International intercomparison of He-Ne lasers stabilized on the saturated absorption of $^{127}I_2$ at λ = 633 nm and of CH_4 at λ = 3.39 µm

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Abstract

The frequencies of He-Ne lasers stabilized on the saturated absorption of $^{127}I_2$ at λ = 633 nm and of CH_4 at λ = 3.39 µm built in the National Institute of Metrology (NIM) and the Bureau International des Poids et Mesures (BIPM) have been compared by beat frequency measurement. These lasers were stabilized by third harmonic locking.

The frequency differences were :

$$f_{NIM2} - f_{BIPM2} = +\ 13.8\ \text{kHz}\ (+\ 2.9 \times 10^{-11})$$
$$f_{NIM1} - f_{BIPM2} = -\ 20.3\ \text{kHz}\ (-\ 4.3 \times 10^{-11})$$

for iodine stabilized lasers and

$$f_{NIM \cdot CH1} - f_{BICH4 \cdot 6} = +\ 0.56\ \text{kHz}\ (+\ 0.6 \times 10^{-11})$$

for methane stabilized lasers.

The frequency shifts caused by the modulation width, iodine pressure and output power changes were also measured.

Introduction

Since the fifth session of the "Comité Consultatif pour la Définition du Mètre" (CCDM), many intercomparisons of iodine stabilized He-Ne lasers at λ = 633 nm [1, 2, 3, 4, 5] and also of methane stabilized He-Ne lasers at λ = 3.39 µm [6, 7, 8, 9] have been carried

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out. However, this is the first time that the NIM lasers have been included in an intercomparison. The measurements were carried out at BIPM from April 2nd to April 25th, 1980.

This comparison is significant because the gain tubes, absorption cells and other auxiliary equipment of the NIM lasers were made in the NIM's laboratory, and the excellent results are therefore very significant.

Results

COMPARISON OF IODINE STABILIZED LASERS

Two NIM lasers (NIM2 and NIM1) were used in this comparison, but NIM2 was the principal laser used ; and, for BIPM, the reference laser was BIPM2.

The gain tubes of NIM2 and NIM1 are 17 cm long and filled with ^3He and natural neon. The intra-cavity iodine cells are made of glass, and have a length of 10 cm. The cavities are 33 cm long and the cavity mirrors have a curvature radius of 120 cm.

The mirrors transmit 0.3 % of the power. The output power was in the range 17 μW to 27 μW over the duration of the comparison. The BIPM2 laser characteristics have been described elsewhere [1] ; its power during the comparison ranged from 25 μW to 43 μW.

The reference iodine pressure (for both lasers) was 17.3 Pa, corresponding to 15 °C ; the laser peak to peak modulation width was 6 MHz. The lasers were stabilized on each of the seven $^{127}I_2$ components d to j, step by step. Generally, the small four by four matrix of frequency intervals (using the d, e, f, g peaks) was measured except for the diagonal elements. Sometimes, the whole seven by seven matrix of frequency intervals was measured, but the frequency differences of the two lasers were determined from the four by four matrix. Three measurements of 10 s were made for each frequency interval.

Thirteen measurements were performed and the beat frequency fluctuations between NIM2 and BIPM2 are shown in Fig. 1.

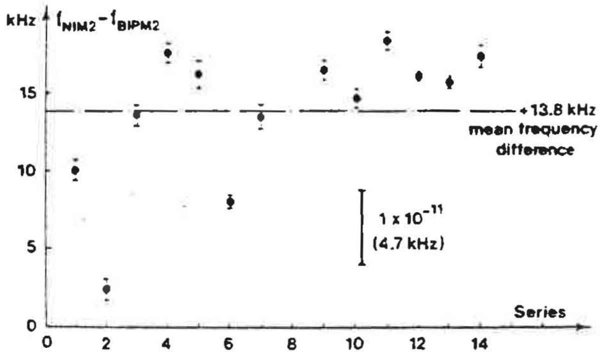

Fig. 1.-The beat frequency fluctuations between iodine stabilized lasers NIM2 and BIPM2.

The mean frequency differences calculated are :

$$f_{NIM2} - f_{BIPM2} = + 13.8 \text{ kHz},$$

with a standard deviation on one measurement : σ = 4.5 kHz ;

$$f_{NIM1} - f_{BIPM2} = - 20.3 \text{ kHz},$$

with a standard deviation on one measurement : σ = 3.8 kHz.

We have measured the dependence of the laser frequency on iodine pressure and on modulation width of NIM2 and NIM1 with BIPM2 as the reference laser. The results are listed in Table 1 and Table 2.

TABLE 1

The measured dependencies of the laser frequencies on iodine pressure [modulation width (peak to peak) : 6 MHz ; 15 Pa < iodine pressure < 21 Pa]

Component	for NIM2 (kHz/Pa)	for NIM1 (kHz/Pa)
d	- 11.1 ± 0.4	- 8.2 ± 1.0
e	- 10.2 ± 0.5	- 8.6 ± 0.9
f	- 9.3 ± 0.5	- 9.2 ± 1.0
g	- 10.0 ± 0.7	- 9.3 ± 1.0
h	- 9.8 ± 0.9	- 8.4 ± 0.6
i	- 9.8 ± 1.1	- 8.8 ± 0.7
j	- 10.8 ± 1.7	- 7.5 ± 0.9

TABLE 2

The measured dependencies of the laser frequencies on modulation width [iodine pressure : 17.3 Pa ; 5 MHz ⩽ modulation width (peak to peak) ⩽ 8 MHz]

Component	for NIM2 (kHz/MHz)*	for NIM1 (kHz/MHz)
d	- 6.6 ± 1.4	- 5.9 ± 0.2
e	- 7.2 ± 1.7	- 7.2 ± 2.8
f	- 7.9 ± 1.5	- 7.9 ± 1.6
g	- 8.6 ± 0.8	- 11 ± 1.4
h	- 6.0 ± 1.2	- 8.6 ± 1.8
i	- 9.6 ± 0.6	- 11.2 ± 0.2
j	- 10.2 ± 1.6	- 8 ± 1.8

*Frequency shift in kHz for one MHz modulation width peak to peak.

We have also measured power shift of the three lasers NIM2, NIM1 and BIPM2. The power variations of the lasers were obtained by changing the current through the gain tube. We obtained :

for NIM2 - (0.05 ± 0.01) kHz/μW,

for NIM1 - (0.06 ± 0.01) kHz/μW,

for BIPM2 - (0.18 ± 0.01) kHz/μW.

The frequency stability between NIM2 and BIPM2 was 6×10^{-13} for 900 s ⩽ τ ⩽ 2 700 s, where τ is the sampling time.

THE COMPARISON OF METHANE STABILIZED LASERS

The methane stabilized laser NIM•CH1 designed at NIM has been compared with the reference laser BICH4•6 designed at BIPM. Table 3 shows the geometrical and optical characteristics of these two lasers.

Both lasers were stabilized by third harmonic locking with sinusoidal length modulation. The modulation frequencies were 1 042 Hz for NIM•CH1 and 1 092 Hz for BICH4•6 respectively. The modulation widths were 1.2 MHz for both lasers.

TABLE 3

Design characteristics of methane stabilized lasers

Laser	Cavity length (m)	Radius of curvature (m)	Mirror reflectivity	CH_4 cell length, pressure (m), (Pa)	Output power (μW)	Detector
NIM•CH1	0.7	2.0, 5.0	0.95, 0.95	0.3, 1.33	100	HgCdTe (0.4 mm^2)
BICH4•6	0.57	1.2, 3.0	0.74, 0.74	0.2, 1.33	100	InAs (0.02 mm^2)

Four measurements were carried out. The mean frequency difference calculated is :

$$f_{NIM \cdot CH1} - f_{BICH4 \cdot 6} = + 0.56 \text{ kHz},$$

with a standard deviation on one measurement : σ = 1.3 kHz.

The dependence of frequency shift of NIM•CH1 on modulation width was measured. When the modulation width (peak to peak) changed from 0.6 MHz to 1.4 MHz, the frequency difference values changed from - 2.9 kHz to + 2.1 kHz. The mean value of modulation shift was (6.5 ± 0.6) kHz/MHz. The discharge current of NIM•CH1 was 2.5 mA during the comparison ; when it was changed from 2.5 mA to 3.5 mA, the frequency difference between NIM•CH1 and BICH4•6 changed from - 1.4 kHz to - 2.5 kHz. The frequency shift due to the discharge current was (- 1.4 ± 0.01) kHz/mA.

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