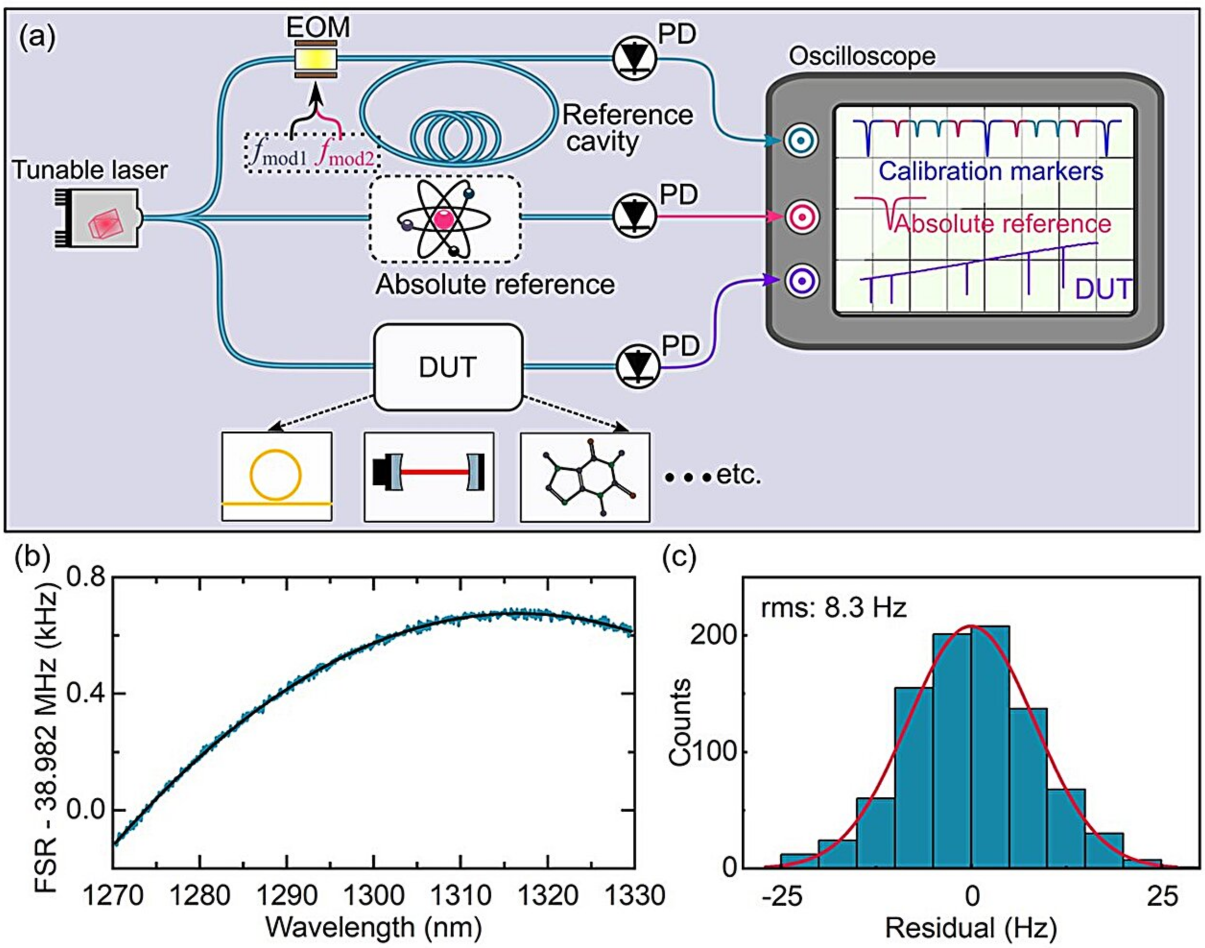
Research team uses tunable laser to develop straightforward broadband spectroscopy method with Hz-level precision

August 12 2024



Principle of a Hz-level broadband spectrometer based on dual RF modulation. (a) Measurement scheme. A tunable CW laser is modulated by two RF signals (f_{mod1}, f_{mod2}) via an electro-optic modulator (EOM). The modulated light is used to probe a reference cavity with quasi-periodic structures, such as a fiber cavity or integrated photonic cavity. The transmitted light is monitored by a photodiode (PD) and recorded by an oscilloscope to provide frequency reference markers for the scanning diode laser. The referenced diode laser is used to spectrally measure devices under test (DUT) such as on-chip photonic devices or gas absorption spectra. Optionally, part of the light probes a narrow linewidth atomic/molecular transition for an absolute frequency reference. (b) Measured FSR evolution (blue) of the fiber loop cavity interrogated by the dual RF modulation scheme, together with a second-order polynomial fit (black). (c) Histogram of the frequency difference between the measure FSR and its polynomial fit and a fitted Gaussian curve with a root-mean-square (rms) deviation of 8.3 Hz. Credit: *Advanced Photonics* (2024). DOI: 10.1117/1.AP.6.4.046003

Since the first demonstration of the laser in the 1960s, laser spectroscopy has become an essential tool for studying the detailed structures and dynamics of atoms and molecules. Advances in laser technology have further enhanced its capabilities. There are two main types of laser spectroscopy: frequency comb-based laser spectroscopy and tunable continuous-wave (CW) laser spectroscopy.

Comb-based laser spectroscopy enables extremely precise frequency measurements, with an accuracy of up to 18 digits. This remarkable precision led to a Nobel Prize in Physics in 2005 and has applications in optical clocks, gravity sensing, and the search for dark matter. Frequency combs also enable high-precision, high-speed broadband spectroscopy because they combine large bandwidth with high spectral resolution.

However, one drawback is the low power per comb mode, which makes detecting trace gases difficult. The gaps between the comb modes also require additional techniques for measuring spectrally narrow features.

In addition, high-precision measurements require comb sources with long-term coherence, which demands complex and sophisticated stabilization systems.

Tunable CW lasers offer high photon flux, long interaction paths, and frequency agility, making them ideal for sensitive molecular spectroscopy, gas sensing, and LIDAR applications with high signal-to-noise ratios (SNR). However, these systems often suffer from fluctuations in the laser frequency scan speed.

Various methods, including interferometric approaches, single-sideband modulation, and optical frequency combs, have been developed to address these fluctuations. Frequency-comb-calibrated tunable laser spectroscopy combines the accuracy of a frequency comb with the tunability and high power of a CW laser. Nonetheless, this method requires a reference frequency comb with a flat optical spectrum and stable polarization over a wide range, which can be challenging to achieve.

Researchers at the Max Planck Institute for the Science of Light have developed a new, straightforward broadband spectroscopy method with Hz-level precision using a tunable laser.

As reported in *Advanced Photonics*, this technique involves on-the-fly calibration of the laser frequency using a fiber cavity and a dual radio frequency (RF) modulation technique. This approach enables the precise tracking of the color of the sweeping laser at every point in time. It provides calibration markers that serve as an easy-to-use optical frequency ruler in order to measure optical frequency distances between spectral features with ultra-high precision.

Using this method, the researchers measured minuscule deviations in the free spectral range of a fiber loop cavity over an 11-THz frequency range with sub-10-Hz precision, an order of magnitude improvement over existing tunable laser spectroscopy methods. The measurement speed was 1 THz/s, limited by the reference cavity's linewidth. Compared to frequency comb-based spectroscopy, this technique offers higher optical probe power and better spectral flatness and polarization stability.

The new method was also used to characterize spectral features of integrated photonic devices like microresonators, and for measuring the molecular absorption spectrum of HF gas with two orders of magnitude improvement in precision compared to existing methods. This robust and straightforward method does not require mode locking or phase locking, making it suitable for out-of-lab applications, including LIDAR systems, 3D imaging, open-path trace gas sensing, characterization of photonic devices, and calibration of astrophysical spectrometers. Its simplicity and robustness make it an excellent choice for use in challenging environments.

More information: Shuangyou Zhang et al, On-the-fly precision spectroscopy with a dual-modulated tunable diode laser and Hz-level referencing to a cavity, *Advanced Photonics* (2024). DOI: 10.1117/1.AP.6.4.046003

Provided by SPIE

Citation: Research team uses tunable laser to develop straightforward broadband spectroscopy method with Hz-level precision (2024, August 12) retrieved 12 August 2024 from https://phys.org/news/2024-08-team-tunable-laser-straightforward-broadband.html