Frequency measurement of the 260-THz (1.15-μm) He–Ne laser

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Received February 5, 1979

Absolute infrared frequency measurement has been extended to 260 THz with the measurement of the strong 1.15-μm laser line in ^{20}Ne. The frequency was synthesized in nonlinear crystals of $CdGeAs_2$ and Ag_3AsS_3 from stabilized CO_2 lasers and the 1.5-μm laser line in ^{20}Ne. The measured frequency is $\nu_{^{20}\mathrm{Ne},\,1.15\,\mu\mathrm{m}} = 260.103\ 284(30)$ THz.

This Letter describes the synthesis and measurement of the frequency of the 260-THz (1.15-μm) laser line in ^{20}Ne (the first cw gas laser[1]). This frequency is the highest ever directly measured and can be easily doubled to give a known frequency in the middle of the visible portion of the electromagnetic spectrum. The synthesis of 260 THz was achieved by using the quadratic nonlinear susceptibility in crystals to mix known laser frequencies. The nonlinear optical effect in crystals has previously been used in precision metrology for wavelength measurements of stabilized CO_2 and 3.39-μm Ne lasers[2,3] and for frequency measurements of CO lasers.[4]

The required 260-THz frequency was synthesized in the following manner. A crystal of $CdGeAs_2$ was used to sum the $R_{\mathrm{II}}(20)$, $^{13}C^{16}O_2$ and the $R_{\mathrm{II}}(22)$, $^{12}C^{16}O_2$ laser frequencies. The 63-THz output frequency (4.7 μm) was then summed with the 197-THz frequency of the ^{20}Ne, 1.5-μm laser in a crystal of Ag_3AsS_3 (proustite). This synthesized radiation (260 THz) was combined with the 260-THz ^{20}Ne, 1.15-μm laser radiation, and the difference frequency (i.e., the beat frequency) was detected on a fast photovoltaic Ge diode. The resulting beat frequency was amplified and measured with a spectrum analyzer.

The experimental setup is shown in Fig. 1. The CO_2 reference lasers were stabilized to the saturated absorption in CO_2,[5] and the CO_2 power lasers were frequency offset locked. The 1.15-μm, ^{3}He–^{20}Ne laser was frequency offset locked to a Lamb-dip-stabilized 1.15-μm, ^{20}Ne laser.[6] The 1.5-μm, ^{3}He–^{20}Ne laser was set to the center of its gain curve. The basic lasers have been described elsewhere[7] with the exception that mirrors and gas fills were changed to enhance laser performance for each particular frequency.

The frequency of the ^{20}Ne, 1.15-μm laser was measured in the following manner. The synthesized frequency can be written

$$\nu_{^{20}\mathrm{Ne},\,1.15\,\mu\mathrm{m}} = \nu_{^{12}\mathrm{C}^{16}\mathrm{O}_2,\,\mathrm{R_{II}}(22)} + \nu_{^{13}\mathrm{C}^{12}\mathrm{O}_2,\,R_{\mathrm{II}}(20)} + \nu_{^{20}\mathrm{Ne},\,1.52\,\mu\mathrm{m}} - \nu_{\mathrm{beat}},$$

where

$$\nu_{^{12}\mathrm{C}^{16}\mathrm{O}_2,\,R_{\mathrm{II}}(22)} = 32.373\ 156(00)\ \mathrm{THz},^{8}$$

$$\nu_{^{13}\mathrm{C}^{16}\mathrm{O}_2,\,R_{\mathrm{II}}(20)} = 30.950\ 409(00)\ \mathrm{THz},^{9}$$

$$\nu_{^{20}\mathrm{Ne},\,1.52\,\mu\mathrm{m}} = 196.780\ 372(25)\ \mathrm{THz},^{10}$$

and

$$\nu_{\mathrm{beat}} = 0.000\ 673(15)\ \mathrm{THz}.$$

Thus

$$\nu_{^{20}\mathrm{Ne},\,1.15\,\mu\mathrm{m}} = 260.103\ 184(30)\ \mathrm{THz}.$$

This number is in agreement with the frequencies derived from wavelength measurements in the spectra tables[11] and a recent, more accurate wavelength measurement.[12] The uncertainty in the ^{20}Ne, 1.15-μm frequency comes from the uncertainties in the ^{20}Ne,

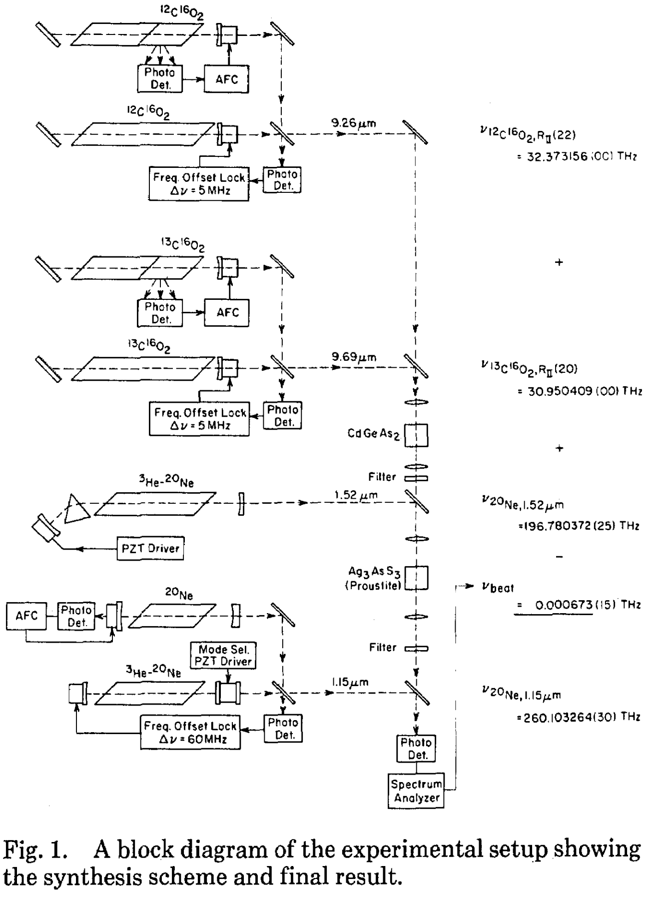

Fig. 1. A block diagram of the experimental setup showing the synthesis scheme and final result.

1.52-μm frequency[10] (25 MHz) and the determination of line center (15 MHz). Although the 260-THz measurement has an uncertainty of 1 part in 10^7, it is anticipated that a remeasurement of the ^{20}Ne, 1.52-μm frequency will improve the overall accuracy by nearly 2 orders of magnitude. Work along this line is currently being pursued.

Previous frequency measurements up to 197 THz (1.52 μm) have utilized the tungsten–nickel, point-contact diode as the nonlinear element for synthesis and detection. Several unsuccessful attempts were made to use this diode in the measurement of the 260-THz frequency before the measurement described above. After this frequency had been successfully measured with the nonlinear crystals, the 4.73-, 1.52-, and 1.15-μm radiations were focused on the point-contact diode in another attempt when the beat frequency was known. All rectified signals were of the order of 1 mV; the polarity of the 1.52- and 1.15-μm signals was opposite that of the 4.73-μm signal. A search was made at the known beat frequency with diode impedances from a few hundred to several thousand ohms. The results were unsuccessful.

Successful measurement of the 260-THz He–Ne laser marks the doorway into the visible domain for direct laser-frequency measurements. The use of nonlinear optical techniques for precision measurements, such as those described in this Letter, will become more and more commonplace. In fact, the frequency stability of the 260-THz laser is known to be excellent,[6] and this frequency can be easily doubled,[13] thereby synthesizing a known stable frequency of 520 THz (576 nm) in the middle of the visible spectrum.

The authors wish to thank J. L. Hall (NBS/JILA) for a wavelength measurement of the ^{20}Ne, 1.15-μm laser and for many helpful discussions. Also, we acknowledge with many thanks the loan of the CdGeAs$_2$ crystal from A. Mooradian and N. Menyuk (MIT Lincoln Laboratory) and the loan of a proustite crystal from R. Deslattes (NBS). We also thank C. Freed (MIT Lincoln Laboratory) for conveying results of recent frequency measurements on $^{13}C^{16}O_2$.

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10. The frequency of the 1.52-μm He–Ne laser was remeasured, and the corrected value is listed. In the previous measurement [K. M. Evenson, D. A. Jennings, F. R. Petersen, and J. S. Wells, in *Laser Spectroscopy III,* J. L. Hall and J. L. Carlsten, eds. (Springer-Verlag, Berlin, 1977), pp. 56–68], a higher-frequency mode of the 1.52-μm laser was not detected, the CO frequencies were not directly measured, and the 1.54-μm laser discharge tube was filled to a total pressure of 324 Pa (with He:Ne = 10:1) instead of the 648 Pa used in the present experiment. The new measurements made with the $^{12}C^{16}O$, $P_{18}(14)$ line only revealed the following corrections: (1) mode +71 MHz, (2) directly measured frequency of $^{12}C^{16}O$, $P_{18}(14)$ [$\nu_{^{12}C^{16}O,\ P_{18}(14)} = 48.862\ 075(3)$ THz] + 11 MHz, and (3) pressure shift [+65(9) kHz/Pa] + 21 MHz. The resultant frequency is $\nu_{^{20}Ne,\ 1.5\mu m} = 196.780\ 372(25)$ THz.
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