ISABELLA

Compact and Frequency-Stabilised Laser Systems for Transportable Quantum Technologies

Optical atomic clocks and other quantum technologies require lasers whose frequencies can be set and stabilised with exceptional precision. To enable these systems to operate outside specialised laboratories, their laser sources must also be compact, robust and reproducibly manufactured. The ISABELLA collaborative research project addressed these requirements. Sacher Lasertechnik developed narrow-linewidth laser systems, methods for stabilising multiple lasers to a shared frequency reference, and semi-automated assembly processes to support future scalable production.

Project at a glance

- **Collaborative project:** Hybrid-Integrated and Frequency-Stabilised Lasers for Reliable Manipulation of Ultracold Atoms in Transportable Systems
- **Acronym:** ISABELLA
- **Project duration:** 1 January 2022 to 31 December 2025
- **Sacher Lasertechnik subproject:** Robust, Narrow-Linewidth, High-Power External Cavity Laser Systems and Laser Amplifiers with Linewidth Reduction for Quantum Technologies
- **Funding reference:** 13N16057

Objectives and Approach

Precise control of ultracold atoms requires multiple lasers operating at different wavelengths. Alongside sufficient optical power, narrow spectral linewidth and reliable frequency stabilisation are essential. Conventional laboratory setups are often complex and require extensive alignment.

ISABELLA therefore aimed to combine compact laser sources with a shared optical frequency reference. During the project, work focused on the wavelengths of 689 and 813 nanometres, which are particularly relevant to strontium atomic clocks. The 689-nanometre laser provides the second stage of laser cooling. The 813-nanometre laser generates the optical lattice that traps the atoms.

Sacher Lasertechnik's Contribution

Sacher Lasertechnik developed and characterised external cavity lasers, associated amplifiers, and laser drive and control systems. An optimised cavity design incorporating a narrowband volume Bragg grating enabled an intrinsic linewidth of less than one kilohertz at 813 nanometres. This established an essential prerequisite for precise frequency stabilisation.

For shared stabilisation, both lasers were coupled to a highly stable reference cavity using fibre-optic components. An FPGA-based digital controller processes the respective error signals and corrects the laser frequencies independently. The demonstrator successfully stabilised both lasers simultaneously to the same reference cavity.

Manufacturing technology was another key focus. Together with Nanosystec, an assembly robot was qualified for building miniaturised lasers. The system actively aligns micro-optical components, monitors optical power and secures the components using UV adhesive bonding. This enables sensitive alignment steps to be performed semi-automatically and reproducibly.

Results and Outlook

The 689-nanometre laser system achieved a fibre output power of 50 milliwatts. At 813 nanometres, a fibre output power of 1.5 watts was achieved using a subsequent amplifier. Both systems provide a tuning range of three gigahertz. Together with the demonstrated intrinsic linewidth below one kilohertz at 813 nanometres and simultaneous stabilisation to a shared reference cavity, these results provide a foundation for further system development.

ISABELLA thus established important prerequisites for compact laser sources in transportable optical clocks. The cavity designs, control methods and assembly processes developed also offer potential for atom interferometry, precision spectroscopy and other applications involving cold atoms. Semi-automated manufacturing additionally provides a path towards higher production volumes and more cost-effective manufacturing of future laser systems.