Absolute Frequency Measurement of the b_{10} component of the R(106) 28-0 Transitions in $^{127}I_2$ at λ=543 nm

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Abstract

An absolute frequency measurement of the b_{10} component in the R(106) 28-0 transitions in $^{127}I_2$ at 543 nm has been made at the International Bureau of Weights and Measures. The mean frequency value found is $f\,(b_{10})$ = 551 580 162 397.1 kHz, u_c = 4.6 kHz for the current group of lasers.

Introduction

The absolute frequency of this radiation has not been directly measured previously. However, two interferometric wavelength measurements have been made in the early nineties: one at the Physicalisch-Technische Bundesanstalt [1] and a second at the National Physical Laboratory [2].

The recent comb generation technique based on femto-second lasers provides a new opportunity to reduce the frequency uncertainty of this recommended radiation in a direct phase coherent frequency measurement. In 2002 a number of National Metrology Institutes were invited to the International Bureau of Weights and Measures (BIPM) for an absolute frequency determination of the 543 nm radiation to establish a more accurate value for the recommended frequency, and at the same time calibrate national standards at this wavelength. Lasers from the CMI (Czech Metrology Institute, Czech Republic), the NIM (National Institute of Metrology, China), the CENAM (Centro Nacional de Metrología, Mexico), the SPRING (Standards, Productivity and Innovation Board, Singapore), the MIKES (Centre for Metrology and Accreditation, Finland), the DFM (Danish Institute of Fundamental Metrology, Denmark) and the BIPM participated. Some characteristic parameters of these lasers are listed in Table 1.

Institute	Laser	Stab. technique	MIFS (u) kHz / MHz	PIFS (u) kHz / Pa	Ref.
CMI	PLG 1	3*f*	-1.5 (2.5)	-4.6 (0.2)	[3]
CMI	PLG2	3*f*	-1.5 (2.5)	-4.6 (0.2)	[3]
DFM	DFM1	3*f*	-3.2 (2.0)	-6.5 (2.0)	[2]
NIM	NIM1	3*f*	-2	-9.2	
MIKES	MGI2	3*f*	-3.0 (2.0)	-4.6 (2.0)	[2]
SPRING	08A01/G10	FM	—	-8.1	
BIPM	BIG 1	3*f*	-0.4 (1.8)	-0.4 (1.2)	[4]
NIM	NIM2	2 mode	—	—	
CENAM	SL-G 021	2 mode	—	—	

Table 1 Participating institutes and lasers, where the applied stabilization method and the sensitivity coefficients for modulation induced frequency shifts (MIFS) and pressure induced frequency shifts (PIFS), with the associated measured uncertainties, are given.

Experimental and measurements

The experimental arrangement of the comb is based an a Kerr-lens mode-locked ring-laser with a repetition rate, $f_{rep,}$ of ~740 MHz, pumped with 5 W from a single frequency continuous wave Nd:YVO_4 laser [5]. A decimetre long photonic-crystal-fiber [6] was used to expand the comb spectrum to include one full octave to allow determination of the carrier-envelope-offset frequency, f_{ceo}; a typical signal to noise ratio from 40 dB to 50 dB in a 300 kHz bandwidth was obtained for the self-referencing signal [7]. All frequency generators and frequency counters used were referenced to a local hydrogen maser for which the frequency is

known to 5 parts in 10^{14}. Both the repetition rate and the carrier-envelope-offset frequency are phase-locked to the same maser. A counter gate-time of 1 second was used for the frequency measurements.
However, the reference component, a_9, recommended in the MeP, appears to be a non-optimal choice due to the presence of two crossover resonances close to it [8]. As pointed out in [8] the R(106) 28-0 transition is in this respect a better choice since its large J value gives low intensity of the crossover lines. The b_{10} component is especially interesting, being well isolated from neighboring spectral components. Modulation amplitudes and iodine pressures corresponding to normal working conditions for each laser were used for the measurements.

Results and discussion

The final frequency value is corrected and applies to a modulation width of 2.0 MHz and an iodine pressure of 4 Pa (0 °C). Due to the specific isotope mixture in each He-Ne tube, the accessible frequency ranges are not identical for all lasers, which made the use of different spectral components necessary. The measured frequencies, transferred to the b_{10} component, are depicted in Fig. 1. This figure shows that the frequency of DFM1 differs significantly from the average value. Before the absolute frequency measurement of DFM1, the laser was compared to MGI2 and BIG1 with a matrix measurement involving the group a_{11}, a_{12}, a_{13}, and a_{14} and the group a_{15}, b_3, b_4, and b_5. The average absolute frequency difference observed was less than 18 kHz for DFM1 versus MGI2 and less than 3 kHz for DFM1 versus BIG1. The lasers were then moved to a different laboratory for the absolute frequency measurements. It was observed that the beam paths through the I_2 cell of DFM1 were misaligned after the relocation. The laser was realigned, but the discrepancy observed in Fig. 1 is possibly due to residual misalignment. The frequency of DFM1 is therefore considered here to be an outlier, and is not included in the calculated weighted average. The weights take into account the statistical uncertainty observed in the measurements of each laser as well as the uncertainty associated with the recommended frequency intervals used for the transfer to the b_{10} component. Finally, a general uncertainty due to the limited internal reproducibility, estimated to 5 kHz for each laser, has been included in the weights. The weighted mean value of the frequency, found for the present group of lasers, is in this way found to be

$$f(b_{10}) = 551\,580\,162\,397.1 \text{ kHz} \qquad u_c = 4.6 \text{ kHz}.$$

This frequency represents the estimated centre value of the group of lasers together with associated uncertainties. However, it should be noted that the group shows a dispersion (one standard deviation) of 7 kHz if all lasers with iodine temperature control are included and the DFM1 laser excluded. This latter value is indicative of the level of reproducibility that at present can be expected for this type of standard.

Conclusion

The present results reinforce the choice of 543 nm lasers as a useful wavelength standard for the realization of the definition of the metre. Just as the 633 nm standard has been shown to be an excellent compromise between performance, cost and simplicity, there are reasons to believe that the 543 nm standards still have an important role to play in dimensional metrology for years to come.

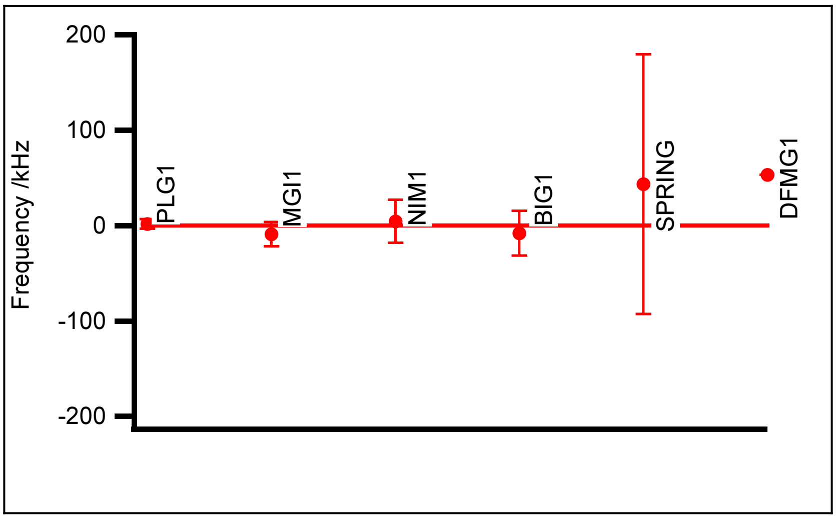

Figure 1. Illustration of the dispersion of the measured laser frequencies for the b_{10} component at a cold finger temperature of 0 °C and a 2 MHz modulation width. The results are given relative to an average frequency for this component (dotted line).

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