Patterns in Nature: Why the Natural World Looks the Way It Does

Philip Ball

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Reading this book is like going to an art gallery with a friend who is very learned. Ball presents a rich variety of patterns that exist in nature and the common principles that explain them, even when they appear in unrelated circumstances.

The Introduction sets the subject in context and shows the geometric designs in ancient architecture and in the natural world of the living and nonliving. Chapter 1 includes examples of bilateral symmetry exhibited by fish, mammals, insects, and birds. Snowflakes and honeycombs with hexagonal symmetry have long been admired, photographed, and studied. Sometimes patterns are obtained by breaking the symmetry. In chapter 2, fractals (hierarchical repetition of the same general form at decreasing scales) are illustrated with examples such as florets of broccoli, tree branches, and coastlines. Chapter 3 discusses logarithmic spirals, in which a cone rolls up, and Archimedean spirals, in which a rope rolls up. Spirals show up in chameleon tails, mollusk shells, and in swirling stars of galaxies. Flowing fluids often organize themselves into spiral vortices, with tornados being a dramatic example. Chapter 4 discusses patterns of flow and the emergence of chaotic behavior. Chapter 5 explains how wave patterns form, as in a plate sprinkled with sand and vibrated. Granules move away from vibrating places and fall onto nodal lines, where the plate is not vibrating, and form what is called a Chladni figure. Cracks due to electric discharge form a wavy pattern called Lichtenberg figures. Sand dunes show wave patterns.

Chapter 6 discusses bubbles and foams, where surface tension and pressure of the gas inside control the patterns to minimize the surface. Chapter 7 includes arrays and tilings, starting with wallpapers and flooring, and progresses to crystals and quasicrystals, which are five-sided and were once considered impossible. Chapter 8 covers how a pattern of cracks forms on dry mud, glazes, and paints on a coated surface. The top layer shrinks as it dries, while the bottom layer is still wet and swelling. As a result, there is a differential stress, released by forming a network of cracks with polygonal shapes. Chapter 9 explains the pattern of spots and stripes on animals, such as the zebra, using the reaction–diffusion model of Turing. In this model, ingredients called activators and inhibitors are present in cells. Depending on how they diffuse and react, chemical waves arise, and patterns are formed.

This book draws many examples from materials science: dendrite growth, crystallography, liquid crystals, quasicrystals, dielectrics, and naturally formed materials, which can inspire the creation of new materials and engineering designs. The book appeals to all scientists and to those who like to see art in science. There are 250 patterns in color pictures, juxtaposed thoughtfully, to bring out common themes. After you read this book, you will enjoy looking for patterns around you.

Reviewer: N. Balasubramanian *is an independent research scholar and science writer working in Bangalore, India.*
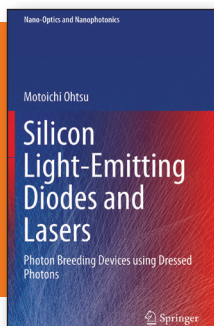
Silicon Light-Emitting Diodes and Lasers: Photon Breeding Devices using Dressed Photons

Motoichi Ohtsu

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192 pages, $129.00 (e-book $99.00)
ISBN 978-3-319-42012-7

The topic of this book is very timely. Direct-bandgap semiconductors are used for conventional light-emitting diodes (LEDs) and lasers. Although there have been tremendous improvements in terms of efficiency, technical challenges remain in fabrication and in handling toxic and rare compounds, such as arsenic and indium. Silicon, being an indirect-bandgap semiconductor, exhibits poor efficiency because electrons must transition from the conduction band to the valence band to emit light spontaneously by electron–hole recombination. However, the momentum of the electron in the conduction band is different from that in the valence band, requiring a phonon in the process to satisfy the net momentum conservation. Modifications of silicon bulk density using porous Si, a superlattice structure of Si and SiO_2, or Er-doped Si have been employed to overcome this efficiency issue with little or no commercial success.

This brings us to the topic of this book: dressed photons (DPs) and dressed photon phonons (DPPs) and their utility to allow silicon bulk crystal into an efficient light-emitting material or device. A DP, unlike a conventional photon, provides a physical picture that illustrates the small size (quantum confinement), meaning that the quasiparticle is created in a nanomaterial or quantum dot material and has short duration, making the quasiparticle a virtual photon. Semiconductor materials have phonon-excited states within the bandgap. Since propagating far-field light cannot

excite electrons from the valence band to these phonon-excited states, these transitions are electric-dipole-forbidden; hence, a DPP can be generated in nanometer-sized (quantum confinement) semiconductor materials that can excite multiple modes of coherent phonons around nanometer-sized structures. In an ideal DPP-assisted process, two-step excitation from the valence band to the conduction band is realized via an intermediate phonon state, and the energy required to create electron–hole pairs is therefore smaller than the bandgap energy.

Chapter 1 lays out the strategy and a case for the book, stating the problems with conventional light-emitting devices and their respective solutions. It also defines the DP, DPP, and photon breeding concepts. Conventional optical technology has used propagating light merely as a tool instead of exploring new types of light. In contrast, DP technology was born as a result of exploring a new type of light (i.e., the DP). Since conventional classical and quantum theories of light cannot be directly applied to describe the DP, novel concepts and theoretical bases are required.

Chapter 2 discusses fabrication and operation of visible LEDs using silicon crystals. Discussions include approaches for increasing light extraction efficiency. Chapter 3 describes infrared LEDs using silicon crystals, emphasizing the fabrication and operation of these devices. The chapter also covers spatial distribution of dopants, such as boron, in the device layers, as well as some plans for ways to improve effective polarization and control.

Chapter 4 covers the contribution and control of coherent phonons and evaluates light emission spectra. Chapter 5 illustrates basic device structures for infrared lasers using silicon crystals. The chapter also discusses ways to decrease the threshold current density and evaluation of optical amplification quantities. It provides thoughts on novel devices with high output optical power using indirect-bandgap semiconductors such as silicon-using DPPs. Chapter 6 discusses silicon carbide as green, ultraviolet, or broad spectral width LEDs using the DPP-assisted process in bulk crystals.

Chapter 7 gives examples using other crystals, such as GaP and ZnO.

Optimum conditions for DPP-assisted annealing are discussed separately for each semiconductor and are assessed in terms of performance.

Chapter 8 reviews applications of the DPP-assisted technique to other devices, such as oscillators, photodetectors, and polarization rotators. This chapter stresses the utility of this new DPP technique outside of LEDs and laser devices.

This book (considered a monograph) has good flow and in-depth content to target a broad audience, including students, professors, academic researchers, and industry folks. It includes many current references for experimentalists and provides mathematical definitions in the appendices for theoreticians. My only critique is that the book could have been organized a little differently by placing figures and tables in places more relevant to the corresponding text. It is a good read for anybody who wants to learn about DPP-assisted silicon light-emitting devices and lasers.

Reviewer: Sudip Mukhopadhyay is a Honeywell Fellow at Honeywell, Calif., USA.
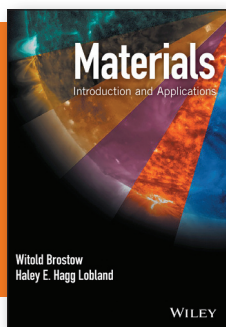
Materials: Introduction and Applications
Witold Brostow and Haley E. Hagg Lobland
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ISBN 978-0-470-52379-7

This book is an excellent introduction to the field of materials science and engineering for students and newcomers. It covers a combination of basic and advanced materials concepts and applications. Chapter 1 introduces the historical background of materials science and engineering and its role in society. Chapter 2 discusses the intermolecular forces, including physical interactions and chemical bonding. Chapter 3 discusses the fundamentals of thermodynamics and different types of phase diagrams. Chapters 4 and 5 deal with the structure and fundamentals of crystalline, non-crystalline, and porous materials. Chapters 6–12 provide an overview of descriptions of details of the structures and fabrication methods for different types of materials, devoting a chapter to each of the following: metals, ceramics, organic raw materials, polymers, composites, biomaterials, and liquid crystals and smart materials. Chapters 13–19 detail the fundamentals and theoretical background of the behaviors and properties of materials, devoting a chapter to each of the following: rheological properties, mechanical properties, thermophysical properties, color and optical properties, electronic properties, magnetic properties, and surface behavior and tribology. Chapter 20 describes the recycling and degradation of materials in the environment. Chapter 21 summarizes the different materials testing techniques, including standard testing and microscopy testing methods.

This textbook is a good resource that provides the fundamentals of materials science and engineering supported by examples, problems, and adequate references for students. It will also serve as an important addition to the libraries of those interested in understanding materials science and engineering and their advanced applications.

Reviewer: Walid M. Daoush of Helwan University, Egypt.