Extension of absolute frequency measurements to 148 THz: Frequencies of the 2.0- and 3.5-μm Xe laser

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Absolute infrared frequency measurement has been extended to 148 THz (the highest frequency directly measured) with measurement of the two strong cw laser lines of Xe. The frequencies were synthesized with stabilized CO_2 and 3.39-μm He-Ne lasers and mixed on a W-Ni point-contact diode. The measured frequencies are $\nu_{Xe(2.0\ \mu m)} = 147.915\,850(15)$ THz and $\nu_{Xe(3.5\ \mu m)} = 85.459\,997(3)$ THz.

(DISPLAY)

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Infrared frequency synthesis is a very powerful technique for generating frequencies in the near infrared.[1] In this paper we describe the use of this technique to measure frequencies of the 2.0- and 3.5-μm Xe laser lines; the 2-μm measurement is the highest absolute frequency yet measured. The required frequencies were synthesized by various line combinations from two $^{12}C^{16}O_2$ lasers, a 3.39-μm He-Ne laser, and a microwave klystron. The CO_2 lasers were stabilized to the standing-wave saturation resonances observed in the 4.3-μm fluorescent radiation from a 0.040-Torr CO_2 absorption cell,[2] and the 3.39-μm laser was frequency locked to the saturated absorption resonance from a 0.010-Torr methane absorption cell.[3] The harmonic generation and mixing all occurred in a W-Ni open-structure point-contact diode.[4] The CO_2 and He-Ne laser frequencies are known from previous measure measurements.[5-7]

The point-contact diode has also been described elsewhere.[4] However, it was observed that the beat signal at 148 THz was observed only when the dc contact resistance was above about 200 Ω. This dc resistance is somewhat higher than that needed at lower frequencies.

The lasers used in this experiment, with the exception of the Xe laser, have been described elsewhere.[5] The Xe laser was 8 m long and had a split discharge with a common tungsten anode and two hollow aluminum cathodes. The plasma tube was filled with 0.5-Torr Xe and 7.5-Torr He. The laser had single-mode oscillation at both 2.0 and 3.5 μm due to gain saturation and had output powers of 50 mW at 3.5 μm and 10 mW at 2.03 μm. A 20-m-radius-of-curative totally reflecting gold mirror and a flat 50% output reflector were used. Due to cataphoresis the final output was about a factor of 4 less than when the plasma tube was first filled and excited.

The frequency of the Xe 3.5-μm laser line was measured in the following manner. The synthesized frequency can be written[8]

$$\nu_{3.5\ \mu m} = 2\nu_{P_I(12)} + \nu_{P_I(16)} + \nu_{\mu w} + \nu_B,$$

where

$$\nu_{P_I(12)} = 28.516\,026\,638(29)\ \text{THz},$$

$$\nu_{P_I(16)} = 28.412\,589\,705(29)\ \text{THz},$$

$$\nu_{\mu w} = \ \ 0.015\,275\,0\ \text{THz},$$

$$\nu_B = \ \ 0.000\,079(3)\ \text{THz}.$$

Thus,

$$\nu_{3.5\ \mu m} = 85.459\,997(3)\ \text{THz} \qquad (\text{Ref. } 9).$$

The klystron was phase locked to a crystal oscillator and its frequency was measured by a counter. The beat frequency was measured with a spectrum analyzer.

In a similar fashion the frequency of the Xe 2.0-μm laser line can be written

$$\nu_{2.0\ \mu m} = \nu_{3.39\ \mu m} + \nu_{P_{II}(36)} + \nu_{P_I(8)} + \nu_B,$$

where

$$\nu_{3.39\ \mu m} = 88.376\,181\,627(50)\ \text{THz},$$

$$\nu_{P_{II}(36)} = 30.922\,915\,421(28)\ \text{THz},$$

$$\nu_{P_I(8)} = 28.616\,541\,749(28)\ \text{THz},$$

$$\nu_B = \ \ 0.000\,211(15)\ \text{THz}.$$

Thus,

$$\nu_{2.0\ \mu m} = 147.915\,850(15)\ \text{THz} \qquad (\text{Ref. } 9).$$

The uncertainty in the frequency of each Xe laser line was mainly due to the uncertainty in the determination of line center, which was more accurately done in the 3.5-μm case where a piezoelectric driver was used to scan the gain curve. Signal-to-noise ratios for the beat frequencies were typically 30 and 15 dB for the 3.5- and 2.0-μm lines, respectively. The 2.0-μm beat note is shown in Fig. 1.

The frequencies measured here are 290 MHz higher for the 2.0-μm line and 350 MHz higher for the 3.5-

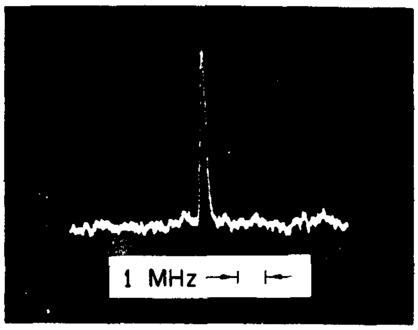

FIG. 1. Beat note at 211 MHz between the 2-μm xenon laser and the synthesized frequency. The spectrum analyzer was set for linear response with rf and video bandwidths of 100 and 1 kHz, respectively. The dc impedance of the diode was 300 Ω.

μm line than those determined from wavelength measurements[10] and the CCDM value of $c = 299\,792\,458$ m/sec.[11] Thus, there is good agreement with the less accurate wavelength measurements.

The success of this measurement provides encouragement for the prospects of absolute frequency measurements in the visible.

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[8] Here, the subscripts I and II refer to the CO_2 10.4- and 9.4-μm bands, respectively, and are derived from the spectroscopic notation for the lower vibrational level of the laser transition.

[9] Quoted uncertainties in the CO_2 and 3.39-μm He-Ne frequencies are 1- standard-deviation estimates from Refs. 5 and 7. Although the lasers used in this experiment were not stabilized as carefully as those used in the referenced papers, these slightly larger uncertainties are not significant in the final error budgets for the Xe frequencies.

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