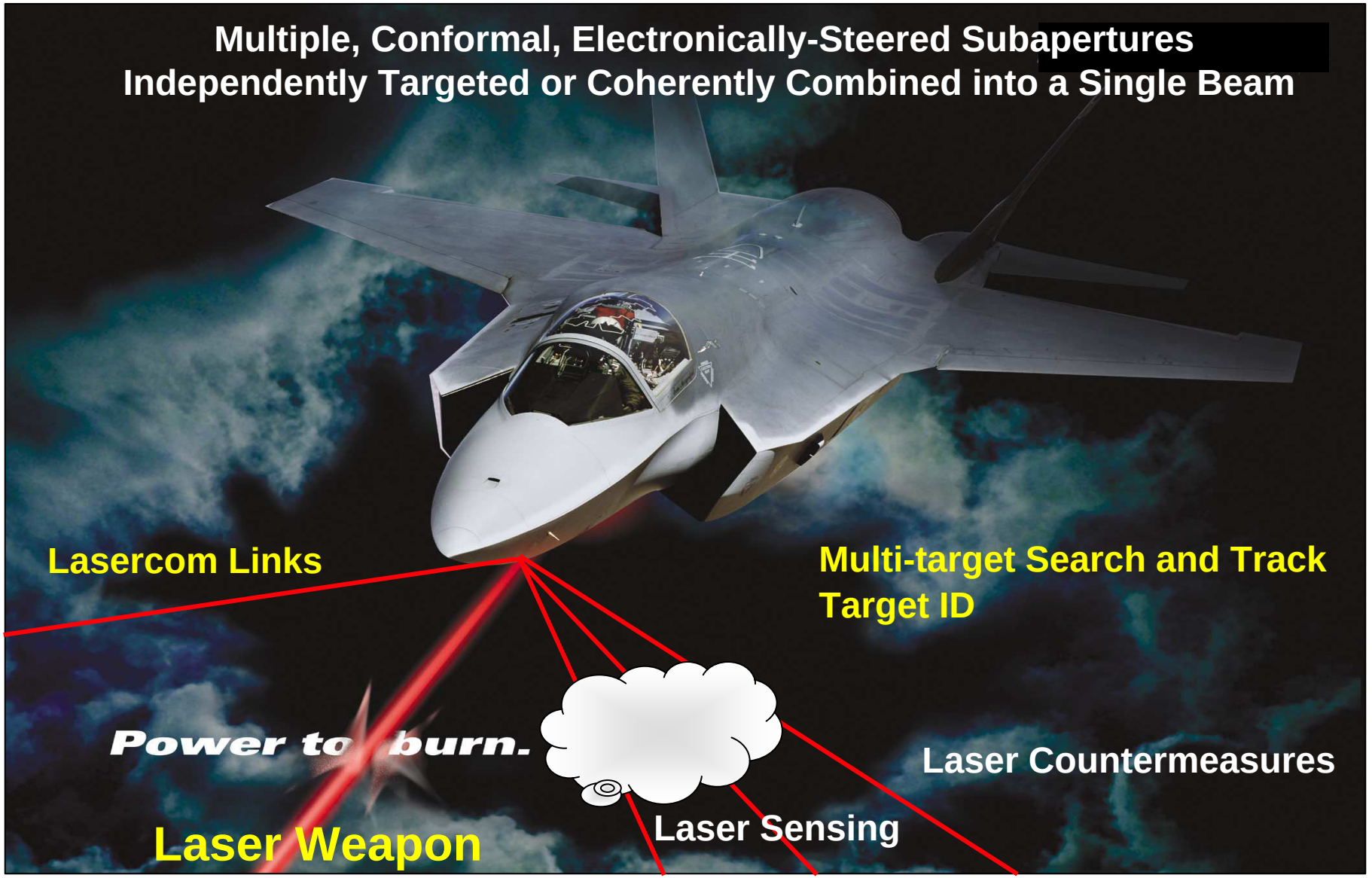
APPLE Beam Director Technology can provide:

- **All-Electronic Beam Steering with 45º Field-of-Regard**
- **Power and Aperture Size Scaling through Coherent Beam Combining of Multiple Sub-apertures (2.5 - 5 cm dimension)**
- **Conformal to Most Military Platforms**
  - **replaces aerodynamically-challenged turret-mounted beam directors**
- **Near-Diffraction-Limited Beam Quality, Corrected for:**
  - atmospheric turbulence
    - **r_o ~ 5 mm/ BW_{atm} ~ 1 kHz**
  - aero-optic effects
    - **r_o ~ 5 cm / BW_{atm} ~ 10 kHz**

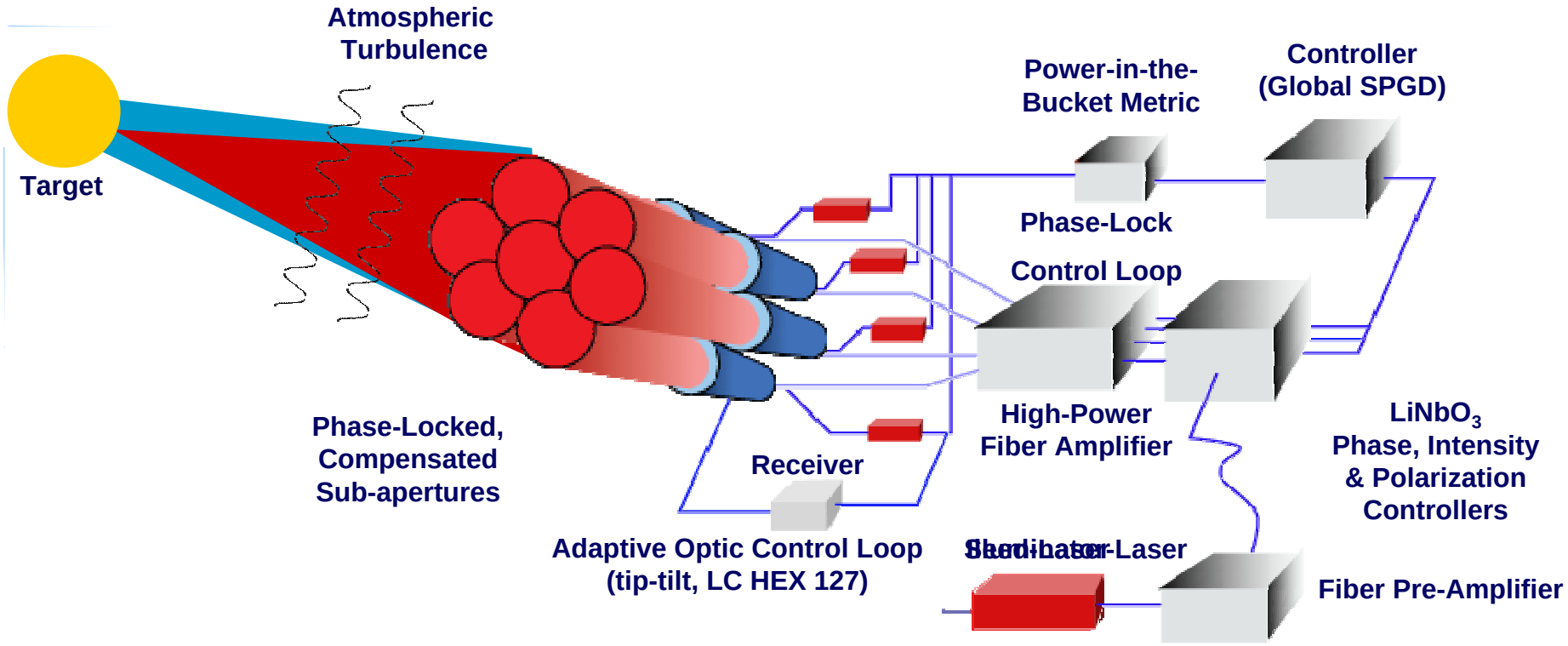
Fast, Electronically-Steered, Optical Phased Array *adaptable* to essentially all DoD Laser Applications

APPLE

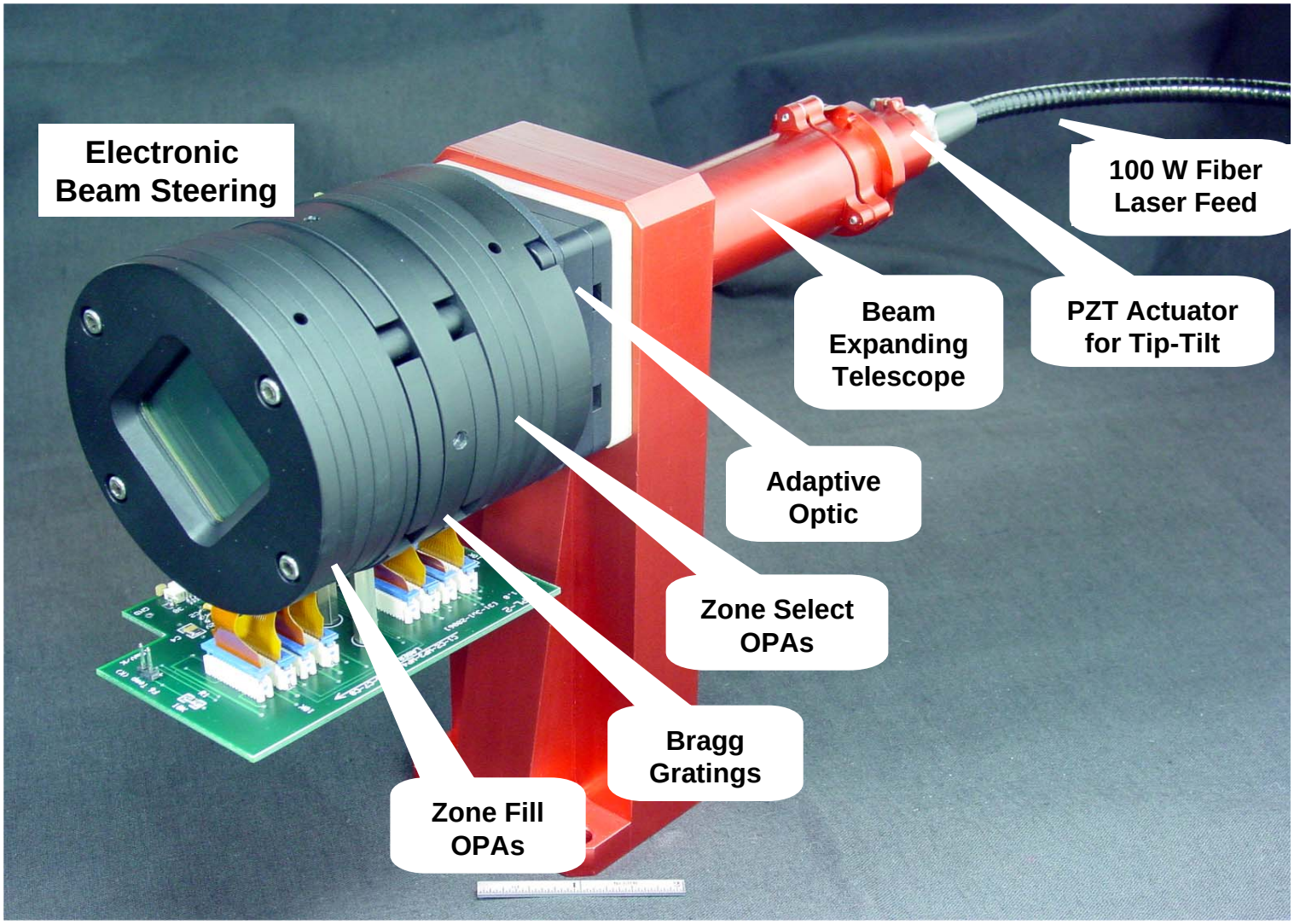
Adaptive Photonic Phase-Locked Elements



APPLE Concept



Assembled APPLE Subaperture

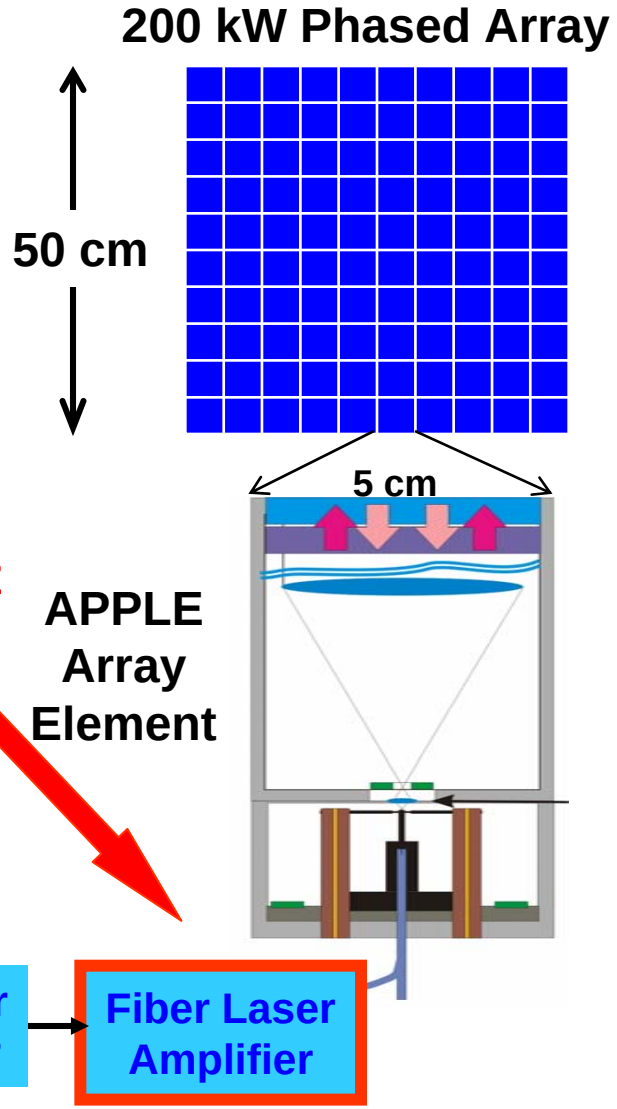


Challenge: Coherent Array of APPLE Subapertures with Fast Adaptive Optics

Weapon Concepts Require *Single-Mode, Narrowline,* Kilowatt-Class Fiber Lasers

- 100 Coherently-Combined Apertures (10 x 10 Array)
- Need High Power Fiber Laser Amplifiers
  - 2 kW
  - Single Transverse Mode
  - Single Polarization
  - < λ/20 Phase Noise – No SBS/SRS - Narrowline
- These 2 kW Fiber Laser Amplifiers do not exist
  - 200 watts Commercially Available

Challenge: Scale these Fiber Amplifiers to 2 kW and Beyond



Coherent, High Power Laser Diode Arrays

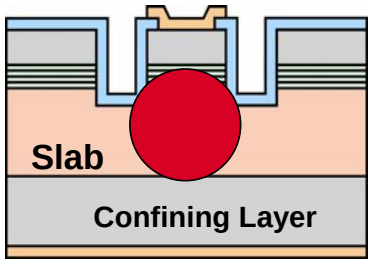
- **Why Coherent Diode Arrays?**
  - **Electrical Efficiency**
    - **Thin Disk Lasers (HELLADS) 15%**
    - **Fiber Lasers 25-30%**
    - **Coherent Laser Diode Arrays 30-50%**

Increasing Risk

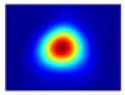
- **Three Approaches:**
  - **Talbot Cavity – Spatially-Coupled Oscillators in Supermode**
  - **Phase-Locked Loops driven from a common seed beam**
  - **Coherent Combining with SPGD Algorithm as in APPLE**

Challenge: Coherently Combine Kilowatt Laser Diode Arrays

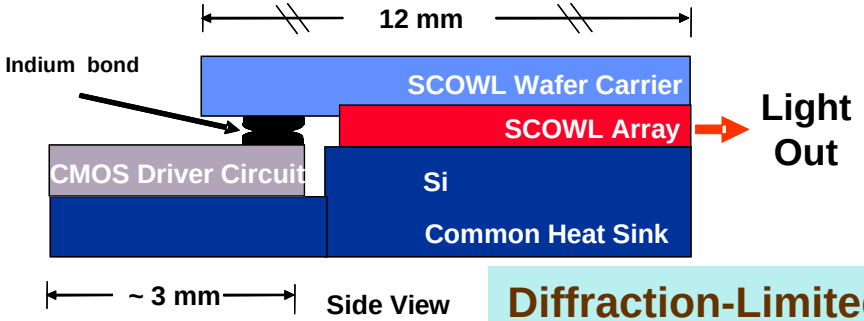
Slab-Coupled Optical Waveguide Laser (SCOWL)



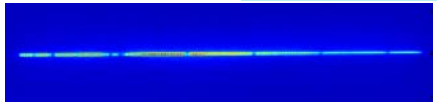
- 1 watt
- Single Mode
- Ultra-low Noise



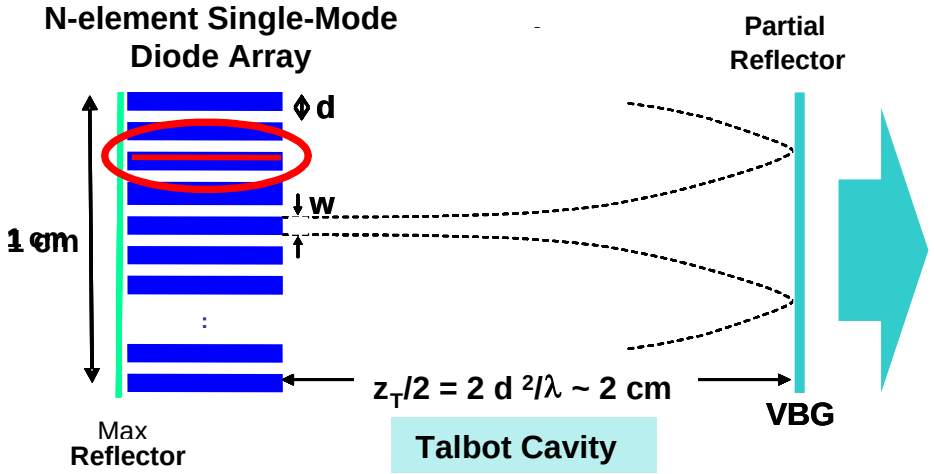
Individually drive Each Emitter in the Bar



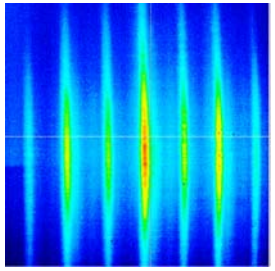
Diffraction-Limited Bar



Talbot Cavity - Laser Diode Phased Array



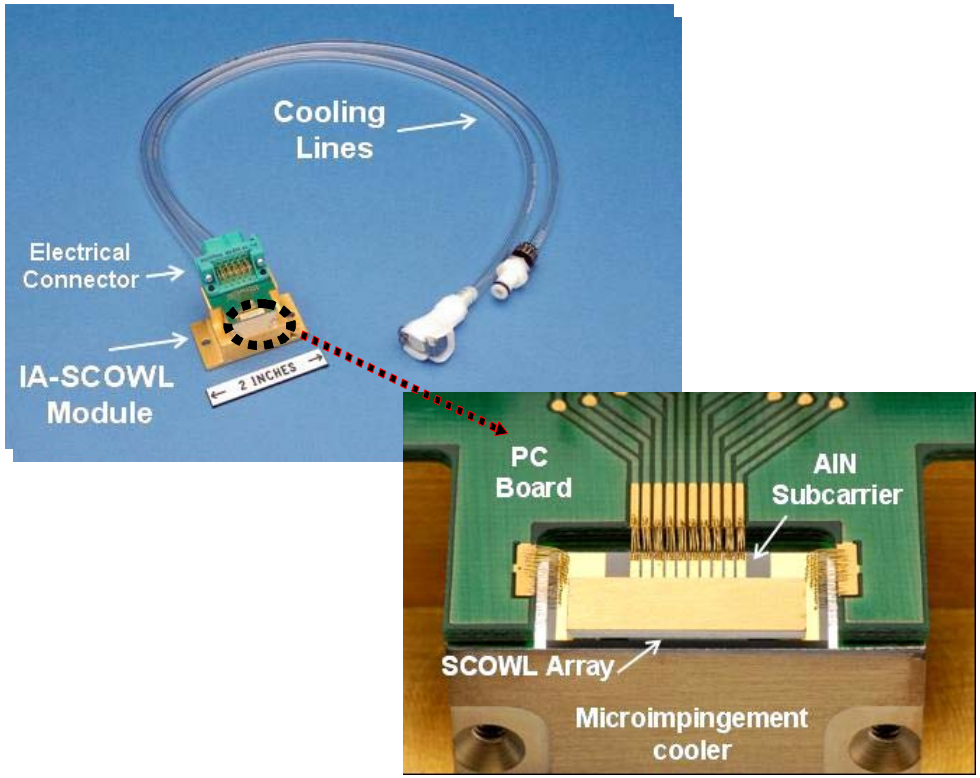
Coherent Output Beam

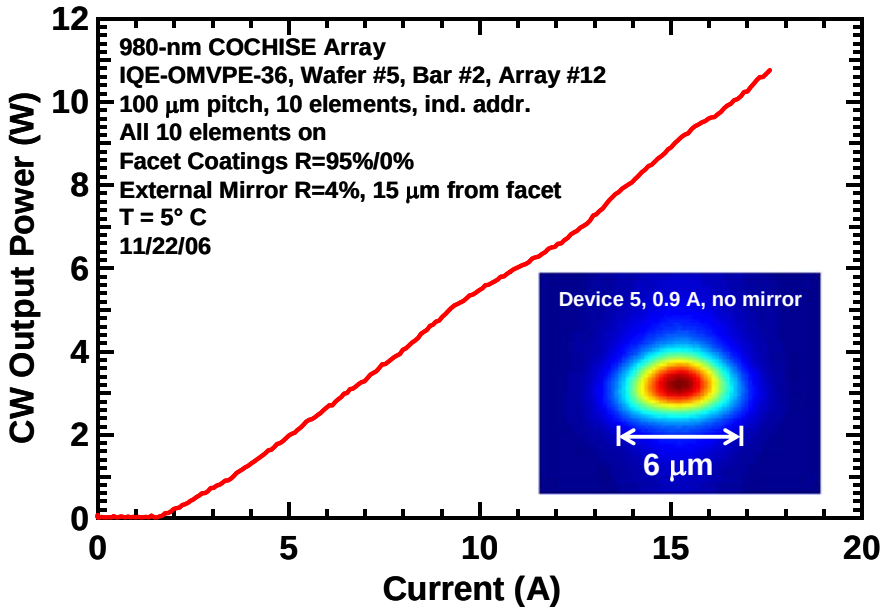


Remove Multi-Mode, Unphaseable Rogue Emitters in 10s of nsec

Drive each Emitter in SCOWL Bar Independently

Independent Drivers for Each Emitter in a 10-Emitter Bar

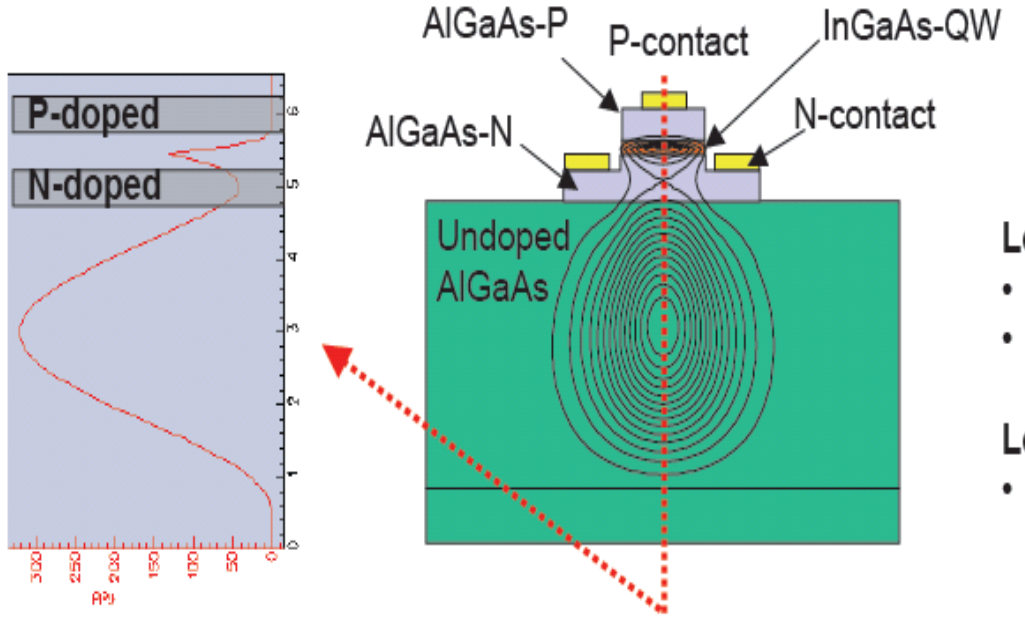




Challenge: CMOS Drivers Conformally Coupled Directly to the Diode Bar for Current Sharing and Phase Control

Vertically-Coupled Large Area (VECLA) Laser

Challenge: 10 watt, low noise, single-mode emitters at 50% Efficiency



Low Optical Loss
- High power
- High efficiency

Low confinement
- Stable spatial mode

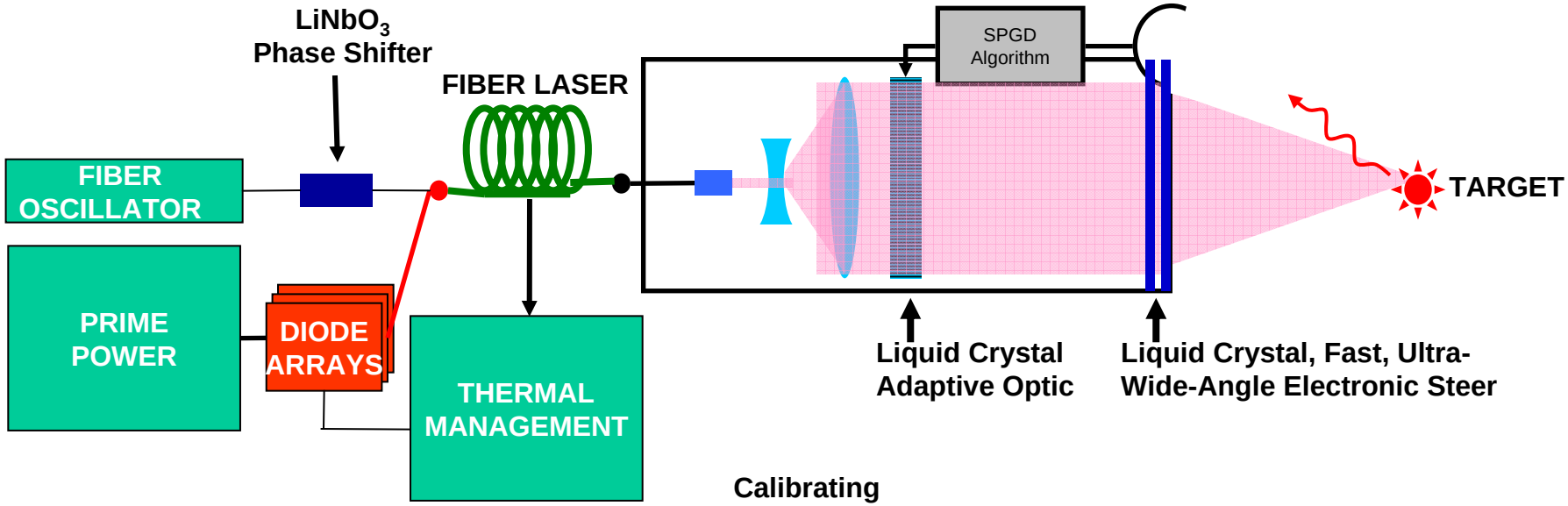
Design Features

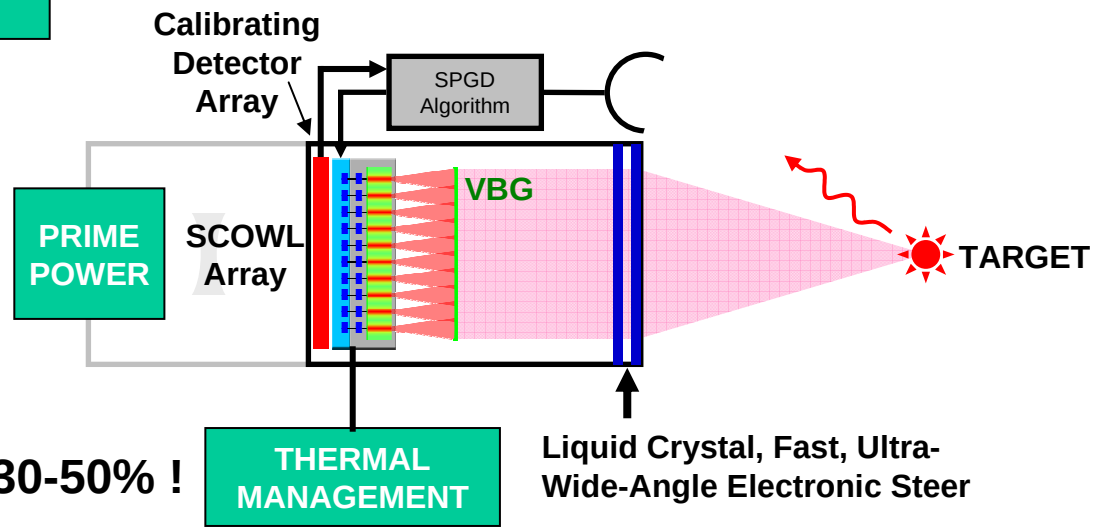
- Low modal overlap to doped layers (<0.02)
- Highly doped cladding layers (~10^{18} cm^{-3})
- Thin top cladding layer (~0.05μm)
- Large optical mode (~4 x 15 μm^2)

Performance

- Very low optical internal loss (<0.2 cm^{-1})
- Very low electrical resistance, but not too low
- Very low thermal resistance (~2°C/watt-mm)

APPLE Sub-aperture driven by a Coherent Fiber Amplifier Array





Overall Electrical Efficiency ~ 30-50% !

Potential: 100 kW Laser Systems at 2 kilograms per kilowatt!

Additional Challenges and Areas of Interest

- **Laser Diode Technology – for pumping Thin Disk Lasers**
  - **Increase SHEDS Diode Bar Power to ≥ 100 watts/bar-cm**
    - **Efficiency ≥ 70%**
    - **Lifetime > 1000 hours**
    - **1 cm bar with 1.5 mm pitch**
    - **Wavelength ~ 808nm (Nd:YLF or Nd:ceramic YAG Pump)**
  - **Thermal Resistance from Junction to Heat Sink is the limiting factor**
- **Fiber Laser Technology – 100 kW**
  - **Explore Ultimate Fiber Amplifier Array Scaling Limits**
    - **Single-Mode ($M^2 < 1.5$)**
    - **Single-Polarization**
  - **Pump Diode Brightness is the limiting factor**

Some of
My Current Program Responsibilities

- **Existing Programs:**
  - **APPLE** – **Conformal Laser Beam Director**
  - **COCHISE** – **Coherent Combining of Laser Diodes**
  - **ADHELS** **Single-Mode Laser Diode Development**
    Laser Diode Reliability and Lifetime
  - **SHEDS** – **Laser Diode Efficiency**
  - **Ultrabeam** – **X-ray Lasers**
  - **Nanowriter** – **E-Beam, Direct-Write, Maskless Lithography Tool**
  - **IM-VAC (DSO)** – **Compact CT Imaging Technology for Battlefield Use**

Briefed Today

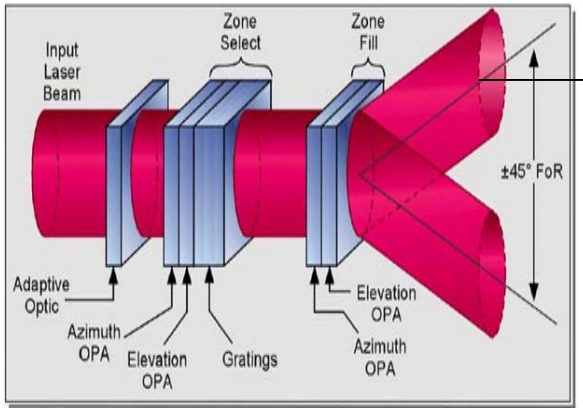
Posters

….so see Dr. John Zolper, Director of MTO now!!!
Get Recruited as a New MTO Program Manager

Back ups

APPLET Components

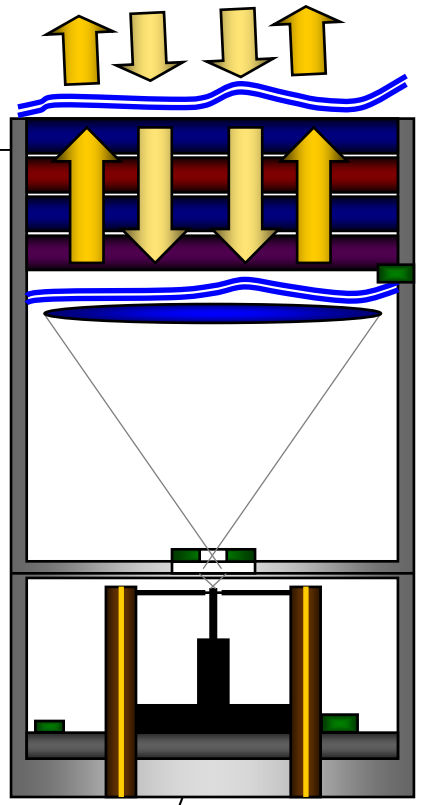
Fast Beam Steering Element



SPGD Algorithm implemented on FPGA

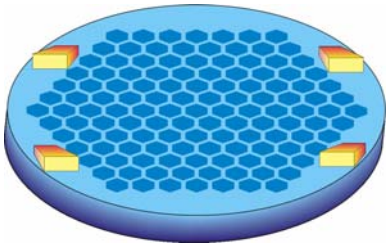
$LiNO_3$ Electric Field Controller

- **Intensity**
- **Phase**
- **Polarization**

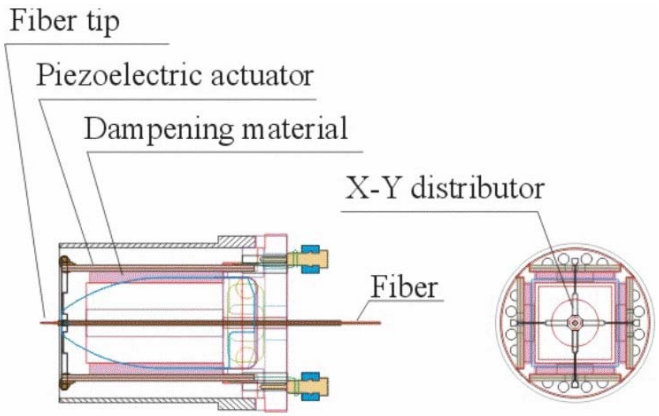


APPLET

Adaptive Optics Element (HEX 127)



Challenge:
– 10x Faster Adaptive Optic Elements



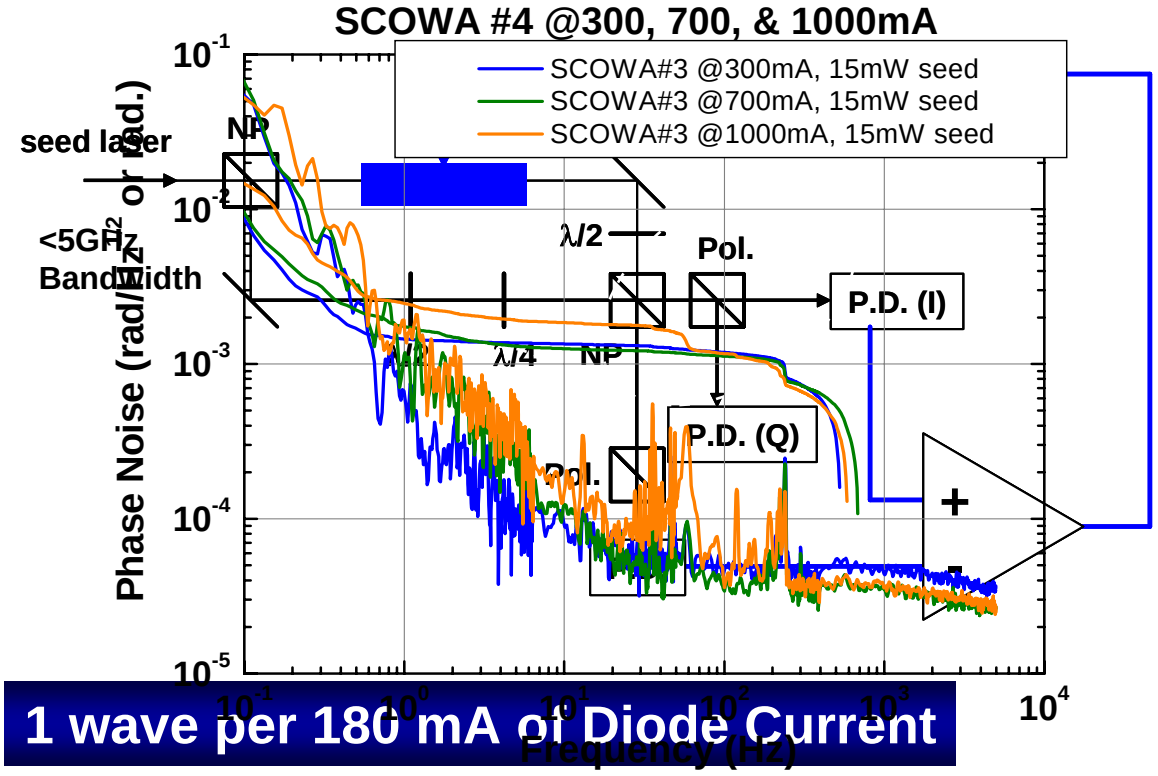
Tip/Tilt Compensator

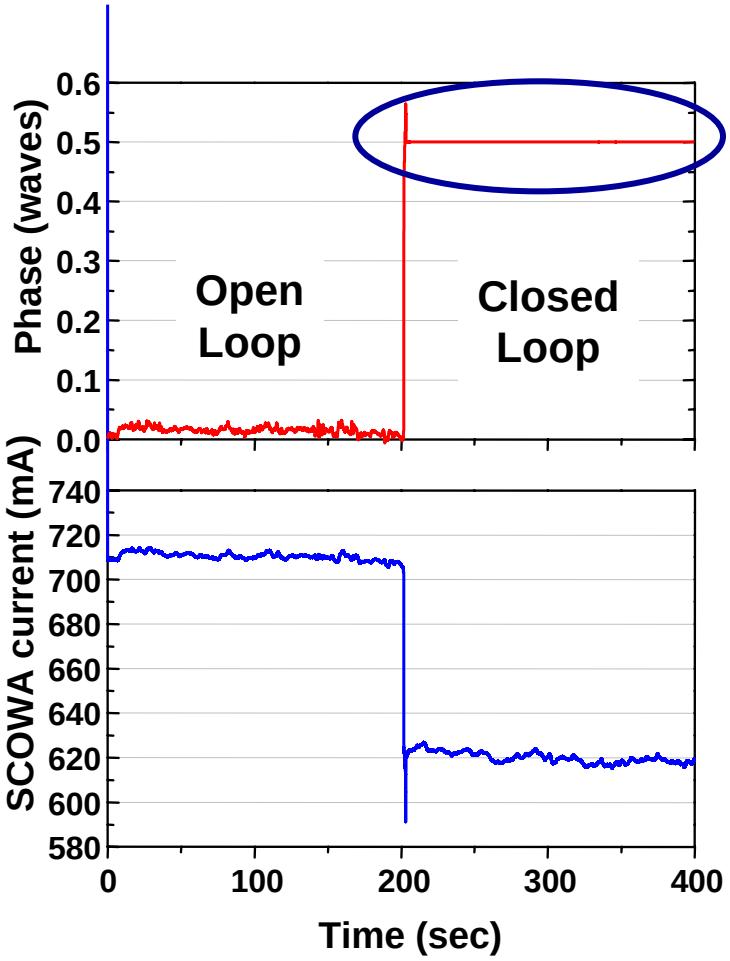
Fiber Laser Amplifier

Phase-Locked Loop around a SCOWL Amplifier

Mach Zehnder Interferometer measures Phase for Feedback Control

SCOWA Phase Noise





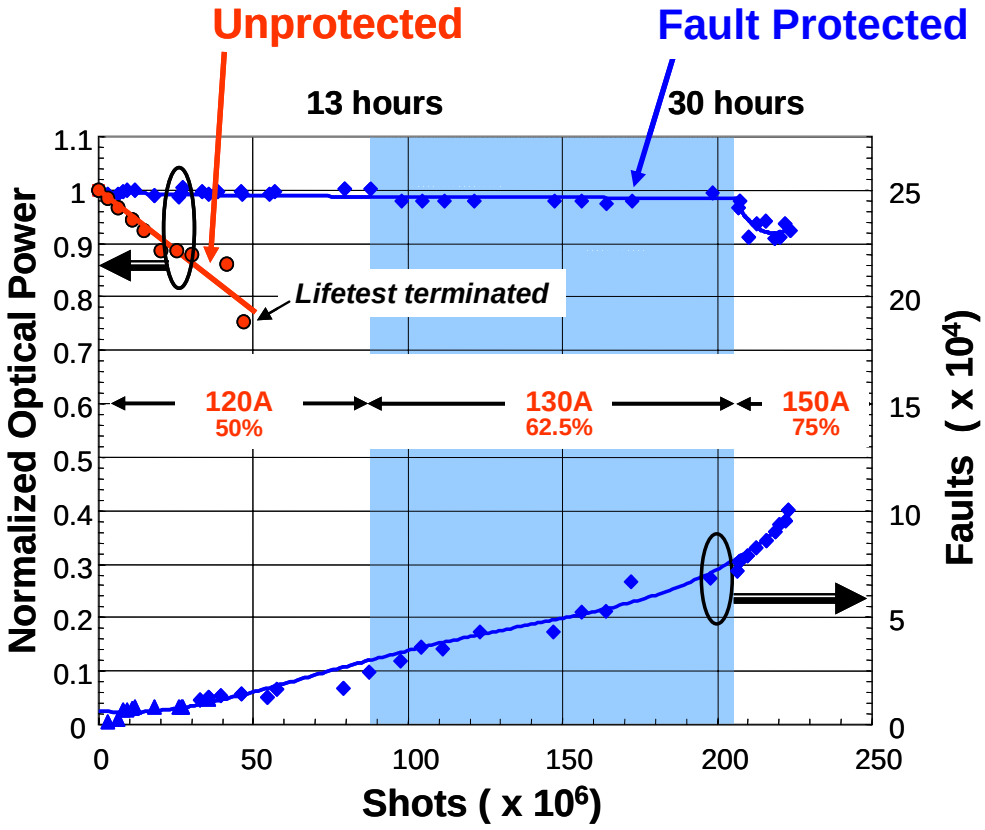
1 wave per 180 mA of Diode Current

Challenge: Coherent Array of High Power Laser Diode Amplifiers at 2 kW

COCHISE Diode Protection Technology
Accelerated Diode Bar Lifetest

Extend Laser Diode Bar Lifetime

- Detect Fault Modes from the Electrical Terminals of the Diode Bar
- Cut Power to the Diode Bar within 1 μsec
- Wait for 300 μsec and Re-apply Power to the Bar



Fault Mode Frequency increases with Diode Bar Current

Eliminating Rogue Modes extends Diode Bar Lifetime by >10x
No Impact on Average Power or Efficiency

COCHISE

Revolutionizing Laser Diode Bar Technology

☑ *Efficiency* = = 50% ⇨ 70% SHEDS

Cochise Program Goals

- *Lifetime* = 10 – 100 hours ⇨ >1000 hrs for HELLADS and SHEDs

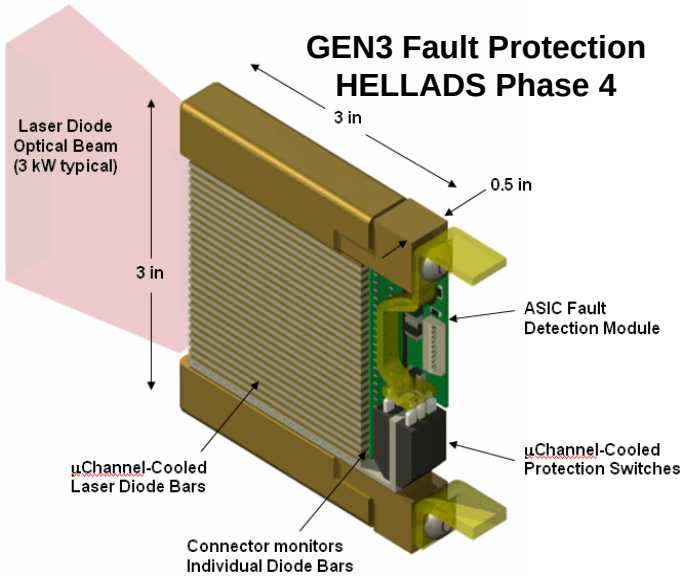
+

- *High Power per Bar* = 85 watts/bar for HELLADS then >100 watts/bar

- *Diode Beam Quality* = 35x Diffraction Limit ⇨ < 1.4x Diffraction Limit

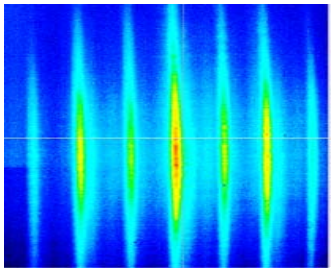
+

- *Coherent Combination* = No ⇨ Yes



Unique COCHISE Diode Protection Extends Diode Lifetime by >10x

Brightness and Coherence



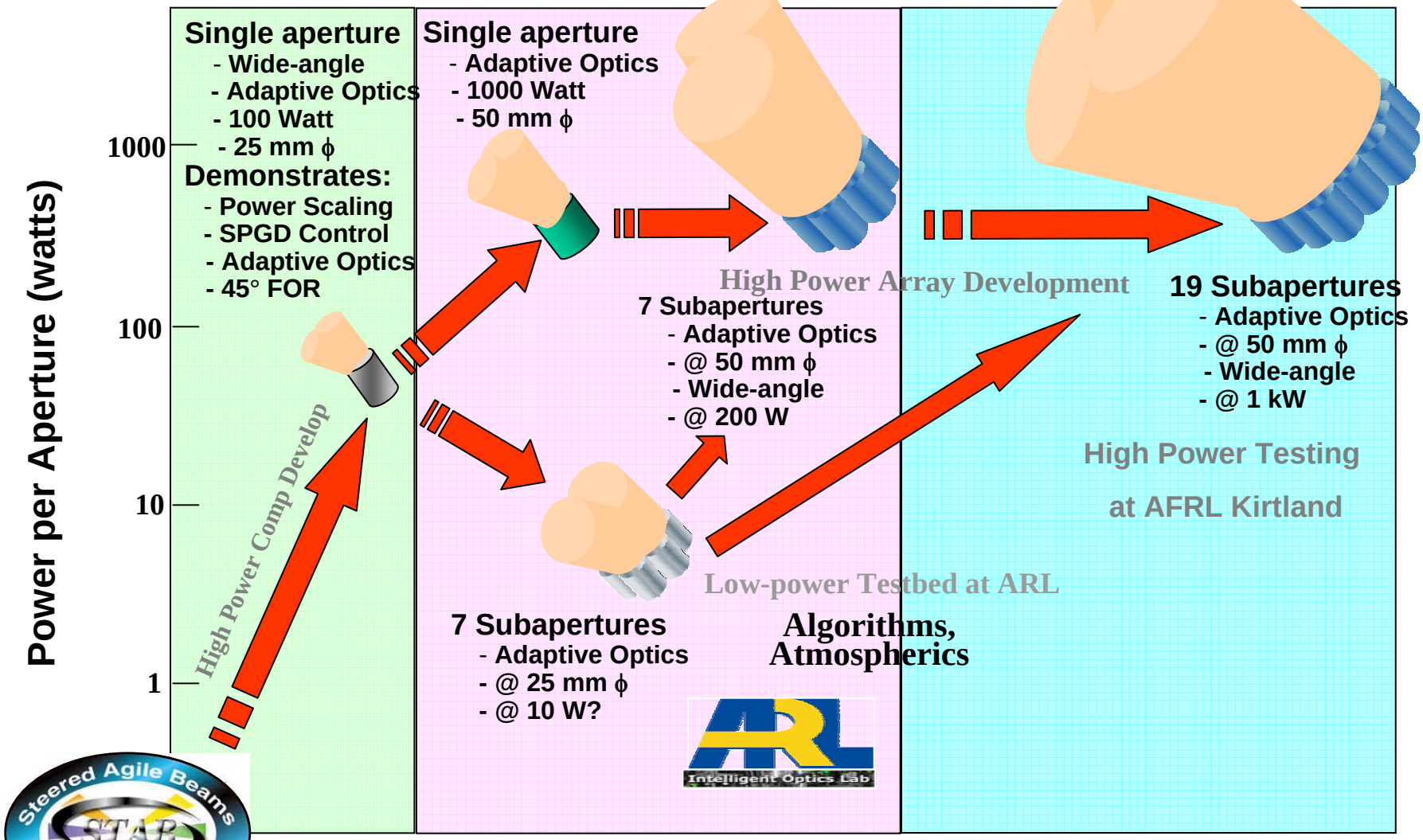
Cochise will increase Power and Safe Operating Temperature of Laser Diode Bars

- **In Year 2, COCHISE will Extend HELLADS Diode Bar Lifetime at Higher:**
  - **Diode Bar Power 85 Watts ⇨ >100 Watts**
  - **Inlet Coolant Temperatures 35°C ⇨ >50°C**

- **Reduce Laser Weapon System Size, Weight, and Cost**
  - **Impacts:**
    - **HELLADS Phase 4**
    - **DARPA Fiber Laser Program**
    - **All DoD Diode-Pumped Solid State Laser Programs**

Challenge: 200 watts/bar-cm by Combining Diode Protection with Improved Bar Cooling Technology

Proposed Roadmap



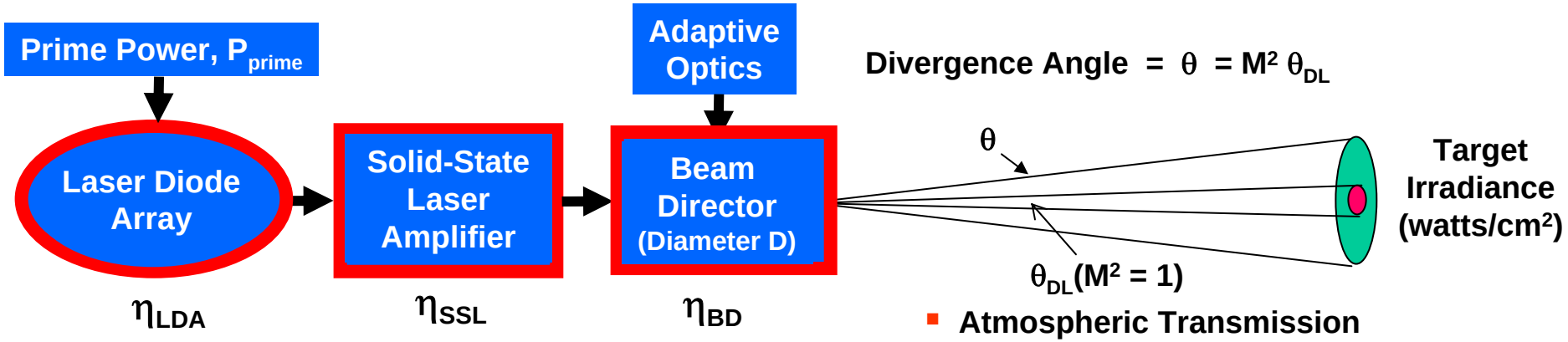
Solid-State Laser Amplifiers

- **Challenges**
  - Scalability
  - Efficiency
  - Beam Quality/Coherence
  - Size, Weight, Power
- **Programs**
  - HELLADS (TTO)
  - HPFL (TTO)
  - ADHELS/COCHISE
- **Technologies**
  - Thin Disks
  - Fiber
  - Coherent Diode Arrays

Beam Directors

- **Challenges**
  - Efficient
  - All-Electronic Steering
  - Scalable to High Power and Aperture Size
  - Conformal to Platform
  - Minimum Size/Weight
- **Program**
  - APPLE
- **Technologies**
  - Conformal Phased Array
  - Risley Prisms
  - Gimballed

Diode-Pumped, Solid-State Laser Systems



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- **Power Delivery Efficiency** ~ $\frac{\eta_{LDA}\,\eta_{SSL}\,\eta_{BD}}{M^4}$

- Challenges
  - Power
  - Efficiency
  - Beam Quality
  - Size and Weight
  - Lifetime/Reliability
  - Electronically-steered, Conformal Optical Phased Arrays with AO

Beam D… …plifiers

- Progr…
  - …
  - …
  - AD…

Agenda:

- APPLE Beam Directors
- COCHISE Coherent Diode Arrays
- Coherent Diode Arrays integrated with APPLE
- Challenges

…ers