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Remote Intense Laser Acoustic Source

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Introduction: NRL is developing a novel underwater acoustic source, in which a tailored intense broadband laser pulse propagates many meters underwater and generates an acoustic pulse at a predetermined remote location. Such a new acoustic source could enable or improve several critical Navy and commercial applications, including acoustic imaging, undersea communications, and navigation. As part of this work we are exploring intense laser propagation physics through both air and water. Air propagation of the laser pulse will be useful for applications where airborne lasers generate underwater acoustic signals. Controlled underwater compression of these optical pulses is achieved using a combination of group velocity dispersion (GVD), which provides longitudinal compression, and nonlinear self-focusing (NSF), which provides transverse compression. The resulting high-intensity laser pulse then causes photoionization, intense localized heating, and shock generation.[1] Recent experiments included the first demonstration of underwater acoustic generation using an intense broadband laser pulse. Intense acoustic source levels were measured, and are in the range of useful levels for some Navy applications. Optical GVD was precisely measured, and characterization of this acoustic source, including power spectrum and radiation pattern, is under way.

Potential Applications: Several applications would make use of a high-repetition-rate pulsed laser. The repetitively pulsed laser can be steered with rapidly movable mirrors. Such a laser, which can be compact and is commercially available with appropriate bandwidth and pulse energy, could be placed on an underwater platform and used for generating phased acoustic arrays. This arrangement can also provide rapid oblique-angle acoustic scattering data for imaging and identifying underwater objects (as depicted in Fig. 5), a significant addition to traditional direct backscattering data. The ability to put the laser on an airborne platform opens many other potential applications, including undersea communications from aircraft, and navigation via remotely generated acoustic beacons. The relative strength of the GVD and NSF effects in water and air are such that a properly designed laser pulse can travel many hundreds of meters through the air relatively unchanged, then quickly compress upon entry into the water.

First Broadband Acoustic Generation Demonstrated: Using lens-assisted focusing, we recently demonstrated the first laser acoustic generation using a broadband laser pulse. The Plasma Physics Division Intense Laser Interaction Laboratory features a 10-terawatt ultrafast broadband laser, operating at a wavelength of 800 nm (deep red). This light was first converted to 400 nm (blue), which propagates underwater, using a nonlinear harmonic generation crystal. We then directed and focused this light into our newly constructed acoustic characterization chamber, shown in Fig. 6, which was outfitted with an array of high-frequency hydrophones. These hydrophones recorded intense pressure traces of the resulting acoustic pulses, a sample of which is shown in Fig. 7. Sound pressure levels (SPLs) up to 170 dB were measured, with pulse durations on the order of 1 μs, and a corresponding peak in the power spectrum near 1 MHz. We also observed strong optical dispersion in water due to rapid stretching and power reduction of the pulse during propagation, as was apparent from the narrow range of underwater propagation distances for which the water was photoionized. The relatively novel use of photoionization and shock generation in our scheme provides several orders of magnitude improvement in photo-acoustic energy conversion efficiency over previous schemes using slow laser heating and thermal expansion. Ongoing experiments aim to increase the SPL as well as increase the acoustic power at lower frequencies.

Precise GVD Measurement: A recently constructed 8-meter-long underwater laser propagation chamber, shown at right in Fig. 6, provided a path for studying long-distance underwater propagation effects, includ-

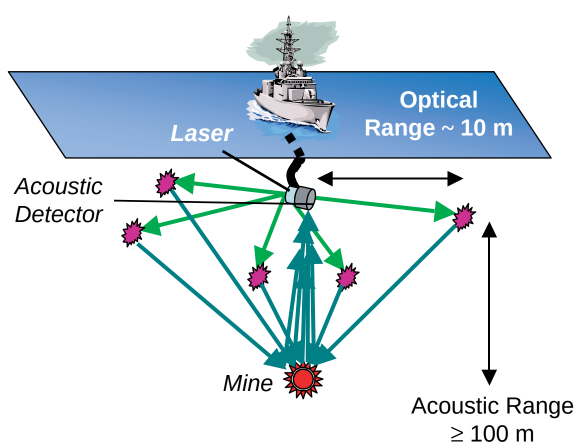

FIGURE 5
A schematic of a laser-based acoustic imaging application shows laser light (light green) propagating to predetermined acoustic generation locations (purple), and the resulting acoustic pulses propagating to and scattering from a target (blue-green).

ing GVD. A custom-tailored optical pulse with a time-varying wavelength can be longitudinally compressed at a predetermined remote location using GVD, in which different wavelengths of light propagate at different velocities. The variation in the speed of light with wavelength is characterized by the GVD parameter β_2, which governs remote optical pulse compression. After several passes through the chamber, an ultra-short, 400 nm broadband laser pulse becomes stretched in time due to the GVD-induced variation in propagation speeds of its different wavelength components. We measured the pulse length after such propagation with a 10-picosecond-resolution streak camera, yielding a value of $\beta_2 = 1.0 \times 10^{-27}$ s^2/cm, in good agreement with the calculated value. This is the first direct measurement of β_2 underwater.

Simulation: The Beam Physics Branch has several years of research experience in atmospheric propagation of intense lasers, and has developed a comprehensive laser propagation simulation code, HELCAP, to simulate the relevant physics. This code has now been adapted to simulate intense underwater propagation. Recent 3D simulations predict controlled underwater optical pulse compression. These simulations also identified a fundamental underwater propagation power limit at approximately 20 MW, due to onset of beam filamentation instabilities.

Summary: The novel underwater laser acoustic source under development at NRL provides the first laser acoustic generation at a predetermined and variable remote underwater location. A driving laser pulse can propagate through water only, or through both air and water, so that a compact laser on either an underwater or airborne platform can be used for remote acoustic generation. This source promises to open an array of potential applications for both Navy and commercial use.

[Sponsored by ONR]

References

[1] T.G. Jones, A. Ting, P. Sprangle, L.D. Bibee, and J. Peñano, "Remote Intense Laser Acoustic Source," U.S. Patent App. 11/268,400, Nov. 2005.

FIGURE 6
The transparent acrylic acoustic characterization chamber (left) provides a clear view of underwater laser-induced breakdown, and fixtures for mounting an array of hydrophones. The 8-meter-long underwater laser propagation chamber (above) allows study of intense light propagation and remote optical compression.

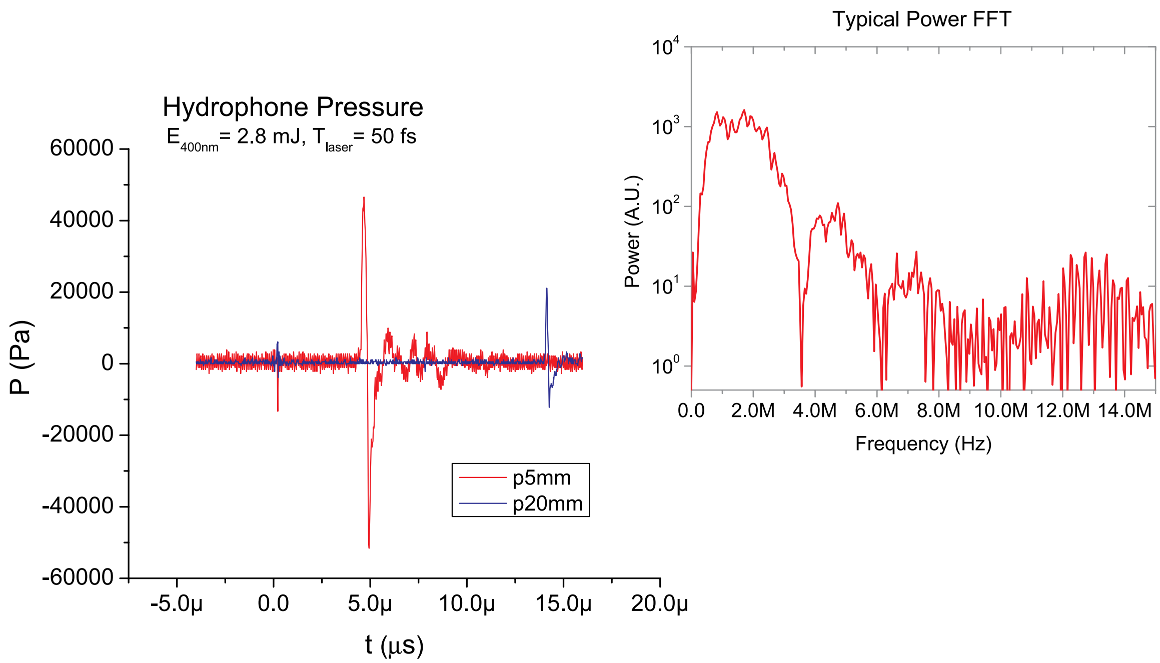

FIGURE 7
A hydrophone trace shows intense acoustic generation with modest laser pulse energy. The red trace shows the pressure evolution at 5 mm from the laser source, and the blue trace shows pressure at 20 mm. The inset shows a power spectrum of the trace at 5 mm. These NRL experiments are the first acoustic generation demonstration using broadband ultra-intense laser beams.