Ultra-stable laser system for metrology and fundamental physics

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Ultra-stable lasers play a crucial role in time and frequency metrology. They are an essential element of optical atomic clocks and stable frequency generation, but today, they are also important in fundamental physics studies[1]. Here we present a network of ultra-stable lasers for all applications.

The network consists of an ultra-stable laser devoted to a strontium optical clock line at 698 nm, a dual-wavelength optical cavity[2] (1064 and 908 nm) designed for two clock lines in mercury clock (266 and 227 nm after quadrupling frequency), two ultra-stable lasers and cavity systems serving as a global flywheel in the system and in fibre dissemination (operating at 1542 nm)[3], and optical frequency comb combing all elements together.

The strontium clock line laser locked to a 10 cm ULE cavity alone would limit our strontium clock stability. Within the presented network, the performance of this laser is improved by feedback form a much more stable laser operating at 1542 nm. At the same time, the strontium clock line laser allows for absolute frequency determination in the whole network. The dual-wavelength optical cavity and laser system for mercury atoms are designed for fundamental physics studies, for instance, for measurements of the King plot between two clock lines and several isotopes of ultra-cold Hg atoms[4], which pave the way for experimental verification of the Standard Model[5]. Two additional ultra-stable lasers operating at 1542 nm serve in the network as a flywheel, allowing for continuous operation and fibre dissemination of the ultra-stable frequency signal. One of the 1542 nm lasers is designed for the best short-term stability and is locked to a cavity with a 30 cm ULE spacer and crystalline mirrors, surrounded by many layers of passive temperature isolation.

Another possible improvements will be discussed, such as implementing large spot sizes of laser light on the cavity mirrors, using an active vibration cancellation system at a low-frequency range with accelerometers and a seismometer, and using nexcera material for the cavity spacer in a cavity designed for long-term stability. The whole network is connected with an optical frequency comb allowing for stability transfer between different wavelengths. Moreover, the output of this network is delivered through a dedicated and stabilized fibre system around Poland.

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