A Laboratory Testbed for Femtosecond Laser Demilitarization Experimentation*

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Abstract

We have demonstrated with small-scale testing that a high-power, femtosecond (fs) laser beam can cut explosive materials and explosives in contact with metal without transferring heat to the explosive. We have cut through samples where metal is in direct contact with explosive both from the metal side and the explosive side. These cuts showed no signs of heating or any reaction in the explosives. We have also successfully sectioned a live detonator and have dissected other weapons components, such as a detonator header and bridge wire, and detonator cable. In addition we have drilled holes of <50 μm diameter through centimeter thick samples of high explosive. These tests demonstrate that the femtosecond laser is an attractive tool for use in demilitarization operations. Attributes such as precision material removal rate and cutting without altering the morphology of the surface make this technique very attractive for enhanced surveillance activities as well as explosive and component machining for the purpose of manufacturing novel new explosive components, such as detonators.

All of the initial demonstration work has been accomplished using an existing experimental femtosecond laser located in a non-explosive area at LLNL. This location has severely limited what we can accomplish in terms of the amount and type of high explosive we can work with and the type of experiments we can carry out. We have initiated a program to build a femtosecond laser and laboratory in the explosive facility in building 191 at LLNL. The laser will be portable so we can take advantage of a 10 kg firing tank already in existence in the building to cut much larger amounts of explosive and ordnance or ordnance mockups. We will be able to determine quantitatively important parameters involving cutting rates, limitation and safety margins in this laboratory as well as demonstrating cutting operations on large-scale assemblies and components. The laboratory will serve as a testbed for investigating new demilitarization ideas for DOD, DOE and defense contractors.

*Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

Introduction

To safely dispose of munitions containing high explosives (HE's) and other hazardous materials, it is necessary to gain access to the interior of the munition so that the contents may be removed. A safe method is needed to cut open munition casings and components that are likely to be in contact or close proximity to HE or other energetic materials. Using conventional machining techniques, there may be a significant risk of an explosive reaction. Other techniques have been developed which may safely cut the explosive but produce an undesirable hazardous waste stream.

Ablation of energetic material by femtosecond laser pulses is potentially an attractive alternative to conventional machining[1,2]. Absorption of these ultra-short laser pulses occurs on such a short time scale that the material is ablated with virtually no heat transfer to the surrounding material[3], resulting in a "cold" laser cutting process and, hence, a safe process. In contrast, laser cutting techniques which use laser pulses longer than ~10 ps first melt, then vaporize the material with significant heat transfer to material outside of the cutting region. Cutting with laser pulses on the order of ~100 – 150 fs, multiphoton ionization and plasma formation occurs on a timescale on the order of the lattice vibrational period of the explosive. Because this time is so short, energy cannot be effectively coupled into the lattice of the material and is carried away from the surface by hydrodynamic expansion and cooling of the plasma.

Each laser pulse removes only a few microns of material. For explosives, the resultant products are mostly carbon and benign gases. The laser footprint can be made very small, on the order of tens of microns, so that very little material is removed during the cut. This combination of mostly benign material and very little of it in the cutting by-products makes the technique very clean relative to other methods used. The small laser footprint also makes it an attractive tool when precision cutting operations are needed.

The femtosecond laser cutting process does not alter the morphology of the surface of the material. This attribute, along with the precision removal of material, makes this tool very valuable for use in surveillance studies of weapons and their components.

Summary of Work to Date

To date we do not have a femtosecond laser in our explosive facility, HEAF, and have done all work in a non-explosive work area in the laser lab in building 298. A special Operational Safety Procedure was written to allow this work to proceed using a small firing chamber and explosive samples less than 500 mg.

We have so far demonstrated (figs 1 and 2) the following:

- Cut through a survey sampling of commonly used secondary explosives: PETN, LX-16 (PETN/binder), LX-14 (HMX/binder), LX-15 (HNS/binder), LX-17 (TATB/binder) and pressed TNT.

• We cut through 1.2 mm of stainless steel and 2 mm of explosive where the metal and explosive were in intimate contact (from both directions).

• We have cut through 1 cm of explosive and ,5 mm of Aluminum in intimate contact (from both directions).

• We drilled <50 µm holes through 1 cm thick samples of explosive.

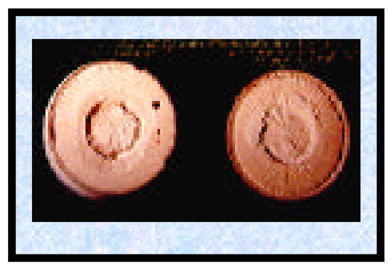
• Sectioned a hemispherical detonator.

• Sectioned a detonator cable to demonstrate the capability of locating defects.

• Sectioned a detonator header and bridgewire giving a clean cross-sectional view of the .0015 inch bridgewire.

• Demonstrated machining capability on explosive samples.

• Cut a novel shaped piece of explosive used to demonstrate a new prototype DOE weapons detonator design.



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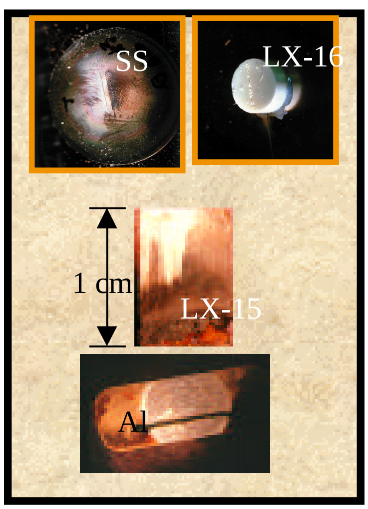

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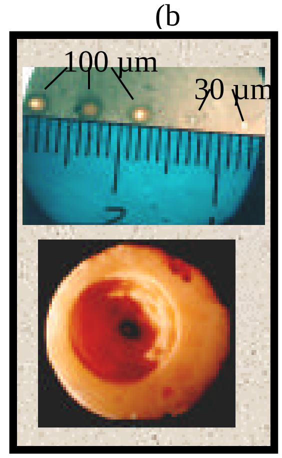

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Figure 1. a) Top: laser cut through 1.2 mm of stainless steel and 2 mm of LX-16. Bottom: cut through 1 cm of LX-15 and .5 mm of Aluminum. b) Sectioned hemispherical detonator consisting of an Al shell, PBX-9407 and a PETN center. C) Top: Several holes drilled through PBX-9407 and bottom: a 3mm-diameter cavity machined in TNT.

The cutting of metals and explosives combinations without any reaction taking place and the sectioning of the hemispherical detonator shows a great deal of promise for the femtosecond laser cutting technique in the arena of demilitarization. Our demonstrations of sectioning detonator components and cables show the tremendous potential in the area of advanced surveillance. The machining and hole drilling demonstration open the door for use of this technique in the development and experimental science involved creating new and improved detonators and explosive related components. We have already put this technique to work in cutting a novel shaped piece of high-surface area PETN for use in the prototype demonstration of a potential new DOE detonator.

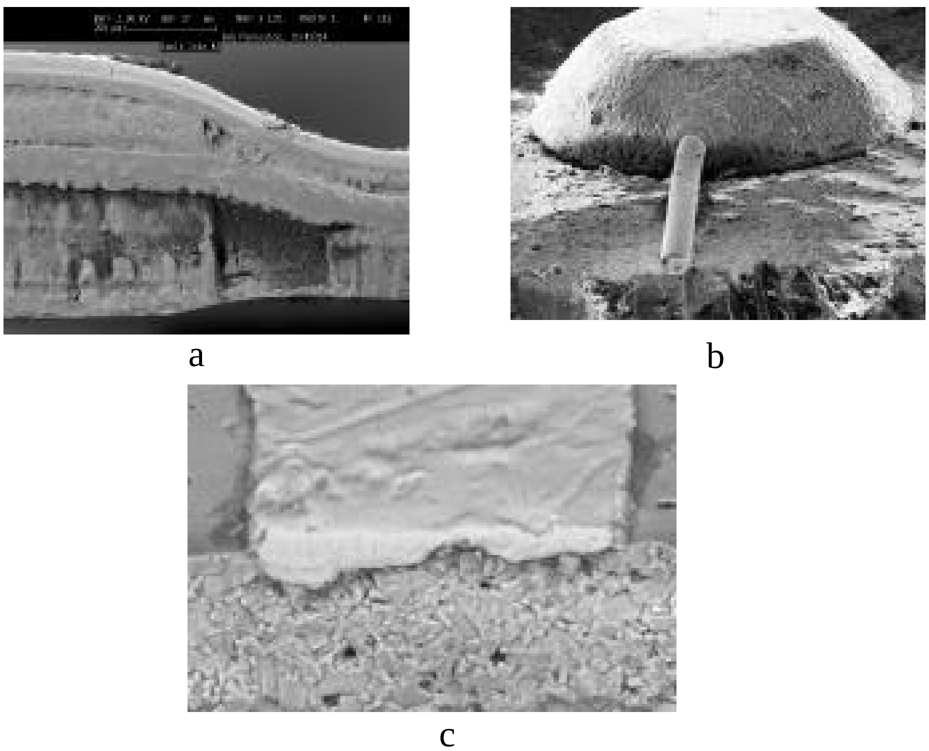

Figure 2. a) Cross section of a detonator cable showing defects b) A 0.0015-in-thick Au bridgewire c) a detonator bridge showing the grain structure in the ceramic base.

Current Work

We are currently constructing a laser laboratory and a 4-6 W average power, femtosecond laser in Building 191 at Livermore. The laser will be on a portable laser table so that it can be taken a short distance from the laser lab to a 10 kg spherical shot tank.

Having the laser in an explosive approved area will allow us to make many tests that were not possible to perform in building 298. It is vital that we obtain quantitative data in the following areas:

- Establish optimum cutting parameters for HE and ordnance systems and components. This involves many small-scale and a few large-scale tests involving laser power, spot size, laser rep rate, focus, beam profile, etc.

- Establish machining rates for various materials and processes.

- Find safety limits for various explosives. These studies will investigate safely cutting explosives as a function of parameters such as power density, laser pulse length, materials being cut, chamber pressure, geometry, cutting thresholds, laser rep rate, etc.

- Establish size, material or geometry limits, if any.

Figure 3 shows a cartoon representation of the laser and a picture of a similar laser that has been constructed for use at Y-12, Oak Ridge National Laboratory.

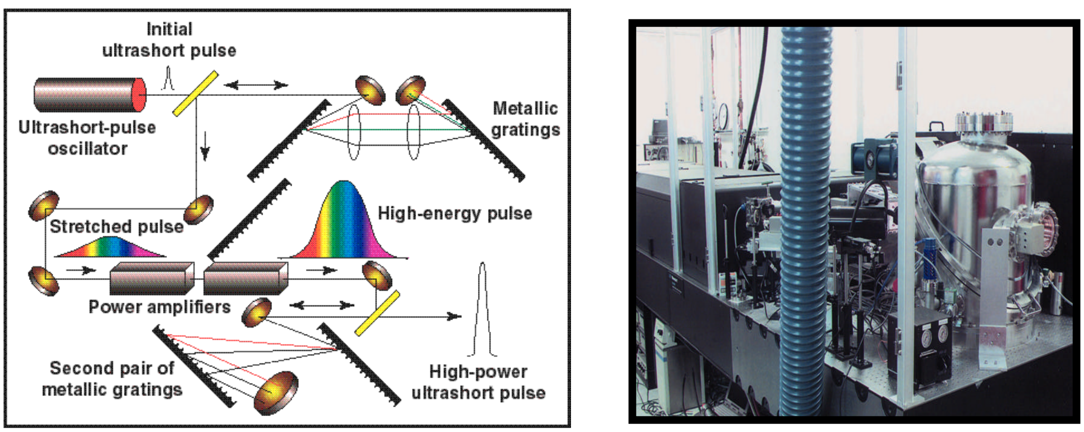

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Figure 3. a) Cartoon of the operation of the femtosecond laser. b) A similar laser that has been constructed for use at Y-12, Oak Ridge National Laboratory.

In parallel with the laser construction, a laboratory (figure 4, 1711 A) is being prepared in the explosive work area of building 191. This lab will house the laser and associated support and diagnostic equipment necessary to run the laser and conduct experiments. An explosive work area (1711B) located adjacent to the lab will provide an efficient area for sample preparation and study after the cutting has taken place

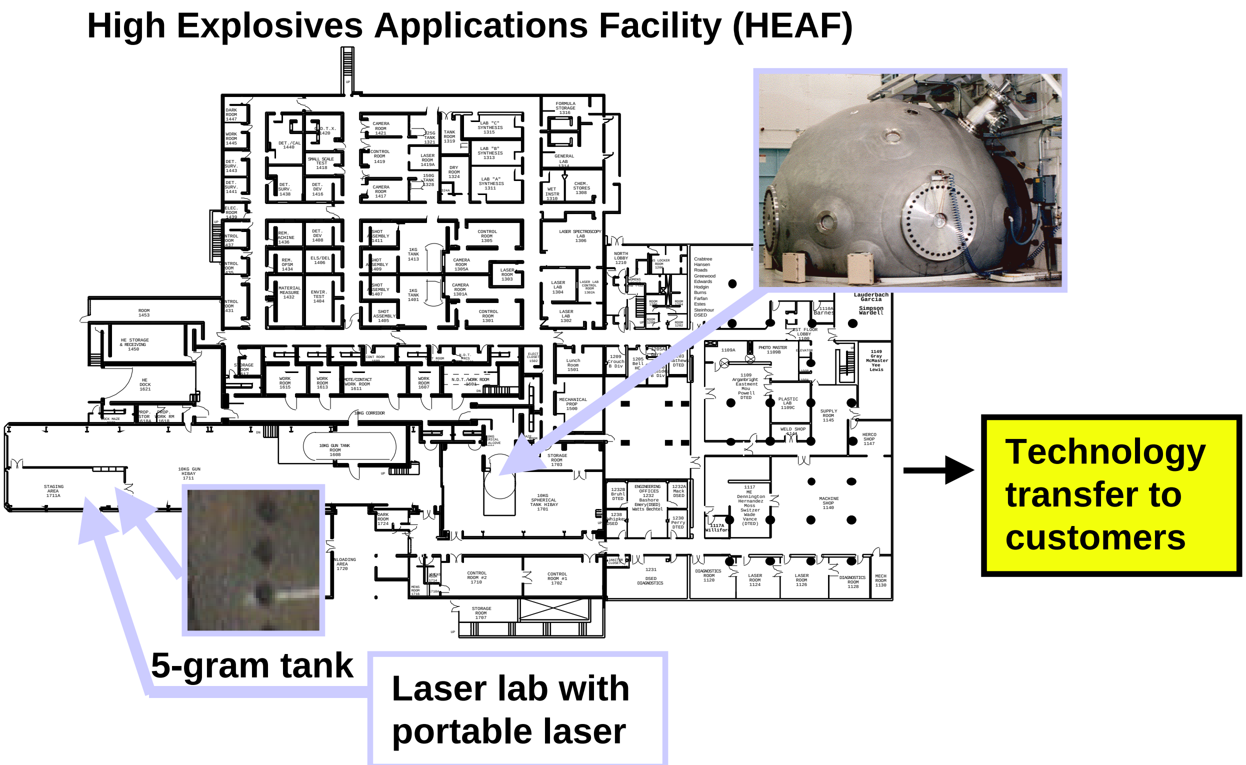

Figure 4. The laser will be housed in a laser laboratory in HEAF where we will be able to do test on energetic material up to 10 kg.

The cutting chamber for the laser laboratory will be a modified existing tank shown in figure 5. This tank, when modified, will be rated at 5 gms of explosive while laser personnel work in the area. This is a 10 times improvement over the limits we were forced to work with in building 298. In addition the tank is much larger and will allow us to cut more efficiently by installing the appropriate plume collection equipment in the tank, thus protecting our windows from attaining a coating of condensed material from the cutting process. We need to do some work to determine the optimum method to do this. We are currently considering apertures, magnets, electrostatic fields, differential pumping or a combination of the above. The tank must be reconfigured, tested and approved by the explosive safety team at HEAF.

Also shown in figure 4 is the 10 kg tank located about 50 meters from the femtosecond laser lab. This is where we intend to cut larger assemblies containing explosives up to 10 kg in weight.

The laser and laboratory construction is presently on schedule and are expected to be completed so that we can have a functional laser laboratory by the end of FY99.

To use the 10 kg tank we must convert it to a vacuum capability. Pump lines from a pump room to the tank are already in place. We have obtained a pair of pumps previously used at LLNL's Magnetic Fusion Program for use as the pumps for this tank. This is being done with LLNL funds and will save a considerable amount of money in bringing the 10 kg tank up to our specifications.

Future Work

We will bring the 10 kg tank to vacuum capability and design a transport system to bring the laser beam into the tank and meet the explosive safety requirements. This work will continue next year with plans to have the capability to perform large-scale test in the 10 kg tank by the start of the following year.

Figure 5 summarizes the future plans over the next few years. In addition to the activities mentioned earlier in this report we plan to initiate modeling studies for the interaction of the laser plasma with the HE. Since we have not been able to make any of our samples detonate to date, the modeling may become very important in calculating where safety limits actually fall and how far away from those limits our operating parameters lie.

Finally, when we thoroughly understand the cutting capabilities and have the safe, efficient cutting parameters mapped out, we intend the transfer this technology to DOD and DOE facilities interested in using this tool on a regular basis. Our laboratory will continue to serve as a testbed for those organizations to work out specific problems and new techniques before they are implemented in a production system.

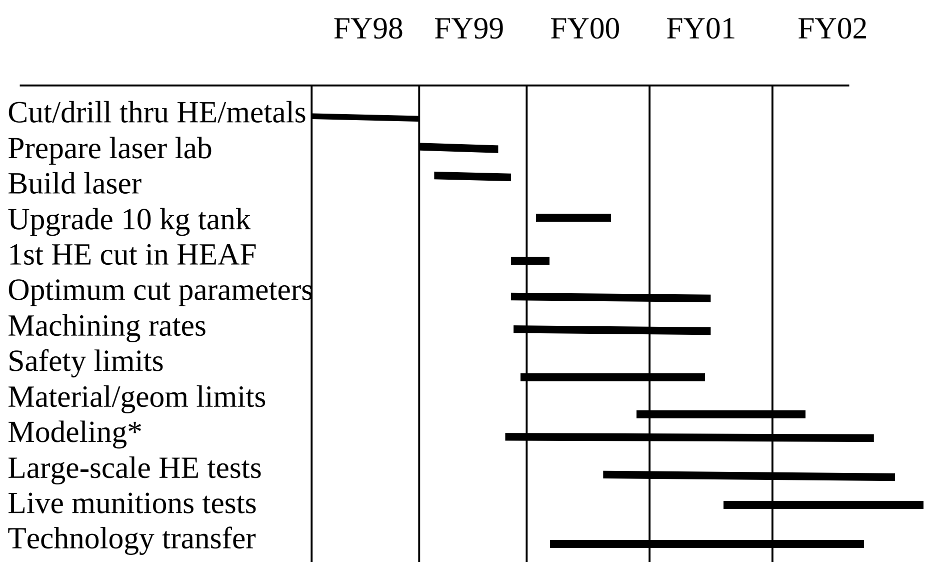

Figure 5. Future plans for femtosecond laser cutting

Conclusions

We have shown that the femtosecond laser is a viable tool for use in areas that are of importance to the DOD such as demilitarization, surveillance and the creation of new ordnance components. Femtosecond laser cutting is expected to be a technique that can be used to disassemble munitions that are difficult to disassemble by other means without safety concerns or the generation of an unacceptable waste stream. The clean, precision cut made by the femtosecond laser makes it an attractive candidate for many surveillance operations. Finally, novel new shapes of explosives which can be cut with relative ease with the femotsecond laser will make possible the development of new weapons system components.

Our initial work had proven the viability of the ultra-short, high-powered laser-cutting technique . Now we are in a phase of constructing a laboratory in an explosive work area where we can obtain good, quantitative data to optimize the cutting procedure while assuring that we are well within sensible safety margins. The new laser will be located near a 10 kg firing tank which will afford us the opportunity to cut large HE assemblies and actual ordnance. Thus the new lab will serve not only to develop the science of femtosecond cutting of explosives but also to serve as a testbed for future ideas in this area.

We have developed a workable plan to meet the goals outlined in this report and expect to have a workable system and the knowledge to transfer this technology to those facilities that have an interest in production use of this technique.

References

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