Laser Weapons for Naval Applications

Dr. Phillip Sprangle

Naval Research Laboratory

March 27, 2012
**Report Documentation Page**

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

<table>
<thead>
<tr>
<th>1. REPORT DATE</th>
<th>2. REPORT TYPE</th>
<th>3. DATES COVERED</th>
</tr>
</thead>
<tbody>
<tr>
<td>26 MAR 2012</td>
<td></td>
<td>00-00-2012 to 00-00-2012</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4. TITLE AND SUBTITLE</th>
<th>5a. CONTRACT NUMBER</th>
<th>5b. GRANT NUMBER</th>
<th>5c. PROGRAM ELEMENT NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser Weapons for Naval Applications</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>6. AUTHOR(S)</th>
<th>5d. PROJECT NUMBER</th>
<th>5e. TASK NUMBER</th>
<th>5f. WORK UNIT NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</th>
<th>8. PERFORMING ORGANIZATION REPORT NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naval Research Laboratory, Washington, DC, 20375</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)</th>
<th>10. SPONSOR/MONITOR’S ACRONYM(S)</th>
<th>11. SPONSOR/MONITOR’S REPORT NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>12. DISTRIBUTION/AVAILABILITY STATEMENT</th>
<th>13. SUPPLEMENTARY NOTES</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>14. ABSTRACT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>15. SUBJECT TERMS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>16. SECURITY CLASSIFICATION OF:</th>
<th>17. LIMITATION OF ABSTRACT</th>
<th>18. NUMBER OF PAGES</th>
<th>19a. NAME OF RESPONSIBLE PERSON</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. REPORT unclassified</td>
<td>Same as Report (SAR)</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>b. ABSTRACT unclassified</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. THIS PAGE unclassified</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Standard Form 298 (Rev. 8-98)  
Prescribed by ANSI Std Z39-18
Outline

- Background

- Laser candidates
  - Free electron lasers
  - Solid state lasers

- Additional capabilities
  - Power beaming
Laser Lethality

- Thermally ablating 1/4 pound of target material requires ~ 1.3 MJ of laser energy

- 1 MJ is equivalent to ~ 1/2 pound of explosive

- 100 kW of absorbed laser power for 2 sec ablates ~ 20 grams (~ 8 pennies)

- For an engagement time of 5 sec the required laser power is > 250kW
Capabilities of Laser Weapons

• Agile speed of light delivery (instantaneous)
• All electric energy source (deep magazines)
• Long range targeting
• Multi-targeting
• Compatible with all electric ships
Extinction Coefficient vs Wavelength
Maritime Atmosphere

Maritime Windows

~ 1 μm
~ 1.25 μm
~ 1.6 μm
~ 2.1-2.3 μm

Generated by MODTRAN
Laser Systems for Naval Applications

• **Free Electron Lasers**
  - Jefferson Lab.  $P > 14$ kW, $\lambda \sim 1.6$ μm

• **Solid State Lasers**
  - IPG fiber lasers, 10 kW/fiber
  - Northrop Grumman JHPSSL
    100 kW (2011), 7 tiles
    $\lambda = 1.06$ μm ($N_d$; YAG)
Free Electron Lasers

- High average power capability
- Output wavelength is tunable (can operate in atmospheric window)
- Wall-plug efficiency ~ 10% (potentially)
- Dimension ~ 4m x 4m x 30m, for 100kW to ~ 1MW
- Ship power requirements > 10 MW (engagement time ~ 10s of minutes)
High-Gain, High Efficiency Free Electron Laser

- Electrons undulate in wiggler field and bunch at optical wavelength
- Optical radiation is amplified

Example: $\lambda_w = 3\text{ cm}, \ E_b = 80\text{ MeV}$  

Goal: $\langle P \rangle \sim 1\text{ MW} \quad \lambda = 1\mu m, 1.6\mu m, 2.3\mu m$
Fiber Lasers

• Compact

• High-Power

\[ P_{\text{fiber}} = \begin{cases} 8 \text{kW} , \text{commercially available} \\ 10 \text{kW} , \text{state-of-the-art} \end{cases} \]

• Robust

• High Wall – Plug Efficiency ( > 30 %)

• High Optical Quality
Fiber Laser

(1 kW, 1.6 kW, 1.6 kW and 2 kW)
Incoherent Combining of Fiber Lasers

- NRL Memorandum Report -6790-06-8963; also JDE 2, 273 (2007)
- U.S. Patent # 7,970,040 B1 (June, 2011)
Four Incoherently Combined Fiber Lasers (NRL), 1.2 km Range

3 kW transmitted, 2.8 kW on target, 11/02/07
Starfire Optical Range (NRL) Propagation Range 3.2 km

Incoherently combined fiber lasers, \(~ 5 \text{ kW}, \text{ cw}, \quad M^2 \sim 1\)
Navy Laser Weapon System (LaWS)

• Based on the successful results of the NRL fiber laser program, the Laser Weapon System (LaWS) program (classified) was started in 2008 by NAVSEA, PMS 405

Power per fiber ~ 5 kW

• Successfully tracked, engaged, and destroyed a UAV while in flight (May 24, 2010)
500 kW Fiber Laser Weapon System

• Laser power, CW: \[ P = 500 \text{kW} \]

• # of Fiber lasers: \[ N = 63 \quad (P_{\text{fiber}} = 8 \text{kW, incoherently combined}) \]

• Wall – plug efficiency \( \sim 30 \% \)

• Beam director: \[ R_{BD} = \sqrt{N} R_o \approx 50 \text{cm} \]

• Volume of optics \( \approx 8 \text{ m}^3 \) \quad \text{excluding power supply and cooling}

• Weight of optics \( \approx 10,000 \text{ lbs.} \)

• Water cooling \( \sim 1,000 \text{ gallons/min.} \)
Solid State Slab Laser

- Joint High Power Solid State Lasers (JHPSSL)
- Wavelength, 1.06 µm
- Power achieved 105 kW (2009) - Northrop Grumman
- Wall-plug efficiency, 20%
- Modular design
- Compact
Laser Power Beaming
New Operational Capabilities for the Navy/DoD

• Multiple kilowatts over multiple kilometers
• Laser power converters can be highly efficient, > 60%
• Fiber lasers are highly compact and efficient making them ideal for this application

Power converter

0.5 – 2 kW required

Power beaming range ~ 4 - 5 km
Laboratory Demonstration of Laser Power Beaming using Fiber Lasers

Semiconducting Convertor: InGaAs Spectrolab

- Efficiency ~ 42%
- 9 chips in series yields ~ 6 V, 8 A
- Total power ~12 x 48 W = 576 W
Challenges

- Laser propagation in a maritime environment
  - turbulence
  - aerosols
  - thermal blooming

- Adaptive optics in deep turbulence

- Scalability to MW power levels

- Thermal management
Back Up Slides