



THESIS

MEASUREMENT OF He-Ne LASER WAVELENGTH FOR CALIBRATION OF METER STANDARD ACCORDING TO THE SI DEFINITION

KANOKPOJ AREEKUL

Graduate School, Kasetsart University

2007



THESIS APPROVAL

GRADUATE SCHOOL, KASETSART UNIVERSITY

Master of Science (Metrology)

DEGREE

Metrology

FIELD

Physics

DEPARTMENT

TITLE: Measurement of He-Ne Laser Wavelength for Calibration of Meter Standard According to the SI Definition.

NAME: Mr. Kanokpoj Areekul

THIS THESIS HAS BEEN ACCEPTED BY

THESIS ADVISOR

(Associate Professor Bancha Panacharoensawad, Dr.Eng.)

COMMITTEE MEMBER

(Captain Sahapong Kruapech, M.S.E.E.)

COMMITTEE MEMBER

(Assistant Professor Teerasak Veerapasong, Dr.Eng.)

DEPARTMENT HEAD

(Mr. Ekachai Hoonivathana, M.S.)

APPROVED BY THE GRADUATE SCHOOL ON _____

DEAN

(Associate Professor Vinai Artkongharn, M.A.)

THESIS

**MEASUREMENT OF He-Ne LASER WAVELENGTH FOR
CALIBRATION OF METER STANDARD ACCORDING TO THE
SI DEFINITION**

KANOKPOJ AREEKUL

**A Thesis Submitted in Partial Fulfillment of
the Requirements for the Degree of
Master of Science (Metrology)
Graduate School, Kasetsart University
2007**

Kanokpoj Areekul 2007: Measurement of He-Ne Laser Wavelength for Calibration of Metre Standard According to the SI Definition. Master of Science (Metrology), Major Field: Metrology, Department of Physics.
Thesis Advisor: Associate Professor Bancha Panacharoensawad, Dr.Ing.
95 pages.

Metrology is a new area of study and research in our country. Standard unit of length is one of seven basic standard SI units that calibration requirement demand is 50% of all. Calibration of length and related quantities require traceability to the SI. According to the SI definition of meter in 1983, CIPM recommends (CI-1983) three methods of meter realization. The possible and accurate method is the application of interferometer to measure the wavelength of some standard source such as stabilized HeNe laser. This thesis is proposed to apply scanning confocal Fabry-Perot interferometer for wavelength measurement.

Student's signature

Thesis Advisor's signature

___/___/___

ACKNOWLEDGMENTS

I would like to express my sincere gratitude and deep appreciation to my advisor, Associate Professor Dr. Bancha Panacharoensawad for his initiative idea, encouragement and always available answers. Grateful acknowledgments are likewise extended to my committee members, Dr. Teerasak Veerapasong and Captain Sahapong Kruapech for their precious suggestion, insight and support.

For much needed technical support and guidance in the laboratory about laser wavelength measurement and usage of the OSA, I would like to special thank Captain Sahapong Kruapech. Special thank to Mr. Panya Kongsawad and Mr. Sakchai Chomkrokroawd for assistance making of many mechanical parts and electronics circuits. For mathematical suggestion I would like to thank Mr. Noparit Jinuntuya and Mr. Sithichai Pinkanchanaroj. Also, I would like to thank student members of MPiR who devoted much of their attempt to carry on many experiments and computer simulation work.

The last but not the least, my special thanks goes to my family, both my side and my wife side, and friends for their inspiration and believing in my dream. Usefulness of this thesis, I dedicate to all of my teachers.

Kanokpoj Areekul

April 2007.

TABLE OF CONTENTS

	Page
TABLE OF CONTENTS	i
LIST OF TABLES	ii
LIST OF FIGURES	iii
LIST OF ABBREVIATIONS	vi
LIST OF SYMBOLS AND VARIABLES	viii
INTRODUCTION	1
OBJECTIVES	4
LITERATURE REVIEWS	5
MATERIALS AND METHODS	53
Material	53
Methods	67
Data Analysis	78
RESULTS AND DISCUSSION	86
Result	86
Discussion	90
CONCLUSION AND RECOMMENDATION	92
LITERATURES CITED	94
APPENDIX	96
Appendix A Spectral Information, Instruments Specification and test certificate	97
Appendix B Experiments procedure	106

LIST OF TABLES

Table		Page
1	Wavelength and brightness comparison for some commercial laser pointer	51
2	Average frequency and standard deviation of the mean of high voltage ramp at the sample frequency and the sample amplitude	78
3	Average frequency and standard uncertainty	78
4	Analysis of amplitude stability	79
5	Linearity of ramp signal at observed amplitude	79
6	Analysis of linearity according to the definition in appendix figure B1	80
7	Evaluate of <i>THD%</i> at difference amplitude	81
8	Evaluation of static sensitivity	81
9	Analysis of the etalon cavity extension co-efficient where the ramp amplitude is change.	83
10	Evaluated the finesse @ 632.8 nm	83
11	Wavelength measurement result of laser LHRP-0151	84
12	Uncertainty budget of wavelength measurement from table 11	85
13	Wavelength measurement result of laser LHRP-0051	85
14	Uncertainty budget of wavelength measurement from table 13	85
Appendix table		
A1	A list of recommended radiations, 1983	102
A2	A list of recommended radiations of Spectral Lamps	103
A3	Possible spectrum of He-Ne laser	104

LIST OF FIGURES

Figure		Page
1	Transmission and reflection of dielectric slab	24
2	Reversibility by the Stokes Relations	26
3	Diagram showing two adjacent parallel transmitted rays for a Fabry-Perot étalon	28
4	Plot of the transmission light	30
5	Plot of the reflected light	30
6	Illustrate the FWHM (ε) and FSR	31
7	Fabry-Perot interferometer	34
8	Plot of transmission interference pattern of Fabry-Perot interferometer which 0.4 and 0.8 reflectance	34
9	Plot of reflection interference pattern of Fabry-Perot interferometer which reflectance of 0.4 and 0.8	35
10	Plot of two wavelength λ_1 (589.600 000 nm) and λ_2 (589.399 850 nm) that satisfy the Rayleigh criterion of a Fabry-Perot etalon which finesse 199	36
11	Scanning Fabry-Perot with controller and oscilloscope display	39
12	Spherical Fabry-Perot	39
13	Computer simulation show successive interference beam transmitted from a FPI	42
14	Instruments setup for relative wavelength measurement	45
15	Computer simulation of FPI which cavity length 10.000 mm, R 0.99 (finesse 312.6)	46
16	The helium-neon laser lasing process	47
17	Basic Structure of Laser Diode	49
18	Optical Spectrum Analyzer System	53
19	Optical Spectrum Analyzer model 240	54
20	Specification of OSA model 240 from its brochure	55
21	Specification of OSA model 240 from its manual	55

LIST OF FIGURES (continued)

Figure		Page
22	The OSA controller model 251	57
23	The Sensor: Silicon PIN Photo Diode	57
24	Silicon PIN Photo Diode relative response	58
25	Spectra-Physics Model 117 Stabilized HeNe Laser System	60
26	543 nm He-Ne laser model LHRP-0051	62
27	TDS 220, Real-Time Digital Storage Oscilloscope	63
28	Agilent 33401A 6½ Digits Digital Multi-meter	64
29	Real-Time FFT Analyzer Tektronix 2642A	65
30	Arbitrary Function Generator Tektronix AFG1501	66
31	Definition of (non)-linearity of ramp signal	68
32	Fourier transform of linear ramp signal	69
33	Rear panel of the controller model 251	70
34	Calculation of slope of input and output triangular wave	70
35	SP117 laser head is aligned direct into the OSA to evaluate the Etalon cavity expansion co-efficient	73
36	Oscilloscope screen show 6 successive interference peak of 632.8 nm Laser	73
37	FSR measurement	74
38	FWHM measurement	75
39	Instruments alignment to measure or compare wavelength of laser diode	76
40	Comparison of 632.8 nm Stabilized HeNe laser (center peak) and 630 nm nominal wavelength of laser pointer	77
41	Shape of harmonic peaks may have ‘side band’ added	80
42	Frequency response of the amplifier of the 251 controller	81
43	Unexposed I-V characteristics	82

LIST OF FIGURES (continued)

Appendix Figure		Page
A1	1 Test certificate of the OSA model 240	98
A2	Specification of SP117 632.8 nm stabilized HeNe Laser	99
A3	Scanned page 1 of the specification of UDT photo-voltaic series	100
A4	Scanned page 2 of the Specification of UDT photo-voltaic series that show specification of PIN 125DPL	101
B1	Measurement definition of ramp linearity	109
B2	Zero Offset Ramp and Ramp with DC Offset	110
B3	Ramp wave form of period 0.5 s, rise time 0.49 s, duty cycle 98%	112
B4	FFT of the same ramp, show 30 peaks harmonics form 300 components	112
B5	Measurement of Diode Characteristic with HM6042	118

LIST OF ABBREVIATIONS

atm	=	atmosphere (relative unit of pressure, not SI)
^A I	=	Symbol of Element “Iodine Isotope A”
BIPM	=	Bureau International des Poids et Mesures
CCDM	=	Consulting Committee for the Definition of the Metre
CCL	=	Consultative Committee for Length
CCM	=	Comité Consultatif pour la Masse et les Grandeurs Apparentées
CCTF	=	Consultative Committee for Time and Frequency
CEI	=	Commission Electrotechnique Internationale
CGPM	=	Conférence Générale des Poids et Mesures
CIE	=	Commission Internationale de l’Eclairage
CIML	=	International Committee for Legal Metrology
CIPM	=	International Committee of Weight and Measures
CO ₂	=	Carbondioxide molecule
Cs	=	Symbol of Element “Cesium”
°C	=	degree Celcius
DTI	=	Department of Trade & Industry (UK.)
esa	=	European Space Agency
Eq.	=	Equation
FIR	=	Far Infrared
FPI	=	Fabry-Perot Interferometer
FSR	=	Free Spectral Range
FWHM	=	Full Width at Half Maximum
fm ₁₉₈₃	=	femtometer (according to 1983 meter definition)
GHz	=	GigaHertz
HeNe, He-Ne	=	Helium Neon
IAU	=	International Astronomical Union
ISO	=	International Organization for Standardization
ISO	=	The Infrared Space Observatory
LASER, laser	=	Light Amplification by Stimulated Emission Radiation

LIST OF ABBREVIATIONS (continued)

LWS	=	Long Wavelength Spectrometer)
mm	=	millimeter
m/s	=	Meter per second
m/s ²	=	Meter per square second
m ₁₉₆₀ ⁻¹	=	per meter (according to 1960 meter definition)
MHz	=	MegaHertz
MRA	=	Mutual Recognition Arrangement
MW	=	Megawatt
mW	=	Milliwatt
nm	=	nanometer
NPL	=	Nation Physics Laboraoty (UK.)
N. A.	=	Not Available
N/A ²	=	Newton per square Ampare
N/V	=	Newton per Volt
OPD	=	Optical Path Difference
OSA	=	Optical Spectrum Analyzer
PTB	=	Physikalisch-Technische Bundesanstalt (Ger.)
RegMet	=	Metrology For Improved Measurement In International Regulation And Trade
SI	=	Systbme International
Torr.	=	Torr. (1 Torr. = 1 mmHg, relative unit of pressure, not SI)
VLB	=	Very Long Baseline Measurements
V·s/A·m	=	Volt-second per Ampare-meter
μm	=	micrometer
⁸⁶ Kr	=	Krypton atom isotope 86
¹⁹⁸ Hg	=	Mercury atom isotope 198
¹¹⁴ Cd	=	Cadmium isotope 114
¹²⁷ I	=	Iodine atom isotope 127
¹²⁹ I	=	Iodine atom isotope 129

LIST OF SYMBOLS AND VARIABLES

A	=	Surface Losses Coefficients
$a(r, z)$	=	Gaussian Beam Distance
\mathbf{b}	=	Gravitation Fields
c, c_{mat}	=	Speed of Light Propagating in Material
c_o, c_{vac}	=	Speed of Light in Free Space or in Vacuum
d	=	Distance of Mirrors, along the optical axis of the cavity
E	=	Photons of energy,
E_t	=	Magnitude of Electric Field Component of transmitted rays
E	=	Magnitude of Electric Field Component, of electromagnetic wave
E_{rp}	=	Magnitude of Electric Field Component of reflected ray “ p ”
E_r^*	=	Conjugate of Magnitude of Electric Field Component
F	=	The Co-efficient of Finesse or Contrast
g	=	Acceleration due to Earth Gravitation
H	=	Plank’s constant
I_r	=	Intensity of Reflected Rays
I	=	Intensity of Rays
I_t	=	Intensity of transmitted Rays
k	=	Coverage Factor
$k(ku_c)$	=	Coverage factor for combine uncertainty
k, k_0	=	Circular Wave Number ($2\pi/\lambda$) in Medium n, n_o
m	=	Mass of Particle
m, n	=	Rectangular Mode Numbers (in metrology only $m = n = 0$ is of interest)
n, n_o	=	Refractive Index
$n(\lambda)$	=	Dispersion of The Refractive Index,
q	=	Number of Nodes, in a standing wave between the mirrors
$q + 1$	=	The order of interference as usual.
r	=	Distance on Radial Direction
r	=	Internal Amplitude Reflection Coefficients
r'	=	External Amplitude Reflection Coefficients

LIST OF SYMBOLS AND VARIABLES (continued)

r_1, r_2	= Radii of Curvature, of the spherical mirrors
R	= Reflectance (= r^2)
t	= Internal Amplitude Transmission Coefficients
t'	= External Amplitude Transmission Coefficients
t	= Time
T	= Transmittance (= tt')
T	= Period of Electromagnetic Wave
THD	= Total Harmonic Distorsion
$THD\%$	= Percentage Total Harmonic Distorsion
$u_c/y, u_{rel}$	= Relative Combine Uncertainty of variable y
u_c	= Combined Uncertainty
U	= Uncertainty (total)
w_0	= Beam Waist
x	= Distance on z Axis
z	= Height, Distance on z Axis
ϵ_0	= Electric Field Constant or Permittivity of the Vacuum
$\Delta\lambda_{FSR}$	= Free Spectral Range (in term of wavelength)
Δf_{FSR}	= Free Spectral Range (in term of frequency)
$\Delta\lambda_{res}$	= Resolution (in term of wavelength)
λ	= Wavelength
φ	= Gravitation Potential
ν	= Frequency of Electromagnetic Wave
Δr	= Traveling Path in Gravitation Potential Field
ν_q	= Resonance Frequency of a Mode Matched Wave,
ν_o	= Frequency Distance Between Neighboring Longitudinal Resonant Modes, counted by the integer q , $\nu_o = \frac{c_o}{2d}$
μ_0	= Permeability of the Vacuum
δ	= Phase Difference Between Adjacent Reflected Rays

LIST OF SYMBOLS AND VARIABLES (continued)

φ, φ_0	=	Phase Difference
$\theta, \theta', \theta_0$	=	Angle
δ	=	Optical Path Difference between two adjacent rays
ω	=	Angular Frequency
σ	=	Spatial Periods per Unit of Length ($k/2\pi$)
\mathfrak{F}	=	Finesse
ϕ	=	Phase Change Upon Reflection