JAPANESE JOURNAL OF APPLIED PHYSICS
VOL. 29, NO. 5, MAY, 1990, pp. 883–884

Short Note

Frequency Modulation Method for a He–Ne Laser Using the Mechanical Resonance of the Laser Cavity

Norikatsu MIO and Kimio TSUBONO
Department of Physics, The University of Tokyo, Bunkyo, Tokyo 113

(Received December 2, 1989; accepted for publication March 17, 1990)

We developed a method for modulating the frequency of an internal-mirror He–Ne laser ($\lambda = 633$ nm) by means of the mechanical resonance of the laser cavity. The servo system for frequency control using this method is also demonstrated.

KEYWORDS: He–Ne laser, internal-mirror laser, mechanical modulation of laser, thermal control, thin-film heater laser

Internal-mirror He–Ne lasers are widely used as coherent light sources, and many methods of stabilizing their oscillating frequency have already been developed using polarization properties[1–5] or Zeeman effect.[6–8] In order to improve their frequency resettability and long-term stability, modulation techniques are indispensable because the modulation signal is necessary to fix the laser frequency on the atomic line center;[8,9] the frequency of the line center is free from Doppler broadening. We show here a method for modulating the frequency by means of the mechanical resonance of the laser cavity, and a frequency control system which makes use of it.

For internal-mirror lasers, it is not easy to modulate the laser frequency. Previously, a PZT actuator driven by a high voltage was attached to induce mechanical distortion of the laser cavity.[8] If an appropriate mechanical vibration mode of the tube is selected to modulate the cavity length, it is possible to obtain a large vibration with a small excitation signal tuned at the resonant frequency of the mode. Since the stress due to the vibration of the eigenmode is distributed over the entire tube, the mechanical damage may be reduced.

The He–Ne laser ($\lambda = 633$ nm) used in this experiment is schematically shown in Fig. 1. In order to excite a mechanical vibration of the cavity, two PZT actuators (nominal sensitivity of 16 μm/150 V) were attached in parallel to the cavity with a silicon-rubber bond. The cavity length L ($L = 17$ cm) can be thermally controlled by a thin-film heater coated directly on the tube; it has been reported[5] that the controlling speed of this heater is 10 times faster than that of the usual wound one.

First, to examine the mechanical property of the cavity, we measured the mechanical vibration caused by the applied voltage across the PZTs as a function of its frequency. As shown in Fig. 2, there are many peaks which indicate the mechanical resonance of the cavity. The largest peak of 10.78 kHz is preferable for obtaining a deep modulation in the laser frequency. To use this mode in a stabilization system, we tested the stability of its vibration. During the 16-hour measurement, the amplitude and phase of the vibration fluctuated within 0.6% and 0.3 deg, respectively. We could not observe serious drift in them after the laser was sufficiently warmed up.

We assembled a servo system for frequency control using the above modulation method shown in Fig. 3. The

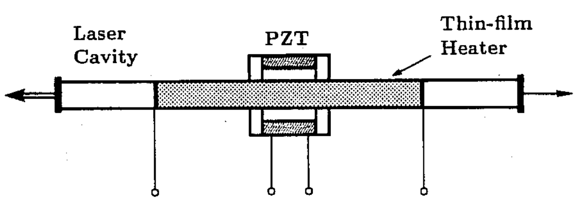

Fig. 1. Schematic of the internal-mirror He–Ne laser ($\lambda = 633$ nm) used in this experiment. Two PZT actuators are attached to the cavity to excite a mechanical vibration mode. The cavity length can be thermally controlled by a thin-film heater coated on the tube.

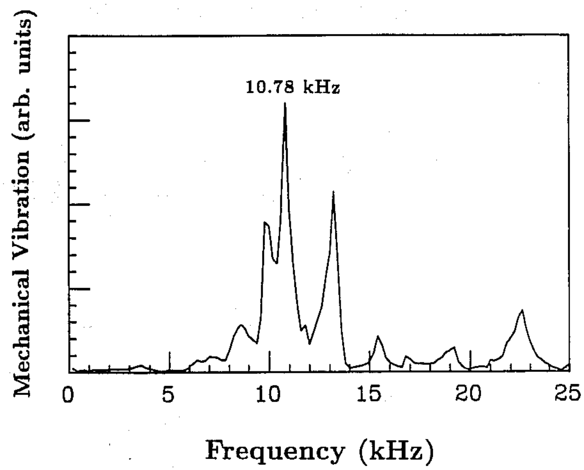

Fig. 2. Mechanical property of the cavity. The vibration caused by the voltage applied to the PZTs is presented as a function of its frequency. There are many peaks showing mechanical resonance.

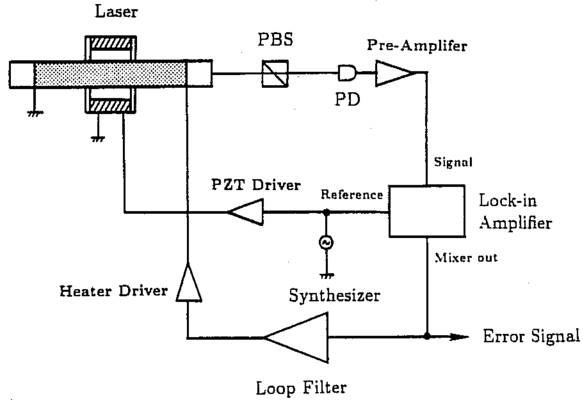

Fig. 3. Block diagram of the feedback system for frequency control. The modulated light detected by a photodiode (PD) is led to a lock-in amplifier and fed back to the heater through a loop filter. In order to separate lights of neighbor longitudinal modes, a polarizing beam splitter (PBS) is inserted between the laser and the PD.

modulated laser light was detected with a photodiode (PD) after a polarizing beam splitter (PBS), which was required to separate light of neighbor longitudinal modes which had orthogonal polarization planes. The output of the PD was demodulated with a lock-in amplifier and fed back to the heater through a loop filter. The error signal and the light intensity are plotted in Fig. 4. While the feedback loop was open, they fluctuated owing to the thermal expansion of the cavity. The error signal is proportional to the derivative of the intensity curve, which was a function of the oscillation frequency of the laser. We estimated that the modulation was about ±1.9 MHz in the laser frequency, which was obtained by applying a signal of 400 $mV_{p\text{-}p}$ to the actuators. The error signal changes almost discontinuously around its vanishing point, where the laser oscillates at the center frequency of its gain curve with the maximum intensity. Since the longitudinal mode spacing of this laser is 880 MHz, it is possible that three modes oscillate simultaneously. In actuality, this was show to be a fact by the intensity curve in Fig. 4, the minimum of which is not zero. The oscillation of the unnecessary modes may affect the gain curve and produce a peak at the center; this peak causes a steep change in the error signal.*

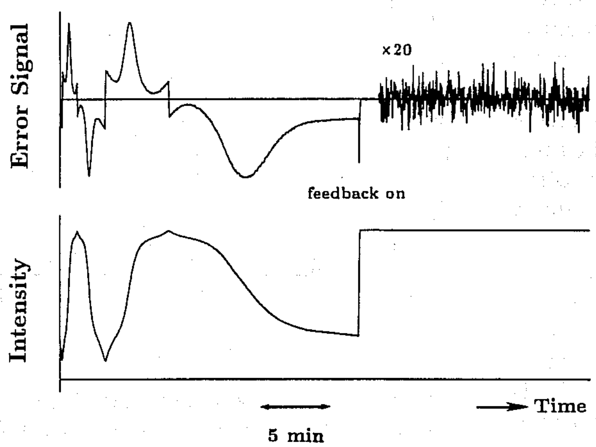

Fig. 4. Measured error signal of the feedback system. The variation of the light intensity is also presented. While the loop was open, these signals fluctuated owing to a thermal expansion of the cavity.

Once the loop was closed, the oscillation frequency was fixed at that point. We may expect an improvement for a long-term stability compared with the nonmodulation methods,[1,2,4-7] because the system is, in principle, not sensitive to the dc-drift of photodevices and electric circuits. Considering the single longitudinal mode, the laser power available with this method was larger than that obtained by the two-mode method.[5] Moreover, we measured the beam jitter due to the vibration with a four-division PD. The horizontal and vertical jitter angles of the modulation frequency were within 30 nrad and 40 nrad, respectively. However, these values were not a serious problem in actual applications; they were very small compared with the low-frequency beam jitter, which was of microradian order.

We can use another vibration pickup attached to the tube to produce a self-excited oscillation of the mechanical mode.[10] The scheme significantly simplifies the stabilization system, because it is not necessary to prepare the independent oscillator or to tune its frequency to the resonance of the mode.

We thank Mitsuru Tanaka, Kazuaki Kuroda and Hirofumi Yamada for valuable discussions.

References

1) R. Balhorn, H. Kunzmann and F. Lebowsky: Appl. Opt. **11** (1972) 742.
2) S. J. Bennett, R. E. Ward and D. C. Wilson: Appl. Opt. **12** (1973) 1406.
3) T. Yoshino: Jpn. J. Appl. Phys. **19** (1980) 2181.
4) P. E. Ciddor and R. M. Duffy: J. Phys. E**16** (1983) 1223.
5) K. Seta and S. Iwasaki: Opt. Commun. **55** (1985) 367.
6) R. H. Morris, J. B. Ferguson and J. S. Warniak: Appl. Opt. **14** (1975) 2808.
7) N. Umeda, M. Tsukiji and H. Takasaki: Appl. Opt. **19** (1980) 442.
8) T. Baer, F. V. Kowalski and J. L. Hall: Appl. Opt. **19** (1980) 3173.
9) K. Shimoda and A. Javan: J. Appl. Phys. **36** (1965) 718.
10) M. Ohashi, K. Tsubono and H. Hirakawa: Jpn. J. Appl. Phys. **25** (1986) L687.

*The profile of the curve was different from that reported in ref. 5, where Lamb's dip was observed at the gain center. Probably, this difference depends on the intrinsic characteristics of individual laser tubes.