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Itiro SHIO, Motoichi OHTSU and Toshiharu TAKO

Research Laboratory of Precision Machinery and Electronics,
Tokyo Institute of Technology, 4259 Nagatsuta-cho, Midori-ku, Yokohama 227

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The frequency of a 3.51 μm He–Xe laser has been stabilized without frequency modulation by means of the derivative signal of the Stark-modulated inverted Lamb dip in the ν_5 transition of H_2CO. We have obtained $\sigma=1.2\times10^{-14}$ as the square root of the Allan variance of the frequency fluctuation for an integration time of 25 s, showing comparable stability to that obtained using a conventional method.

Frequencies of several lasers have been stabilized by using saturated absorption spectra in atoms or molecules to develop new wavelength standards.[1-4] In these samples, the derivative signals of the saturated absorption spectra, i.e., the inverted Lamb dips, have been used as frequency discriminators. To obtain these signals, the laser frequencies have been modulated by applying a.c. voltage to piezoelectric transducers (PZTs).

In the present work, the frequency stabilization of a He–Xe laser at 3.51 μm is demonstrated by the Stark modulation technique. The derivative signal of the inverted Lamb dip in H_2CO $(5_{1,5}(v_5=0)\text{-}6_{0,6}(v_5=1))$ is obtained by applying an a.c. electric field (the Stark field) to H_2CO molecules. By using this signal, the laser frequency can be stabilized without any need for frequency modulation.

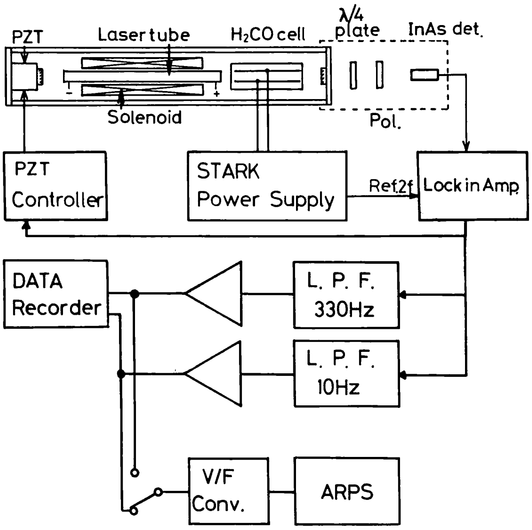

Fig. 1. Experimental apparatus: ARPS represents an Allan variance realtime processing system using a micro processor.[7]

The experimental apparatus is shown in Fig. 1. A laser tube with a discharge part of 5.8 mm inner diameter and 750 cm length is used. The total pressure is 4.0 Torr and the pressure ratio of Xe to the total pressure is 0.025. The discharge current is 3.8 mA. Since the center frequency of the spectrum in H_2CO is about 200 MHz higher than the center frequency of the gain curve of a He–Xe laser, an axial d.c. magnetic field of 124 G is applied to the laser tube to compensate for this frequency gap. Under the axial magnetic field, the two oppositely circularly polarized Zeeman components (σ_+ and σ_-) oscillate.[5] The σ_+ mode is used in the present work because the center frequency of the gain curve of this mode coincides with the absorption line frequency of H_2CO. A quarter-wave plate and polarizer are used to separate the σ_+ mode from the σ_- mode. One of the cavity mirrors is mounted on a PZT for frequency tuning. The absorption cell contains Stark electrodes of 10 mm separation and 26 cm length. The electrodes are made of 36 silver coated steel wires of 0.1 mm in diameter which are separated by 1 mm. An a.c voltage of up to 6 kV (peak-to-peak value) is applied to the electrodes for Stark modulation. The second harmonic signal of the applied electric field is used as the reference for the phase sensitive detection. This is because the absorption line shows the second order Stark effect, i.e., the frequency shift is proportional to the square of the electric field.[6] Its Stark coefficient is $5.90_0 \times 10^2$ kHz/(kV/cm)^2.* The ARPS represents an Allan variance realtime processing system using a micro processor developed by the authors.[7]

The first derivative signals of the inverted Lamb dip are shown in Fig. 2. Figure 2(a) shows the signal obtained by using the conventional method of cavity modulation, i.e., by applying the a.c. voltage to the PZT. In this figure, the value of the maximum frequency deviation used is 770 kHz. Figure 2(b) shows the first derivative signal using the Stark modulation mentioned above. The a.c. electric field of 2.5 kVp-p/cm is applied and the modulation frequency is 3 kHz.

The linear part between the two peaks of this signal is used as a frequency discriminator to control the laser frequency. The control system consists of a lock-in amplifier and a PZT driver with an integrator, a proportional amplifier and a differentiator.[8] As the derivative signal using Stark modulation has a d.c. offset value, it is compensated by the lock-in amplifier.

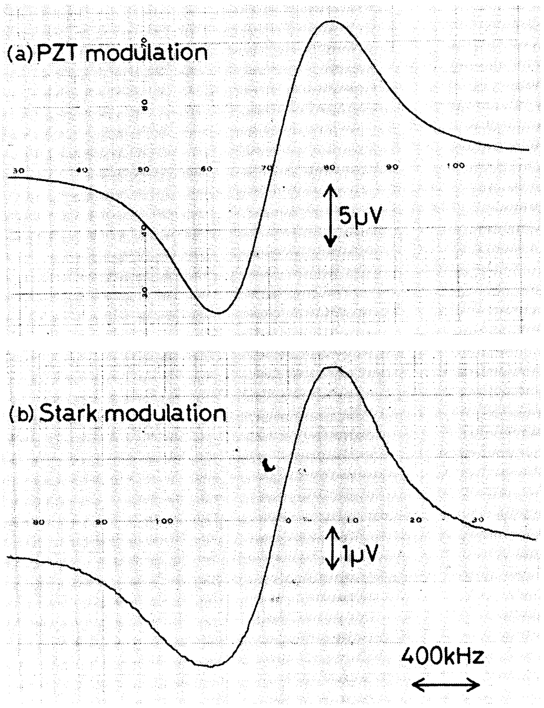

Fig. 2. The first derivative signal of the inverted Lamb dip in H_2CO, using PZT modulation (a), and Stark modulation (b).

Error signals from the lock-in amplifier are proportional to the fluctuations of the laser frequency, and are recorded and analyzed by means of the square root of the Allan variance[9] σ^2, which is the measure of frequency stability. The results are shown in Fig. 3, where τ and N represent the integration time and the number of data, respectively. The curves A and B show the results of stabilization using conventional cavity modulation and Stark modulation, respectively. It can be seen that the result obtained by using Stark modulation exhibits better stability than that obtained using cavity modulation for $\tau \geq 0.1$ s.

As mentioned above, it is necessary to compensate for the d.c. offset value for the stabilization required when the Stark modulation is employed. By using the sixth harmonic of the a.c. Stark field as the reference signal for the phase sensitive detection, the third derivative signal can be obtained for stabilization and the d.c. offset is eliminated. Curve C shows the result of laser stabilization using the third derivative signal. As the intensity of the third derivative signal is about one half that of the first derivative signal in the present work, the stability of the stabilized laser using the third derivative signal (curve C) is worse than that for the first derivative (curve B).

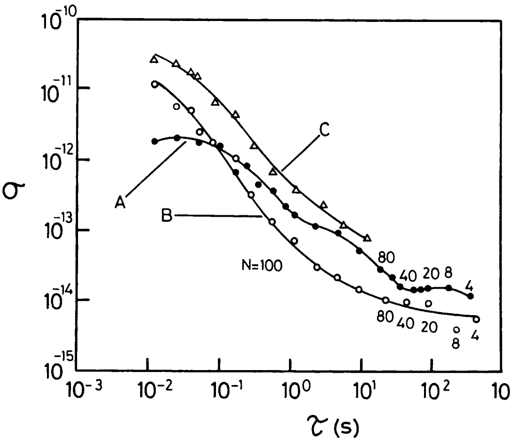

Fig. 3. The square root of the Allan variance σ^2 of the frequency fluctuations. N and τ represent the number of data and the integration time, respectively: Curves A, B and C represent results of stabilization using cavity modulation, Stark modulation (first derivative signal) and Stark modulation (third derivative signal), respectively.

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*K. Uehara: Dr. Thesis, Faculty of Science, University of Tokyo, Hongo, Tokyo, 1968.

On the three curves in this figure, the minimum values are,

curve A; $\sigma=1.7\times10^{-14}$ at $\tau=40$ s,

curve B; $\sigma=1.2\times10^{-14}$ at $\tau=25$ s,

curve C; $\sigma=8.3\times10^{-14}$ at $\tau=12$ s.

By comparing these results, it can be said that the frequency stability obtained by using Stark modulation is as high as that using conventional cavity modulation. This stabilized laser is considered to be almost free from frequency modulation, apart from some slight modulation owing to the dispersion effect in H_2CO. An evaluation of the dispersion effect can be obtained from a measurement of the beat frequency between two stabilized lasers.

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