Stabilization of internal-mirror He–Ne lasers

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Simultaneous frequency and amplitude stabilization of a commercial internal-mirror He–Ne laser by a new simple method is reported. In this method, the back beam intensity of one polarization of the orthogonally polarized modes is fed back as a heater current to control the cavity length of the laser. The relative frequency stability and amplitude stability achieved are, respectively, $\pm 2.5 \times 10^{-9}$ and $\pm 0.13\%$ over a period of 1 h.

I. Introduction

Frequency-stabilized internal-mirror He–Ne lasers are essential as light sources for high accuracy laser interferometry. An amplitude-stable light source is also desirable in many light measurement techniques. A number of frequency stabilization schemes for internal-mirror He–Ne lasers oscillating in a few modes have been reported in the literature. One popular approach is the so-called two-mode method.[1–3] It is based on balancing the output of the orthogonally polarized modes. Several authors have also investigated amplitude stabilization of He–Ne lasers,[4–6] usually by controlling the discharge current. Simultaneous frequency and amplitude stabilization of internal-mirror He–Ne lasers by a simple method was recently demonstrated by Sasaki and co-workers.[7–9] They used the total laser back beam intensity as the feedback signal to control either the laser resonator length or the discharge current. The laser discharge current was regulated to $\pm 0.01\%$. A relative amplitude stability of $\pm 0.1\%$ and frequency stability of $\sim\pm 5 \times 10^{-9}$ were attained for a period of 10 min or longer. The relative merits of the two-mode method and the total power method have also been investigated in our laboratory.[10,11]

In this paper we report excellent frequency- and amplitude-stability results for an internal-mirror He–Ne laser by detecting and feeding back the back beam output of one polarization of the orthogonally polarized modes as a heater current to control the laser tube length. This new single-polarization method is attractive because it employs just a Polaroid and a single photodiode instead of the more expensive polarizing beam splitter and dual detectors as in the two-mode method. It is also advantageous over the total power method with its more sensitive frequency discriminator. In the following, we first briefly outline the basic principles of this method. We then describe the stabilized laser system and present our experimental results.

II. Basic Principles

For internal-mirror He–Ne lasers, the major cause of frequency and amplitude fluctuations is the change in cavity length of the laser due to thermal expansion/contraction. It is well known that this type of laser oscillating in two axial modes has unique polarization properties: each mode is linearly polarized and their polarization directions are mutually perpendicular.[12] The polarization behavior of multimode lasers is more complex.[13,14] As the laser tube expands or contracts, the modes drift across the gain profiles and the output power of each mode changes. The total laser intensity, $I_{\text{total}} = I_\sigma + I_\pi$, and the intensity difference, $\Delta I = I_\sigma - I_\pi$, changes accordingly, where I_σ and I_π are, respectively, the intensities of the orthogonally polarized modes. The peak-to-peak value of ΔI, $\Delta I_{\text{p-p}}$, of a free-running laser corresponds to a frequency change of one axial mode separation. It thus provides a convenient measure for frequency variation of the laser. These are schematically illustrated in Fig. 1 for our test laser (a Spectra-Physics model 155, oscillating in two or three models). It can be readily seen from Fig. 1 that by maintaining laser cavity length, a constant using either I_σ or I_π as the feedback signal, ΔI and I_{total} will also be constant. That is, simultaneous frequency and amplitude stabilization of the laser can be achieved,

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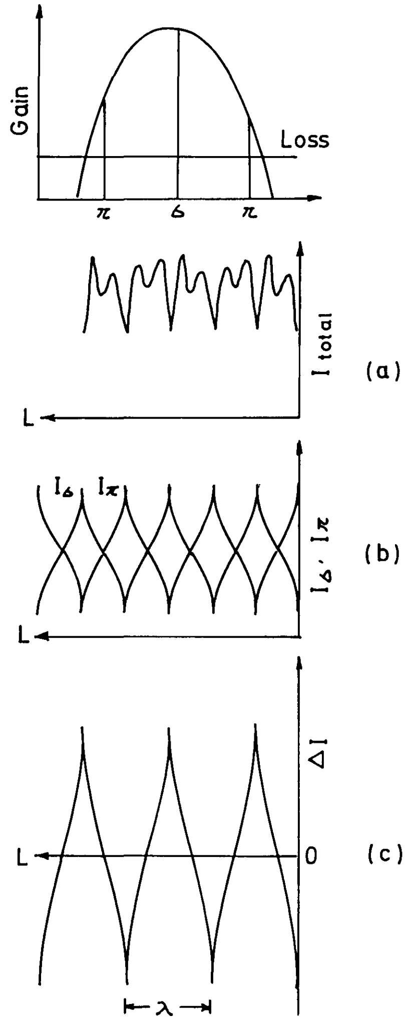

Fig. 1. Schematic representations of an arbitrary laser gain profile, (a) total laser intensity, (b) intensities of the orthogonally polarized output of the laser, and (c) difference in intensities of the two polarizations as a function of laser cavity length L. λ is the wavelength of the laser.

assuming change in the laser cavity length is the only cause of laser output fluctuations.

If a heater coil is used to regulate the laser tube length, the laser itself must be in an effective cooling mode. This is achieved by using a preheating cycle to expand the cavity length of the laser to a few wavelengths longer than that of the laser in thermal equilibrium. The actual operating temperature of the laser system is chosen to be slightly lower than that at the end of the preheating cycle while still higher than that for the system in thermal equilibrium. Thus an effective cooling rate for the laser can be realized.

Typically, the laser tube length is controlled using the linear portions in Fig. 1(b). For stabilization of both the frequency and output power of the laser, the gradients of Figs. 1(a) and (c) must be similar to that of Fig. 1(b) at the chosen control point. Because either I_σ or I_π is detected, laser power fluctuations due to other causes such as power supply fluctuations and discharge instabilities should also be minimized.

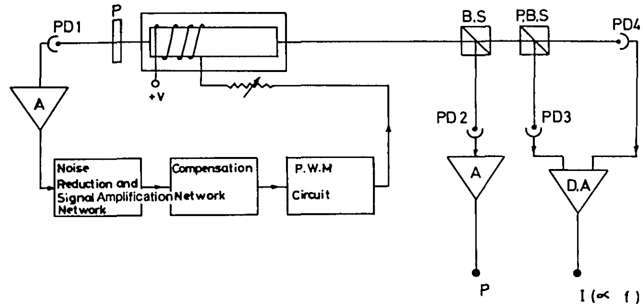

Fig. 2. Block diagram of the experimental apparatus: P, polarizer; $PD1$–$PD4$, photodiode detectors; BS, beam splitter; PBS; polarizing beam splitter; A, amplifier; $D.A$, differential amplifier.

III. Experimental

A block diagram of our experimental apparatus is shown in Fig. 2. The commercial laser (SP155) used is a sidearm type with a mode separation of ~550 MHz. To regulate the laser cavity length, we used a coil (Nickel wire, 15 Ω/m) wound around an ~8-cm length of the laser tube near the cathode. The laser tube itself is enclosed in an acrylic box (10 × 10 × 35 cm). The original Spectra-Physics power supply is used without modification. At 6 mA, the discharge current regulation of this laser is ±3%. The laser back beam passes through a polaroid, which rejects either I_σ or I_π, before entering a photodiode (HTV S1226-5BK). Care has been taken in positioning the optics to avoid the optical feedback effect.[15] The laser front beam is used for laser frequency and amplitude-stability measurements.

The laser stability control electronics is shown in Fig. 3. Figure 3(a) consists of a noise reduction and

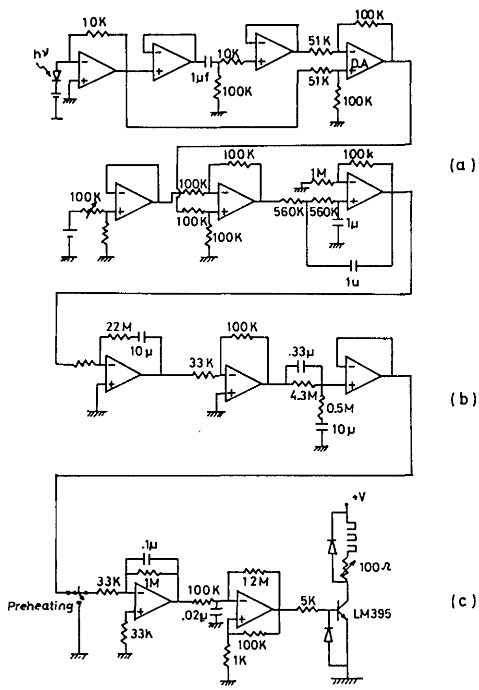

Fig. 3. Control circuits for laser stabilization. All the operational amplifiers used are 13741.

signal amplification network: common mode noises such as 60-Hz harmonic noise from the power supply and discharge current fluctuations are subtracted from the photodiode signal and differentially amplified. This takes advantage of the fact that the thermal noise spectrum lies at much lower frequencies than that of the discharge noise spectrum. The position of the modes on the gain curve, i.e., the control point, is selected by subtracting the output of the differential amplifier from a stable reference voltage. An additional active filter with a cutoff frequency of 0.5 Hz further reduces the noise.

The thermal behavior of the laser and its enclosure is rather complex. By using a simple model assuming radial flow of heat only, it can be readily shown that the transfer function for the thermal equivalent circuit of the laser system has a main pole very close to zero and would cause system oscillation.[3] To remedy this, we have employed a compensation network[16] as shown in Fig. 3(b). It consists of an integrator to reduce steady-state error, a zero to cancel the main pole, and a lead-lag network near 1 Hz to increase the gain and phase margin of the system. Finally, a pulse width modulation (PWM) type circuit [Fig. 3(c)] is used to convert the error voltage to heating power. Its carrier frequency is 700 Hz and the linear dynamic range is ~20 mV. Preheating is achieved easily by adjusting the load resistance with zero input error voltage. For our system, the optimum preheating power is ~80 mW.

IV. Results and Discussions

In the free-running mode, the relative frequency stability of the test laser over a period of tens of minutes approaches $\pm 1 \times 10^{-6}$ and the amplitude stability approximately ±5% after the laser has been turned on for ~2 h. We have also monitored the temperature of the laser tube and found that the cavity length initially rapidly expands due to the discharge and more than 90% of the laser tube expansion occurs in the first 15 min after turning on the laser. The preheating cycle employed has been described in Sec. II. We typically close the feedback loop after the laser tube has expanded for a length of ~46λ from a cold start. Figures 4(a) and (b) show typical results for frequency and amplitude stabilization of the test laser over a period of 1 h. The peak-to-peak frequency fluctuation of the laser, $\pm\Delta f$, is ±1.19 MHz, calibrated using the peak-to-peak value of ΔI while the laser is free running. This corresponds to a relative frequency stability, $\pm\Delta f/f_0$, of $\pm 2.5 \times 10^{-9}$. The laser amplitude stability, $\pm\Delta p/p_0$, also improves to ±0.13%; f_0 and p_0 are, respectively, the center frequency and rms output power of the laser.

It is well known that, in addition to variation in the cavity length, fluctuations in the discharge current due to power supply fluctuations and instability of the space charge at the cathode contribute significantly to laser amplitude fluctuations.[4] In the present method, the laser cavity length is controlled by using either I_σ or I_π as the feedback signal. The length of the laser tube will also be compensated whenever the laser amplitude varies due to power supply or discharge current fluctuations. This results in frequency drifts as the cavity length is changed to accommodate these fluctuations. For simultaneous frequency and amplitude stabilization by this method, the laser tube and power supply must therefore be relatively quiet. In preliminary experiments[11] we reported a relative frequency stability of $\pm 2.8 \times 10^{-8}$ and an amplitude stability of ±0.4% using a simple controller in which the heater coil was regulated at a level set by subtracting the photodetector signal from a stable reference voltage. By incorporating the noise reduction network and compensation circuit described earlier, significant improvement in stability of the laser results. The power of these circuits can be appreciated when one notes that the discharge current regulation of our power supply is ~300 times worse than that employed by Sasaki and coworkers[7–9], yet our stabilization results are comparable with theirs. It is expected that, by using a constant current power supply, laser stability can be further improved.

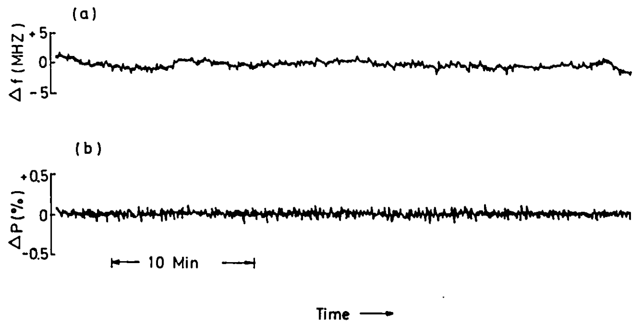

Fig. 4. Typical results for (a) frequency and (b) amplitude stabilization by the single-polarization method.

Compared with the two-mode method, the present method is attractive because it requires just a Polaroid and a single photodiode instead of the relatively expensive polarizing beam splitter and dual photodetectors for the two-mode method. It also employs a sensitive discriminator: for a given change in cavity length, the corresponding change in either I_σ or I_π is one-half of ΔI and twenty times larger than that of I_{total}.

V. Conclusions

We have demonstrated a relative frequency stability of $\pm 2.5 \times 10^{-9}$ and an amplitude stability of ±0.13% over a period of 1 hr for an internal-mirror He–Ne laser by using a new simple method. In this method, the back beam intensity of one polarization of the orthogonally polarized modes is fed back as a heater current to control the cavity length of the laser. The special features of this method are: (1) the optical system is simpler, it requires just a Polaroid and a single photodetector; (2) its frequency discriminator is ~20 times more sensitive than that for the total power method. It is expected that with a better-regulated power supply, further improvement in frequency and amplitude stabilization of the laser can be achieved.

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Australian Science Archives Project Gets Underway

by R. W. Home

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The Australian Science Archives Prcject (ASAP) began operations in March 1985 with the appointment of an archivist. Ostensibly modelled on the Contemporary Scientific Archives Centre in Oxford, England, the Project's aim was to locate, sort, list and finally place in suitable repositories the professional and personal papers of selected Australian scientists, scientific societies and institutions. As the end of our first year approaches and we reflect on the paths taken, it becomes evident that the different circumstances prevailing in Australia have led us somewhat away from the Oxford pattern.

During its first year, the ASAP has taken on thirteen collections and has recently published its first listing. This documents the papers of Sir Ian William Wark, an industrial chemist who worked on electrolysis and mineral flotation. This particular collection will be housed at the Basser Library of the Australian Academy of Science in Canberra. Other major collections in hand include the papers of Nobel Laureate Sir Macfarlane Burnet, F.R.S., the geneticist M. J. D. White, F.R.S., the biochemist V. M. Trikojus, and the zoologist A. J. (Jock) Marshall. Repositories that have received collections from us include as well as the Basser Library, the University of Melbourne Archives, the University of Adelaide Archives and the National Library of Australia in Canberra.

Among various small collections that have been handled were some papers of **Kerr Grant**, professor of physics at the University of Adelaide, 1911–1948. Kerr Grant led an expedition to Cordillo Downs in the far northeast corner of South Australia in 1922, in parallel to the Lick Observatory expedition to Western Australia, to observe a total eclipse of the sun and to test the "Einstein effect" of the deflection of light in a gravitational field. Other Australian physicists whose papers are being negotiated at the moment are **George Henry Briggs**, 1893-, Chief of the Division of Physics, Commonwealth Scientific and Industrial Research Organisation (C.S.I.R.O.), 1945–1958, and an early advisor to the Australian government on atomic energy matters; astrophysicist **Ronald Gordon Giovanelli**, 1915--1984, also Chief of the Division of Physics, C.S.I.R.O., 1958–1976; and **Walter Geoffrey Duffield**, 1879–1929, the founding Director, 1924–1929, of Australia's well known Mt. Stromlo Observatory.

The only extant publication listing Australian science archives, "A Guide to the Manuscript Records of Australian Science" by Ann Mozley (now Moyal), was released in 1966 and though useful has become quite out-of-date. ASAP has therefore built up its own data base in an ad-hoc way as an ancillary to the processing of personal papers. This is currently in manual form but we hope in due course to process the information electronically. No other body in Australia has attempted to collect information of this kind regarding our science archives. Indeed many archivists and librarians are not even aware of the extent of their own holdings in this field.

Those wishing further information should write to R. W. Home, Dept. of History and Philosophy of Science, University of Melbourne, Parkville, Vic. 3052, Australia.