Final Report: Compact, Rugged, and Low-Cost Wavelength-Versatile Burst Laser

We completed successfully the construction of three prototype burst lasers for CBRNE detection applications. The lasers are very compact, low cost and meet all the original solicitation specifications. In addition, it delivers 266nm and can operate on portable battery for field applications.

The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.

14. ABSTRACT

We completed successfully the construction of three prototype burst lasers for CBRNE detection applications. The lasers are very compact, low cost and meet all the original solicitation specifications. In addition, it delivers 266nm and can operate on portable battery for field applications.
Final Report: Compact, Rugged, and Low-Cost Wavelength-Versatile Burst Laser

ABSTRACT
We completed successfully the construction of three prototype burst lasers for CBRNE detection applications. The lasers are very compact, low cost and meet all the original solicitation specifications. In addition, it delivers 266nm and can operates on portable battery for field applications.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations
Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received | Paper
---------|--------

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received | Paper
---------|--------

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received | Paper
---------|--------

TOTAL:
Number of Manuscripts:

<table>
<thead>
<tr>
<th>Books</th>
</tr>
</thead>
<tbody>
<tr>
<td>Received</td>
</tr>
<tr>
<td>TOTAL:</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Received</th>
<th>Book Chapter</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL:</td>
<td></td>
</tr>
</tbody>
</table>

Patents Submitted

Patents Awarded

Awards

Graduate Students

<table>
<thead>
<tr>
<th>NAME</th>
<th>PERCENT_SUPPORTED</th>
</tr>
</thead>
</table>

| FTE Equivalent: | 0.30 |
| Total Number: | 1 |

Names of Post Doctorates

<table>
<thead>
<tr>
<th>NAME</th>
<th>PERCENT_SUPPORTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dylan Burns</td>
<td>0.30</td>
</tr>
</tbody>
</table>

| FTE Equivalent: | 0.30 |
| Total Number: | 1 |
Names of Faculty Supported

<table>
<thead>
<tr>
<th>NAME</th>
<th>PERCENT_SUPPORTED</th>
<th>National Academy Member</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dryver Huston</td>
<td>0.20</td>
<td></td>
</tr>
</tbody>
</table>

FTE Equivalent: 0.20
Total Number: 1

Names of Under Graduate students supported

<table>
<thead>
<tr>
<th>NAME</th>
<th>PERCENT_SUPPORTED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

FTE Equivalent: 
Total Number: 

Student Metrics
This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: ..... 0.00
The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields: ..... 0.00
The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields: ..... 0.00
Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale): ..... 0.00
Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering: ..... 0.00
The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense: ..... 0.00
The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields: ..... 0.00

Names of Personnel receiving masters degrees

<table>
<thead>
<tr>
<th>NAME</th>
<th>FTE Equivalent</th>
<th>Total Number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Names of personnel receiving PHDs

<table>
<thead>
<tr>
<th>NAME</th>
<th>FTE Equivalent</th>
<th>Total Number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Names of other research staff

<table>
<thead>
<tr>
<th>NAME</th>
<th>PERCENT_SUPPORTED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

FTE Equivalent: 
Total Number: 

Sub Contract Award Date (f-1): 4/18/13 12:00AM
Sub Contract Est Completion Date (f-2): 4/17/15 12:00AM

Inventions (DD882)

Scientific Progress

see attachment

Technology Transfer
# Compact, Rugged, and Low-Cost Wavelength-Versatile Burst Laser

(ARMY STTR)

**Final Technical Report**

April 18, 2013 to April 17, 2015

*Proposal Number: A2-4987*

*Contract Number: W911NF-13-C-0050*

## Table of Contents

1. Project Objectives .............................................. Page 3
2. Work Performed .................................................. Page 4
   2.1 Phase II Technical Objectives and Approach ............... Page 4
   2.2 Kickoff Meeting (May 2013) .................................. Page 4
   2.3 Year 1 Schedule ............................................. Page 5
   2.4 Year 2 Schedule ............................................. Page 5
   2.5 Laser System Concept ....................................... Page 5
   2.6 Master Oscillator Power Amplifier (MOPA) Laser Configuration ............................................. Page 6
   2.7 Diode Arrays for the New MOPA Configuration .......... Page 8
   2.8 Q-Switched MO ............................................. Page 8
   2.9 Power Amplifier (PA) ....................................... Page 10
   2.10 MOPA Performance ......................................... Page 10
   2.11 Wavelength Converters ................................... Page 12
      2.11.1 1570nm Converter .................................. Page 12
      2.11.2 355nm Converter .................................. Page 13
      2.11.3 266nm Converter .................................. Page 14
   2.12 Wavelength Separator .................................... Page 16
   2.13 Low Cost Design Considerations ......................... Page 17
   2.14 Compact Low Cost Laser Driver ......................... Page 25
   2.15 Low Cost Q-Switch Driver ................................ Page 26
   2.16 Battery / Inverter Pack .................................. Page 26
   2.17 Complete Systems ......................................... Page 28
4. Cost Estimates .................................................. Page 29
5. Results Obtained .............................................. Page 29

1. List of Illustrations

1. Figure 1 – Block diagram of the burst laser system ................................................................. Page 6
2. Figure 2 – 4 pass Laser MOPA configuration ................................................................. Page 6
3. Figure 3 – 4 pass Laser MOPA layout ................................................................. Page 6
4. Figure 4 – 4 pass Laser MOPA design (left), and photograph (right) ................................. Page 7
5. Figure 5 – 2 pass Laser MOPA configuration ................................................................. Page 8
6. Figure 6 – New high pulse energy Q-switched MO ................................................................. Page 8
7. Figure 7 – Q-switch MO 8ns FWHM temporal pulse ................................................................. Page 9
8. Figure 8 – Q-switch MO pulse energy ................................................................. Page 9
9. Figure 9 – Q-switch MO spatial beam profile ................................................................. Page 9
10. Figure 10 – Photograph of the PA laser head ................................................................. Page 10
11. Figure 11 – MOPA layout on the right with the wavelength converter, and the actual MOPA on the left without the wavelength converter ................................................................. Page 11
12. Figure 12 – 1064nm MOPA pulse energy versus laser diodes’ drive current (left) and the temporal pulse (right) ................................................................. Page 11
13. Figure 13 – Spatial burn of the 1064nm MOPA pulse (4mm diameter and 50mJ/pulse) ................................................................. Page 12
14. Figure 14 – Eye safe OPO KTP converter and wavelength separator ................................................................. Page 12
15. Figure 15 – 1570nm converter pulse energy and temporal pulse ................................................................. Page 13
16. Figure 16 – 355nm converter set-up using SHG followed by a THG ................................................................. Page 13
17. Figure 17 – 355nm converter pulse energy temporal pulse (9ns) ................................................................. Page 14
18. Figure 18 – 266nm converter set-up using SHG followed by a FHG ................................................................. Page 14
19. Figure 19 – 266nm converter pulse energy and temporal pulse (10ns) ................................................................. Page 15
20. Figure 20 – SolidWorks model of display cases ................................................................. Page 15
21. Figure 21 – Dust proof storage enclosure for the various wavelength converters ................................................................. Page 16
22. Figure 22–PB Prism mount ideas ................................................................. Page 16
23. Figure 23– 3D printed model of PB rotating mount ................................................................. Page 17
24. Figure 24 – Pellin-Broca prism arrangement for the wavelength separation ................................................................. Page 17
25. Figure 25– CAD model of custom mounting ................................................................. Page 18
26. Figure 26– CAD model of case with grommets ................................................................. Page 19
27. Figure 27– 3D model ................................................................. Page 19
28. Figure 28– CAD model of breadboard and case assembly ................................................................. Page 20
29. Figure 29– 2D CAD drawing of part to be fabricated ................................................................. Page 20
30. Figure 30 – Machined components ................................................................. Page 21
31. Figure 31– Anodized Parts assembled on breadboard ................................................................. Page 21
32. Figure 32 – Custom designed laser rod mount ................................................................. Page 22
33. Figure 33 – SolidWorks model of new system design ................................................................. Page 22
Project objectives

Many laser-based sensor technologies like Raman, Laser Induced Fluorescence (LIF), UV Laser Photo-Dissociation (UV-PD), and Laser Induced Breakdown Spectroscopy (LIBS) are being developed for close contact and standoff threat chemical, biological, radiological, nuclear and explosives (CBRNE) analysis. These operate in a burst laser mode with a finite number of laser pulses required for the measurement. This is because either the sample/target is chemically altered with repeated laser shots, or the technique limits the number of shots for rapid sensor response.

The typical pulsed lasers currently used in these systems are Commercial off the Shelf (COTS) systems that have been designed for continuous operation for many hours. Therefore, these lasers are over engineered with regards to size, weight, cooling capacity, and cost.

Currently the most affordable pulsed laser systems are flashlamp pumped. However, diode pumped lasers are more desirable due to ruggedness, higher efficiency, and smaller size. So far, the Diode Pumped Solid State (DPSS) lasers have cost significantly more than flashlamp pumped lasers.

Our STTR project has the goal of producing DPSS burst laser that is (1) high pulse energy in a rapid burst mode, (2) wavelength agile to cover the eye-safer regions in the UV and near-IR, as well as (3) smaller, lighter, and much more affordable than current COTS systems.
Phase I started on August 31, 2011 and ended on February 28, 2012. Although the Phase I requirement was to produce an engineering model for the burst laser, we have taken it much further and built a breadboard demonstrator and successfully demonstrated its performance.

Burst Laser Goal Requirements:

- 50mJ/pulse @ 1064nm
- 5 - 10ns pulse duration
- <3xDL (Diffraction Limited) beam quality
- Other wavelengths options of 1.5μm and 355nm
- Up to 100 pulses burst
- <100Hz repetition rate (10Hz is sufficient)
- <1 minute between bursts
- <33% of current laser size (<850 cubic inch)
- <25% of current laser weight (<8.5lbs.)
- <33% of current laser cost (<$8,500)

In Phase II (April 18, 2013 to April 17, 2015) our goal was to engineer, design and construct three prototype burst laser systems that show the feasibility of producing such lasers while meeting all of the above goal requirements.

Work Performed and Results Obtained

Phase II Technical Objectives and Approach
The technical objective of Phase II is to build and test three low cost prototype burst lasers that meet all the US Army requirements.

The approach to reach the above objective is by performing the following tasks: 1) design, fabrication, components procurement, assembly and testing of first prototype laser system based on Phase I effort, 2) incorporate new low cost diode arrays and address minor modifications if needed in updated design, then fabricate, procure components, assemble and test the next two prototype lasers and upgrade the first laser to the latest design.

Kickoff Meeting (May 2013)
The Phase II program started with a kickoff meeting that included the US Army representatives. Planned actions were described, followed by an open discussion on any deviations from the intended plan.
Laser System Concept

The laser system under development in Phase II is intended for both in house and field applications. It is designed to be used with a standard wall plug of 115Vac or with a 12Vdc and 115Vac inverter as shown in figure 1.
The Diode Pumped Solid State (DPSS) laser module produces 50mJ per pulse at 1064nm. The wavelength can be converted to 1570nm, 355nm or 266nm via the wavelength converters. The laser drive electronics is a separate module connected via a cord to enable more flexibility of operation. The laser driver plugs to 115Vac and has trigger IN and trigger OUT for synchronizing it with other detection equipment. For field application, a 12Vdc battery and inverter to 115Vac is provided. It can be hooked to a car battery with inverter or the provided battery pack.

Master Oscillator Power Amplifier (MOPA) Laser Configuration

Lasers that are used for LIBS and other optical based detections like LIF, Raman, etc. are simple laser oscillator design and flash lamp pumped for low cost. Operating a simple laser oscillator at high energy per pulse requires a trade-off between energy per pulse and beam quality. Higher energy per pulse translates to lower beam quality. We have chosen to go with diode pumped MOPA laser configuration for high performance. For this proposed burst laser we want high beam quality to allow for generating micro-plasma for LIBS at large standoff distance, and also for improved performance of the wavelength converters.

Figure 2 shows our 4 pass Master Oscillator Power Amplifier (MOPA) laser configuration.
The Master Oscillator (MO) is a longitudinally pumped Q-switched Nd:YAG laser. The pump diode builds up the population inversion in the Nd:YAG rod during the pump duration of about 200μs. The polarizer and the quarter waveplate prevent any lasing until the Pockels cell activates and undoes the quarter waveplate to allow lasing. The laser light escapes the resonator through the output coupler (OC). In this configuration, the pulse duration depends on the gain and the resonator length. The Power Amplifier (PA) is a passive four pass amplifier that boosts up the energy per pulse without affecting the beam properties.

In Year 1 of Phase II we constructed and tested the 4 pass MOPA laser. Figure 3 shows the layout of the laser.

![Figure 3 – 4 pass Laser MOPA layout](image)

Figure 4 shows the design and a photograph of the 4 pass laser.

![Figure 4 – 4 pass Laser MOPA design (left), and photograph (right)](image)

By designing the laser for small size it was more difficult to get the laser to reach its desired performance. In addition, the high cost and weight of the Faraday rotator was a concern. In order to reduce the cost and weight, we modified the design. We increased the power out of
the Master Oscillator (MO) and changed the Power Amplifier (PA) configuration to 2 passes as shown in Figure 5.

![Figure 5 – 2 pass Laser MOPA configuration](image)

**Diode Arrays for the New MOPA Configuration**

Diode arrays are the major cost components of the laser. We selected low duty cycle diode arrays with no cooling. The diode arrays were tested using 100 pulse bursts. The red shift of the arrays was ~1.5nm which is within the required range of 3nm. We observed the wavelength shift live using a real time spectrometer.

**Q-Switched MO**

The new MOPA configuration requires higher energy per pulse in order to achieve the 50mJ output after only two pass amplification. We modified the MO design to have higher pump power and larger laser rod. A laser diode array is transversely pumping a 4mm diameter rod.

Figure 6 shows the MO that we designed and constructed.

![Figure 6 – New high pulse energy Q-switched MO](image)
This MO delivers ~15mJ per pulse and 8 to 10 ns pulse duration.

Figure 7 shows the MO temporal pulse.

![Temporal Pulse](image)

**Figure 7 – Q-switch MO 8ns FWHM temporal pulse**

Figure 8 shows the MO output pulse energy versus the drive current the diode array.

![Energy vs Drive Current](image)

**Figure 8 – Q-switch MO pulse energy**

Figure 9 shows the spatial beam profile. The slight elongation is due to the pump array, but the beam is nearly diffraction limited and Gaussian in profile.

![Beam Profile](image)

**Figure 9 – Q-switch MO spatial beam profile**
**Power Amplifier (PA)**

Burst mode operation is different than a typical laser operation. A typical solid state laser must run at a constant loading to maintain steady thermal conditions. Solid state lasers change their performance as components change their temperature. Laser diodes undergo red wavelength shift at elevated temperature, the laser crystals and harmonics generation crystals start lensing and the thermal stress induce birefringence. All this change need to be compensated to avoid laser performance degradation. Burst mode operation takes the laser components from low temperature to elevated temperature during the burst duration. In this case we have to ensure that the laser components will be within the range of acceptable performance.

The PA was designed and fabricated completely in house. It consists of a single diode array that transversely pumps a 4mm Nd:YAG laser rod. A photograph of the PA laser head is shown in figure 10.

![Figure 10 – Photograph of the PA laser head](image)

**MOPA Performance**

The MOPA layout is shown in figure 11.
The MOPA pulse energy and temporal pulse are shown in figure 12. The FWHM was between 8ns to 10ns for the various burst lasers constructed.

Figure 13 is the burn pattern of the MOPA output pulse.
**Figure 13** – Spatial burn of the 1064nm MOPA pulse (4mm diameter and 50mJ/pulse)

**Wavelength Converters**

The laser system has the option to generate other wavelengths of interest by converting the fundamental wavelength of 1064nm.

**1570nm Converter**

For safe operation in the field, it is a standard practice to use eye safe wavelength like 1.5μm. There are several techniques for shifting the fundamental to longer wavelengths. The most elegant, efficient and compact is by using OPO (Optical Parametric Oscillator). The set-up for the converter is shown in figure 14.

**Figure 14** – Eye safe OPO KTP converter and wavelength separator

The optical coatings are done on the crystal itself in order to reduce size and cost.

We obtained pulse energy of about 3.3mJ at 1570nm, and pulse duration of 10ns as shown in figure 15.
Figure 15 – 1570nm converter pulse energy and temporal pulse

355nm Converter

The set-up for generating the third harmonics of 355nm is shown in figure 16.

Figure 16 – 355nm converter set-up using SHG followed by a THG

The wavelength separation is done via the two Pellin-Broca prisms. We obtained up to 6mJ/pulse in the third harmonics.

Figure 17 shows the pulse energy and the temporal pulse of the third harmonics.
Figure 17 – 355nm converter pulse energy temporal pulse (9ns)

266nm Converter

The set-up for generating the third harmonics of 355nm is shown in figure 18.

Figure 18 – 266nm converter set-up using SHG followed by a FHG

The wavelength separation is done via the two Pellin-Broca prisms. We obtained up to 1.5mJ/pulse in the forth harmonics.

Figure 19 shows the pulse energy and the temporal pulse of the forth harmonics.
Display cases for keeping the unused wavelength converters dust free were designed and fabricated (Figure 20)

Figure 21 shows the storage enclosure for the three wavelength converters.
Wavelength Separator

There are several ways to separate the wavelengths and point the desired beam in the right direction. We selected to use a pair of Pellin-Broca prisms for minimizing replacing optics at different wavelengths. But the angles of the prisms need to be adjusted to the desired wavelength in order to maintain the beam pointing.

Several different systems were considered and designed for mounting the PB prisms in such a way that they could be rotated accurately to the correct angles. (Figure 22)

A 3D printed model of the final design selection of the PB rotating mount was created (Figure 23)
The final successful implementation is shown in Figure 24.

**Figure 24**– Pellin-Broca prism arrangement for the wavelength separation

**Low Cost Design Considerations**

The number one goal was low cost. One way that we managed to reduce cost was through the selection of optical components. Multiple vendors were sourced and a cost benefit analysis was performed to find the least expensive option that still meets all of the necessary specifications.

During the component selection process a table was created and constantly update to keep track of the cost, weight, and vendor of all the components for the setup. Cost estimates with price breaks for larger volume orders were also tabulated.
One way that was found to reduce cost, weight and size was to design and fabricate custom mounting plates for the optics. (Figure 25)

An enclosure was selected and designed for the breadboard layout. This was again modeled in SolidWorks. Along with the enclosure, an anti-vibration system was designed for the case using rubber grommets. (Figure26)
Another way to keep the cost low was to research the most cost effective methods for fabrication of components. Larger volume runs for machining and anodizing lead to large cost savings per part in the long run.

Before having parts fabricated, a 3D model was printed to verify dimensions and clearances. (Figure 27) These parts were assembled on the breadboard to verify clearance and fit.

After mocking up the system with the 3D parts, any modifications that were needed were then updated in the SolidWorks model. This process of drawing modifications followed by a 3D mockup was repeated several times before converging on a final design with correct dimensions. (Figure 28)
Once this final design was updated for the SolidWorks model, all of the individual parts files that need to be fabricated were transformed into 2D CAD files. (Figure 29)

These drawing files were then sent over to the machine shop where the parts were created using the correct materials (aluminum for the majority of parts). These parts were then mounted to the bread board just as the 3D printed parts had been, and again double checked for clearance fit and positioning. (Figure 30)
After any modifications were done to these parts and the final version was converged upon, the parts were then sent off to be anodized. The final anodized parts were assembled back on the bread board. (Figure 31)

Another way to reduce costs, along with saving weight and space, was in the creation of custom parts. It was found that in several cases this proved to be cheaper and more efficient than purchasing an existing off the shelf product that may still need to be modified. One of these custom pieces was the laser rod mount design, which was first designed in SolidWorks. (Figure 32)
As new parts were designed and added, and old parts were modified, the overall system assembly was continuously updated to reflect these revisions. (Figure 33)

After the new version of the system was completed in SolidWorks, the parts were then sent to the 3D printer and a mockup was assembled using these parts. (Figure 34)
After the clearance and fit of the parts were verified with the 3D print parts mock up, the next step was to send the drawings of these parts to the machine shop to be fabricated. Many of these parts would also need to be anodized as well. A layout of the parts that were to be anodized was created in SolidWorks. (Figure 35, 36)
After several further modifications and adjustments to the layout design, mounts and components, multiple boards were populated with anodized parts. (Figure 37)

These boards were then fitted into the rubber mounted packaging cases (Figure 38)
Compact Low Cost Laser Driver

The laser driver contains: 1) An internal pulse oscillator for generating 1Hz, 10 Hz, and 100Hz. 2) A pulse width modulator to vary the drive pulse duration which control the laser output pulse energy. 3) A high current electronic switch to drive the diode arrays. 4) A trigger pulse for the Q-switch driver. 5) A push button to activate the laser. 6) A trigger IN and a trigger OUT for synchronizing with other detection equipment. Figure 39 shows the block diagram of the laser driver.

We developed and successfully tested a laser driver for burst mode operation. Commercial drivers are designed and built for continuous operation and not burst mode. Therefore, they are larger and very expensive. Our driver is extremely inexpensive. The material cost is under $50 and it can be packaged into a 1.5”x2”x5” enclosure. It contains the power supply and drive electronics. It also contains a trigger to automatically trigger the Q-switch and trigger IN and trigger OUT for synchronizing with a detection system. Figure 40 shows the driver and the current pulse it generates to drive the entire set of diodes used in the laser system.

Figure 39 – Block diagram of the laser driver

Figure 40 – Extremely compact and low cost laser driver (includes power supply, diode driver, and Q-switch trigger) and it’s current pulse
The drive electronics is capable of delivering up to 500A peak current. The driver was tested under all of the required burst modes conditions and is currently used to drive the laser system.

**Low Cost Q-Switch Driver**

A commercial Q-switch driver costs nearly $2,000. We had to reduce the cost of the Q-switch driver to meet the goal requirements. We designed a new circuit and constructed it. Figure 41 shows the new compact Q-switch driver.

![Figure 41 – Extremely compact and low cost Q-switch driver](image)

The material cost of the driver is under $150 which is about 1/10 of the cost of a commercial driver. We did not have a single failure of the new Q-switch driver.

**Battery / Inverter Pack**

The power consumption of the burst laser is about 2W for 1Hz continuous operation, and about 20W at 10Hz burst. During the OFF time between bursts, the power consumption is only few mW. Therefore, the average power consumption is very low.

Since the average power required is low. A battery can be used to run the laser for autonomous field operation or on small robotic vehicles. In order to widen the potential applications of the laser system, 12Vdc would be the preferred choice since most vehicles has 12V battery. A rechargeable12V polymer Li-ion battery pack was constructed to power the laser system. An inverter to convert the 12Vdc to 115Vac is used; therefore, plugging the laser power cord to the inverter instead of the wall plug enables us to use the laser system in the field.
A case for external battery power supply needed to be designed and built. This case needed to be low cost, lightweight, portable, suitable for outdoor applications and easy to carry. An initial design was created in SolidWorks for an insert to hold the batteries, inverter and wiring in place inside of a rugged off the shelf carrying case. (Figure 42, 43)

After the SolidWorks design was revised and finalized the model was then converted to the appropriate file type and sent to the 3D printer. This 3D insert was installed in the Pelican case along with the batteries, inverter and wiring. (Figure 44)
Complete Systems

A photograph of the complete system is shown in figure 45. It contains the laser module, the laser driver unit that plugs to 115Vac and the wavelength converters that can be inserted into the laser module for operating at 1570nm, 355nm, or 266nm.

![Complete laser system](image)

*Figure 45 – Complete laser system (laser module in center, laser driver on left, and wavelength converters on right)*

The laser system and battery pack are housed in a small briefcase (18”x13”x6”) for easy transportation and storage. (Figure 46)

![Burst laser in a briefcase](image)

*Figure 46 – Burst laser in a briefcase*
Figure 47 shows the fully completed three prototypes burst lasers in their briefcases.

![Figure 47](image)

**Figure 47** – *Three completed prototype burst lasers in their briefcases*

**Manual**

A manual like the one shown in figure 48 for powering and operating the burst laser is attached to each of the laser systems. The burst laser is maintenance free and the operator should not attempt to troubleshoot or repair the laser system.

![Figure 48](image)

**Figure 48** – *Operator manual for the prototype burst laser*
Cost Estimates

The cost to produce the burst laser is the number one goal. We have made every effort to minimize the cost of the system. We were able to build a laser system for a total material cost of about $5,500 (not including wavelength converters and battery pack). The options for wavelength converters, wavelength separator, and battery pack will add to the material cost about $2,000. High volume production should reduce the material cost at minimum by 25% and possibly by over 50%. Therefore, the selling price per unit at high volume may well be under $8,000.

Estimates of Technical Feasibility

The final goal is to have low cost and compact commercial burst lasers to be integrated in CBRNE detection applications. Phase II clearly demonstrated the feasibility of clearing the way toward commercial systems that meet the desired low cost, size and weight. With the design and component selection of this prototype it was possible to reduce the cost as compared to the present readily available lasers on the market that have comparable specifications.

The prototype laser has been designed to be used indoor and in outdoor field scenarios. The size and weight was optimized so that the laser and battery pack could easily and comfortably be carried. The packaging was also designed to be rugged and to reduce vibrations.

All that is left to do is: 1) add temperature control to expand the current range of 70F – 80F to a wider range if needed, 2) control the laser remotely via WiFi, Blue Tooth, etc. with smart phone if needed, 3) add safety features like interlocks, warning lights, etc. if needed, 4) do reliability, shake and bake testing, and 5) engineer it for mass production.

The transition time to mass production will vary on the added requirements, but should take as low as one year and up to three years at the most.