SOLID STATE LASERS

Tunable Sources and Passive Q-Switching Elements

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Yehoshua Kalisky

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To
Ofra
Tomer
Efrat
Itai
Aminadav

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Preface

The possibility of controlling and continuously changing laser emission wavelengths in a wide spectral range without using external elements based on nonlinear optics (to shift the fundamental wavelength) is of primary importance to scientists. However, for years the tunable laser sources were based on liquid dye lasers, which provided only a limited solution to the demand for tunable sources due to their inherent limitations. Since that time there have been impressive advances in experimental and theoretical research in solid state physics, as well as in the optics and spectroscopic properties of solids. Quantum mechanical tools provided further insights into light–matter interaction, photophysical processes, elementary excitations, and host–dopant interactions. Combining those tools with advanced experimental techniques has yielded a means of observing and understanding the optical properties of active ions, such as rare earths and transition metals, and their potential as laser sources. A fundamental understanding of the mutual interactions between the *d* orbitals of transition-metal ions and the crystal field of various hosts, coupled with the effects of the crystallographic sites and crystalline symmetries, led to a better understanding of ion–host interaction.

Comprehension of the basic spectroscopic and crystallographic properties allowed for the prediction and engineering of new tunable solid state lasers by adjusting the crystal field of a large number of crystalline hosts according to the desired spectral range, from the UV (Ce^{3+}-doped crystals) into the visible mid-IR (Cr^{3+}- and Cr^{4+}-doped hosts). With the advent of novel high-power pumping sources, it became possible to design and operate a new class of tunable solid state laser devices for various applications.

This book is a continuation and a companion volume to my previous book *The Physics and Engineering of Solid State Lasers* (SPIE Press, 2006), and it provides an updated overview of tunable solid state lasers and passive Q-switches based on *d*-element ions. The main purpose of this monograph is to coherently demonstrate the design of new laser materials based on quantum mechanical principles, spectroscopic properties of transition-metal ions, and ion–host interaction. This approach includes the theory of the electronic structure of transition-metal ions, modeling of energy transfer and non-radiative processes, and symmetry considerations in the spectroscopic analysis of *d* orbitals. Each chapter features a list of references to support the data and encourage readers to extend their knowledge in the relevant subject.

Another aspect of the transition-metal-ion-doped crystals stems from the unique combination of optical and thermo-mechanical properties that makes them ideal candidates as passive Q-switching devices for Nd:YAG and Yb:YAG lasers. The theory, properties, design, and updated performance of passive Q-switched systems is presented and accompanied with recent advances and applications.

I would like to extend my gratitude to Dr. Gregory J. Quarles (Opto-electronics Management Network, United States) and Prof. David Titterton (DSTL, United Kingdom) for their illuminating remarks and advice. I am especially grateful to my wife, Dr. Ofra Kalisky, for her valuable comments, constant support, and inspiration. Last but not least, I would like to thank SPIE for promoting the idea of writing my second book that facilitates the understanding of *d*-element lasers and devices. By doing this, interested physicists and engineers can gain an integrated comprehension of lasers and laser technology, based on rare earth and transition-metal ions. I would particularly like to thank Tim Lamkins and Scott McNeill for their patience, flexibility, valuable comments, and continuous support.

Yehoshua Kalisky
Beer Sheva, Israel
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List of Abbreviations and Acronyms

A	Einstein coefficient for spontaneous emission
B	bulk modulus
B	Einstein coefficient for stimulated transitions
$BeAl_2O_4$	alexandrite
AR	antireflecting (coating)
at. %	atomic percent
BBO	β-barium borate
CNC	colloidal nanocrystals
CW	continuous wave
DPSSL	diode-pumped solid state laser
Dq	crystal-field-strength parameter
LuAG	lithium aluminum garnet
E	Young's modulus
ESA	excited-state absorption
FOM	figure of merit
FWHM	full width at half maximum
G	shear modulus
$GdVO_4$	gadolinium vanadate
GGG	gadolinium gallium garnet
$g(\nu)$	spectral lineshape function
HEM	heat exchange method
K	segregation coefficient
KGW	$KGd(WO_4)_2$
KLM	Kerr-lens mode locking
KYW	$KY(WO_4)_2$
LiCAF	lithium calcium aluminum fluoride ($LiCaAlF_6$)
LiSAF	lithium strontium aluminum fluoride ($LiSrAlF_6$)
LiSGaF	lithium scandium gallium fluoride ($LiSrGaAlF_6$)
LLF	$LiLuF_4$
LS coupling	Russell–Saunders coupling
M	hardness, Moh

Mg_2SiO_4	forsterite
ML	mode locking
$<n>$, n, m	phonon occupation number
NA	numerical aperture
R_T	thermal shock parameter
RTA	$RbTiOAsO_4$
SA	saturable absorber
SESAM	semiconductor saturable absorption mirror
SHG	second harmonic generation
T_0	small-signal transmission of the saturable absorber
$Ti{:}Al_2O_3$	titanium-doped sapphire
YAG	yttrium aluminum garnet ($Y_3Al_5O_{12}$)
YLF	yttrium lithium fluoride ($YLiF_4$)
YOS	Y_2SiO_5
YSGG	yttrium scandium gallium garnet
YVO_4	yttrium vanadate
Z	atomic number
ZGP	$ZnGeP_2$
θ	strain
νp	Poisson's ratio
$\rho(\nu)$	energy density per unit frequency
σ_a	absorption cross-section
σ_{ab}	absorption cross-section of a lasing center
σ_{eff}	effective cross-section of a saturable absorber
σ_{em}	emission cross-section of a lasing center
σ_{es}	excited-state absorption cross-section of a saturable absorber
σ_{esa}	excited-state absorption of a lasing center
σ_{gs}	ground-state absorption cross-section of a saturable absorber
τ_{spon}	spontaneous lifetime