Process Engineering Analysis in Semiconductor Device Fabrication

By Stanley Middleman and Arthur K. Hochberg, McGraw-Hill, Inc., 1993, 774 pp. + xvii.

It is a collaborative effort by an engineering physicist/electrical engineer (Hochberg) and a chemical engineer (Middleman) to bring the chemical processing and mathematical modeling principles of the chemical engineering community to the concepts, processes and fabrication methods pioneered and developed by researchers in the former field. There is a clear need for suitable textual material, since increasing numbers of chemical engineers have been entering the microelectronics industry in recent years and courses on microelectronics processing have been incorporated into chemical engineering curricula. Books written for students in applied physics and electrical engineering have been understandably lacking in the treatment of process chemistry and modeling, areas where chemical engineers can make a unique contribution. But a book solely concerned with the application of traditional chemical engineering principles to microelectronics processing would be too shallow. Chemical engineers, to be successful in this area and to interact with traditional practitioners of semiconductor processing, must understand the underlying physics. This book covers the traditional areas of microelectronics processing, shows where the application of chemical engineering ideas is useful, and gives many illustrative examples.

The first two chapters provide background material that will be unfamiliar to most chemical engineering students. Chapter 1 introduces basic concepts in solid-state physics, and chapter 2 covers the *p-n* junction, transistors and other semiconductor devices, and provides an overview of the many step fabrication process. Chapter 3 presents the basic balances (chemical species, momentum and thermal and mechanical energy), which should be familiar to students who have had a course in transport phenomena.

The next three chapters treat the important issues of cleanliness and chemical purity, with material on particle filtration and clean rooms, the fundamentals of particle deposition and removal, and four examples of the production of high-purity chemicals. This section illustrates the application of traditional chemical engineering principles and unit operations to important aspects of microelectronics processing where chemical engineers can have a significant impact by increasing the yield of usable devices.

Chapters 7 to 14 cover a range of subjects, all important to device fabrication, that are normally included in texts for nonchemical engineers. The authors have kept the spirit of the engineering physics approach while working in the chemical engineering slant on things wherever appropriate. Chapter 7 discusses the production of high-purity, single-crystal Si wafers via the Siemens process and Czochralski growth, and Chapter 8 presents the critical Si surface oxidation process and the Deal-Grove model. Chapter 9 covers microlithography, primarily by e-beam and γ-radiation development of resists. Material in this chapter on resist chemistry and on spin coating of resist provides another example where chemical engineering expertise can be useful. There is, however, no coverage of photo lithography. Chapter 10 deals with the formation of *p-n* junctions by doping with impurities and with solid-state diffusion, while Chapter 11 treats the removal of thin solid films by etching. In the latter, both plasma etching and wet etching are covered. This is followed by a long chapter on chemical vapor deposition (CVD), no doubt, reflecting the fact that this subject has attracted the attention of many chemical engineers. The emphasis is on the development of mathematical models and the role of chemical reactions, both on the growth surface and in the gas phase. A serious omission here is the absence of any description of recent developments in the application of computational fluid mechanics and detailed chemical kinetic models to CVD modeling. Finally, Chapter 13 covers ion implantation, and Chapter 14 covers metallization. At the end of each chapter a number of appropriate problems are set, and useful lists of references are given.

This is a substantial book of 774 pages. The authors suggest that about 80% of the material can be covered in two ten-week academic quarters comprising four lecture hours per week. This winter at the University of Minnesota this text was required in a survey course in microelectronics processing given in the Department of Chemical Engineering and Materials Science for chemical engineering seniors and beginning graduate students. In the ten-week, 40-lecture academic quarter, approximately 55% of the text was covered. The coverage consisted of Chapters 1, 2, 7–10 and 12–14. Chapter 1 was supplemented with additional material on band theory of solids and crystallography, and Chapter 2 with material on Schottky barriers and field effect transistors. Chapter 3 was not presented as a unit, but conservation equations were taken and used as needed in later portions of the course. Due to time constraints, it was decided to omit Chapters 4, 5 and much of the detail in 6 to emphasize steps in device fabrication. Chapter 9 was supplemented with some material on photolithography, and contact and proximity printing. Considerable emphasis was placed on Chapter 12 on CVD supplementing this with the discussion of supercomputer models. The course was concluded with lectures on lattice matching for heterostructures and on optoelectronic devices taken from other sources.

The text is written well and clearly. There are, of course, the inevitable errata of the first printing, a list of which was supplied by the publisher, but a number of others were found, including a serious error in the Fermi-Dirac distribution in Chapter 1. The students appeared to think well of the book. Weekly problem sets were assigned from problems at the end of each chapter. They are suitable both in terms of length and level of difficulty for a course at the advanced undergraduate/beginning graduate level.

This book is clearly the best one on microelectronics processing for chemical engineers that is currently available. It is enthusiastically recommended.

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Pressure Swing Adsorption

By Douglas M. Ruthven, Shamsuzzaman Farooq, and Kent S. Knaebel, VCH Publishers, New York, 1994, 352 + xxiii pp., $95.00.

The authors of this book have wide experience in both the adsorbent and process sides of pressure swing adsorption (PSA), as evident from the depth and breadth of their backgrounds. Also evident is the writing style which makes it relatively easy for a novice in the field to pick up the book and find something to learn on his or her level almost immediately.

The issue of the level and audience at which a book should be "pitched" is a key these days. In practice, very few engineers in industry actually do detailed design calculations. More and more, separation processes are being designed by specialized companies and sold to those companies which actually use the processes in their plants. In the case of adsorption processes, the adsorbents are also being supplied by specialized companies. So the vast majority of engineers, who reside in companies which use separation processes, don't need to know the fine structure of design and construction details nor the minute details of mass separating agents like adsorbents. These engineers are more concerned about such issues as: Is PSA a viable option for solving a given separation need? How do economics and performance of PSA compare with, for example, those of membranes? How can I make a given process perform better? Will a different adsorbent or adsorbent geometry bring some benefit to the process? To deal with these and many other questions, the engineer needs to know how a PSA process works and how adsorbents work, but not the excruciatingly complex details of process design. To the authors' credit, they seem to have appreciated more than most of their compatriots the plight of this engineer. Information is not only clearly presented, but also in a manner which progresses from simple, qualitative explanations to complex and involved descriptions.

Take, for example, the way in which the authors handle the issue of how the actual cycles of PSA processes are organized. For most people, the bewildering array of co- and countercurrent pressurization, feed, co- and countercurrent blowdown, pressure equalization, purge, and other steps—to say nothing of when and when not to use each one—is about as mysterious as quantum physics. To go about explaining PSA cycles, the authors first present in Chapter 3 a table which qualitatively explains the various steps and why they are used. They proceed to show in a qualitative fashion how concentration profiles move through the bed under the influence of these steps. Then, they illustrate how cycles are organized in several commercial processes. Only after all of this, do the authors "get mathematical" and develop: first the equilibrium theory of PSA (Chapter 4) and then dynamic modeling of a PSA system (Chapter 5). The format works. One can find an entry point into the book at whatever level of knowledge about PSA one currently possesses.

One appendix gives a useful and interesting synopsis of the patent history of PSA, replete with brief explanations of the significance of some of the most important patents. Such an addition is rather rare for a separation book.

Lest the reader of this review think that the book is totally without flaws, I must mention a few concerns. The first deals with the last chapter, whose purpose is to draw a comparison between membrane processes and PSA. For our archetypal engineer in a producing company, a key issue is often, which separation process should I use in a particular situation? So I eagerly turned to this chapter to see what the authors had to say. Unfortunately, the analysis is limited to only air separation and is quite qualitative, so that many questions are left unanswered. Nevertheless, the authors need to be congratulated even here. At least they tried to address the really important issue of how one decides which process to use. How many other books have you read in which this issue is even raised? A second concern is the lack of much discussion (see p. 251 ff) on the use of PSA and for the removal of trace contaminants in gas streams such as process vents and storage-tank vents. Separations of this sort will burgeon in the future, and already at least two companies—AWD (a subsidiary of Dow) and UOP—are offering PSA processes and process help in this area. Finally, although the information on adsorbents is beautifully presented, the discussion could have been usefully extended to cover the effects of adsorbent-particle size and shape on bed performance.

Overall, the book is well written and covers the field of adsorbents and PSA processes very well. Given this and the fact that PSA does not have a wide breadth of applications, there does not seem to be the need for another process-oriented book in this area for quite some time. This one is just fine for the vast majority of readers.

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An Introduction to Coal Technology

By Norbert Berkowitz, Academic Press, New York, 1994, 2nd ed., 398 pp.

The scope of this book is well described in the preface to the first edition: "... an overview that tells what coal is, how it came into being, what its principal physical and chemical properties are, and how it is handled or processed for particular end uses." This clearly attempts to appeal to all readers. Coal, however, is studied by people with a wide range of interests—mining engineers, geologists, and of course chemical engineers. Hence, any book on coal is bound to have problems in satisfying all interested parties.

The book is divided into two parts, with the first dealing with the origins, formation and properties of coal, and the second dealing with coal upgrading, handling and processing. The preface to the second edition indicates that relatively few substantial changes have been made in Part I since the first edition (published in 1977), while Part II has been rearranged and "modestly expanded."

Part I, Chapters 1-7, comprises an interesting background for chemical engineers. In these and all subsequent chapters, however, I was struck by the