RESEARCH NEWS

LASER 2025

Laser Sources of the Future: the Key to Technological Sovereignty

From manufacturing to medicine, from quantum technology to nuclear fusion — lasers are the basis for many critical applications. However, without rare-earth elements and crystals from third countries, it is becoming increasingly difficult to produce them. Not only are export restrictions, war and restrictive customs policies putting pressure on industry, but they are also threatening Germany's technological sovereignty. Fraunhofer is researching alternatives in crystal growing and processing as well as glass fiber development. They will be on display at the LASER trade show in Munich from June 24–27.

Germany's dependence on these critical raw materials became apparent once again following the customs dispute in April, when China restricted exports of rare-earth elements and other elements to the U.S. and, consequently, to Europe. The laser industry, along with other high-tech and defense companies, is also feeling the effects of the supply shortage. This is because the elements are needed for laser crystals and active laser fibers as an amplification medium to generate laser radiation, among other things. Materials worth a few hundred euros thus determine the manufacture of systems worth hundreds of thousands of euros.

"Guaranteeing the availability of adequate laser crystals and fibers and having control over their processing is vital not only for the competitiveness and independence of the German and European economies but also for our security," says Marc Eichhorn, director of the Fraunhofer Institute for Optronics, System Technologies and Image Exploitation IOSB in Ettlingen and Oberkochen. There, the Laser Technology department, headed by Christelle Kieleck, conducts research into new laser sources and improved, more powerful crystals as well as fiber-optic components as the basis for the further development of laser systems. From the simulation and design of new materials to demonstrators, the institute covers the entire value chain of laser production.

Growing and processing laser and non-linear crystals

Laser crystals are integral to every laser. They amplify light by storing optical energy at higher energy levels and, depending on their doping with certain rare-earth elements, release it as laser radiation at defined wavelengths. If there are no laser crystals available for certain wavelengths, a conversion using non-linear optical materials (NLO) is possible. Due to their optical properties, these materials can convert the wavelengths

Contact
Monika Landgraf | Fraunhofer-Gesellschaft, Munich, Germany | Communications | Phone +49 89 1205-1333 | presse@zv.fraunhofer.de
Ulrich Pontes | Fraunhofer Institute for Optronics, System Technologies and Image Exploitation IOSB | Phone +49 721 6091-300 |
Fraunhoferstrasse 1 | 76131 Karlsruhe, Germany | www.iosb.fraunhofer.de | ulrich.pontes@iosb.fraunhofer.de

(and therefore colors) of a laser beam, halving, tripling or even mixing several wavelengths. This allows the laser light to be modified in a controlled manner within a defined range, enabling stronger interaction with materials, detection of specific molecules and higher-resolution microscopy. Applications involving laser radiation that can damage the eyes, such as distance measurements, can be shifted to harmless wavelength ranges using NLO. These sources therefore enable new applications in medical technology, environmental analysis and defense.

For both laser and NLO crystals, the quality of the available crystals has often been a limiting factor. After all, not all crystals are the same: “In addition to the doping, the optical quality and absorption as well as the thermal conductivity and polarization properties of the crystals play a decisive role in their performance,” says Eichhorn. This can result in temperature differences within the crystal at higher performance levels, which negatively affects efficiency and beam quality. That is why growing and processing laser crystals is truly a science in itself. “A great deal of expertise is required. Many processes cannot be automated,” adds Kieleck. “Raw crystals have to be cut, ground, polished, coated or microstructured. This particular processing method is crucial in ensuring efficiency and resilience. That's why we need to maintain and expand this process knowledge so that we can continue to develop the technology further.”

The researchers first simulate the composition of the crystals by gradually varying the degree of doping and the growing conditions to improve their properties. They are then grown in special furnaces and examined using X-ray diffraction. High pressures and safety requirements pose a challenge to the production process. In the laboratory, the optical components are then sawed out of the crystals, further processed using specific methods and polished. One aim is to use certain processes to increase the damage threshold, i.e, the robustness of the crystal when exposed to laser radiation. To achieve this, the researchers at Fraunhofer IOSB have set up a new test stand that uses the latest measurement technology to determine optical damage thresholds. Finally, the sources are tested in laser systems, which in turn are optimized according to crystal quality and geometry.

Glass fiber research for customized optical fibers

In addition to crystals and NLO materials, the researchers are also developing active laser fibers and new fiber components for specific applications — from material processing to laser surgery. The focus here is on the short-wave and mid-infrared spectrum. To generate laser radiation in fiber lasers, in which the doped core of a glass fiber serves as the active medium, the researchers are focusing on rare-earth-doped quartz glass fibers and fluoride laser fibers. “At our new location in Oberkochen, we will produce customized and robust high-performance fibers for lasers with low volume, weight and energy requirements in-house,” says Kieleck.

Fraunhofer IOSB will be presenting its crystals, non-linear optics, damage threshold measurement technology and fiber lasers at the LASER trade show in Munich, Hall A2, Booth 415, from June 24 to 27.

Fig. 1 Various oxide laser crystals with different active dopants (rare-earth elements and transition metals).

© Fraunhofer IOSB / indigo

Fig. 2 Octagonal fiber preform, glass gobs from the beginning of the fiber drawing process and active laser fiber on carrier roller.

© Fraunhofer IOSB / indigo