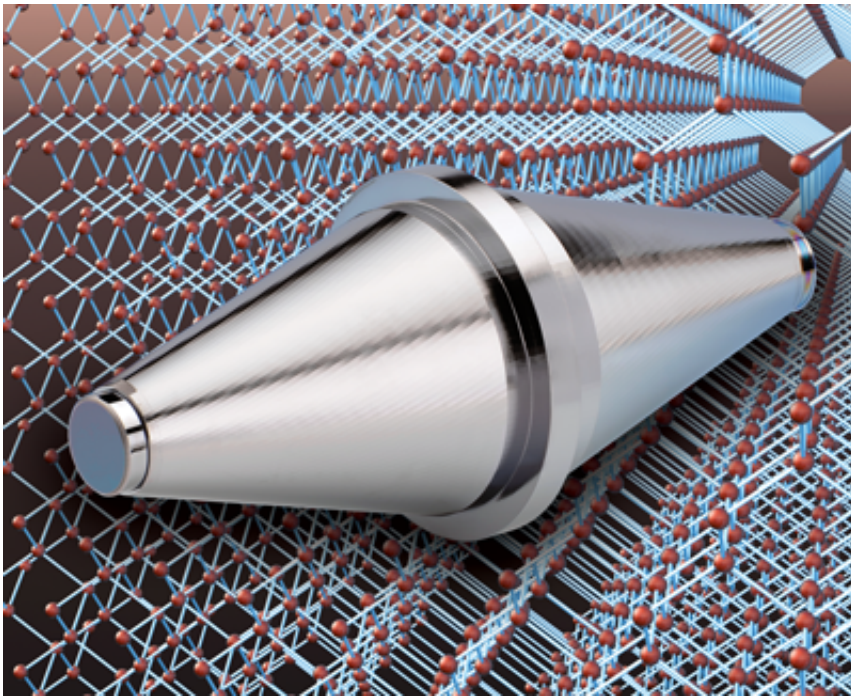


The world's most stable laser also promises heightened test precision

September 11 2012, by Jun Ye



(Phys.org)—The world's most stable laser – with frequency variation of no more than 2 parts in 10,000 trillion – has been developed and tested by an international collaboration of scientists at NIST/JILA in Boulder, CO and a group at Physikalisch-Technische Bundesanstalt (PTB), the German counterpart of NIST.

The work, reported in advance on-line publication in *Nature Photonics*,

represents a new approach for constructing high-quality optical cavities that will bring more than an order of magnitude improvement over prior designs. In particular, it will accelerate progress in development of optical clocks, which operate at frequencies more than 10,000 times higher than the approximately 9.2 GHz microwaves used as the basis of the current worldwide time standard.

In addition, the novel [laser design](#) is expected to usher in a new level of precision to research in gravitational wave detection on Earth and in space, and precision tests of relativity as well as fundamental physics research in cavity quantum electrodynamics and quantum optomechanics.

"The previous stability limit of about 2×10^{-16} was good," says study co-author Jun Ye of JILA and PML's Quantum Physics Division. "But it prevented us from exploring the full potential of modern optical [atomic clocks](#) where the atomic coherence time can be exceedingly long. The potential of pushing the laser stability better by an order of magnitude will allow us to realize atomic clocks that have unprecedented stability approaching 1×10^{-17} over 1 second.

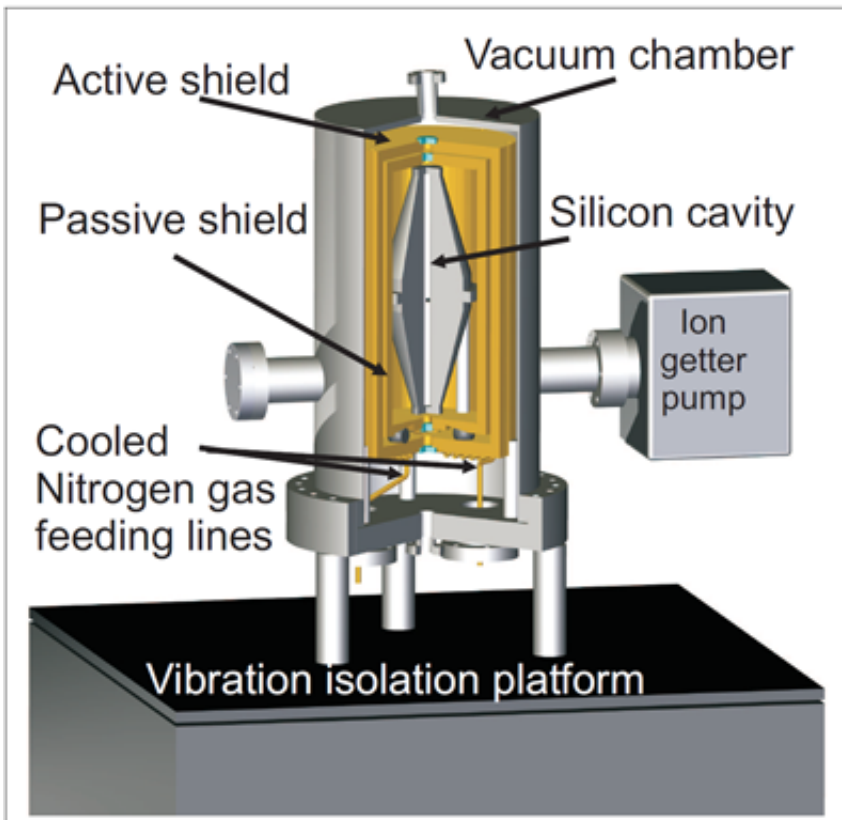
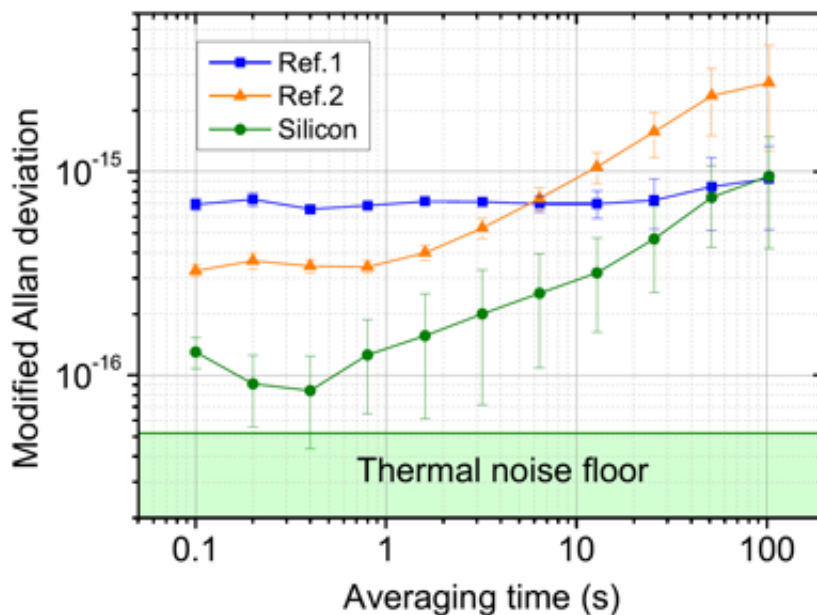


Diagram of the device interior. Credit: Thomas Kessler

"It will also have a dramatic impact on large-scale precision measurement instruments such as space-borne optical interferometers for gravitational-wave detection with baselines of many thousands of kilometers. And it may be of intense interest to the communications industry, since our system was tested at a familiar telecom wavelength of 1.5 micrometers." That is the wavelength with the lowest loss in fiber-optic networks.

Research on ultra-stable lasers typically employs some kind of optical-cavity interferometer, comprising a spacer with mirrors at each end. That design severely restricts the range of optical frequency which can resonate in the cavity. By superimposing the cavity output beam on

another highly controlled reference beam, the interference effects (periodic reinforcement "beats") can reveal stability with exquisite sensitivity. Such systems, however, have historically been subject to thermal fluctuations that alter the cavity dimensions, and hence reduce frequency stability.



Graph comparing average instability over time of the new design (green) to two ultra-stable ULE units: Ref. 1 (blue), a PTB laser, and Ref. 2 (orange), a JILA laser.

"We addressed that problem in several ways," says Ye, who began to collaborate on the project in 2007 while visiting PTB in Germany on a grant from the Alexander von Humboldt Foundation. The German team was headed by Uwe Sterr and Fritz Riehle. Ye also recruited a student, Michael Martin, and a visitor in his lab, Lisheng Chen. "By far the most significant factor was our decision to substitute single-crystal silicon for the ultralow expansion glass (ULE) or fused silica customarily employed

in the cavity mirrors and spacers."

Single-crystal silicon has a coefficient of thermal expansion that approaches zero at 124 K, "so an all-silicon interferometer can be made insensitive to temperature fluctuations" at that point, the authors write in [Nature Photonics](#). In addition, at 124 K the crystal has a much lower mechanical loss compared to conventional optical glass, and a much higher Young's modulus. Both mechanical properties combine to minimize the fundamental thermal fluctuations. The group used extensive computer modeling to create a design that reduced the effects of environmental vibrations on the 21 cm long resonator, which they mounted in a vertical configuration after testing its response to external forces in all three dimensions.

Finally, the German researchers devised a novel and simple cryostat design using evaporated liquid nitrogen gas as the coolant. The gas flows through superinsulated vacuum tubes to an outer heat shield, and careful control of the flow limits temperature deviations in the system to about 1 mK from the 124 K target.

The new all-silicon unit was tested for 24 hours against two of the best-performing conventional ULE-based optical cavity-stabilized lasers – one from [JILA](#) and one from PTB, with thermal noise variation in the range of 6×10^{-16} and 2×10^{-16} respectively. The results, Ye says, "show that the all-silicon system surpasses the performance of any other [optical cavities](#) ever reported." As a long-term stable frequency reference, a preliminary test has shown that it is equivalent to the stability of a hydrogen maser at time intervals up to 1,000 seconds.

The scientists are already at work to improve those figures. Among other modifications, they will attempt to reduce feedback errors due to spurious amplitude modulation, suppress noise from the cryostat, and experiment with different optical coatings on the silicon mirrors. The

very thin optical coatings now remain the only significant contribution to the thermal noise of the cavity and new approaches are already being investigated jointly with Markus Aspelmeyer's group at the University of Vienna.

Many of most critical experiments in atomic physics require lasers with extremely narrow linewidth and extremely stable output to interrogate clusters of ultracold atoms or single trapped ions. "Stable lasers such as the one reported are already unlocking some of the mysteries of minute atomic interactions that are otherwise hidden," Ye says.

More information:

www.nature.com/doifinder/10.1038/nphoton.2012.217

Provided by National Institute of Standards and Technology

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