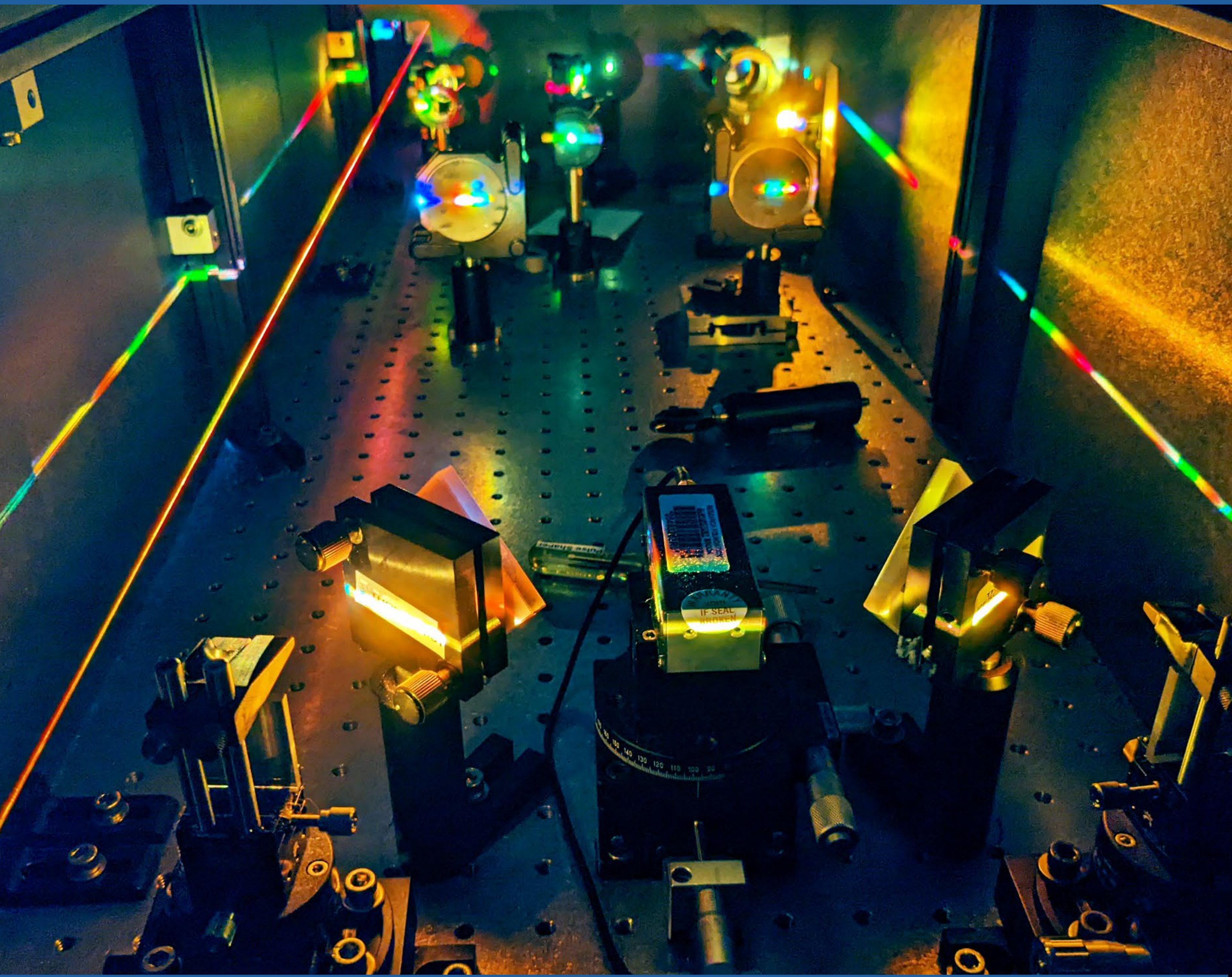
Basic Research Needs for

Laser Technology



Illuminating Tomorrow: Unraveling Laser Mysteries for Scientific Breakthroughs

Foundational Research in Laser Technology to Enable Science

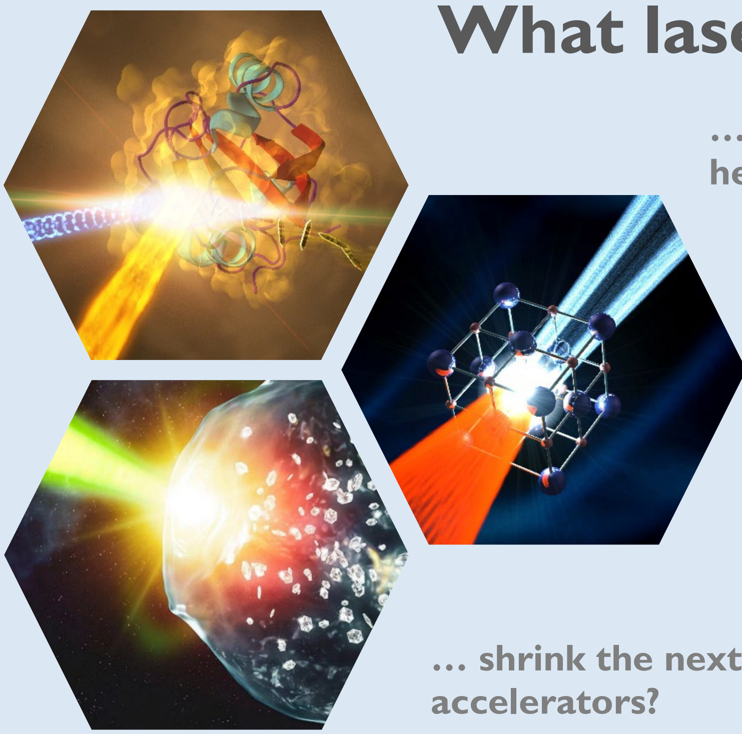
A new generation of lasers is crucial to reach the next frontier of scientific discovery.

Breakthroughs in laser technology have multiplied the intensity of focused light by more than ten billion over the last seven decades and made flashes of light so short that the motions of electrons can be seen. Scientific research has been propelled by these laser advancements which have fostered a global expansion in laser facilities and earned Nobel Prize recognitions.

However, significant advances in power, efficiency, pulse rate and precision across a vastly increased spectral range are essential for the next generation of lasers. These further advances will open new fields of science and support societal applications from health to national security.

In August 2023, experts from domestic and international universities and laboratories convened for a workshop to address Basic Research Needs for Laser Technology. The participants identified the laser needs of a wide range of science disciplines, and discussed what the lasers and laboratories of the future will look like.

The workshop participants formulated crucial research directions to advance laser technologies. The workshop full report is available at https://science.osti.gov/ardap/Resources or via the QR code.



What laser will…

… recreate the conditions at the hearts of stars and planets?

… control and probe chemical reactions?

… create matter out of vacuum?

… transform materials to gain advanced functionality?

… shrink the next generation of particle accelerators?

Priority Research Directions

Revolutionize Laser Power, Energy, and Precision Control

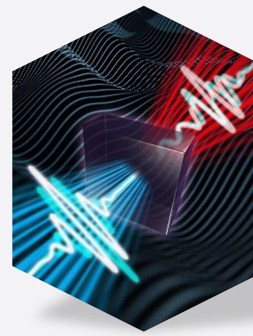
Key question: *How do we extend ultrashort pulse laser energies, average powers, and peak intensities to address ultra-intense science needs in the next decade?*

Substantial increases in ultra-intense laser energy, power, pulse rate and precision control are essential for transformative advances in creating/studying extreme physical states of matter in the universe, and in accessing new regimes of energetic particle generation. This revolution will propel fundamental science and unlock high-impact applications in medicine, advanced materials, nuclear engineering, and beyond.

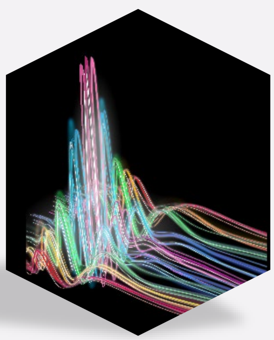
Transform Mid-Infrared Sources for Science from THz to X-Rays

Key question: *Can we meet the significant demands for high average and peak power mid-infrared science, and drive secondary sources with extreme spectral coverage?*

Infrared (IR) light plays a central role in the study of chemical reactions and material transformations either by driving vibrational motions directly or by generating light at other wavelengths that drive wide-ranging molecular and material responses. Advances in ultrashort IR pulse generation will enable dramatic improvements in our capacity to observe and control molecular and collective transformations.



Revolutionize Approaches to Frequency Conversion and Field Control



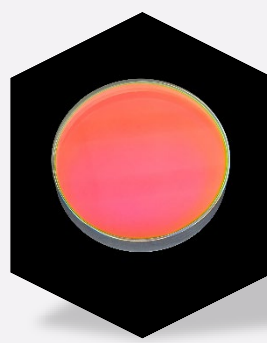
Key question: *Can we simultaneously advance and simplify laser light manipulation with wavelengths efficiently extended from the deep ultraviolet to THz ranges?*

Controlling and probing materials at the pace of the motion of their internal parts requires a wide array of laser tools, including pulses of light with wavelengths broadly covering the electromagnetic spectrum and synchronized pulsed electron beams. This requires technologies to extend the spectral range of powerful lasers and manipulate the form of the emitted light with efficiency, precision, and robustness.

Reinvent Materials and Optics for Intense Laser Science

Key question: *Can we reinvent optical materials and optical components to drastically advance ultrahigh intensity and average power laser technologies?*

Exploring new frontiers in physical sciences and laser applications necessitates reinventing laser system materials and optics. Novel designs must be explored to overcome material degradation or failure due to optical and thermal stress. Cultivating the next generation of leaders in optical materials science and engineering is an integral part of this effort.



Summary

Lasers are one of humankind's greatest tools for scientific discovery. The research directions that emerged from the workshop will steer the development of laser technologies for the next decade and beyond, paving the way for revolutionary scientific advancements.

With more powerful and intense laser systems that are able to deliver pulses at a higher rate, scientists can create and study matter in the laboratory that can only otherwise be found at the centers of stars. These lasers can also be bright sources of high-energy electrons, positrons, protons, neutrons, X-rays, and gamma rays.

New laser light wavelengths and greater control of the laser light will enable scientists to manipulate molecules and materials at an unprecedented level. New lasers will reveal the elementary events that guide photochemical reactions, probe and control quantum properties of materials down to attosecond timescales, and enable control of the electrical, magnetic, and optical properties of materials.

Optimized for reliable and robust operation as well as high performance, laser systems will be a key tool in many scientists' laboratories, large research hubs, and throughout industry, security, and medicine.

From ideas to beams:
laser innovations rely upon people and partnerships.

Training and welcoming individuals from all backgrounds into laser science is essential to ensure continued growth and breakthroughs in the field.

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