PHYSICS TODAY

Introduction to Semiconductor Physics

Holger T. Grahn; Eric D. Jones

Check for updates

Physics Today **53** (9), 66–67 (2000);
https://doi.org/10.1063/1.1325242

View Online
Export Citation
CrossMark

06 December 2024 17:31:06

unthinkable. At 10^{-5} sec, hadrons in the universe should have overlapped and the exponentially rising number of particle states (with mass) should have led to a limiting thermodynamic temperature. The Standard Model of particle physics opened the door: The early universe was a dilute gas of weakly interacting quarks, leptons, and other particles. Speculations about physics beyond the Standard Model (grand unification, supersymmetry, and superstrings) introduced intriguing new cosmological possibilities.

While *Quintessence* surveys the standard cosmology and many of the bold theoretical ideas that came from the 1980s, the centerpiece of the book is "The New Improved Standard Model" as Krauss aptly calls it: The hot Big-Bang model supplemented by inflation and cold dark matter, the most compelling ideas to emerge from connecting quarks to the cosmos. (Alan Guth's inflation theory holds that the universe went through a very early spurt of tremendous growth, whose consequences resolve almost all of the fundamental questions left unanswered by the standard cosmology.) The cold dark matter part of this paradigm asserts that the long-sought dark matter that holds the universe together consists of slowly moving (cold) elementary particles left over from the earliest, fiery moments.

By the early 1990s, the inflation-plus-cold-dark-matter paradigm had established itself as the most important set of ideas in cosmology since the Big Bang. If correct, it would extend the standard cosmological model back to a time when the largest structures were quantum fluctuations and the heat of the Big Bang existed in the form of false-vacuum energy. The philosophical implications of this paradigm rival those of Copernican theory: If correct, we are not made of the primary stuff of the cosmos, and what we call the Big Bang was in fact just a rapid burst of exponential expansion driven by false-vacuum energy. And it was not a singular event—there should have been an infinite number of such little big-bang events, creating an infinity of causally disconnected bubbles. According to inflation, the universe is actually a multiverse.

Because of inflation's attractiveness and boldness, observers and experimenters were eager to disprove it, producing the tension between theorists and experimenters that characterizes all healthy fields of science. That's where Krauss left off when *Fifth Essence* was published.

The soft spot that observers were aiming for was the hallmark prediction of inflation—a spatially flat universe whose total density of matter and energy summed to the critical density. The tremendous expansion during inflation makes the universe appear flat; Einstein's theory says a flat universe must have the critical density. While there was growing evidence that the bulk of the matter that holds the universe together is not made of baryons—consistent with the idea of cold dark matter—most measurements of the amount of dark matter fell far short of the critical density. Evidence for particle dark matter was compelling enough that large experimental efforts were launched to detect the most promising particle suspects: the axion and the neutralino.

Cold dark matter received a major boost in 1992. The Cosmic Background Explorer (COBE) detected small variations in the temperature of the cosmic microwave background that gave evidence for the primeval lumpiness that seeded all structure. The amplitude of the matter inhomogeneity (about 1 part in 10^5) is just what is needed to account for all the structure that exists today, provided the dark matter is nonbaryonic. In 1998 the Superkamionade neutrino observatory experiment showed at least one neutrino species to have sufficient mass to enable relic neutrinos to contribute as much to the mass budget of the universe as stars do. Particle dark matter is no longer a conjecture, although the bulk of it still remains to be identified.

While cold dark matter was looking good, flatness was not: matter could only account for about $^1/_3$ of the required critical density. A surprising (to some) turn of events came in 1998 with the discovery that the universe is accelerating, not slowing, and does indeed have the critical density predicted by inflation. The missing $^2/_3$ of the critical density is in the form of "the dark energy" that is causing the acceleration. That startling finding brings us to the present day and Krauss's revised book. While the simplest explanation for the accelerated expansion is a tiny, but nonzero, value of the cosmological constant (the zero-point energy of the vacuum), an idea Krauss and I and several others suggested independently more than a decade ago, there is a slight problem. The contributions of the known particles to the zero-point energy exceed the critical density by at least 55 orders of magnitude!

This suggests that some deep principle might zero out the cosmological constant. If this is so, then something else must be causing the universe to accelerate. It must be dark, it must be smooth, and it must have large, negative pressure. Some have called it "Quintessence," the name also used by Krauss to refer to particle dark matter (the fifth essence); I prefer dark energy in analogy to Fritz Zwicky's naming of dark matter 70 years ago. The existence of dark energy received independent confirmation with the results of the Boomerang cosmic microwave background experiment, reported in April, which showed the universe to be flat. Krauss tries to take advantage of this double use, which is the only confusing part of the book.

In the epilogue, Krauss says that even more remarkable than the theoretical ideas that we have about the birth of the universe is the fact that we will be able to test them, and soon. With the explosion of precision cosmological measurements and observations, I fully agree. I would add: Equally remarkable is how prophetic his book was; after more than a decade, only a new preface and one new chapter were needed to bring it up to date.

Michael S. Turner
The University of Chicago
Chicago, Illinois

Introduction to Semiconductor Physics

Holger T. Grahn
World Scientific, River Edge, N.J., 1999. 183 pp. $28.00 hc
ISBN 981-02-3302-7

The first part of Holger Grahn's *Introduction to Semiconductor Physics* is based on a course of that name Grahn gave in the department of Physical Electronics at Tokyo Institute of Technology during the 1995–1996 academic year. The second part, in particular the extensive discussion of optical properties, including the effects of external fields, is based on his lecture, entitled Optical Properties of Semiconductors, given within the Institute of Solid State Physics at the Technical University of Berlin in 1997. There have been similar publications treating optical properties of semiconductors; perhaps one of the most popular, as defined by its presence on many office bookshelves, is Jacques Pankove's *Optical Processes in Semiconductors* (Dover, 1976.)

Introduction to Semiconductor Physics has fourteen chapters cover-

06 December 2024 17:31:06

ing 183 pages. Its introduction describes what a semiconductor is and presents a classification scheme; Chapters 2 and 3 treat the subjects of crystal structure, reciprocal lattice, and electrons in a periodic potential. In chapter 3, Grahn presents the Kronig–Penney model in detail, in a treatment that is not only instructive but could also serve as a concise review for many researchers. Chapter 4 discusses the effective mass model and band structure in terms of **k·p** theory. The **k·p** derived energies and masses of the principal conduction and valence band states for direct gap zincblende structures are conveniently summarized in this chapter. An excellent presentation of the density of states for one-, two-, and three-dimensional systems is found in Chapter 5, which also discusses the effects of critical points on the density of states. Finally, Fermi–Dirac and Bose–Einstein distribution functions are treated and applied to n- and p-type semiconductor systems. The subject of carrier transport is reviewed in Chapter 6. Phonons, phonon statistics, and phonon scattering processes are treated nicely in Chapters 8 and 9.

The second part of the book (Chapters 10–12) is about optical absorption and emission processes in semiconductors. Grahn treats both band-to-band and excitonic processes for zero temperature and also includes an excellent discussion of the effects of temperature. The change in the absorption line shape caused by externally applied electric and magnetic fields is also discussed in some detail. Grahn outlines the free carrier magneto-absorption line shapes for two-dimensional and three-dimensional geometries in these chapters. He presents relevant references to other monographs in Chapter 13, while showing the important fundamental constants and equivalent units as a table in Chapter 14.

One important aspect of *Introduction to Semiconductor Physics* is the number of tables containing summary information about the physical and electronic properties of III-V, II-VI, and group IV semiconductors. For example, there are tables on lattice constants, band-gap energies, effective masses, density of states, optical phonon frequencies, exciton binding energies, exciton Bohr radii, and the like. Other tables contain functional forms for reciprocal lattice vectors, electron–phonon scattering processes, critical points, and the density of states, for example. While this information is chronicled in many places, it is extremely convenient (and useful) to have all of this kind of information in one place.

However, the title of this book—*Introduction to Semiconductor Physics*—may be somewhat misleading; perhaps it should have been entitled "Selected Topics in Semiconductor Physics." Topics such as alloying, strain, doping effects, and heterojunctions are not discussed. These omissions should not be viewed as serious flaws; only so many subjects can be discussed in a short book, especially if any detail is presented.

This book could be used as an outline for an introductory course on semiconductor physics using other complementary references for more detail. One or all of the following monographs that could serve this purpose are *Fundamentals of Semiconductor Physics* by Peter Yu and Manuel Cardona (Springer, 1997), *Semiconductor Physics: An Introduction* (Springer, 1997) by Karlheinz Seeger or *Quantum Processes in Semiconductors* by B. K. Ridley (Clarendon, 1993.) With all of the new up-to-date data presented in the tables, I feel that Grahn's *Introduction to Semiconductor Physics* may become the replacement for Pankove's older book.

Eric D. Jones
Sandia National Laboratories
Albuquerque, New Mexico

The Lyotropic State of Matter: Molecular Physics and Living Matter Physics

Alexander G. Petrov
Gordon and Breach, Amsterdam, 1999. 549 pp. $149.00 hc
ISBN 90-5699-638-X

It is difficult not to raise eyebrows at a title like *The Lyotropic State of Matter: Molecular Physics and Living Matter Physics*. And if the title is not enough, the book's 550 equally ponderous pages are bound to make a lasting first impression. Alexander Petrov's *opus magnum* deals with the lyotropic state of matter, which translates into density-dependent properties of mesogenic molecules. The lyotropic state is presumed to be the state of matter favored by living systems. One realizes quite soon that the ponderous title hides, in fact, an incredibly detailed introduction to the physics of lipid membranes, which are probably one of the better-known examples of the lyotropic state of matter.

The book deals with the expected

06 December 2024 17:31:06

Circle number 33 on Reader Service Card