

Principles and Choice of Laser Treatment in Dermatology

With Special Reference to the
Asian Population

Jae Dong Lee
Jong Kook Lee
Min Jin Maya Oh

Principles and Choice of Laser Treatment in Dermatology

Jae Dong Lee • Jong Kook Lee
Min Jin Maya Oh

Principles and Choice of Laser Treatment in Dermatology

With Special Reference to the Asian
Population

 Springer

Jae Dong Lee
MISODAM Clinic
Daejeon
Republic of Korea

Jong Kook Lee
Research and Development
Cyberlogitec, Inc.
Seoul
Republic of Korea

Min Jin Maya Oh
ARA Clinic
Incheon
Republic of Korea

ISBN 978-981-15-6555-7 ISBN 978-981-15-6556-4 (eBook)
<https://doi.org/10.1007/978-981-15-6556-4>

© The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature Singapore Pte Ltd. 2018, 2020

This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed. The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd. The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Preface

I run a small aesthetic clinic in Korea. During years of skin laser procedures, many questions came to my mind, which I tried to answer by searching for relevant papers or books. Searching for these answers led me to write this book. I would like to clarify that this book is about Korean patients, and from the perspective of a private-practice laser physician. Since Korean skin is similar to Chinese or Japanese, this book may be helpful to private-practice doctors in China or Japan. Also, because the principle of lasers does not change, I believe that by applying the principle of lasers this book may also be of help to private-practice doctors in other countries. Most of all, I am sure that this book will help you answer many of the questions that the laser physician faces daily during skin laser procedures.

It would be ideal to write a medical book based on the papers that the author has personally experimented and published, but in private practice this is quite difficult. This is why I selected and inserted various portions of papers and books that I found relevant and which matched my experience. I also added my personal comments regarding these contents.

From childhood, I found memorizing without understanding very difficult. This led me to love mathematics and physics. Biology and medical studies were rather difficult for me. Fortunately, understanding skin laser required a lot of physics, which made this topic so intriguing for me. However, most papers regarding skin lasers disregarded physics and compared only clinical results, resulting in inconsistent results from paper to paper. Also, it was disappointing to see that most private-practice physicians used only the manufacturer's recommended parameters without thinking about the principle. Fortunately, through the papers and books of world-renowned scholars, I was able to think straight. In particular, I would like to thank and pay tribute and respect to Richard Rox Anderson and Edward Victor Ross Jr.

I would especially like to thank my wife, Mi Ran. Without her support this book would not have been possible. I would also like to thank my two children, my trustworthy and kind firstborn son Jeong Jin and cute and diligent youngest son Yoo Jin. Jeong Jin! You are a son that every father wants. You can do anything! Please remember that your Dad loves you very very much.

Finally, even though it is becoming increasingly difficult for private practices, I hope that my book may be a small beacon for private-practice laser physicians. Let us all shout a Korean cheer!

Aza Aza Fighting!

Daejeon, Republic of Korea
30 April 2020

Jae Dong Lee

Contents

Part I Understanding Lasers and Laser-Tissue Interactions

| | |
|---|----|
| 1 Principles of Laser | 3 |
| 1.1 Generation of Laser | 3 |
| 1.1.1 Electromagnetic Radiation. | 3 |
| 1.1.2 Principles of Laser Generation. | 4 |
| 1.1.3 Composition of Laser. | 7 |
| 1.1.4 Three-Level and Four-Level Lasers. | 9 |
| 1.2 Characteristics of Laser | 11 |
| 1.2.1 Parameters | 11 |
| 1.2.2 Spatial Mode of Beam | 13 |
| 1.2.3 Temporal Mode of Beam | 15 |
| 1.2.4 Q-Switched Laser. | 16 |
| 1.3 Skin Optics. | 16 |
| 1.3.1 Reflection and Refraction | 16 |
| 1.3.2 Optical Penetration Depth | 17 |
| 1.3.3 Scattering | 20 |
| 1.3.4 Spot Size | 20 |
| 1.4 Absorption | 22 |
| 1.4.1 Monochromaticity and Chromophore | 22 |
| 1.4.2 Absorption Coefficient. | 23 |
| 1.5 Laser-Tissue Interactions | 23 |
| 1.6 Theory of Selective Photothermolysis | 25 |
| 1.6.1 Thermal Relaxation Time | 26 |
| 1.6.2 Pulse Duration Versus TRT | 28 |
| 1.6.3 Three Parameters in the Theory of Selective Photothermolysis | 29 |
| 1.7 Definition of Parameters | 30 |
| 1.8 Clinical End Points | 30 |
| 1.9 Surface Cooling | 31 |
| 1.10 Conclusion | 32 |
| 1.10.1 Principles of Laser Therapy | 32 |
| 1.10.2 Comments by Author. | 33 |
| References. | 34 |

| | | |
|----------|---|----|
| 2 | Laser-Induced Tissue Reactions | 37 |
| 2.1 | Intersection of Physics and Dermatology | 37 |
| 2.2 | Laser–Tissue Interactions | 37 |
| 2.3 | Plasma | 39 |
| 2.3.1 | Generation of Plasma. | 39 |
| 2.3.2 | Laser-Induced Optical Breakdown | 40 |
| 2.4 | Plasma-Induced Ablation. | 41 |
| 2.5 | Photodisruption | 41 |
| 2.5.1 | Three Effects Generated by the Plasma of Photodisruption | 44 |
| 2.5.2 | Reactions of Q-Switched Lasers and Picolasers | 45 |
| 2.6 | Plasma-Induced Ablation Versus Photodisruption. | 46 |
| 2.6.1 | Stress Confinement Time. | 48 |
| 2.7 | Photothermal Effect. | 50 |
| 2.8 | Photoablation. | 52 |
| 2.9 | Photochemical Effect. | 53 |
| 2.9.1 | Biostimulation | 54 |
| 2.10 | Conclusion | 54 |
| | References. | 54 |
| 3 | Important Laser Principles | 57 |
| 3.1 | Advanced Theory of Selective Photothermolysis | 57 |
| 3.1.1 | Thermal Kinetic Selectivity. | 57 |
| 3.1.2 | Extended Theory of Selective Photothermolysis. | 58 |
| 3.1.3 | Subcellular Selective Photothermolysis. | 59 |
| 3.1.4 | Fluence Calculation for Melanosomes. | 62 |
| 3.2 | Selection of Parameters | 62 |
| 3.2.1 | Difficulty in Determining Parameters | 62 |
| 3.2.2 | Effect Versus Safety? | 63 |
| 3.3 | Wavelength. | 63 |
| 3.3.1 | Absorption Coefficient. | 63 |
| 3.3.2 | Optical Penetration Depth | 64 |
| 3.3.3 | Backscattering | 65 |
| 3.4 | Pulse Duration | 66 |
| 3.4.1 | Thermal Relaxation Time | 66 |
| 3.4.2 | TRT Determined by Wavelength | 67 |
| 3.4.3 | TRT Determined by Skin Structure | 68 |
| 3.5 | Spot Size | 68 |
| 3.5.1 | Rule of Thumb in Spot Size. | 68 |
| 3.5.2 | Spot Size Effect | 69 |
| 3.6 | Fluence. | 71 |
| 3.6.1 | Relation Between Fluence and Pulse Duration | 71 |
| 3.6.2 | Epidermal Cooling in Epidermal Pigmentation. | 71 |
| 3.6.3 | Arrhenius Equation | 72 |
| 3.7 | Frequency. | 74 |
| 3.7.1 | Optical Thermal Model | 74 |
| 3.7.2 | Tissue Degeneration Process | 74 |
| 3.7.3 | Pulse Sequence. | 75 |

| | | |
|-------|--|----|
| 3.7.4 | Tissue Degeneration Process in Vascular Therapy. | 75 |
| 3.7.5 | Repeat Pulse Method. | 77 |
| 3.8 | Strategy | 77 |
| | References. | 78 |

Part II Lasers and PIH in Asian

| | | |
|----------|--|-----------|
| 4 | Etiology and Treatment of Postinflammatory Hyperpigmentation. | 83 |
| 4.1 | Overview of PIH | 83 |
| 4.2 | Epidemiology and Possible Etiology of PIH. | 83 |
| 4.3 | Risk Factor for PIH | 84 |
| 4.3.1 | Incidence of PIH Due to Cosmetic Procedures | 84 |
| 4.4 | Predicting PIH Occurrence | 87 |
| 4.5 | Clinical Manifestations of PIH | 87 |
| 4.5.1 | Diagnosis and Differential Diagnosis of PIH | 88 |
| 4.6 | Prognosis of PIH | 88 |
| 4.6.1 | Prognostic Factors of PIH | 89 |
| 4.7 | Pathogenesis of PIH. | 89 |
| 4.8 | Treatment of Post-Laser PIH. | 91 |
| 4.9 | Conclusion | 92 |
| | References. | 93 |
| 5 | Korean Skin and Types of Lasers | 95 |
| 5.1 | Characteristics of Darker Skin. | 95 |
| 5.1.1 | Difference Between Caucasian Skin and Darker Skin | 95 |
| 5.1.2 | Absorption Curve of Melanin | 96 |
| 5.1.3 | Increased Epidermal Melanin Content. | 97 |
| 5.2 | Safer Laser Treatment of Darker Skin | 98 |
| 5.2.1 | Fitzpatrick Skin Typing System. | 98 |
| 5.2.2 | Patient Selection. | 100 |
| 5.2.3 | Lancer Ethnicity Scale. | 101 |
| 5.2.4 | Longer Wavelength (Epidermal Bypass Effect). | 101 |
| 5.2.5 | Petechia Due to Q-Switched Lasers. | 104 |
| 5.2.6 | Longer Pulse Duration. | 105 |
| 5.2.7 | Epidermal Cooling. | 105 |
| 5.2.8 | Test Shot and Preoperative Procedure | 106 |
| 5.2.9 | Homecare | 106 |
| 5.3 | Conclusion | 107 |
| 5.4 | Types of Lasers | 107 |
| | References. | 108 |

Part III Lasers and Energy Devices in Cutaneous Disorders

| | | |
|----------|---|------------|
| 6 | Vascular Lasers and Treatment of Erythema. | 113 |
| 6.1 | Choice of Wavelength | 113 |
| 6.1.1 | Absorption Curve of Hemoglobin | 113 |

| | | |
|----------|--|------------|
| 6.1.2 | Absorption Curve of Methemoglobin | 114 |
| 6.1.3 | Multiplex Lasers | 115 |
| 6.1.4 | Optical Penetration Depth by Wavelength | 116 |
| 6.1.5 | Thickness of Blood Vessels by Wavelength | 116 |
| 6.2 | Types of Vascular Lasers | 118 |
| 6.2.1 | 500–600 nm Wavelength Vascular Laser (Green–Yellow Light and Laser) and Melanin | 118 |
| 6.2.2 | Near-Infrared Vascular Laser | 119 |
| 6.2.3 | Types of Vascular Laser by Pulse Duration | 120 |
| 6.2.4 | Vascular Laser for Koreans | 121 |
| 6.3 | Determination of Pulse Duration | 122 |
| 6.4 | Spot Size | 124 |
| 6.5 | Clinical End Point | 125 |
| 6.5.1 | Disadvantages of Long-Pulsed Nd:YAG Lasers | 127 |
| 6.6 | Pulsed Dye Laser | 128 |
| 6.6.1 | Macropulse | 128 |
| 6.6.2 | Are Laser Parameters Interchangeable? | 130 |
| 6.6.3 | True Long Pulse Versus False Long Pulse (Macropulse) | 131 |
| 6.6.4 | Arrhenius Equation | 131 |
| 6.6.5 | Regeneration and Recurrence of Blood Vessels | 133 |
| 6.6.6 | Ideal Macropulse | 134 |
| 6.7 | Parameters of Vascular Laser Therapy | 136 |
| 6.8 | Side Effects of Vascular Laser Therapy | 136 |
| 6.9 | Non-laser Treatments for Vascular and Erythema Treatment | 137 |
| 6.10 | Treatment of Ecchymoses by Vascular Laser and IPL | 138 |
| | References | 139 |
| 7 | Pigment Lasers | 141 |
| 7.1 | Pigmented Lesions in Darker Skin | 141 |
| 7.2 | Mechanism of Pigment Removal | 141 |
| 7.2.1 | Types of Pigment Lasers | 141 |
| 7.2.2 | Melanin Shuttle | 142 |
| 7.2.3 | Mechanism of Pigment Removal | 142 |
| 7.2.4 | Types of Pigment Lasers by Location | 145 |
| 7.2.5 | Photothermal Versus Photomechanical Effect | 145 |
| 7.3 | Wavelength | 148 |
| 7.3.1 | Pigment Laser for Koreans | 148 |
| 7.3.2 | Q-Switched Laser Selection | 149 |
| 7.4 | Pulse Duration | 150 |
| 7.4.1 | Simple Rule of Thumb | 150 |
| 7.4.2 | Pulse Duration Selection in Long-Pulsed Lasers | 150 |
| 7.5 | Spot Size | 151 |
| 7.6 | Fluence | 151 |
| 7.6.1 | Tissue Degeneration Process | 151 |
| 7.6.2 | Repeat Pulse Method | 152 |

| | | |
|----------|--|------------|
| 7.7 | Reducing Optical Penetration Depth | 153 |
| 7.7.1 | R20 Method | 153 |
| 7.7.2 | Kono Technique | 154 |
| 7.8 | Strategy for Pigment Treatment | 155 |
| 7.8.1 | Strategy for Epidermal Pigment Treatment | 155 |
| 7.8.2 | When Epidermal Cooling Is Not Effective | 157 |
| 7.8.3 | Strategy for Dermal Pigment Treatment | 157 |
| 7.9 | Treatment of Lentigines | 157 |
| 7.9.1 | Target Cell and Chromophores of Lentigines | 157 |
| 7.9.2 | My Treatment of Lentigines | 158 |
| | References | 158 |
| 8 | Laser Hair Removal | 161 |
| 8.1 | Introduction | 161 |
| 8.1.1 | Structure and Function of Hair Follicle | 161 |
| 8.1.2 | Hair Growth Cycle | 163 |
| 8.1.3 | Indications for Hair Removal | 164 |
| 8.1.4 | Traditional Hair Removal Method | 165 |
| 8.2 | Laser Hair Removal | 165 |
| 8.2.1 | Follicular Stem Cell | 165 |
| 8.2.2 | Target Cell and Chromophores of Laser Hair Removal | 165 |
| 8.2.3 | Optimal Treatment Period | 166 |
| 8.2.4 | Mechanism and Extended Theory of Selective Photothermolysis in Laser Hair Removal | 166 |
| 8.2.5 | Hair Growth Cycle and Laser Hair Removal Interval | 167 |
| 8.2.6 | Permanent Hair Removal or Reduction | 168 |
| 8.3 | Wavelength | 169 |
| 8.3.1 | Optical Window and Types of Hair Removal Lasers | 169 |
| 8.3.2 | 810-Nm Diode Laser | 169 |
| 8.3.3 | Problems of Comparative Studies Between Hair Removal Lasers | 172 |
| 8.3.4 | Long-Pulsed Nd:YAG Laser | 172 |
| 8.4 | Hair Removal Laser Selection | 173 |
| 8.4.1 | Hair Removal in Darker Skin | 173 |
| 8.4.2 | Hair Removal Laser for Koreans | 174 |
| 8.4.3 | Paradoxical Hypertrichosis | 175 |
| 8.5 | Pulse Duration | 176 |
| 8.5.1 | Pain and Pulse Duration | 177 |
| 8.6 | Spot Size and Epidermal Cooling | 177 |
| 8.6.1 | Epidermal Cooling | 178 |
| 8.7 | Clinical End Point of Laser Hair Removal | 179 |
| 8.8 | Strategy and Parameters for Laser Hair Removal | 180 |
| 8.9 | Effect of Laser Hair Removal | 181 |
| 8.9.1 | Effect of Laser Hair Removal Depending on Ethnicity | 181 |

| | | |
|-----------|--|------------|
| 8.10 | Procedure | 182 |
| 8.10.1 | Patient Selection and Pretreatment | 182 |
| 8.10.2 | Treatment Procedure | 183 |
| 8.10.3 | Posttreatment Care | 183 |
| 8.11 | Recent Hair Removal Strategy | 183 |
| 8.12 | Trichostasis Spinulosa | 183 |
| | References | 184 |
| 9 | Non-ablative Lasers | 187 |
| 9.1 | Skin Rejuvenation | 187 |
| 9.1.1 | Non-ablative Laser in Darker Skin | 187 |
| 9.2 | Mechanisms of Photorejuvenation | 188 |
| 9.2.1 | Collagen Remodeling | 189 |
| 9.2.2 | Thermal Reactions of Skin Tissue | 190 |
| 9.2.3 | Arrhenius Equation | 191 |
| 9.2.4 | Tissue Damage | 191 |
| 9.2.5 | Partial or Total Denaturation of Collagen | 193 |
| 9.2.6 | Two Methods in Nonablative Rejuvenation | 194 |
| 9.3 | Genesis Technique | 195 |
| 9.4 | Fibroblasts in Papillary and Reticular Dermis | 198 |
| 9.5 | Nonablative Lasers | 201 |
| 9.5.1 | Absorption Curve of Collagen and Water | 201 |
| 9.5.2 | Nonablative Laser Classification by Mechanism | 201 |
| 9.5.3 | Nonablative Lasers for Koreans | 202 |
| 9.6 | Drawbacks of Nonablative Lasers | 203 |
| 9.7 | Conclusion for Nonablative Laser | 204 |
| 9.8 | Photomodulation | 204 |
| 9.8.1 | Arndt–Schultz Curve | 204 |
| 9.8.2 | Light-Emitting Diode | 205 |
| 9.8.3 | Karu’s Photo-Biomodulation Band | 205 |
| 9.8.4 | Mechanism of Low-Level Light Therapy by LED | 206 |
| 9.8.5 | Nonablative Rejuvenation by Photomodulation | 206 |
| 9.8.6 | Consensus on LED | 207 |
| 9.8.7 | Personal Comments on Photomodulation | 208 |
| | References | 208 |
| 10 | Ablative Lasers and Fractional Lasers | 211 |
| 10.1 | Wavelength and Types of Ablative Laser | 211 |
| 10.2 | Mechanism of Ablative Laser | 212 |
| 10.2.1 | Mechanism of Ablative Rejuvenation | 212 |
| 10.2.2 | Water Vaporization Threshold | 212 |
| 10.2.3 | Residual Thermal Damage | 213 |
| 10.3 | Determining Pulse Duration | 214 |
| 10.3.1 | Absorption Coefficient and Optical Penetration Depth | 214 |
| 10.3.2 | Thermal Relaxation Time in CO ₂ Laser | 215 |
| 10.3.3 | Comparison of Ablative Lasers | 215 |
| 10.4 | Spot Size | 215 |
| 10.4.1 | Spot Size in Ablative Laser | 215 |

| | | |
|---------|---|-----|
| 10.5 | Fluence | 216 |
| 10.5.1 | Parameters on the Panel | 216 |
| 10.5.2 | Defocusing Methods (Low Fluence Methods). | 216 |
| 10.6 | Power Density | 217 |
| 10.6.1 | High- Versus Low-Power Density Laser | 217 |
| 10.6.2 | Charring | 218 |
| 10.7 | Fluence Adjustment and Multiple Passes | 219 |
| 10.7.1 | Depth of Ablation and Residual Thermal Damage | 219 |
| 10.7.2 | Multiple Passes. | 219 |
| 10.8 | Er:YAG Laser. | 221 |
| 10.8.1 | Er:YAG Laser | 221 |
| 10.8.2 | Pros and Cons of Er:YAG Laser. | 222 |
| 10.8.3 | Selection of Ablative Lasers in Koreans | 222 |
| 10.9 | CO ₂ Laser Techniques | 222 |
| 10.9.1 | Single-Pass Technique in CO ₂ Laser Treatment. | 222 |
| 10.9.2 | Derma-Epidermal Sliding Effect | 223 |
| 10.9.3 | Q-Switched Nd:YAG Laser Treatment for Removing Melanocytic Nevus | 224 |
| 10.9.4 | My Protocol of CO ₂ Laser in the Removal of Melanocytic Nevus | 225 |
| 10.10 | Ablative Rejuvenation | 225 |
| 10.10.1 | Skin Resurfacing or Rejuvenation | 225 |
| 10.10.2 | Traditional Skin Resurfacing of CO ₂ Laser | 226 |
| 10.10.3 | Comparison of Rejuvenation Methods. | 228 |
| 10.10.4 | Laser Selection in Rejuvenation. | 228 |
| 10.11 | Fractional Laser | 229 |
| 10.11.1 | Fractional Laser in Ethnic Skin | 229 |
| 10.11.2 | Types of Fractional Lasers | 230 |
| 10.11.3 | Parameters in Fractional Laser. | 230 |
| 10.11.4 | Fractional Laser Parameter Selection in Koreans | 231 |
| 10.11.5 | Fractional Laser Techniques. | 232 |
| | References. | 233 |

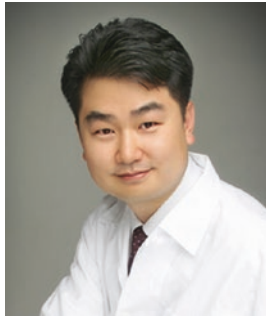
Part IV Treatment of Scar and Melasma

| | | |
|-----------|--|------------|
| 11 | Various Treatments of Scar | 237 |
| 11.1 | Types of Scars | 237 |
| 11.1.1 | Atrophic Acne Scar Subtypes. | 238 |
| 11.2 | Wound Healing Process | 239 |
| 11.3 | Histology of Scar Tissue | 241 |
| 11.3.1 | Histology of Mature Scar Tissue | 241 |
| 11.3.2 | Histology of Atrophic Acne Scar Tissue | 241 |
| 11.4 | Treatments for Atrophic Acne Scars | 242 |
| 11.4.1 | Punch Techniques. | 244 |
| 11.4.2 | Botulinum Toxin and Facelift. | 244 |
| 11.4.3 | Subcision | 244 |
| 11.4.4 | Volume-Related Modalities | 245 |

| | | |
|-----------|---|------------|
| 11.4.5 | Dermabrasion | 246 |
| 11.4.6 | Microneedle Therapy System. | 246 |
| 11.4.7 | Chemical Reconstruction of Skin Scars Method . . . | 247 |
| 11.4.8 | Laser Resurfacing. | 250 |
| 11.4.9 | Fractional Laser | 251 |
| 11.4.10 | Platelet-Rich Plasma and Polydeoxyribonucleotide | 251 |
| 11.4.11 | Nonablative Laser | 252 |
| 11.4.12 | Fractional Microneedle Radiofrequency | 253 |
| 11.4.13 | Picolasers | 253 |
| 11.4.14 | Novel Therapeutic Modalities | 255 |
| 11.5 | Combination Therapy | 255 |
| 11.5.1 | Order of Combination Therapies | 256 |
| 11.6 | Sculpting Technique. | 256 |
| 11.7 | Conclusion | 257 |
| 11.8 | Facial Pores | 258 |
| 11.9 | Isotretinoin. | 260 |
| | References. | 261 |
| 12 | Etiology and Treatments of Melasma | 263 |
| 12.1 | Introduction | 263 |
| 12.1.1 | Definition of Melasma | 263 |
| 12.1.2 | Differential Diagnosis of Melasma | 264 |
| 12.2 | Issues of Melasma | 264 |
| 12.3 | Causes and Theories of Melasma. | 265 |
| 12.3.1 | Pathology of Melasma | 266 |
| 12.3.2 | Recent Papers on Melasma | 268 |
| 12.3.3 | Defective Barrier Function and Pigment Incontinence | 271 |
| 12.3.4 | Sensitive Skin. | 273 |
| 12.4 | Probable Causes of Melasma. | 273 |
| 12.5 | Treatment of Melasma | 274 |
| 12.5.1 | Consensus on Melasma Treatment. | 274 |
| 12.5.2 | Consensus on Medical and Chemical Peeling Treatment for Melasma. | 275 |
| 12.5.3 | Triple Combination Therapy | 276 |
| 12.5.4 | Tranexamic Acid | 277 |
| 12.5.5 | Glycolic Acid Peeling | 279 |
| 12.6 | Laser Toning | 281 |
| 12.6.1 | Conventional Laser Toning | 281 |
| 12.6.2 | Subcellular Selective Photothermolysis. | 282 |
| 12.6.3 | Effects of Laser Toning | 282 |
| 12.6.4 | Prognosis of Laser Toning | 286 |
| 12.6.5 | Side Effects of Laser Toning | 287 |
| 12.6.6 | Golden Parameter. | 291 |
| 12.6.7 | Dermal and Mixed Type Melasma. | 292 |
| 12.6.8 | Laser Toning Parameter Suggestion. | 293 |

- 12.7 Principle and Choice of Laser in Melasma Treatment. 295
- 12.8 Issues in Recent Papers on Laser Treatment
for Melasma. 296
- 12.9 Laser Treatment for Melasma 297
 - 12.9.1 Long-Pulsed Alexandrite Laser 297
 - 12.9.2 Nonablative Fractional Laser 298
 - 12.9.3 Comments on Nonablative Fractional Laser 299
 - 12.9.4 Vascular Laser 300
 - 12.9.5 Picolaser. 301
- 12.10 Combination Treatment 301
- 12.11 Effective Therapy. 302
- 12.12 Advices on Melasma Treatment. 303
- References. 303

About the Authors



Jae Dong Lee, MD Graduated from Medical College of the Catholic University of Korea

The degree of Master of Medical Science in the Catholic University of Korea

The Chief Academic Officer in Korean Medical Skin Care Society

The Laser Academic Officer in Korean Aesthetic Surgery and Laser Society

The Chairman in Korean Dermatologic Laser Association

Director in MISODAM clinic in Daejeon, Korea

(Writing)

The principles and choice of laser in dermatology (Korean language)

Melasma, diagnosis and treatment of melasma (Korean language)

Laser dermatology: Choice and treatment (Korean language)



Jong Kook Lee Bachelor of Physics in Korea University

Master of Statistical Physics in Korea University

Ph.D. Candidate of Software Engineering in Soongsil University

Manager of R&D team in Cyberlogitec, Inc.



Min Jin Maya Oh, MD Graduated from Medical College of the Catholic University of Korea

The Academic Officer in Korean Academy of Melasma

The Vice-Chairman in Korean Dermatologic Laser Association

Former AsiaPacific Regional Therapeutic Expert for Botox, Allergan

Former Medical reviewer for MFDS (Ministry of Food and Drug Safety)

Director in ARA clinic in Incheon, Korea

Part I

**Understanding Lasers and Laser-Tissue
Interactions**

1.1 Generation of Laser

The world consists of light and matter. When light and matter meet, they interact with each other and make various physical and chemical changes. For example, if you stand under the clear autumn sky, you can feel your body warming up even in the cool weather (Fig. 1.1). This phenomenon occurs when light is converted into heat in the skin. Conversely, light can be created by applying energy to a material. This phenomenon is used when laser is made.



Fig. 1.1 Light and matter

1.1.1 Electromagnetic Radiation

Light refers mainly to the visible range (400–760 nm). But visible light refers to light in the narrow sense, while light in the broad sense refers to electromagnetic radiation (EMR). Electromagnetic waves are all the energy that travels in space in the form of waves by electric and magnetic fields [2]. Electromagnetic waves range from visible rays to short wavelengths of γ -rays and X-rays to the long wavelengths of microwaves and radio waves (Fig. 1.2). Electromagnetic waves have both the properties of waves and energy-bearing particles

(photons). This is called wave–particle duality [3]. In the macroscopic world, which is usually visible, it exhibits properties of waves, but in the microscopic world, which can only be seen under a microscope, it exhibits properties of particles.

Each electromagnetic wave has its own wavelength and frequency [4]. Lasers used mainly in the dermatologic field express electromagnetic waves with nanometer (nm), which is a unit of wave. The electromagnetic spectrum used in the dermatological field includes ultraviolet (UV), visible, near-infrared (NIR), mid-infrared (MIR) and far-infrared (FIR) (Table 1.1) [2].

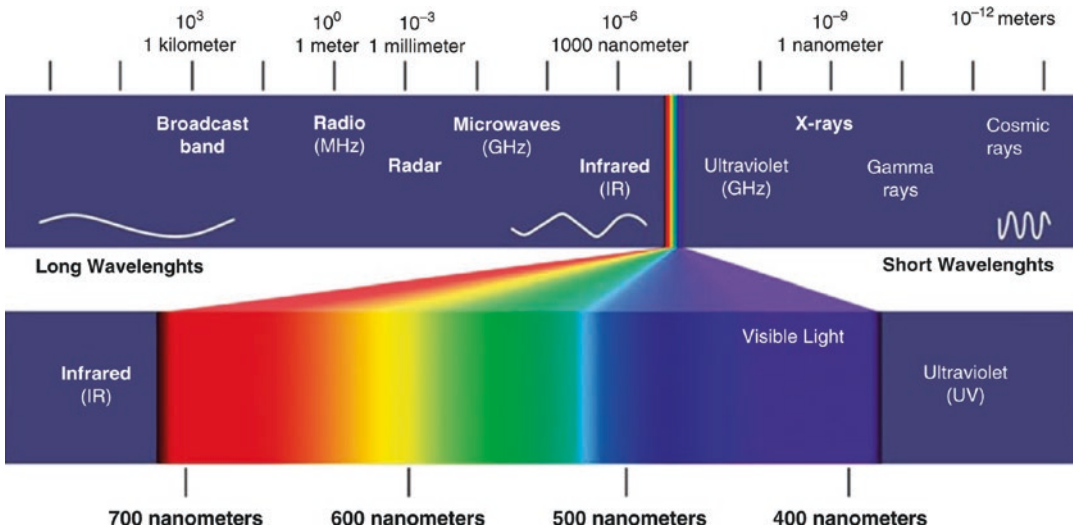


Fig. 1.2 The electromagnetic spectrum. (Reproduced from [1])

Table 1.1 The range and wavelength of electromagnetic waves

| Range | Nanometer |
|---------------------|-----------|
| Ultraviolet (UV) | 200–400 |
| Visual | 400–760 |
| Near-infrared (NIR) | 760–1400 |
| Mid-infrared (MIR) | 1400–3000 |
| Far-infrared (FIR) | >3000 |

1.1.2 Principles of Laser Generation

The most basic unit of light is photon and the most basic unit of matter is atom. Atoms are composed of a nucleus, containing positively charged protons and neutral neutrons. Negatively charged electrons orbit the nucleus (Fig. 1.3). Electrons orbit in a stable resting state (ground state). This state is the state of lowest energy. When energy comes in from the outside (this is called pumping), the ground state electrons jump to a higher energy level at a position further from the nucleus and will then be in an excited state. But the excited state is a very unstable state and the electron will try to return to the stable ground state. As the excited electrons return to their resting state, they release the energy in the form of photons with the orbit energy difference. This is called spontaneous emission [2].

An Intuitive Explanation about Spontaneous Emission. (Explanation by Physicist Dr. Jong Gook Lee) [5, 6]

To intuitively explain the principle of laser such as spontaneous and stimulated emission, the interaction of atoms and light should be first understood.

First, let's think of light as a particle (photon) and not as wave. Particles are countable (one, two...). Atoms can be excited or unexcited when they receive energy. Atoms are composed of a nucleus and electrons. Light interacts with electrons. When the electron absorbs light, it becomes excited and the energy of the electron increases, and when the electron emits light, the energy of the electron decreases. Now let's suppose that atoms are a staircase on which electrons go up and down. The excited state of atoms means that electrons go up on the staircase. (Atoms and electrons will be distinguished in the following contents. Electrons can be thought of as particles that go up the staircase.)

When we played rock-paper-scissors during our childhood, we went up one

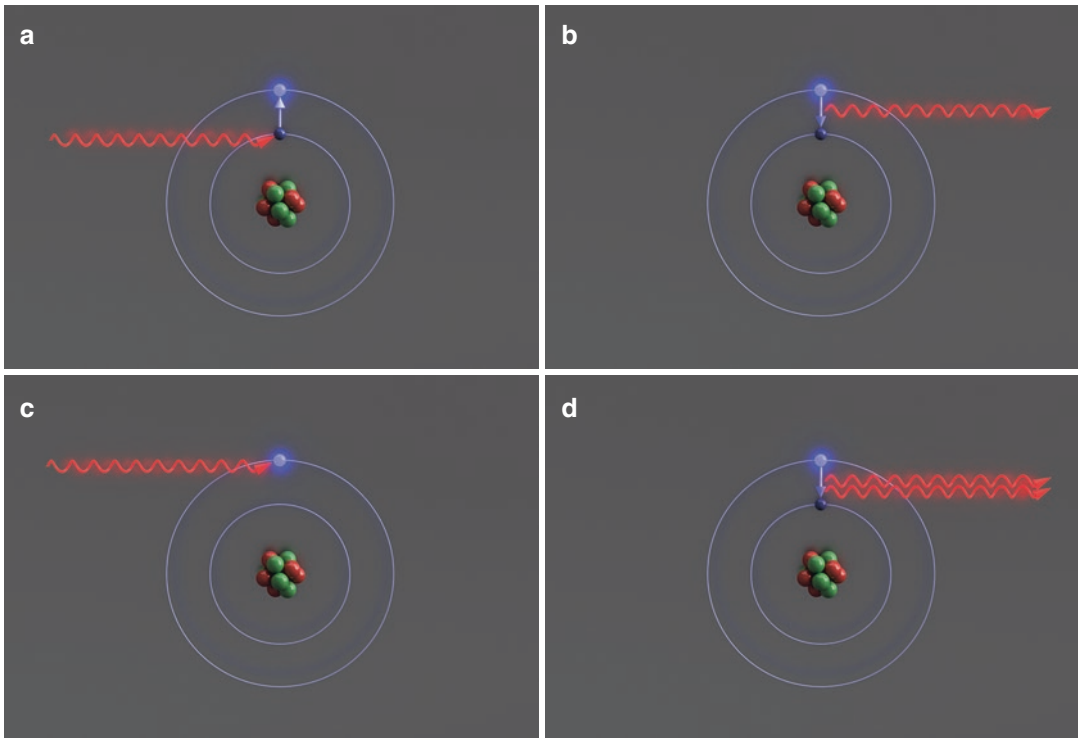


Fig. 1.3 Spontaneous and stimulated emission. The electron is usually located in a low energy orbit (resting state). (a) If an electron absorbs energy, it goes up to the excited state. (b) As the electron in the unstable and excited state goes back to the low energy state (resting state), it emits photons (spontaneous emission). (c) If the already excited

electron absorbs yet another photon, (d) as the electron return to the resting state, it will emit two photons with the same energy, direction, and frequency (stimulated emission). (Published with kind permission of © Jin Kwon Cho 2019. All rights reserved. Modified from [1])

staircase if we won and went down one staircase if we lost. Similarly, when electron receives a photon, it goes up the staircase and is excited. The bottom of the stairs is the lowest energy state, which is the resting state. The stairs (atoms) on which electrons go up and down are already determined. Let's think about an atom of which the staircase consists only of a resting state and an excited state.

The input light (Fig. 1.4) is considered as a particle (photon) from the atom's point of view. The light enters as a wave but is a particle from the atom's perspective. This concept is called wave-particle duality. The electron in the resting state absorbs photons and goes

up the staircase and become excited. The height of the stairs varies from atom to atom, which represents the energy of the photon which can be absorbed by electrons. If a photon with a higher or lower energy than the height of the stairs is thrown at the electron, the electron will not be able to absorb the photon. Electrons have a picky appetite. Electrons can only stay in an excited state for a short period of time and as the excited electrons return to their resting state, they must emit the same number of photons previously absorbed. The emitted photon should have the energy corresponding to the height of the stairs. In conclusion, electrons release the energy previously absorbed (Fig. 1.5).

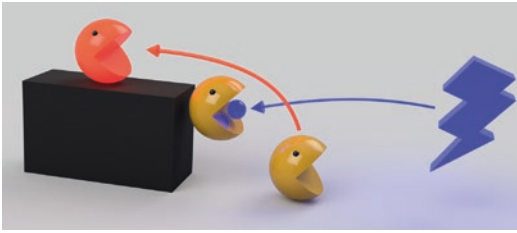


Fig. 1.4 The electron (packman) in the resting state becomes excited when it absorbs light (photon). (Published with kind permission of © Jin Kwon Cho 2019. All rights reserved)

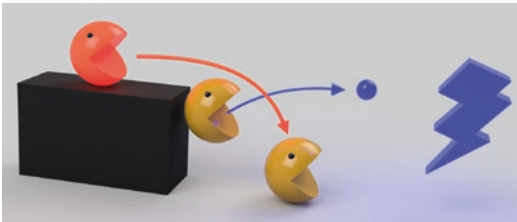


Fig. 1.5 The excited electron (packman) emits light (photon) when returning to the resting state. (Published with kind permission of © Jin Kwon Cho 2019. All rights reserved)

The higher the height of the stairs, the more energy the electron returns. If the height of the stairs is very high, the energy becomes X-rays and γ -rays. If the height of the stairs is very low, the energy becomes infrared light (Energy is inversely proportional to wavelength.)

$$E = h \cdot \nu = \frac{h \cdot c}{\lambda}$$

E : energy of radiation, h : Planck's constant (6.6×10^{-34} Js), ν : frequency, c : constant velocity (299,790 km/s), λ : wave.

Another thing to note is that the excited electrons do not always return to the resting state. However, it is likely that electrons return to the resting state. Also, the electrons in the resting state do not always absorb photons but have a high probability of absorbing photons. Thus, everything

in the atomic world is represented by probability.

The above is summarized as follows:

1. Light behaves as particles when entering a microscopic world such as atoms, but they behave as waves in the macroscopic world.
2. Each atom has its own energy staircase.
3. Whether the electron is in the ground state, goes up to the excited state, or comes down from the excited state to the ground state is all decided by probability.
4. Eye for an eye: Electrons return the same amount of energy previously absorbed.
5. The electron only absorbs photons with energy as high as the height of the stairs.

The emitted photons produce the light of a certain wavelength depending on the atoms. In nature, various lights are produced because various atoms are mixed in nature. For example, light from a match is usually red, while light from the stove is mostly blue. This can be easily understood if atoms are thought of as springs. Some springs are strong while others are weak. Regardless of the force applied, the time that spring is stretched and reduced according to its strength is constant. Similarly, atoms have their own frequency (or wavelength) which is called the atom's natural frequency. Atoms emit light as much as it vibrates and the wavelength of the emitted light is inversely proportional to the atom's natural frequency. Thus, if made up of single atoms, only one wavelength of light will be produced. This is the principle of monochromaticity, a characteristic of laser [4].

In some cases, the naturally emitted photons may meet electrons of atoms in excited states. An interesting phenomenon occurs at this time. As the electrons return to the resting state, they emit two photons. This phenomenon is called stimulated emission [2]. The two stimulated emitted

photons have the same energy, same shape in time, and space just like twins. This is the principle of coherence, a characteristic of laser [2]. If these two twin photons meet two electrons, then four twin photons are emitted. The four photons emit 8, 16, and 32 photons again, i.e., they increase exponentially. This is the principle of high intensity, a characteristic of laser.

In 1917, Einstein published the theory of stimulated emission of radiation, which is the principle of laser generation [4].

An Intuitive Explanation about Stimulated Emission. (Explanation by Physicist Dr. Jong Kook Lee)

In the above explanation of spontaneous emission, only the irradiation of light to the atoms in resting state was considered. Now let's think about what will happen when light is irradiated to an excited atom. Light with the energy which is equal to the height of stairs should be irradiated; nothing will happen if the energy is larger or smaller. As previously explained, all is decided by probability in the atomic world. Let's think of the electron on top of the stair as a person on top of the mountain. If the wind blows softly, there is little chance that the person will fall from the top but if a typhoon blows, the chances are greater. Likewise, if a photon is thrown at an excited electron, the likelihood that the electron falls to the ground is greatly increased. Throwing photons at excited electrons and making them fall to the resting state is called stimulated emission. The excited light is not absorbed by the electrons, but rather the photons shake electrons, just as the wind shakes the person. However, the electron that falls to the ground must emit photons, so two photons pop out (Fig. 1.6).

Two photons mean that light with twice the energy comes out. In other words, the light coming out is twice as bright as the input light. Matter consists of many atoms.

What if all the atoms are excited and they all receive one photon? Because the electron that receives one photon returns two photons and the electrons that receive these photons also return two photons each, ultimately, numerous photons pop out of the matter (Fig. 1.7). These photons have the same energy and become light with the same wavelength, which is laser.

1.1.3 Composition of Laser

The conversion of electrons into the excited state is called "population inversion" [2], and in this state, photons are created exponentially with as many as 10^{20} photons when stimulated emission occurs [4]. Because light travels, if the medium is long enough, it can produce many photons. But because of space constraints, two mirrors are placed at each end of the laser medium and the photons travel between the two mirrors, creating photons exponentially. In this process, the photons that are not reflected vertically to the mirror disappear and only the vertically reflected photons remain (Fig. 1.8). That is the principle of collimation, a characteristic of lasers [2].

One of the two mirrors reflect 100% of light, another mirror passes through the light partially so that some of the stimulated photons go off the two mirrors, past the delivery device, and are col-

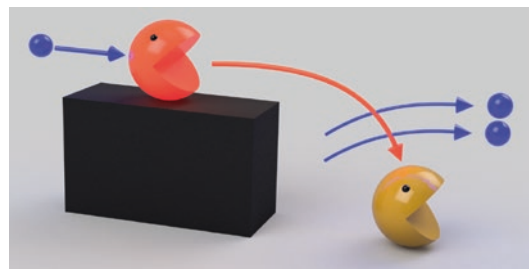


Fig. 1.6 When an excited electron (packman) meets a photon, they fall down to the ground state and two photons pop out. These two photons have the same energy. (Published with kind permission of © Jin Kwon Cho 2019. All rights reserved)

Fig. 1.7. Two photons meet four excited electrons and create four photons. In this way, photon is amplified to produce bright light. (Published with kind permission of © Jin Kwon Cho 2019. All rights reserved)

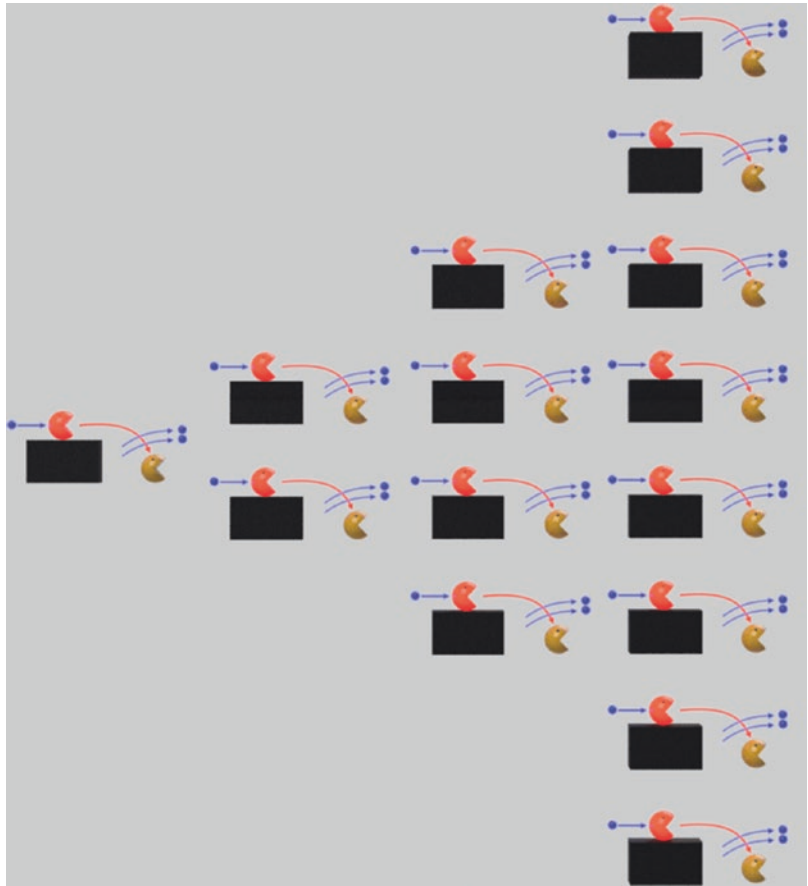
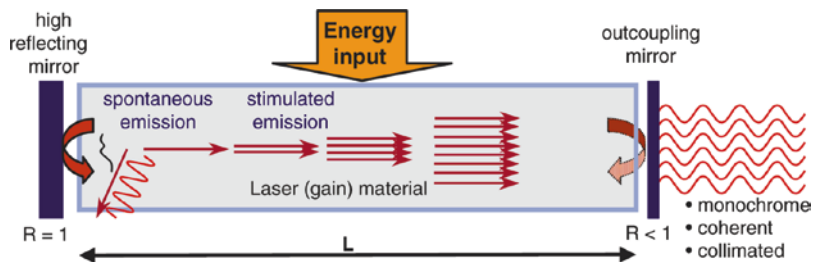


Fig. 1.8 Principle of a laser. (Reproduced from [3])



lected in one place by the lens. Ultimately photons are delivered to the skin (Fig. 1.9).

If you look inside the laser machine, they consist of three parts: pumping system, laser medium, and optical cavity with two mirrors [2]. Additional devices are the cooling device and the delivery system. External energy source serves to supply energy (pumping) and laser medium excites the electrons by the energy received from outside. Electricity or flashlamp is used as an external energy source. The typi-

cal laser that uses electricity as external energy source is CO_2 laser and the typical laser that uses flashlamp as external energy source is Q-switched laser.

In laser mediums, there are gas types (CO_2 and argon), liquid types (dye), and solid types (ruby, alexandrite, Nd:YAG, and diode). The wavelength of the laser is determined by the laser medium [2]. For example, CO_2 generates 10,600 nm wavelength, ruby 694 nm wavelength, and alexandrite 755 nm wavelength (Table 1.2).

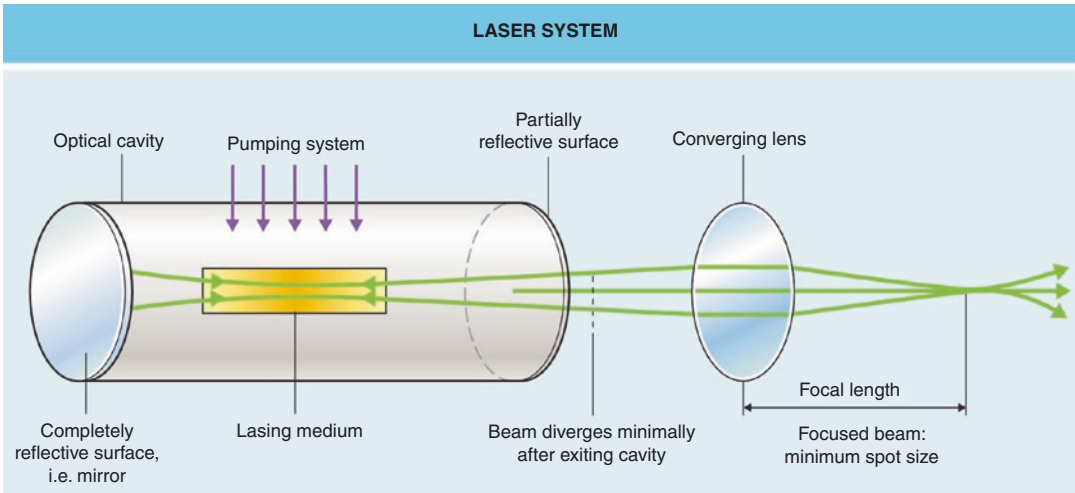


Fig. 1.9 Laser system. Laser consists of lasing medium, pumping system, optical cavity, and delivery system. (Reproduced from [7])

Table 1.2 Laser media and wavelength. (Modified from [2])

| Laser type | Lasing media | Wavelength (nm) |
|------------|-----------------|-----------------|
| Liquid | Dye | 585, 595 |
| Gas | CO ₂ | 10,600 |
| | Argon | 510 |
| | Excimer | 308 |
| Solid | Ruby | 694 |
| | Alexandrite | 755 |
| | Er:YAG | 2940 |
| | Nd:YAG | 1064, 1320 |
| | Diode | 808, 810, 1450 |

So, when we talk about the type of laser, when you say ruby laser we know that the wavelength of the laser is 694 nm, and vice versa. Therefore, we must know the wavelength corresponding to the laser medium.

However, Nd:YAG laser can produce 1064, 1320 nm, etc., and diode laser can produce 808, 810, 1450 nm, etc. In other words, some lasers are able to produce multiple wavelengths with one medium. This is why when describing a laser, the wavelength and medium must be described together. For example, “694-nm ruby laser.” In addition, because the laser machine itself varies depending on the irradiation time, the irradiation time should also be described. However, I say simply “Q694” or “long1064” in conversation or lectures because of long name.

IPL (intense pulsed light) is different from laser in that it does not have a laser medium and optical cavity. It only has flashlamp as the external energy source [4]. Flashlamps are different from single-wavelength lasers because they emit a variety of lights. Flashlamps are surrounded by water so that wavelength above 1000 nm with high water absorption coefficient is absorbed by the water and disappear, so that only the light below 1000 nm is emitted. If UV wavelength is cut off by the optical cutoff filter, 500–1000 nm wavelength light can be emitted. Various wavelength bands can be selected depending on the optical filter. For example, 640-nm filter emits light in the wavelength range of 640–1000 nm.

1.1.4 Three-Level and Four-Level Lasers

For stimulated emission, the electron in the ground state should move to the excited state. But excited state is unstable so that electrons should move to the ground state before stimulated emission. Therefore, there are no two-level lasers in which only the ground state and the excited state exist. To prevent returning to the ground state, mediums with metastable state—which is a stable state between ground state and excited state—are used in real lasers [8].

An Additional Explanation of Laser Principle (Explanation by Physicist Dr. Jong Kook Lee)

The principle of laser cannot be understood perfectly, with only the concept of stimulated emission described earlier. The reason for this is because atoms in excited states may not only be emitted by stimulation but may also be emitted spontaneously. Even if you try to put electrons in the excited state, and try to induce stimulated emission by irradiating light, it is of no use if the electrons are already spontaneously emitted. And electrons fall at random in any state during spontaneous emission (in the previous figures, ground state was expressed as if it was one, but in fact, there are several ground states) so that miscellaneous kinds of light are emitted and some of the light are absorbed by the electrons again. As a result, light with less energy than the input is emitted. Therefore, it is necessary to have a mechanism that suppresses spontaneous emission and proceeds only with stimulated emission (Fig. 1.10).

In Fig. 1.10, the concept of metastable state is introduced. Special materials can be used to create metastable states. The rule for changing electron's state is as follows

1. The electrons in the ground state rise up to the excited state by the pumping process.
2. But the excited electron cannot fall to the ground state. It can only fall to the metastable state.

The excited electrons accumulate in a metastable state over time. When a lot of electrons accumulate in the metastable state and light is irradiated, strong light is emitted and the laser we want can be produced.

Thus, the laser which has ground, excited, and metastable state is called the three-level laser and the laser that has two metastable state is called the four-level laser. The typical three- and four-level lasers are ruby laser and Nd:YAG laser (Figs. 1.11 and 1.12) [3].

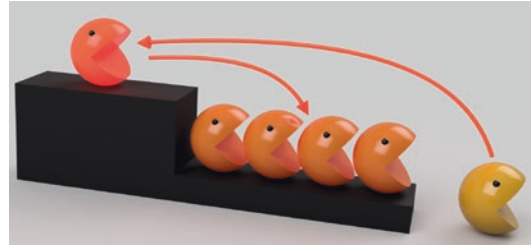


Fig. 1.10 When the electrons in the ground state rise to unstable excited state, it falls back to metastable state. (Published with kind permission of © Jin Kwon Cho 2019. All rights reserved)

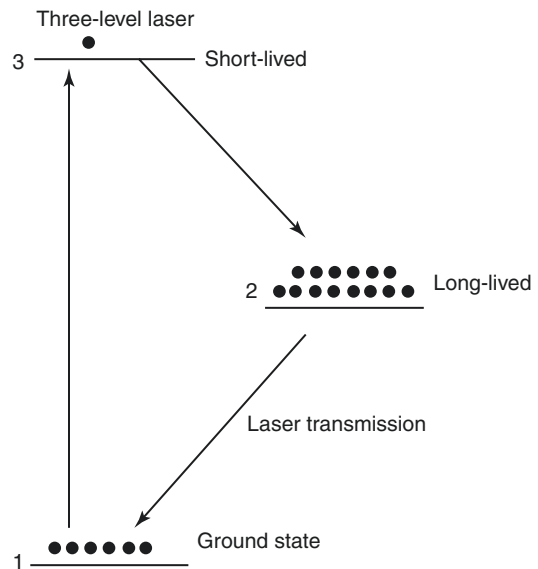


Fig. 1.11 For a three-level laser system, it is possible to achieve a larger population of level 2, as compared to the ground state, by very intense pumping from level 1 to level 2. (Reproduced from [9])

In three-level laser, lower laser level is ground state so that there are many electrons in low energy level. Therefore, high energy is needed for population inversion and a flash lamp with high output is used. Thus three-level lasers are usually pulsed-wave lasers. Because three-level laser needs high output, this makes them expensive but, the laser can produce very high energy (pulse energy 20 J). On the other hand, four-level lasers need low energy for population inversion so that low output flashlamp can be used. Therefore, most continuous-wave lasers use four-level laser [3].

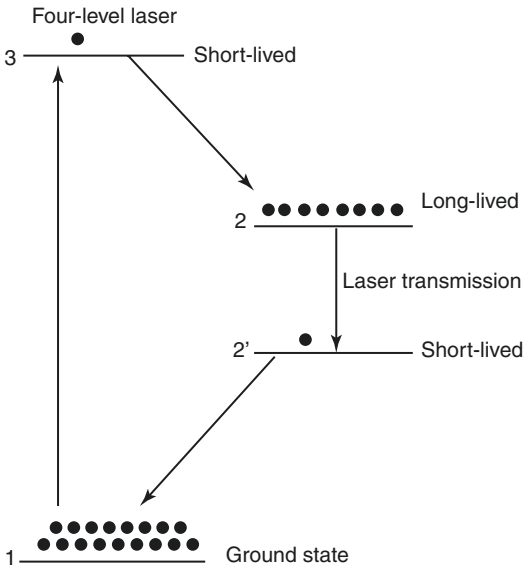


Fig. 1.12 For a four-level laser system, it is possible to achieve, even by weak pumping into the long-lived level 2, a population inversion as compared with the short-lived level 2', due to its short life, level 2 empties immediately. (Reproduced from [9])

and the laser of high intensity can be produced. Therefore, laser can also be called the machine which amplifies low-output light and converts to high-intensity light. However, from the laser physician's point of view, monochromaticity is more important because laser should be selected by target chromophore. Monochromaticity will be discussed later.

Unit conversion of a second should be understood (Table 1.3). In most laser texts, for example, it is not written as 10^{-3} s, but rather in milliseconds, or simply the abbreviation ms. The novice laser physician may be confused by the unfamiliar second unit. The least you need to know is which units are bigger or smaller. Also, since all the units are shorter than 1 s, you might think that there isn't a big difference between each unit, but you must remember that there's more than 1000 times the difference.

1.2 Characteristics of Laser

Laser is named LASER after the first letter of Light Amplification by Stimulated Emission of Radiation [2]. Currently, lasers can produce from 100 nm to 3 mm wavelength. In dermatology, from 308-nm excimer laser to 10,600-nm CO₂ laser is used. Laser can be divided into continuous wave and pulsed wave by irradiation method; the time of irradiation is from second to femto-seconds (10^{-15} s). Also, laser with a high output density of up to 10^{10} W/cm² can be produced [4].

Lasers have four characteristics which are different from light (Fig. 1.13). First, the photons with one wavelength are emitted depending on the laser medium (monochromaticity), and second, the two twin stimulated emitted photons have the same shape in time and space (coherence). Third, the laser goes straight without spreading sideways (collimation). And finally, photons are increased exponentially up to 10^{20} (high intensity). Of the four characteristics, coherence is important for laser manufacturing. Because of coherence, the wavelengths of the photons are overlapped so that the energy of the photons cannot be canceled out

1.2.1 Parameters

Laser has various parameters of energy (Table 1.4). Energy is the number of emitted photons during a single pulse. Because high-quality laser emits a lot of photons during a single pulse, energy is used to represent the power of laser in pulsed wave laser in which irradiation time is fixed. On the other hand, power is the number of emitted photons in unit time. The time concept is included in the power compared with energy. Because power is the number of photons "per hours" in engineering concept, the concept is the output, capacity (force) of a machine. Because "energy = power × time," energy means "the total amount of applied force" or "the amount of work which a machine has done." Power is mainly used to represent the output of continuous-wave laser [10].

Thus, energy and power are all used to express the output of laser. But, for laser physicians, the number of irradiated photons on skin is important, which is why the concept of unit area is needed. Therefore, the parameters of energy density and power density are used. Energy density

Fig. 1.13 Four laser properties. (Modified from [2])


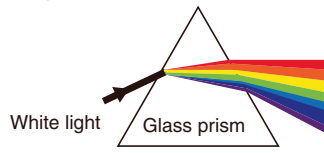



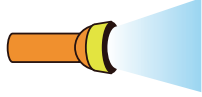
| | Laser light | Non-laser light(e.g., flashlight) |
|---|--|---|
| ① | <p>Monochromatic</p>  | <p>Polychromatic</p>  |
| ② | <p>Coherent</p>  | <p>Incoherent</p>  |
| ③ | <p>Collimated</p>  | <p>Divergent</p>  |
| ④ | <p>High intensity</p> | <p>Low intensity</p> |

Table 1.3 Unit conversion of a second

| Units | Second |
|------------------------|------------|
| Millisecond (ms) | 10^{-3} |
| Microsecond (μ s) | 10^{-6} |
| Nanosecond (ns) | 10^{-9} |
| Picosecond (ps) | 10^{-12} |

Table 1.4 Energy parameters of optical radiation

| Parameter | Units | Formula |
|-----------------------------|-------------------|---|
| Energy | Joule (J) | Energy = power \times s |
| Power | Watt (W) = J/s | Power = energy/s |
| Energy density (fluence) | J/cm ² | Energy density = energy/cm ² |
| Power density (irradiation) | W/cm ² | Power density = power/cm ² |

is the number of irradiated photons in a single pulse, in unit area of skin. It is often called fluence. Power density is the number of photons which are irradiated on skin, per unit time and unit area.

So which parameter is more important? Fluence or power density? When laser contacts skin, temperature rises. In other words, light energy is converted into thermal energy. The more the number of photons, the higher

the temperature will be. Because the number of photons is included in both fluence and power density, the higher fluence or power, the higher temperature will be. But if the number of photons is the same, which temperature is higher? Ten photons in skin per 1 s or 10 photons per 10 s? Of course, in the former case, the temperature will be higher. For example, in both the former and the latter, fluence is 10 J/cm². But power density is 10 W/cm² in the former case and 1 W/cm² in the latter case. That is, power density is more important than fluence to us. But, you may think that fluence is more important because only fluence appears in the panel of commonly used Q-switched laser and only the fluence can be controlled in Q-switched laser. In even CO₂ laser, the unit of power is not W/cm² but Watt. Therefore, laser physicians should keep power density in mind even if power density is not represented in the laser panel.

Table 1.5 shows the fluence and pulse duration, which is often used clinically for each laser. Corresponding power density was also calculated. The table shows some interesting phenomena. The vertical line of the pulse duration shows that power density increases rapidly as the pulse duration decreases [4]. Even when fluence decreases,

power density rises sharply. As mentioned previously, there is a big difference in (1) fluence that is displayed and the (2) real power density.

There is another thing to note in Table 1.5. Power density is somewhat related to the power of the laser because the concept of power is included in power density. The power determines the value of laser machine. Currently, Q-switched laser is much cheaper and there are some IPLs that are expensive, but in the past, Q-switched

laser was much more expensive than IPL. Also, according to selective photothermolysis (this will be explained later), smaller targets may be treated by shorter pulse duration. In other words, expensive lasers treat more targets because of the shorter pulse duration, while cheaper laser cannot treat certain targets because it cannot shorten the pulse duration.

The other parameters used for the lasers are shown in Table 1.6.

Table 1.5 My parameters for various lasers

| Radiation | Fluence (J/cm ² = W/cm ² × s) | Pulse duration (ms) | Power density (W/cm ²) |
|--|---|---------------------|------------------------------------|
| Frequency double Nd:YAG laser (e.g., telangiectases) | 18 | 10 | 1800 |
| IPL (e.g., freckles) | 17, broadband | 7 | 2428 |
| Pulsed dye laser (e.g., port-wine stains) | 5.5 | 0.45 | 12,222 |
| Q-switched ruby laser (e.g., tattoos) | 4 | 0.00004 | 1 × 10 ⁸ |

Frequency double Nd:YAG laser means 532-nm laser. Because frequency and wavelength are inversely proportional, frequency double Nd:YAG laser means 532 nm, which is half of Nd:YAG’s wavelength, 1064 nm

1.2.2 Spatial Mode of Beam

Beam profile is a term that describes the spatial mode of laser beam and represents the spatial distribution of laser intensity. Typical beam profiles are Gaussian mode and flattop (top-hat) mode (Figs. 1.14 and 1.15). There are many other different beam profiles; each beam profile

Table 1.6 Parameters of optical radiation [2]

| Parameter | Units |
|----------------|--|
| Pulse duration | Seconds, milliseconds, microseconds, nanoseconds |
| Frequency | Hertz (Hz) = pulses per second |
| Wavelength | Nanometers (nm) |
| Spot size | Millimeters (mm) |

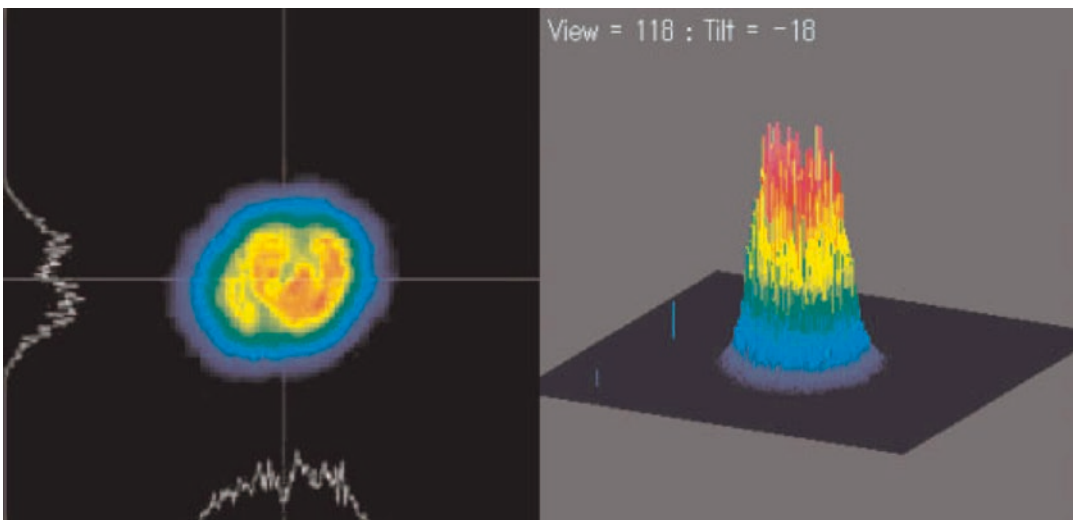


Fig. 1.14 Gaussian mode. 3D-beam profile of the C3 laser (wavelength 1064 nm, spot size 4 mm, energy per pulse 450 mJ/cm², pulse duration 8–10 ns, pulse fre-

quency 10 Hz) produced by DataRay v.500 M4 software. This is the typical “Gaussian” profile. (Modified from [11])

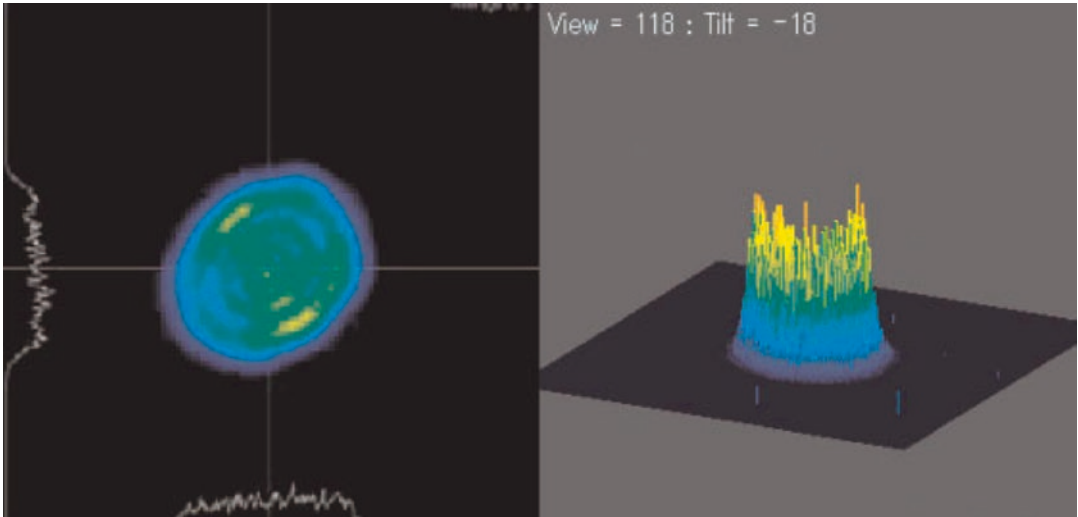


Fig. 1.15 Flat-top mode. 3D-beam profile of the C6 laser (wavelength 1064 nm, spot size 4 mm, energy per pulse 1000 mJ/cm², pulse duration 8–10 ns, pulse frequency 10 Hz) produced by DataRay v.500 M4 software. The dis-

tribution of the energy density is more homogeneous as compared with C3. The C6 beam has a flat top and most of the area is equal to the average of the energy applied. (Modified from [11])

is represented by the number beside the word of TEM (transverse electromagnetic mode). For example, Gaussian mode is basic mode, called as TEM₀₀ and TEM₁₀, TEM₂₀ are doughnut-shaped and target-shaped mode [3].

Beam profile is determined by the shape of mirror in optical cavity [3]. Also, beam profile is determined by the delivery system and, in flat-top mode, 80–90% in the center of the cross section has uniform distribution because countless reflections occur in the flexible fiber delivery system of fiberglass [12].

In Gaussian mode, the laser intensity is like Gaussian normal distribution in which the center of the spot is highest in intensity and decreases toward the edge. In Gaussian mode, the point where the laser's intensity drops to 86% is defined as the beam diameter (Fig. 1.16) [2].

Gaussian mode may not be the shape we want. For example, when treating lentiginos, the center of the beam may be very strong so that PIH occurs, the middle of the beam may remove lentiginos without side effects, while the edge of the beam may not be able to remove lentiginos due to very weak energy. Though some degree of overlapping is required to make uniform distribution, it is technically very difficult unless a scanner is

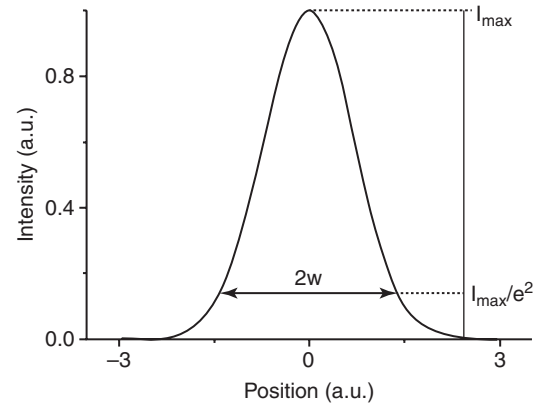


Fig. 1.16 Gaussian output beam distribution; $2w$ shows the spot size diameter measured at a value where the intensity decreases to $1/e^2$ of its maximum. (Reproduced from [13])

attached and mechanically matched correctly. Therefore, flat-top mode is a suitable form to remove lentiginos. But it's not right to simply say that flat-top mode is good and Gaussian is bad. It may vary depending on the treatment target which mode should be selected. For example, Gaussian mode is more appropriate than flat-top mode in treating melanocytic nevi.