

DEPARTMENTS

BOOK REVIEWS

Frequency Stabilization of Semiconductor Laser Diodes

Tetsuhiko Ikegami, Shoichi Sudo, and Yoshihisa Sakai, 358 pages including preface, illustrations, index, and references. ISBN: 0-89006-648-5. Artech House Inc., 685 Canton Street, Norwood MA 02062 (1995) \$88 hardbound.

Reviewed by John L. Hall, JILA, University of Colorado and NIST, Boulder, CO 80309-0440.

This is a useful book on the subject of stabilizing lasers, mainly semiconductor lasers, onto various atomic and molecular reference lines. It has a huge number of references (more than 500) and is profusely illustrated with figures and tables of data. The authors begin their six-page introduction with a nice quote from Professor A. L. Schawlow concerning the unpredictability of the human creative force when presented with challenge and a new science-based opportunity. Remarkably, only one paragraph discusses why the interest in frequency-stabilized lasers is timely or important, and so this reviewer expands the question briefly: During the 35 years of the laser epoch, we have seen frequency-stable sources in the rf domain transformed from power-hungry expensive laboratory devices into ubiquitous digital devices operating in the rough environment of the human wrist. In years past, even if there had been a need (which I doubt), the original technology would have been available to just a few of the wealthiest individuals. Nowadays I suppose digital wristwatches are available to perhaps 10% of all the earth's people. Frequency standards in the optical domain, though, do not yet appear to fill such a great and universally direct purpose. Indirectly, however, the effects and needs may be beginning to materialize from our insatiable desire for communication bandwidth—the upcoming fiber-to-the-home revolution—with its movies, two-way video, and speedy access of remote libraries. Clearly the first area for improvement is more speed, but such clever, cost-effective increases in fiber communication speed can be further enhanced by better organizing the light-based digital information packets zooming down the installed fiber optic cables. One of the currently discussed best schemes is to use multiplexing based on multiple wavelengths, thereby in-

creasing the channel capacity for each fiber by perhaps 100-fold or more. For robustness, one would like all stations on such a network to have independent capability to realize the allocated wavelength channels. A minimum capability would be a cold-start way to know optical channel 137 from channel 11, for example. In this, we basically are talking about absolute wavelength/frequency standards. The emphasis must be on the "good enough" and cost effectiveness, since a call to Grandmother will pass through dozens of amplifier/demultiplexer stations on its way. One conclusion is that communication engineers need to learn about optical frequency standards, hence this book by three engineers working for NTT in Japan..

These authors suppose their readers to be technical people, but not necessarily up to speed about diode lasers and frequency stabilization ideas. So in an appropriate, if brief, section, they present the construction and general frequency-stability properties of various laser diodes realized via different physical structures. Generally the controlling phenomena for laser diodes are traceable to their extremely small size, with the diode laser cavity length being only some few hundred micrometers. This leads to a broad resonance for the optical cavity and a correspondingly large "natural" linewidth. As shown by Henry, the situation is even worse because there is a coupling of intensity changes into optical phase changes within the laser resonator. Thus in a solitary diode, linewidths seldom reach the sub-MHz domain. Another issue is the very high power dissipation per unit volume and large intrinsic temperature-dependent gain wavelength, requiring thermal servo control to maintain a fixed lasing frequency. However, for communications purposes, the frequency drift issues seem not too troubling since, after all, in communications one is looking for some rapidly-varying bit pattern or other modulation. Stabilization requirements show up when we want to distinguish multiple laser beams on the basis of their wavelength.

The authors have a useful 42-page presentation of the fundamental concepts of frequency stabilization, beginning with time-delayed heterodyne measurements conveniently implemented with an optical fiber delay line. As one begins to become fully quantitative, it is appropriate to consider

the optical electric field as the basic physical quantity. For the purpose of bringing an outsider some first views of the field, this chapter may be quite suitable. For professionals in this frequency control business, a lot of issues are left unaddressed. Probably the only principle worth fighting about in this context is the obvious statement that a measurement means comparing two sources. For example, with a single frequency discriminator used in a servo loop, the observation that the error point has become quiet is an indication of success in an electro-optic servo design only! It carries no meaning for the linewidth or stability of the servo-controlled system. It is a pity that the book's authors have not imposed their own judgment onto the often-inflated claims made by the authors of several quoted journal articles. Also the bibliography on frequency stabilization regrettably does not include any of the fundamental resources in the frequency metrology field, such as the tutorial publications by NIST (for example, NIST Technical Note #697, "Frequency Measurement Tutorial" and Technical Note #1337, "Characterization of Clocks and Oscillators," the series of Application Notes by Hewlett Packard, and the annual IEEE Frequency Control Symposia.)

The most valuable part of the book in this reader's opinion is the 118 pages in Chap. 4 devoted to atomic and molecular frequency references, with some 270 journal citations. The authors have brought together a first-pass view of molecular spectroscopy, along with perhaps a thousand potential reference lines offered by a few dozen simple molecules. Many of these molecules are included and noted by their application already for stabilizing lasers. The new thrust is to use molecular overtones, transitions from thermally occupied levels to higher vibrational levels with upper-state vibrational quantum numbers 2, 3, 4.... The utility is that these ever weaker transitions occur with shorter wavelengths, and the density of possibilities increases rapidly. If one were equipped visually to utilize absorptions of 1:10,000 or 1:1,000,000, we would enjoy an exceedingly detailed and colorful visible spectrum!

The subject of Chap. 5 is a detailed presentation of the many papers in which various lasers have been stabilized onto various absorption lines. In this way the authors offer us a big data dump: 105 pages and 292 refer-

ences on laser locking. For me, one of the tragedies of this approach is that the understanding and overview of the book's authors have not operated to filter this data. Rather, we get the original authors' opinion and the often inflated claims of what stability was achieved. Quite often one finds a melange in which several different capabilities are discussed as if they were coexisting. If some of these results just sound too good to be true, there may be an easy explanation! Simple reality-checking is recommended for the reader. One particular early estimation of achievable stabilization deserves comment, since the author supposed to use linear spectroscopy of the Doppler-broadened line of methane, some 70-MHz wide at the proposed liquid nitrogen triple point. This gives a stable linewidth something below 1 ppm. But I believe it is unreasonable for modern workers to take seriously the prospect to resolve this (or any) resonance into 10^8 elements and so produce a stability better than 10^{-14} . While the calculated signal/noise ratio may indeed support such a result, the best linesplitting achieved so far is by professionals in the Cesium clock business, reaching "only" one part-per-million after some 40 years of effort! Those of us working 25 years with iodine-stabilized lasers are doing $\sim 1:10^4$. I wish the authors had imposed modern reality standards on these literature reports: it would have increased the value of this book for students.

Some of the weaknesses of the book arise from working in four languages: physics, communication engineering, Japanese, and English. I found a few of the translations confusing, but the ideas usually can be clarified by the context or the graphical data. Another shock came from incorrect translation of a single word, "selection," as used in "selection rules" for transitions between quantum energy levels. "Selective" rules in Chap. 4 are just not the right thing. This language misuse may not be too serious, whereas I found the "explanation" on page 132 of pressure-induced vibration-rotation frequency shifts in terms of the second-order Doppler effect to be just wrong physics. The issue is that collisions lead to energy-level shifts of both the upper and lower states involved in the transition. In hf molecules, these shifts are different and they also depend conspicuously on the rotational quantum number. So you get red or blue shifts depending on whether you increase (R-branch) or decrease (P-branch) the rotational quantum number during the transition.

In summary, this is a useful book with a huge amount of data brought together. I expect it will be permanently "borrowed" by

students in other research groups and so I have bought two copies for my lab.

Ultrafast Fiber Switching Devices and Systems

M. N. Islam, 214 pages, illustrations, index, references, and three appendixes. ISBN 0-521-43191-3. Cambridge University Press, 40 West 20th Street, New York, NY 10011-4211 (1992) \$54.95 hardbound.

Reviewed by Mansoor Sheik-Bahae, University of New Mexico, Department of Physics and Astronomy, Albuquerque, NM 87131.

Among the numerous tantalizing promises that nonlinear optics offered, the most ambitious idea, in retrospect, was the possibility of all-optical switches replacing electronic devices. In the early 1980s, topics such as optical bistability and optical computing dominated many journals and conferences. Although certain practical problems with such concepts have caused the initial optimism to fade, this area of research is by no means forgotten. Work on all-optical switches is continuing, but with attention now directed at a specific, tractable problem: switching and routing of data at an optical fiber interconnect. Islam's *Ultrafast Fiber Switching Devices and Systems* targets this important topic. This book is timely for two reasons. First is the industry's incessant demand for increasing bandwidth utilization in optical communication networks. An all-optical switch will remove anticipated transmission rate bottlenecks caused by conventional interfaces. Second is the need to convey a sense of urgency about the pace of current research. If commercially feasible devices are not introduced before the end of the decade, the all-optical switching concept could be shelved indefinitely.

This book is written from the perspective of time-domain soliton switching, an area the author pioneered while at AT&T. It would make a good complement to existing introductory texts that offer a more elementary treatment of nonlinear optical phenomena in fibers and waveguides. As evident from the title, the author focuses on technical issues pertaining to optical switching in fibers, particularly those involving solitons. Fundamental physics issues are only briefly discussed in three appendixes. Chapter 2 gives a good overview of guided-wave switching techniques, though the core of the book is in Chap. 3 and deals with digital soliton logic gates (DSLGS). The following chapters concern key practical issues associated with implementing DSLGs in a 10 to 100 Gbit/sec data transmission environment. Chapter 5 is particularly important and well placed be-

cause it provides detailed, practical system applications of ultrafast fiber switches. This is significant because there are many books and articles that treat all-optical switches on an elementary level. Islam's book, which targets the practicality of optical switching at the system level, is most welcome.

In summary, this book focuses on ultrafast soliton switching in fibers and addresses issues ranging from essential device features to system applications. It would make a useful addition to the library of anyone with an interest in optical switching, optical communications, and nonlinear optics in general.

BOOKS RECEIVED

Detection of Light: From the Ultraviolet to the Submillimeter, by George H. Rieke. xiv + 344 pp., illus., subject index, problems following each chapter, references at end of book, and two appendixes, including answers to problems. ISBN 0-521-41028-2. Cambridge University Press, 40 West 20th Street, New York, NY 10011-4211 (1994) \$69.95 hardbound. Provides a comprehensive overview of the important technologies for photon detection from the millimeter-wave through the ultraviolet spectral regions. Topics discussed include: photography, intrinsic photoconductors, extrinsic photoconductors, photodiodes, amplifiers and readouts, arrays, photoemissive detectors, bolometers, visible and infrared coherent detectors, and submillimeter- and millimeter-wave heterodyne receivers.

Optical Engineering is currently seeking reviewers for the books listed in the "Books Received" section. In exchange for a publication-worthy critique, reviewers will receive a complimentary copy of the book they review. Interested individuals should contact Dr. Bradley D. Duncan, Book Reviews Editor, The University of Dayton, Center for Electro-Optics, 300 College Park, Dayton, OH 45469-0245. E-mail: bduncan@engr.udayton.edu. Phone: 513/229-2796.

Note from the Publisher

Listings of Short Courses and Meetings will no longer be printed in *Optical Engineering*. They will appear in future issues of OE Reports, SPIE's monthly newspaper.