Accurate Visible Frequency Measurements of the 633 nm and 576 nm Iodine Lines

C. R. Pollock, D. A. Jennings, F. R. Petersen, R. E. Drullinger, E. C. Beaty, J. S. Wells, J. L. Hall, H. P. Layer, and K. M. Evenson
National Bureau of Standards Boulder, Colorado, USA

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Accurate visible frequency measurements at 520 and 473 THz (576 and 633 nm) were related to the methane stabilized He–Ne laser frequency at 88, 376, 181.609(9) MHz (the most accurately known of all laser oscillators) via CO_2 lasers used as transfer standards. The 88 THz standard was used to measure the $R_I(30)$, $^{12}C^{16}O_2$ frequency which in turn was used to measure the transfer standards $P_I(50)$, $^{13}C^{16}O_2$ and the $R_I(26)$, $^{13}C^{18}O_2$.

The *o* hyperfine component of $^{127}I_2 17-1\,P(62)$ transition at 520 THz was measured with respect to the 26 THz $P_I(50)$, $^{13}C^{16}O_0$ laser via a color center laser at 130 THz and a He–Ne laser at 260 THz, all used as transfer oscillators. Five harmonics of the CO_2 laser were generated in a point contact diode and the second harmonics of 130 THz and 260 THz were generated in separate lithium niobate crystals.

The frequency of the 473 THz He–Ne laser (633 nm) stabilized on the *i* hyperfine component of the $^{127}I_2 11-5\,R(127)$ transition was measured by comparing its frequency with a known frequency synthesized by summing the radiation from three lasers in a He–Ne plasma. The three lasers were 1) the 88 THz CH_4 stabilized laser (3.39 μm), 2) the 125 THz color center laser [2.39 μm with its frequency referenced to the $R_I(26)$, $^{13}C^{18}O_2$], and 3) the 260 THz He–Ne laser (1.15 μm) referenced to an I_2 stabilized dye laser at 520 THz (0.576 μm).

The frequencies are:

576 nm: 520, 206, 808, 547 (80) kHz
633 nm: 473, 612, 214, 789 (70) kHz

The fractional uncertainties in the frequencies of both iodine lines are 1.5×10^{-10} due mainly to a 1×10^{-10} fractional uncertainty in the CH_4 standard and 1×10^{-10} reproducibilities in the stabilized lasers themselves.

A Phase-Locked Waveguide CO_2 Laser for Broad-Band Saturation Spectroscopy with kHz Resolution and Absolute Frequency Accuracy. First Observation of Superhyperfine Structures in the ν_3 Band of SF_6*

Ch. Salomon, Ch. Bréant, A. van Lerberghe, G. Camy, and Ch. J. Bordé
Laboratoire de Physique des Lasers, Associé au C.N.R.S. L.A. 282, Université Paris-Nord, Avenue J. B. Clément, F-93430 Villetaneuse, France

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We report major recent improvements of our spectrometer using cw CO_2 or N_2O lasers [1–4]. The waveguide CO_2 laser is now phase-locked to a conventional low pressure laser with a tunable frequency offset [5], over tuning ranges larger than ±250 MHz. Over these tuning ranges the spectral width of the waveguide laser is reduced to about 10 Hz. We have used this spectrometer for a new study of the SF_6 ν_3 band. About 100 vibration-rotation lines have been investigated with a kHz resolving power revealing their hyperfine structure and in may cases superhyperfine structure [6].

As a frequency reference, a highly stable conventional low-pressure laser is locked to a narrow (30 kHz HWHM) saturation peak using a third-derivative servo-loop. The beat note, ν_b, between this laser

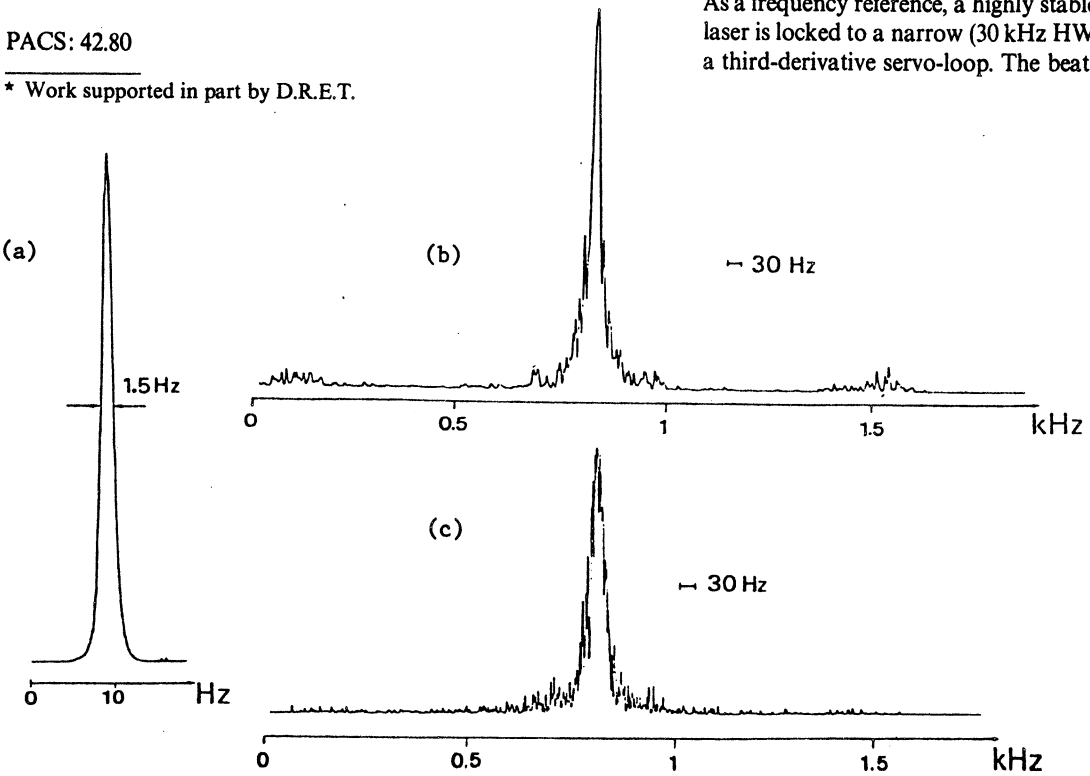

Fig. 1a–c. Spectral purity performances illustrated by various beat frequency spectra between two CO_2 lasers (vertical scales are linear): (a) The waveguide laser is phase-locked to a conventional laser. Resolution of the spectrum analyzer: 1 Hz. Total sweep time: 5 min. (b) Two conventional lasers are locked independently to the $P39$ A_1^2 and A_2^2 components of OsO_4 (30 Hz resolution). Total sweep time: 1 min. (c) Same as (b) but one conventional laser has been replaced by the waveguide laser

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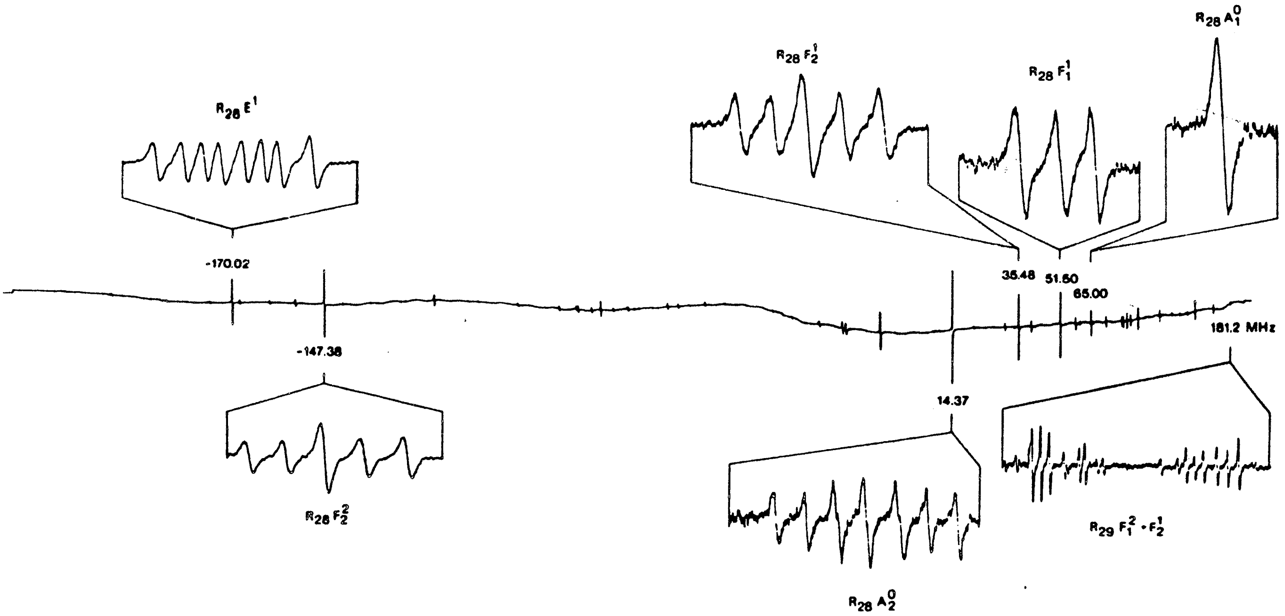

Fig. 2. The saturation spectrum of SF_6 for the $P(14)$ CO_2 line illustrates the hyperfine structure for various symmetry species of VR lines in the $R(28)$ manifold of the ν_3 band. Also the $R(29)$ F_1+F_2 structure is a typical example of strong hyperfine mixing of VR states [7, 8]. Frequencies are in MHz from the OsO_4 line at 28,464,676.938 MHz [3] and the linewidth (HWHM) is of the order of 1.5 kHz. (The precise frequency calibration has been omitted for the sake of clarity but will be found in future more detailed publications of these spectra)

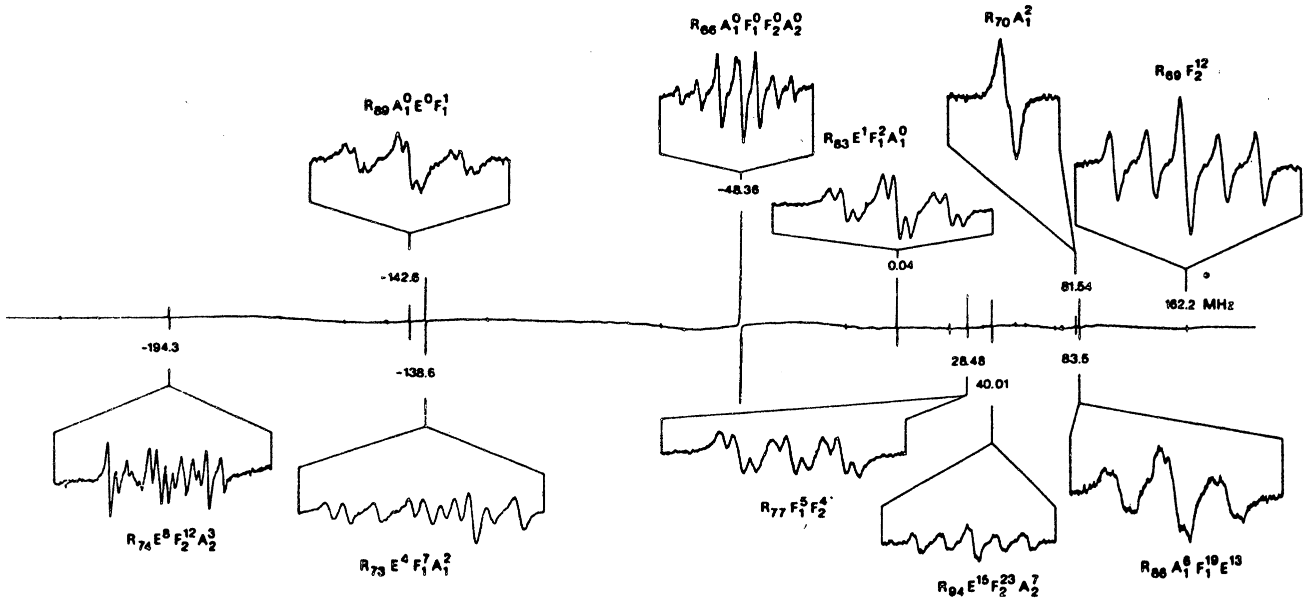

Fig. 3. The saturation spectrum of SF_6 for the $P(12)$ CO_2 line illustrates the superhyperfine structure in the case of various clusters. Another interesting feature is the $R(70)$ A_1^2 inversion doublet which splits into its u and g components. Frequencies are in MHz from the OsO_4 $P(39)$ A_2^3 reference line at 28,516,051.989 MHz [3]

and either another conventional laser or a waveguide laser is then mixed with an auxiliary rf synthesizer (0–500 MHz) in order to obtain the difference frequency, $\nu_b - \nu_{rf}$. The 5 MHz reference clock of this rf source also provides a phase reference. After suitable division of these two frequencies their respective phases are compared in a phase-frequency detector which yields an error signal. This signal is then fed into servo-systems, driving both fast and slow piezoelectric transducers of the waveguide laser. With this technique the frequency stability of the reference laser can be totally transferred to the waveguide laser. Figure 1a demonstrates a spectral purity better than 1 Hz, for the beat frequency ν_b, using a spectrum analyzer with 1 Hz resolution. In addition, longterm drifts of this beat frequency are smaller than 1 Hz per hour. Frequency tuning and modulation are then achieved by driving the rf frequency. Consequently, the residual frequency instabilities of the waveguide laser arise only from the frequency fluctuations of the reference laser. These fluctuations can be reduced below 10 Hz by appropriate servo-systems. Indeed, Fig. 1b displays the beat frequency spectrum between this reference laser and another conventional CO_2 laser locked independently to a separate saturation peak. Finally, Fig. 1c illustrates a 30 Hz spectral purity for the waveguide laser when locked directly to an OsO_4 line.

The beam from the frequency-controlled waveguide laser is expanded in a large absorption cell (18 m long, 70 cm diameter) to a waist radius of 3.6 cm [2]. Under these conditions with the SF_6 molecule at 10^{-5} Torr pressure and with a few μW intensity we currently obtain a 1.2–1.7 kHz linewidth (HWHM) mostly limited by transit effects. This resolution combined with the 550 MHz tuning range of our waveguide laser has enabled us to record many types of hyperfine or superhyperfine structures for several spherical tops (SF_6, OsO_3, SiH_4,...). The absolute frequency of all these structures is known with a few uncertainty with respect to the primary frequency standard [3]. Some examples of observed structures for SF_6 can be seen in Fig. 2 and 3. For this molecule, superfine, hyperfine and superhyperfine structures are presently systematically and, up to now, successfully compared to theoretical predictions using the theory of [7].

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Experiments with MIM Diodes at 60 THz

K. J. Siemsen and H. D. Riccius
National Research Council of Canada

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It was found that diodes can operate without an insulating oxide layer between the two metals. If thick metal oxide layers are present they must undergo a nonmetal-metal transition caused by the very high contact-pressure of the whisker before the diode will operate. Best results were obtained with two different metals having different work functions. However, harmonic generation was also observed using the same metals; a difference in the work function might still arise because of different crystal orientations.

Gold whiskers and gold-coated tungsten whiskers contacting a tungsten substrate have also produced the second harmonic of 30 THz. However, the beat signal was considerably reduced because of the increased capacity of the junction.

To understand metal-insulator-metal diodes as harmonic generators several different metal combinations have been investigated in the 30 THz to 60 THz frequency region. Two CO_2 and one CO laser were used to produce a low frequency beat signal. The strength of this signal as a function of the diode parameters was investigated.

Characterization of Relaxation Oscillation Pulses from Semiconductor Diode Lasers

A. S. Südbø

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When subject to pulsed current excitation, semiconductors lasers may emit short (< 50 ps FWHM) pulses of light, due to relaxation oscillations of the carrier/photon density in the active region of the laser. Common practice has been to excite these pulses using microwave circuit techniques and step recovery diodes to generate short current pulses. However, short optical pulses may be generated using current pulses lasting much longer, of the order of 1 ns, and no microwave circuitry is necessary.

We have measured laser pulse shapes for a number of commercially available GaAlAs diode lasers. Various combinations of dc bias current and injected current pulse shapes were employed. The optical pulses were detected by a fast photodiode in an integrating configuration, followed by a sampling oscilloscope with digital signal processing for pulse shape recovery. Resolution of the detector setup was better than 50 ps FWHM. Using non-collinear SHG in a $LiIO_3$ crystal, optical pulse autocorrelation measurements were also performed. Thus independent pulse shape data was obtained, together with spectral information about individual laser pulses.

Using current pulses of about 1 ns duration, we observed emission of single laser pulses lasting down to less than 50 ps FWHM, duration depending on current pulse amplitude, dc bias, and laser type. Peak powers of 10–20 times the cw power ratings of the diodes were easily obtainable. Each pulse contained in its spectrum many longitudinal laser modes, even for laser types that emit in a single longitudinal mode when operated cw.

Due to their high peak power, short duration, and ease with which these diode laser pulses may be generated, they are useful for high bit rate fiber optic communication links, in fiber optic measurement and testing, in integrated optical gates and switches and in optically switched or gated fast electronics.