DARPA Seeks Ultrafast Laser technology to improve range and resolution of next generation military navigation, communication, imaging and radar systems

Defense applications, such as geo-location, navigation, communication, coherent imaging and radar, depend on the generation and transmission of stable, agile electromagnetic radiation. The Program in Ultrafast Laser Science and Engineering (PULSE) seeks to enable efficient and agile use of the entire electromagnetic spectrum by linking it to the output of an ultrafast laser. The expected outcome of the program is to develop novel sources of radiation that improve upon existing state-of-the-art performance, size, weight, and power.

The broad laser spectrum is a consequence of the Fourier-transform relationship between time and frequency, and each pulse results from the coherent superposition of many frequencies. The high-peak power results from temporal confinement of the laser energy. A laser operating with a 50-femtosecond pulse and a 100-megahertz pulse rate will have a peak power that is 200,000 times higher than a continuous-wave laser operating at the same average power.

PULSE program is developing the technological means for engineering improved spectral sources, such as ultra-fast optical lasers—advances that in turn could facilitate more efficient and agile use of the entire electromagnetic spectrum and generate improvements in existing capabilities such as geolocation, navigation, communication, coherent imaging and radar, and perhaps give rise to entirely new spectrum-dependent capabilities.

Improved radiation sources—for example, lower noise microwaves or higher flux x-rays—could enhance existing capabilities and enable entirely new technologies. Advances in ultrafast pulsed lasers operating at optical wavelengths could benefit biomedical imaging, threat detection and more: The technology could coherently link radar on Navy ships at sea, improving the systems' range and resolution, allowing them to identify more distant objects and characterize them with greater reliability; it also could be used in a tabletop x-ray imager that could image not only single cells but also the structures within, providing invaluable 3-D information to test responses to drugs and discover new treatments.

Recent PULSE demonstrations include synchronization of clocks with femtosecond precision across kilometers of turbulent atmosphere, corresponding to a 1,000-fold improvement over what is possible using conventional radio-frequency techniques, said Arati Prabhakar Director, DARPA.

“Pulse is a basic research program initially focused on component technology,” said Jamil Abo-Shaeer, program manager for Pulse. “Our primary concern isn't demonstrating a specific application, rather making these tools a reality at a practical scale by overcoming current obstacles like size and thermal management. The range of potential applications is enormous.”

In particular, PULSE aims to develop devices and techniques that will result in low phase-noise microwave oscillators, practical optical time/frequency transfer techniques, tabletop sources of high-quality secondary radiation and high flux isolated attosecond pulses, and other DOD-relevant applications.

Ultrafast Laser pulses

Lasers differ from other light sources because they emit light coherently in space and time. The photons that make up the beam are identical and move in the same direction and in phase. Spacial coherence allows the laser to be focused to a light spot. It allows a laser beam to stay very narrow over long distances thereby enabling applications such as laser pointers. Laser also have temporal coherence which allows them to have a very narrow spectrum i.e., they only emit a single color of light. Temporal coherence can also be used to produced pulses of light as short as femtoseconds (10^{-15}) and attoseconds(10^{-18}) seconds.

Ultra short femtosecond pulses are usually generated with passively mode-locked lasers, but some times also with optical parametric amplifiers (possibly using a supercontinuum as input) or with free electron lasers. It is also possible to start with longer pulses and apply some method of pulse compression.

For certain problems in present-day research, how-ever, the temporal resolution which can be attained using femtosecond lasers, is no longer sufficient, for example, when it is intended to ob-serve the motion of electrons in an atom. For this reason, physicists in a considerable number of research institutes are intensively searching for possibilities to produce light pulses of even shorter duration. Since a light pulse has to contain at least a complete vibrational cycle of the electrical field, this can be achieved only at much shorter wave-lengths than that available with the presently prevailing femtosecond lasers. A possibility to reach shorter wavelengths is offered by the generation of high harmonics of the wavelength of a femto-second laser. Using this technique, pulse durations below 100 attoseconds in a wavelength region around 15 nm can be attained at present.

For the first time ever, physicists from three continents have been able to completely measure and describe the quantum-mechanical wave function of an ionized electron by using attosecond science techniques. This breakthrough was made by physicists from the National Research Council of Canada (NRC) and the University of Ottawa in Canada, the Max-Born Institute for Nonlinear Optics and Short Pulse Spectroscopy in Germany, and Waseda University in Japan. Attosecond light pulses can profoundly change the states of matter.

“Attosecond research is still in its infancy,” says Canadian research lead Dr. David Villeneuve, Research Officer at the NRC and adjunct professor at the University of Ottawa. “It is only because of very recent developments in quantum photonics that experiments of this kind have become possible. Attosecond experiments allow us to view at the quantum level the electrons within atoms and molecules.”

Program in Ultrafast Laser Science and Engineering (PULSE)

The Program in Ultrafast Laser Science and Engineering (PULSE) seeks the technological means for such improved radiation sources. Through precise spectral engineering in the optical domain, more efficient and agile use may be made of the entire electromagnetic spectrum. By generating and engineering waves in the optical domain, where engineers already exercise exquisite stability and control, these waveforms may be down or up-converted to the desired wavelength.

The Program in Ultrafast Laser Science and Engineering (PULSE) applies the latest in pulsed laser technology to significantly improve the precision and size of atomic clocks and microwave sources, enabling more accurate time and frequency synchronization over large distances. Recent PULSE demonstrations include synchronization of clocks with femtosecond precision across kilometers of turbulent atmosphere, corresponding to a 1,000-fold improvement over what is possible using conventional radio-frequency techniques.

These capabilities are essential to fully leverage super-accurate atomic clocks, as clocks such as those that QuASAR seeks to build are more precise than our current ability to synchronize between them. If successful, PULSE technology could enable global distribution of time precise enough to take advantage of the world’s most accurate optical atomic clocks.

Defense applications, such as geo-location, navigation, communication, coherent imaging and radar, depend on the generation and transmission of stable, agile electromagnetic radiation. Improved radiation sources—for example, lower noise microwaves or higher flux x-rays—could enhance existing capabilities and enable entirely new technologies.

PULSE will also aim to apply this technology to enable synchronization, metrology and communications applications spanning the electromagnetic spectrum, from radio frequencies to x-rays. By building on established ultrafast laser techniques, PULSE seeks to:

- Develop agile, low phase-noise, portable radio frequency oscillators;
- Demonstrate techniques compatible with worldwide distribution of the world's most accurate optical clocks;
- Construct tabletop sources of coherent x-rays in the water window (3-5 nanometers); and
- Produce efficient, isolated attosecond pulses as a stroboscopic probe of electron dynamics in materials.
- Precision timing in distributed engagement and surveillance architectures

The high coherence and full time synchronization demonstrated here could enable applications from time distribution to long-baseline radio

Precision timing in distributed engagement and surveillance architectures

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The future architecture of DOD is moving towards distributed engagement and surveillance that requires synchronized timing of distributed platforms. The ability to distribute the precise time and frequency from an optical clock to remote platforms could enable future precise navigation and sensing systems. Researchers have recently demonstrated tight, real-time synchronization of a remote microwave clock to a master optical clock over a turbulent 4 km open-air path via optical two-way time–frequency transfer.

Once synchronized, the 10 GHz frequency signals generated at each site agree to 10^−14 at 1 s and below 10^−17 at 1000 seconds. In addition, the two clock times are synchronized to 13 femtosecond over an 8-hour period. The ability to phase-synchronize 10 GHz signals across platforms supports future distributed coherent sensing, while the ability to time-synchronize multiple microwave-based clocks to a high-performance master optical clock supports future precision navigation / timing systems.

One of the application is multistatic synthetic aperture radar where an array of microwave oscillators are synchronized to a single master optical oscillator; LO, local oscillator. The master site’s clock is based on a laser stabilized to an optical cavity (optical oscillator). The remote site’s clock is based on a combined quartz oscillator and DRO. This remote microwave clock is tightly synchronized to the optical clock over a folded 4 km long air path via O-TWTFT. The time and the frequency outputs from each clock are compared in a separate measurement to verify femtosecond time offsets and high phase coherence of the synchronized signals

US team lands $7M grant for attosecond laser development

The US Defense Advanced Research Projects Agency (DARPA) is funding the effort, which features researchers from the University of Central Florida (UCF), the University of Ottawa and the University of California, Berkeley.

Under program manager Jamil Abo-Shaeer at DARPA, the “program in ultrafast laser science and engineering” (PULSE) will seek to build on established ultrafast lasers to develop more accurate optical clocks, table-top sources of X-ray sources emitting at 3-5 nm wavelengths, and deliver efficient, isolated attosecond pulses as a stroboscopic probe of electron dynamics in materials.

Ultimately, thinks DARPA, the work could lead to applications in defense such as navigation and communications. “By generating and engineering waves in the optical domain, where engineers already exercise exquisite stability and control, these waveforms may be down or up-converted to the desired wavelength,” says DARPA in its project brief.

UCF’s Zenghu Chang, whose team last year produced a laser with a record-breaking pulse of just 67 attoseconds in duration, will lead the project work. Quoted in a UCF release, Chang said: “There have been a lot of new discoveries made in attosecond lasers in the last 12 years. Now an opportunity has arrived to do something that has previously only been done in principle.”

The first stage of the project will focus on building a new femtosecond laser capable of producing higher energy pulses to drive the process of attosecond pulse generation. That laser will be housed in a 2400 square-foot space at UCF.

The facility should help the US to compete with research developments that could result from the European Extreme Light Infrastructure (ELI) project – although the latter enjoys substantially more funding.

Chang will be joined by the University of Ottawa’s Paul Corkum, and Steve Leone and Dan Neumark from the University of California, Berkeley, on the project.

Attosecond physics

The attosecond pulses give scientists a new tool to view quantum mechanics in action – potentially enabling physicists to monitor some of fastest physical processes in the natural world, such as the motion of electrons and chemical reactions.

Although Chang and his team’s work on the subject has produced record-breaking results, the intensity of the attosecond pulses remains extremely weak.

“The priority is to increase the attosecond pulse energy,” he said. “At the present time, isolated attosecond pulses are so weak (nanojoules) that we have to combine them with strong femtosecond lasers to observe electron dynamics.”

Chang’s approach uses a “double optical grating” technique, and he believes that it will be possible to generate isolated attosecond pulses that are intense enough for conducting true attosecond pump/probe experiments in the future.

References and resources also include:

https://www.academia.edu/6490867/REVIEW_OF_LASER_MATTER_INTERACTION_AND_APPLICATIONS

https://www.photonics.com/Article.aspx?AID=51623

http://optics.org/news/4/8/26