Fraunhofer IZM

Press Release

ISABELLA

Scalable laser system enables optical atomic clocks for a wide range of applications

In the future, optical atomic clocks are expected to measure time 40,000 times more accurately than established atomic clocks. As part of the ISABELLA project, a consortium of industry and research partners has demonstrated key technologies for miniaturizing laser systems for this type of atomic clocks. These developments offer a wide range of benefits to science - from climate research to the verification of physical constants.

Microwave atomic clocks are currently the international standard for time measurement. They measure the number of oscillations of a cesium atom using microwaves and use this as a reference for the duration of a second. This forms the basis for Coordinated Universal Time (UTC), which is indispensable in many fields, such as meteorology, satellite navigation, mobile communications, and the stock market. However, with ever-faster communication standards, atomic clocks are reaching the limits of their accuracy.

Using visible red light and strontium atoms allows for the measurement of even higher frequencies, enabling the second to be defined with an precision that is more than 40,000 times greater. This benefits not only the globally relevant reference time but also research. However, setups that bring this concept to life are currently only found in specialized laboratories. Existing solutions are too bulky.

Advanced technologies in a compact system

The ISABELLA project, which concluded in 2025, was a major step toward an industrially viable optical atomic clock. The consortium of industry and research partners developed components for a laser system as small as a matchbox, making it ten times more compact than current laboratory systems. This could enable the operation of optical atomic clocks even for non-stationary applications, such as in satellites.

The individual components, such as semiconductors and the resonator, were manufactured by the project partners and finally assembled. The Fraunhofer Institute for Reliability and Microintegration IZM developed the heart of the laser: a periodically modulated, glass-based waveguide that can be used to control a specific frequency range of the laser. Scientist Dr. Wojciech Lewoczko-Adamczyk explains: “We write onto a waveguide a grating that reflects only the desired wavelength back into the laser, where it is amplified until only this portion of

the light passes through. This so-called Bragg grating was written into the waveguide with high precision at a period of 2 micrometer."

Prospects for Science

The embedding of the grating into the waveguide represents a significant step toward fully integrated laser systems for optical atomic clocks. The laser beams serve as a cooling medium and trap for the atoms, as well as a counter for atomic oscillations. However, further efforts are required to develop a complete optical atomic clock in a matchbox-sized format.

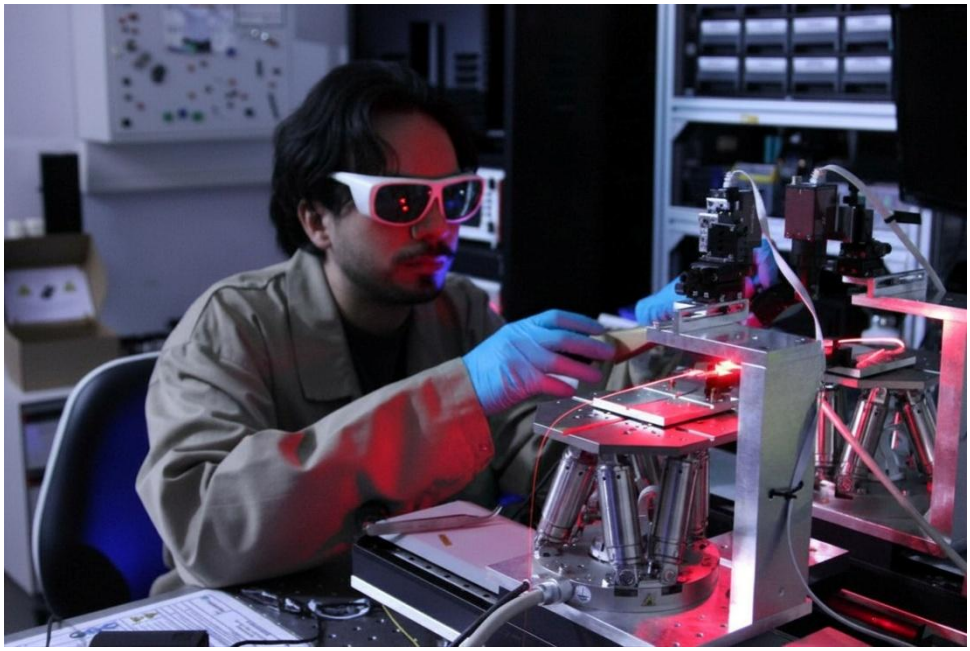
Once completed, these compact clocks would also be of interest to the scientific community. Comparative measurements with two ultra-precise clocks could aid in determining physical constants or enable precise geodetic measurements, for example to observe plate tectonics.

There is also a learning effect from ISABELLA for the project participants.. As Lewoczko-Adamczyk says: "We have made significant progress in our waveguide technology, enabling it to be used with visible wavelengths. This will advance our research even beyond the scope of the project."

About the ISABELLA Project

The ISABELLA project, short for "Hybrid-Integrated and Frequency-Stabilized Lasers for Reliable Manipulation of Ultracold Atoms for Transportable Systems", was carried out from 2022 to 2025. The project consortium consists of representatives from industry and research. Participants in the project included Sacher Lasertechnik GmbH in a coordinating role, sensor photonics GmbH, VACOM Vakuum Komponenten & Messtechnik GmbH, the Fraunhofer Institute for Reliability and Microintegration IZM, and Heinrich Heine University Düsseldorf with its Faculty of Mathematics and Natural Sciences and the Institute of Experimental Physics. As part of the "Enabling Technologies for Quantum Technologies" program, the project received support and funding from the Federal Ministry of Research, Technology, and Space (grant number 13N16060).

(Text: Steffen Schindler)



ISABELLA represents a significant step toward the development of a compact optical atomic clock. To do this, student researcher Carlos Gomez is conducting measurements on the optical properties of a glass-based photonic chip at Fraunhofer IZM. | Color image in print quality: www.izm.fraunhofer.de/pics

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The **Fraunhofer Institute for Reliability and Microintegration IZM** is one of the world's premier research institutions for electronics packaging. With its dedication to developing miniaturized, high-reliability electronics in cutting-edge lab facilities, the institute works to maintain the competitive edge of Germany and Europe.