PRESS RELEASE

Joint project PriFUSIO explores technological paths to commercialize inertial fusion

New foundation for laser fusion research

Boost for Inertial Fusion Energy (IFE) in Germany: The PriFUSIO research project aims to systematically develop key technologies for climate-neutral fusion power plants of the future. The consortium, led by the ILT in Aachen, brings together fusion start-ups, medium-sized companies, large corporations, the Laser Zentrum Hannover, and the Fraunhofer Institutes IOF in Jena and ILT in Aachen, creating a diverse collaboration of industry and public research institutions. The project will focus on principles for targeted component development and explore practical photonic approaches for the commercial utilization of laser-driven IFE. The Federal Ministry of Education and Research has allocated 18 million euros for the project over the next three years.

For decades, fusion research has pursued the goal of making energy from nuclear fusion available around the clock. In the Unites States, researchers at the Lawrence Livermore National Laboratory at the National Ignition Facility achieved a significant breakthrough: tapping the sun's energy source using laser-driven inertial confinement fusion on Earth. On December 5, 2022, they succeeded in igniting a fusion plasma using high-energy lasers. Since then, they have repeated the experiment several times, proving that the physics of ignition and self-sustaining combustion of a fuel mixture of the hydrogen isotopes deuterium and tritium can be controlled. The nuclear fusion reaction is triggered by directing energy through focused laser beams, which are generated by large high-energy lasers, such as those used in the NIF facility, which spans three soccer fields in size.

This significant achievement in fusion research has the potential to open doors towards a clean and reliable energy source. If it can be economically feasible, IFE holds the promise of providing mankind with an abundant and carbon-free energy source. Fusion is achieved by using small pellets containing light atomic nuclei, such as deuterium and tritium, and igniting them with ultraenergetic laser pulses. This process causes the nuclei to fuse into helium, releasing energy due to the mass difference between the resulting helium nucleus and the combined mass of the original nuclei. For example, one gram of fusion fuel can generate as much energy as burning eleven tons of hard coal. Fusion is very different from conventional fission plants: Unlike conventional fission plants, fusion does not generate long-lived radioactive waste that necessitates geological storage, and it completely eliminates the risk of nuclear meltdowns.

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PriFUSIO network joins forces to research basic technologies

Nevertheless, for fusion power plants to become viable, numerous key technologies must still advance to maturity. The German industry is well positioned for the development of these technologies, owing to its market-leading status in the laser and optical technology sector. In doing so, it has the potential to generate substantial value in this visionary field for Germany. This is precisely where PriFUSIO comes into play. The consortium, comprising seven industrial partners and three research institutes, aims to investigate pivotal photonic components for laser-driven fusion and facilitate their integration into industrial applications. The Federal Ministry of Education and Research (BMBF) will provide funding of 18 million euros for their project over the next three years. It is part of the "Fusion 2040 – Research towards the fusion power plant" funding program. The German government will invest up to five billion euros in this program. The objective is for Germany to become one of the pioneering nations in the world to develop fusion technologies and construct a fusion power plant.

"We want to build a fusion ecosystem of industry, start-ups and R&D that pools existing strengths and creates synergies between the various players," said Bettina Stark-Watzinger, Federal Minister of Education and Research, when the program was announced. "We must not miss this huge opportunity – especially when we consider our growth and prosperity." The excellent research landscape and strong industry offer excellent conditions for this.

Tackling challenges with determination

There are a number of challenges on the path to commercial use of IFE technology. These include the development of powerful, reliable and cost-effective laser sources and optics as well as automated solutions for fuel supply and the efficient use of the waste heat generated. With its primary focus on fundamental plasma experiments rather than energy generation research, the National Ignition Facility fires only a few shots per day. For a power plant, a laser system is needed that can generate roughly the same amount of energy but can repetitively fire it more than ten times per second. To accomplish this goal, it is necessary to enhance their average power by at least 5 times five orders of magnitude (500,000 times) in comparison to the NIF laser system.

PriFUSIO will primarily research fundamental questions on how to develop the next generation of high-power lasers suitable for power plants, lasers that compress the millimeter-sized fuel pellets and ignite fusion at temperatures of over 100 million degrees Celsius. On the one hand, this means that laser beams must be generated and manipulated at high energy levels and with unprecedented power. On the other, resulting plasma must be controlled completely in order to harness the fusion energy released. The power required places extremely high demands on the materials, the engineering and the highly complex optical system.

Wanted: Materials for efficient high-energy lasers and resilient optics

The consortium includes Focused Energy GmbH and Marvel Fusion GmbH, two German start-ups that are working on different technological paths towards the commercial use of IFE technology. They are formulating requirements for the necessary high-power lasers, from which the Fraunhofer Institutes for Laser Technology ILT in Aachen and for Applied Optics and Precision Engineering IOF in Jena are deriving the specific research and development required to implement these specifications. "The performance and efficiency of the high-power lasers depend directly on the properties of the optical components used," explains Hans-Dieter Hoffmann, head of the Lasers and Optical Systems department at the Fraunhofer ILT.

For this reason, not only are leading suppliers of optical glass and coating materials, Schott AG and the Heraeus Group, represented in the project, but also highly specialized medium-sized companies from the field of processing and coating optical components, LAYERTEC GmbH from Mellingen and LASEROPTIK GmbH from Garbsen. TRUMPF Laser AG contributes its expertise in the field of complex high-power lasers.

Comprehensive expertise along the process chain

"PriFUSIO will bring together the expertise of the partners along the process chain," explains Hoffmann. The aim of the project is to develop precisely coated high-end optics that can permanently meet the performance requirements in IFE reactors. Laser-induced damage threshold tests conducted at the Laser Zentrum Hannover e.V. (LZH) will serve as benchmark to support this.

According to Hoffmann, one technical challenge in IFE power plants is the use of large-area optical elements whose optical properties must remain stable despite operating with high energies and high average power. Although the absorption of the laser energy – and therefore the heating of the optics – can be minimized through the material properties and coatings, heat must be dissipated efficiently. It is also important to reduce costs by developing efficient machining and coating processes. "If we succeed in meeting these stringent requirements, PriFUSIO will also result in synergies for industrial lasers that go beyond the application in IFE technology," Hoffmann is convinced.

Fraunhofer Institutes contribute expertise in laser development and optics manufacturing

As part of the joint research project, Fraunhofer ILT will be working on developing computer simulations for efficient high-energy lasers and laser-based manufacturing processes for high-end optics. "We will work closely with LAYERTEC in optics production and also pursue hybrid approaches with conventional and laser-based processes," explains the ILT department head.

The Fraunhofer IOF in Jena is contributing its know-how in the field of optical gratings and thin-film deposition to the project and will also provide expertise in the multispectral and highly sensitive characterization of the absorption of optical components and their angle-dependent scattered light behavior. Among other things, this involves research into new approaches based on hybrid nano-optical layer systems for power scaling of pulse compressor gratings, which are required for fast-impedance laser systems.

To this end, IOF is investigating new materials, new grating concepts and adapted processes for the deposition of low-defect optical coatings. In addition to investigating innovative concepts for laser-resistant pulse compressor gratings, the IOF team will work closely with the LZH to investigate resistance to laser irradiation and conduct root cause analyses of damage events along the entire process chain. The findings will guide the project partners in how they can better develop optical components and optimize manufacturing processes.

Solving the heating problem

Which laser materials and optical components will be used is still open. The NIF in California uses solid-state lasers pumped with flash lamps built using neodymium-doped laser glass. Although flash-lamp-pumped lasers are cost-effective, they have weaknesses when it comes to converting electrical energy into effective laser energy. Semiconductor lasers must, therefore, be used as a pump source for the next generation of lasers in order to achieve a significant increase in laser efficiency in the ultraviolet range to values above ten percent. The investigation will also consider the use of ceramic or crystalline materials as a laser medium. These materials allow for new architectures and more efficient cooling, as they possess better thermal conductivity compared to glass that is used in NIF.

In contrast to the research facility NIF, power plant operation will require ten to twenty laser pulses per second. "The key determining factor in this case will be the effectiveness of dissipating heat from the laser medium," explains Fraunhofer ILT researcher Hoffmann. The spectral bandwidth, low-cost production and the ability to efficiently store and retrieve energy during laser operation speak in favor of glass. However, it is unclear whether it can meet the requirement for high average power operation in a power plant. "We will investigate this in the PriFUSIO project and also clarify how feasible it is based on the comprehensive optical and materials science expertise of the project partners," he says. The objective of the research project is to shift from fundamental research to research with practical applications in mind. According to Hoffmann, the expected research results will also have a positive impact on the further development of high-energy lasers and optical components beyond laser fusion. "For this reason, PriFUSIO will help strengthen the participating industrial partners in their respective markets," he is convinced. Through active involvement in the advancement of IFE technology, German industry can seize a promising opportunity to not only enhance its knowledge and expertise in high technology but also generate positive spillover effects by accessing new markets for related technologies.

Image 1:
Fusion energy: clean and virtually inexhaustible energy source of the future.
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