INNOVATION PARTNERSHIPS
UNIVERSITY OF MICHIGAN

Next-Generation Laser Drivers of Secondary Radiation Sources for Medical, Industrial, and EUV Lithography Applications

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Accelerate Blue Foundry - 2025 (Physical Sciences)

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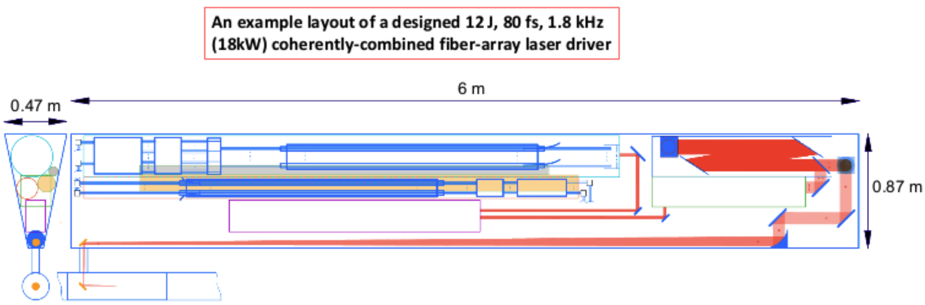
OVERVIEW

Several fiber laser technology innovations introduced and developed at the University of Michigan are enabling novel next-generation ultrashort-pulse laser drivers with orders of magnitude improved average power and efficiency, compact footprints, and robust monolithic system integration. When combined with state-of-the-art techniques developed at the Center for Ultrafast Optical Science and elsewhere, which use high-intensity laser pulses to produce so-called secondary radiation such as, for example, high energy accelerated electrons or ions, X-rays, gamma rays, and neutrons, these next generation laser drivers open access to multiple novel and transformative high-power laser applications in science, medicine, industry, national security, and defense.



DESCRIPTION

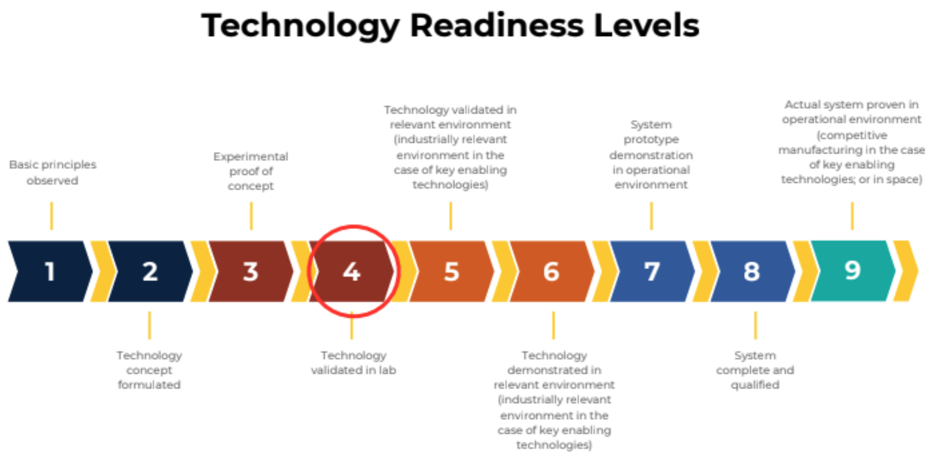
Our laser approach represents a paradigm shift in high-intensity ultrashort pulse laser technology. In conventional lasers power and energy scaling is pursued by increasing size of laser crystals, optics, and cavities, which leads to very large systems (typically occupying a large room/hall) that have limited reliability, and are susceptible to detrimental thermal effects that restrict laser operation to low average power. Our approach coherently adds multiple laser signals from a multitude of compact, monolithically integrated, and efficiently scalable to high average power individual fiber laser units. In effect, it is akin to the transition from the old vacuum tube technology to compact and efficient solid-state electronics. As a result, our innovations enable orders of magnitude increase in laser power, while shrinking the laser size down to a lab- or factory-friendly footprint, and offering unprecedented robustness and reliability of electronics-like systems.

Furthermore, the modular nature of this approach provides a high degree of flexibility in laser architecture, allowing to tailor this technological platform to serve diverse practical applications, as well as to access a wide range of powers, energies, and pulse formats. For example, this platform can be configured for high intensity femtosecond pulses for driving secondary radiation sources, or can be configured for nanosecond pulses for EUV lithography or Directed Energy.

VALUE PROPOSITION

- **Power:** Power scalable well beyond current state-of-the-art. Can provide high intensity femtosecond or nanosecond pulses with tens of joules in energy, and average power scalable to ~10kW (near-term), and 100s kW to MW power (mid-term to long-term).
- **Compact:** Achieves high energy and power levels with footprints that are at least one to two orders of magnitude smaller than current state-of-the-art.
- **Robust:** Provides high robustness and reliability achievable only with monolithically integrated systems.
- **Plug-and-Play Adaptability:** Modular design is compatible with many different laser configurations that are customizable for various pulse durations, shapes, burst formats, and energies and powers, tailoring them to the needs of a particular application.

TECHNOLOGY READINESS LEVEL



Key innovations of coherent pulse stacking amplification, and coherent spatial beam combining of high energy ultrashort fiber laser pulses have been demonstrated at high pulse energies in the lab. Currently a prototype coherently-combined 12-channel system aiming to demonstrate high power scaling potential has been built in the lab, and is in the midst of commissioning and validation experiments. Related, supplementary but important innovations of the pre-pulse cleaning have been theoretically demonstrated and now in the stage of experimental demonstration. We also had completed DARPA-funded, and currently are carrying out JDETO (Directed Energy) funded design-study programs in collaboration with Optical Engines Inc. (and Lawrence Berkeley National Laboratory), which had produced preliminary system-level design of a laser. This includes development of several components that are key for monolithic system integration.

INTELLECTUAL PROPERTY STATUS

Key patent on coherent pulse stacking has been granted (US 9,865,986). Coherent pulse synthesis, and pre-pulse cleaning are pending. There is also a related granted patent on a pulsed fiber laser configuration suitable for EUV lithography (US 8,107,167), which might be complementary to the described technology.

MARKET OPPORTUNITY

There is a critical and growing demand in a wide range of areas associated with compact particle or ion acceleration (e.g., for compact particle colliders or advanced cancer therapies), laser-driven X-ray and gamma-ray sources (for advanced medical imaging, cancer therapies, and nuclear spectroscopy for new materials development or homeland security), and high-precision industrial materials processing, that need ultra-short high-energy and high power laser pulses. This technology enables the next generation of high-intensity lasers to operate at much higher powers and energies, and be built in a much more practical (compact, reliable, and cost-effective) fashion, thus fulfilling that need.

Globally, the laser market for high-energy scientific and industrial systems is expected to surpass $20B by 2030, with short and ultrashort pulse formats, high efficiency, and high average power among the top design requirements for growth. Our laser platform serves a wide range of existing, or completely new game-changing market opportunities. Some possible new-market entry points could be, for example, a laser-driven neutron source for medical radionuclide production, which would replace a need for medical facilities to be in a close proximity of an accelerator facility or a nuclear reactor. Another example of a possible existing-market entry point could be a replacement of existing CO2 laser drivers in EUV lithography, which currently are very inefficient and cumbersome/large size facilities. Our coherently-combined, modular fiber laser architecture could provide an order-of-magnitude more efficient, more power scalable, much more compact, and cost-effective alternative.

REFERENCES

- "Near-complete extraction of maximum stored energy from large-core fibers using coherent pulse stacking amplification of femtosecond pulses"
- "Near-complete extraction of maximum stored energy from large-core fibers using coherent pulse stacking amplification of femtosecond pulses: **supplement**"