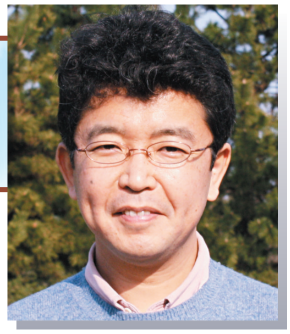
Science & Engineering

Ultra-precise time measurement with optical lattice clocks



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【Background】

One second in the International System of Units (SI second) was defined using the microwave transition frequency of a cesium atom in 1967. The 15-digit level uncertainty of an SI second is the global standard. Seeking for better time and frequency references, researchers began to work on developing more accurate optical atom clocks based on optical transitions of atoms around 1980. A single ion clock was initially considered to be a promising candidate for an optical atom clock. It is ideal as it can prevent not only interaction among atoms but also changes in frequency introduced by the atomic trap. But in the late 1990s, researchers began to debate as a realistic problem the limits of the clock's quantum projection noise, which stems from measurements of single ions.

【Results】

In 2001, our research group proposed a new atomic clock idea based on optical lattices created by standing waves of light tuned to the magic wavelength, which can avoid a frequency shift caused by an atomic trap generated with light (Fig. 2). In this optical lattice clock, about 1 million atoms can be observed simultaneously, while the lattice potentials reduce atomic interactions by arraying atoms in a three-dimensional lattice with an interval of microns between them. As a result, quantum projection noise limited stability, the drawback of the single ion clock, was expected to drastically improve. We demonstrated the usefulness of this method for the first time in the world in 2001-2003. In 2008, our team developed and operated two optical lattice clocks simultaneously. We achieved a mutual comparison of the two clocks more accurately than that realized by an SI second. Optical lattice clocks are now under development at research institutes in Japan, the US, France and other countries. They realized international comparisons of optical lattice clocks at the uncertainty of the realization of an SI second. In 2006, the Comité International des Poids et Mesures (CIPM) adopted as one of the “secondary representations of a second” a strontium atom-based optical lattice clock that is a favorite candidate for next-generation atomic clocks. The committee may redefine the second with such a clock.

【Outlook】

Highly accurate atomic clocks have a significant engineering impact such as improvement in accuracy of the Global Positioning System (GPS). They will also be very instrumental in precise verification of quantum mechanics and the theory of relativity by raising the measurement accuracy; testing the constancy of the fundamental physical constants is one of such challenging topics. At uncertainty of the 18-digit level that optical atomic clocks are expected to achieve in the near future, the only last digit of time changes due to a gravity shift corresponding to a height difference of 1 cm near the earth surface as predicted by the general theory of relativity. In remote comparison of highly accurate atomic clocks, the clocks are probes that shed light on time-space curved by gravity. We believe that such highly accurate clocks will have new applications, including searching for natural resources in the ground and detecting movements of the earth's crust.

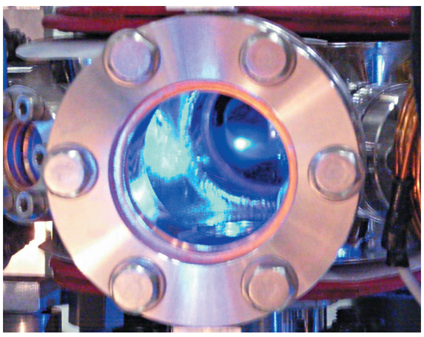

Fig. 1 Millions of laser-cooled strontium atoms that are the heart of an optical lattice clock

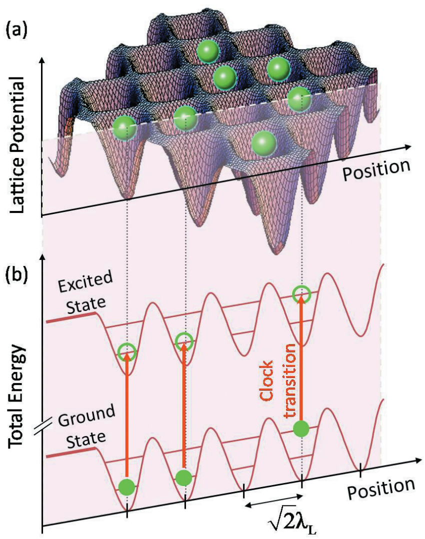

Fig. 2 Conceptual illustration of optical lattice clock Atoms are spatially isolated with the barrier of the optical lattice (a). By equalizing the potential barrier height in the excited and ground state of atoms, the energy shift arising from the lattice is canceled out (b) in the atomic clock transition.

Related Grants-in-Aid for Scientific Research:
FY2002-2003 Grant-in-Aid for Young Scientists (A): “Research on ultra-accurate optical frequency standards of strontium atom with optical lattice clock”