High Energy Laser
Joint Technology Office

Progress on Development of High Energy Laser Sources for Defense Applications

Presented by Albert Ogloza
Navy Representative to JTO-HEL
April 2009
CREOL
Outline

• JTO Overview
• Joint High Power Solid State Laser Phase 3 Project
• JTO Thrust Areas
• Robust Electric Laser Initiative
• Summary
JTO Mission

• MANAGE
  – A portfolio of government/industry/academia HEL R&D projects

• COORDINATE
  – Joint HEL activities among the Services & Agencies

• ADVOCATE
  – Joint HEL technology development for the DoD

• DEVELOP
  – JTO technology investment strategy with DoD’s HEL community
FY08 Funds
$60M HEL Investment

- 26 S&A Funding - $20.1M
  - Competitive Call - $11.2M
  - M&S award - $1.9M
  - Lethality award - $3.5M
  - FEL demo - $3.5M

- 35 BAA awards - $14.8M

- 18 MRI projects - $9.9M
  - 13 FY07 awards - $7.3M
  - 4 FY05 awards - $2.6M

- JHPSSL - $14.4M

- Educational Initiatives - $625K
FY2008 JTO Portfolio - Breakdown by Acquisition Method

<table>
<thead>
<tr>
<th>Acquisition Method</th>
<th>Dollars (in millions)</th>
<th>Percentage</th>
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</thead>
<tbody>
<tr>
<td>Service and Agency (S&amp;A)</td>
<td>18.5</td>
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<td>Broad Area Announcement (BAA)</td>
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<td>JHPSSL</td>
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<td>Multi-University Research Initiative (MRI)</td>
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<td>JTO Operations</td>
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<td>Navy FEL Technology Programs (Navy INP)</td>
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<td>Taxes and Withholdings (T&amp;W)</td>
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<tr>
<td>Educational Grants (EDU)</td>
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<td><strong>Total</strong></td>
<td><strong>$66.3</strong></td>
<td><strong>100%</strong></td>
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## FY2008 JTO Portfolio - Breakdown by Thrust Area

### Thrust Area Dollars (in Millions) %

<table>
<thead>
<tr>
<th>Thrust Area</th>
<th>Dollars (in Millions)</th>
<th>%</th>
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<tbody>
<tr>
<td>JHPSSL</td>
<td>12.10</td>
<td>21%</td>
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<tr>
<td>Solid State Laser (SSL)</td>
<td>11.80</td>
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<tr>
<td>Beam Control (BC)</td>
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<td>Free Electron Laser (FEL)</td>
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<td>Gas Laser (GL)</td>
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<td>Advanced Concepts (AC)</td>
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<td>Lethality</td>
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<td>Modeling &amp; Simulation (M&amp;S)</td>
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<td>Educational Grants (EDU)</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>$59.65</strong></td>
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JTO HEL Program Distribution

Laser Device
- Solid State (17)
- Gas (8)
- Free Electron (12)
- Advanced (5)

Beam Control (13)
- Atmospheric Propagation
  - Thermal Blooming
  - Turbulence

Beam Conditioning
- Power Conditioning
- Beam Combining

Beam Conditioning & Adaptive Optics

Example: Solid State Laser

Engagement & System Modeling

Target

Laser-Target Interaction

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Challenges of Scaling Solid State Lasers

- **Largest Challenge:** scale up power to 100’s - 1000 kW while maintaining good beam quality (Diffraction Limit ≤ 2)

- Need to reduce thermal energy generation (increase efficiency) and remove thermal energy generated (thermal management).

- Thermal energy in gain media distorts the beam phase front, reduces overall gain, affects the polarization, can lead to damage

- Thermal energy is waste energy in a laser engine. Heat is generated in:
  - incomplete conversion of electrical energy to diode pump energy
  - incomplete conversion of diode pump energy to gain media excitation
  - incomplete conversion of gain media energy to laser energy

- For multiple apertures, need to combine beams efficiently

Increased efficiency both reduces prime power and thermal management systems for reduced size and weight
Joint High Power Solid State Laser (J-HPSSL) Phase 3

• Purpose: Develop a 100 kW-Class, Diode-Pumped SSL Laboratory Device with Excellent Beam Quality
• Optical Output Power Threshold $\geq 100$ kW
• Beam Quality Threshold $< 2 \times DL$ with a Goal $< 1.5 \times DL$
• Electro-Optical Efficiency Threshold $\geq 17\%$ with a goal $\geq 19\%$
• Run Time Threshold: Maintain a 5 Second Shot Every 6.6 Sec for 3 (5 Goal) Initial Shots, Followed by Additional Shots on Duty Cycle (DC) $= 20\%$ (25% Goal), for Total Time $= 200$ (300 Goal) Seconds
• Includes Options for Weapon System Concept Studies to Integrate Laser on Air and/or Land Platforms – Executed Land Option March 2006

Competitive Contracts Awarded to NGST & Textron in Dec 2005 – PDRs Successfully Completed in July 2006
Joint High Power Solid State Laser (JHPSSL) Thrust

Technical Objectives

• Enable rapid movement to weapon prototypes with high-power lab demo

• Show 100kW by 2009 end with beam quality, run time, and efficiency

• Hardware packaging option for tailoring laser to Service-specific tactical weapon system platforms

Background/Accomplishment

• Joint Budget: $108M FY06-FY09

• Phase 1 successes:
  20 kW, < 2xDL BQ, >300 sec run time
  Robust beam combining
  High performance adaptive optics

Schedule

• 2005 - 25 kW Phase I completed, 3 contractors, one National Lab

• 2005 - 100kW Phase III program launched, 2 contractors

• 2009 - planned 100 kW demonstrations

POC Info

• Don Seeley, HEL-JTO

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Textron JHPSSL III Architecture

Thin Solid state material suspended between fused silica plates

Coolant flow can be longitudinal or vertical

Zig-Zag beam path off outer walls averages out pump non-uniformities

Lasing material excitation can be from a range of options:
- Flashlamps
- Other lasers
- Diode laser arrays

Liquid coolant removes waste heat

Aspect ratio

Thin slab
fused silica window outer surface
Coolant channels
Optical axis passes thru liquid coolant
Combine Six ThinZag® modules into a single aperture power oscillator.

Far Field Intensity

Near Field Intensity (GRM)
Textron JHPSSL Phase III Status

• Apr 07 - Demonstrated 15 kW of power from a high-power module
• Jul 07 - Completed Ground-Based Platform System Study
• Dec 07 – Demonstrated initial coupling of two high-power modules to produce 32 kW
• Mar 08 – Demonstrated 30 second run at approximately 20 kW using two coupled TZ3 modules in a stable resonator configuration
• Sep 08 – Enhance the performance of the two coupled modules by extending the run time, increasing power and improving the beam quality
• Ongoing – integrate remaining modules for full power demonstration
• Single, low power Master Oscillator injects Power Amplifier chains
• MOPA outputs are wavefront corrected, coherently combined and coaligned to form a High Power SSL beam with excellent BQ

JHPSSL2 demonstrated 2-chain 27kW technology

Vesta demonstrated a compact 15kW chain

JHPSSL3 will demonstrate >100kW with 8 compact modular chains in an integrated package
NGST JHPSSL Phase III Status

- Feb 07 - Demonstrated 3.7 kW from first gain module
- Feb 07 - Completed Ground-Based Platform System Study
- Dec 07 - Demonstrated high power Laser Chain (LC) 1 operation at 15 kW with excellent beam quality (~2 x DL) and long run time > 100 secs.
- Jul 08 – Demonstrated Beam Combiner and Optical Diagnostics with LC1 and LC 2 at full power level while maintaining beam quality
- On schedule to complete full power integration and demonstration with 8 LCs in December 08
## SSL Technology Thrust

### Accomplishments
- US YAG ceramic closing gap on Japan
- 225 watt 2.1 μM Tm fiber laser
- Robust coherent and incoherent combining
- 70 percent efficient diode bars (DARPA)
- Rapid single fiber laser progress
  - 3 kW with good beam quality (commercial)
  - 500 W with good BQ and combinable

### Portfolio Synopsis
- **On-going Efforts**
  - FY08 BAA: 9 projects
  - FY07 S&A: 10 projects
  - FY07 MRI: 5 projects

POC
Dr. Gary Wood, ARL

### Technical Objectives
- New ceramic materials
- Eye safer wavelengths
- Beam combining techniques
- Efficient diode arrays
- High power fibers

Cleared for public release RD08-0700
### Characterization Parameters:

- **Polarization** – Need linearly polarized and high polarization extinction ratio.
- **Phase Stability** – Need low phase noise and high stability.
- **Spectral line width** – Need narrow line width and stability.
- **Optical beam quality** – Need near diffraction limited, low $M^2$.

### Important Measurements:

- **Polarization extinction and stability**: Compare master oscillator (seed signal) to amplified levels.
- **Phase stability**: Compare master oscillator phase stability to amplified levels. Measure amplified stability with external perturbations.
- **Spectral line width**: Beat master oscillator with amplified signal(s). Use RF spectrum analysis to extract spectral line width and stability.
- **Compare $M^2$ of master oscillator to amplified levels**.
**Power Scaling Yb-doped fiber Amplifiers: Year 2**

**Background/Accomplishments**

- Nufern have delivered monolithic PM single frequency fiber amplifiers operating at ~180W to AFRL and demonstrated in year 1 a monolithic broadband fiber amplifier delivering ~860W.

**OBJECTIVES**

- To develop the required infrastructure (fibers, couplers and diodes) for monolithic, fiber amplifier building blocks to operate at the kilowatt power level, suitable for beam combining to 100kW.

**Nufern**

- Principal Investigator: Bryce Samson
- Company: Nufern
- Phone: (860) 408 5015

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Rare Earth Doped Fiber Development for Fiber Lasers and Amplifiers

**Objectives**

- The objectives of this program are the development, fabrication, and assessment of rare earth doped fibers capable of multi-kilowatt (10 kW target) output power levels.

**Key Milestones**

- Demonstration of 1kW polarized free-space coupled MOPA
  - Results in review
- Evaluation of preliminary all-fiber integrated MOPA with various Master Oscillators
- Fiber fabrication and assessment for high birefringence at high power
- Demonstration of 300W single-mode all-fiber integrated PM-MOPA

**Results**

- 2.1kW (pump-limited) single-mode result and thermal analysis
  - Establishes feasibility of 10kW single-mode operation
- 1.7kW (pump-limited) at 300MHz effective linewidth
  - Establishes feasibility of 2-5kW single frequency
- 168W (pump-limited) PM, single-mode all-fiber integrated MOPA with 150MHz effective linewidth
  - Advances capabilities of deployable architectures

Ken Dzurko
SPI Lasers
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Payne’s Law: Fiber Laser Power Doubles Every Year

- 2.1kW (pump-limited) single-mode result and thermal analysis
- 1.7kW (pump-limited) at 300MHz effective linewidth
- 168W (pump-limited) PM, single-mode all-fiber integrated MOPA with 150MHz effective linewidth
Scaling of Efficient, High-Power, Tm-doped Fiber Lasers

Objectives

In general, Q-Peak will scale the power of efficient, thulium (Tm)-doped, eyesafe (2000 nm) silica fiber lasers to levels comparable to those of non-eyesafe fiber lasers.

Q-Peak will demonstrate 1000 W of power from a free-space-pumped Tm:fiber, with >50% optical efficiency and 300 W of power from an all-glass fiber-laser system.

2- Fiber coupled diode stacks
1000 W at 793 nm, 1000 um 0.22 NA

Double-clad Tm-doped fiber

Background/Accomplishments

Our work to date has developed Tm:silica, double-clad fiber designs, leading to a record 263 W output at 2050 nm, with >50% efficiency, and near-diffraction-limited beam quality.

• Principal Investigator/PM: Peter F. Moulton
• Company: Q-Peak, Inc.
• Phone: 781-275-9535 X601
Coherent Fiber Beam Combiner

Diffractive Optical Element (DOE)

- 99+% possible in central lobe for diffractive optical element (DOE) combination
- Single wavelength for easy atmospheric propagation and very temperature insensitive

Objectives

- The objective is to coherently combine 5 200W class fiber amplifier chains into one beam with excellent beam quality using a diffractive optical element.
- Northrop Grumman will cooperate with AFRL/DEL to demonstrate diffractive beam combination using AFRL’s high power fiber testbed developed under JTO funding.

Background/Accomplishments

- Phase one demonstrated >90% beam combination efficiency with $BQ = 1.04 \times$ diffraction limited using a diffractive optical element with 5 low power beams.
- Principal Investigator/PM: Michael Wickham
- University/Agency/Company: Northrop Grumman Corp
- Phone: 310-812-0082
Objective

- A monolithic element containing 4 gratings
- A laser with passive wavelength control by PTR Bragg gratings

Background/Accomplishments

- The proposed approach is based development of high efficiency volume Bragg gratings in PTR glass which are tolerable to high power laser radiation.
- Spectral beam combining of 5 channels with efficiency of 93% and quality of a combined beam of $M^2=1.15$ is demonstrated.
- Principal Investigator: Dr. Leonid Glebov
- University of Central Florida, CREOL
- Phone: 407-823-6983
# Beam Control Technology Thrust

## Technical Objectives
- **Disturbances**
  - Atmospheric propagation
  - Algorithms
- **Optical Components**
  - Windows
  - Coatings
- **Aim-point Maintenance**
  - Precision tracking
  - Jitter control

## Portfolio Synopsis
- **On-going Efforts**
  - FY08 BAA: 10 projects
  - FY07 S&A: 8 projects
  - FY07 MRI: 3 projects

## Success/Accomplishments
- Zero optical path distortion glass
- C-130 Aero-optics characterization
- Optical coatings
- GBL atmospheric propagation measurements
- Deformable mirror advances (MEMS, LCSLM, Pocket Mirror)
- Fast stirring mirror performance improvement
- Maritime environment measurements and cataloging
- Jitter mitigation

## POC
Dr. Rich Carreras, AFRL

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Gas Laser Technology Thrust

Accomplishments

- Sealed Exhaust Systems demonstrated by Boeing (COIL) and Lockheed (DF)
  - ATL ACTD integrated with aircraft
  - Field tests conducted in 2007
- Laser Fuel Electrochemical Regeneration
  - Needed for ground-based forward deployable missions
- EOIL and DPAL concepts have been shown to work on small scale

Technical Objectives

- Sealed exhaust and closed-cycle COIL operation
- Regeneration of Laser Chemicals on ground
- Electric Oxygen Lasers
- Diode-pumped Alkali Lasers

Portfolio Synopsis

- On-going Efforts
  - FY08 BAA: 5 projects
  - FY07 S&A: 3 projects
  - FY07 MRI: 2 projects

POC
Dr. Kevin Hewitt, AFRL

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## Free Electron Laser Technology Thrust

### Technical Objectives
- High Current Guns
- High Brightness Injectors
- High Gradient RF Structure
- Improved Optics
- Efficient RF sources to accelerate the electron beam
- Scaling to tens of kW
- Ship-board integration

### Portfolio Synopsis
- **On-going Efforts**
  - FY08 BAA: 5 projects
  - FY07 S&A: 6 projects
  - FY05 MRI: 2 projects

### Success/Accomplishments
- 15 kW at 1.6μm indefinite time at JLAB
- First use of cryo-cooled optics
- Gain of $10^4$ with optical guiding
- Development of IOT for RF at >70% efficiency
- SRF cryo-module at BNL by AES
- Harmonic Lasing to reduce beam energy requirement by ~ 70%

**POC**
Mr. Quentin Saulter, ONR

Cleared for public release RD08-0700
Advanced Laser Technology Thrust

Success/Accomplishments

- Recent advances in the modeling of ultra short pulse laser interactions with various materials provide the basis for predicting system effectiveness
- Continuous improvements towards the development of high efficiency nanoceramic gain media materials have been achieved

Technical Objectives

- Novel Gain Media
- Short Pulse (Femtosecond) Phenomena
- Metamaterials
- Advanced Beam Control Techniques
- Advanced Processing and Characterization of Polycrystalline Ceramics for High Power Lasing

Portfolio Synopsis

- On-going Efforts
  - FY08 BAA: 7 projects
  - FY07 S&A: 3 projects
  - FY07 MRI: 2 projects

POC
Dr. George Simonis, ARL

Cleared for public release RD08-0700
Lethality Technology Thrust

Success/Accomplishments
- Expanded Tri-service Vulnerability Assessment Methodology
- Broadened Lethality Analysis Tools (Physics Models (RCO / Predictive Kill), Vulnerability Modules, Complex Target Models, Signature Analysis, Integrated Multi-service Elements)
- Analyzed Vulnerability of Broad Range of Targets (SAMs Cruise Missiles, UAV, MANPADS, Mortars, Fast Moving Boats) / Target Materials (Urban, UAV, Electronics, Energetics, RAM)
- Conducted Vulnerability Tests on Variety of Targets (IED Components, Energetic Materials, Electronics / Wiring Bundles, UAVs, RAM (Fuse))
- Established Damage Criteria - Myriad of Components
- Establishing Robust Interaction with System Models (Complex Aimpoint Selection, Interactive Response)

Technical Objectives
- Focus Objective
  - Provide basis for eventual predictive modeling that can assess lethality of new targets with minimal need for new laboratory tests
- Key factors
  - Target Vulnerability
  - Component Response
  - Laser Interaction Phenomenology
  - Vulnerability Assessment

Portfolio Synopsis
- Lethality Science, AFRL
- Vulnerability Modeling & Testing, SMDC
- HEL Material and Component Effects Program, NAVSEA
- Lethality Architecture, TAWG IPT

POC Info
- Dr. J. Thomas Schriempf, NAVSEA
- Dr. Nick Morley, AFRL
- Mr. Charles R. LaMar, SMDC

Cleared for public release RD08-0700
Modeling & Simulation Technology Thrust

Success/Accomplishments

• Performed Mission Tools Development
  – Upgraded EADSIM and BRAWLER
• Successfully developed DE DIS Protocol Data Units
• Performed scenario applications of integrated mission levels
• TAWG Engagement Tools upgrade
  – Incorporation into JMEM and support of M&S Community
• HELEEOS distributed to >130 requestors
• HELCOMES distributed to >60 requestors
• 29 Publications and Presentations of M&S efforts by AMRDEC, SMDC, NAVAIR, AFIT and AFRL

Technical Objectives

• Develop Engagement Models
• Develop HEL Representation
  • Implement in EADSIM, IDEEAS
• Develop Data Summaries
  • Scaling Laws, Weather, etc
• Validation, Verification and Accreditation (VV&A) and Anchoring of Model
• Enhancement and Increased Fidelity of Modeling Tools
• Insertion of TAWG models into mission level codes

Participants

• Navy Air Warfare Center and Surface Warfare Center
• Air Force Research Laboratory and Institute of Technology
• Army Aviation and Missile Research, Development and Engineering Center and Space and Missile Defense Command
• One FY-08 BAA Awarded

POCs

Robert Ackerman, Chairman, U.S Navy, NAVAIR
Stan Patterson, Vice Chairman, U.S. Army AMRDEC
Educational Initiatives

- Executed via Grant currently with the Directed Energy Professional Society
- Graduate Scholarships for Students in HEL related Sciences
- Summer Intern Programs at Military Laboratories and Graduate Schools
- HEL Educational Initiatives for Military Academies
- K-12 Initiatives in Optical Science
- Journal of Directed Energy
  - Unclassified published quarterly
  - Classified version planned
- Professional Short Courses in HEL Technologies
- HEL Textbook being developed by AFIT
Robust Electric Laser Initiative

- **Description:** Proposed program to involve HEL-JTO and service investments to continue advancement of electric laser technology
  - Leverage successes of JHPSSL
  - Increase efficiency
  - Packaging for military utility
  - Options for eye safety operation

- **Status:**
  - Request for Information released 1 Aug 08
  - Service roadmap and requirements exercise on-going
  - Program plan to be finalized for late FY-09 program initiation
RELI Objectives

- Science and technology development efforts that mature and demonstrate the attractive qualities of electric lasers for military applications
- Laser Source Goals
  - Relevant power levels from a modular architecture
  - Beam combining approaches that demonstrate excellent beam quality
  - Overall high system efficiency
- Militarization Goals
  - Robust, light weight, and smaller packaging to achieve higher TRL, larger application space and improved fieldability
  - Component and diode development efforts to support efficient and robust power scaling
- Eyesafe Wavelength Goals
  - Develop Laser sources at eyesafer wavelengths comparable to one micron sources (power, beam quality, mode)

Realize the opportunity of electric lasers for military utility
JTO Success Stories

- High Power Fiber Testbed – Air Force Research Laboratory
- 1 kW Thulium Fiber Research – Q peak
- Textron 15KW Thinzag demonstration-JHPSSL Phase 3 award
- Domestic ceramic material – Raytheon Advanced Material Lab
- 400W single mode, polarized fibers – Southampton Photonics
- Closed-cycle COIL demonstration – Boeing LEOS
- ABL Fast Steering Mirror Development – ATA
- FEL Optimum Propagation Wavelengths – Naval Research Lab
- High Power Liquid Crystal Spatial Light Modulators- Teledyne Scientific
Summary

• HEL-JTO programs are having an impact
  – Service initiatives: ATL, HELTD and other programs are leveraging JTO developed technologies
  – Important developments in High Power Fibers and Beam Control for next generation HEL systems
• JHPSSL path to 100 kW having good progress toward successful demonstrations with good beam quality, efficiency and run time
• RELI will mature technology to higher efficiency and packaging