Journal of Statistical Physics, Vol. 83, Nos. 5/6, 1996

Book Review: *Fractal Concepts in Surface Growth*

Fractal Concepts in Surface Growth. A.-L. Barabási and H. E. Stanley, Cambridge University Press, Cambridge, England, 1995.

In the early stages in the development of a research field, information about new results and ideas is primarily exchanged through papers published in specialized journals. After significant numbers of papers have been published and new results have been obtained, researchers wishing to obtain an overview of the field begin to turn to review articles, book chapters, and conference proceedings in addition to original papers. The next phase occurs when a number of discoveries and breakthroughs have been made and these ideas have been tested and verified experimentally. By this time it is no longer possible to get a comprehensive survey of the field from specialized articles and the need naturally arises for a book that would sort out these different ideas and provide a coherent summary of the major developments in the field. The present book is such a book. This is the first textbook that brings together a wide range of important topics in the rapidly developing field of surface and interface growth phenomena.

The observation that surfaces can be fractal was first made by Benoit Mandelbrot in his book, *Fractal Geometry of Nature* (Freeman, San Francisco, 1982). This leads to the conclusion that certain features of a fractal surface must reappear at finer and finer length scales. However, surfaces and interfaces are generally isotropic in the sense that if we observe them from far away, they look flat. The roughness is perpendicular to the surface and shows up when the surface is studied at smaller and smaller length scales. This implies that surfaces and interfaces are examples of *self-affine fractals*, because they exhibit fractal behavior only when they are rescaled with different factors in directions along the surface and in directions perpendicular to the surface. The subject of the present book is the study of the morphology and the temporal evolution of self-affine fractal surfaces. These studies try to answer such important questions as: How are surfaces formed? How can we describe the evolution and the morphology of

0022-4715/96/0600-1255$09.50/0

growing surfaces? What are the processes which control the dynamics of growing surfaces? These questions arise in different contexts in almost all fields of science and technology which deal with surfaces. However, despite the fact that the answer to these questions is often useful for solving important practical problems, until recently little progress had been made in this direction. The main impediment had been the fact that no standard theory of far-from-equilibrium growth phenomena exists and therefore such problems have been viewed as intractable.

This book meets an especially important need, because it demonstrates that scaling and fractal concepts represent an extremely promising approach for describing surface growth phenomena. The authors have intended this book for a wide audience from many different disciplines with only a general scientific background. For this reason they introduce and discuss examples from a variety of fields throughout the book. They have also included a number of problems in each chapter. In addition, the bibliography, which consists of 508 references, is up to date, making it easy to consult original papers. These features make this book quite novel, because although it is a book on advanced topics, it is suitable both as a textbook and for self-study.

The book is divided into seven parts consisting of 28 chapters and three appendices. Part 1 introduces the concepts of surface and interface growth, as well as scaling and fractals, which are basically the language of this field. For example, dynamic scaling, discussed in Chapter 2, is the key concept used by researchers in the analysis of the morphology and evolution of surfaces and interfaces.

A variety of both discrete and continuum models of surface growth are discussed in Part 2. The authors begin with exactly solvable models and then go on to discuss more realistic models. They provide a nice and pedagogical introduction to the renormalization group (RG) concepts in Chapter 7. This material should provide sufficient background for most readers to follow the applications discussed in other parts of the book, but not perform a nontrivial RG calculation. Appendix B, however, provides a very clear and quite pedagogical introduction to the dynamic RG as applied to a nonlinear surface growth equation.

One of the most challenging classes of problems in surface growth involves the study of interfaces in random media. Perhaps the best example of this type of problem is the motion of the interface between two fluids moving in a porous medium, such as paper. When a piece of paper towel is wet, at some point the fluid begins to spread and displace the air in the pores of the paper. The moving front separating the wet and the dry parts of the paper is an example of an interface moving in a disordered medium. Due to the generality of such problems, the study of interfaces in random media has received a great deal of attention. The basic phenomenon is discussed in Chapter 9 and the role of quenched randomness, which in this case arises from the medium, is discussed in Chapter 10. The results of these models are compared with several related experiments in Chapter 11. In Part 4, the authors discuss the problem of molecular beam epitaxy (MBE). MBE is one of the most effective techniques for growing high-purity materials, including a variety of semiconductors and magnetic materials used in electronic and optoelectronic devices. In this method a constant flux of atoms impinges under ultrahigh-vacuum conditions on a substrate held at a fixed temperature to grow a high-quality crystalline material. The long-standing scientific challenge is how to model epitaxial growth and understand the fundamental processes that control the evolution and the morphology of the surface. Chapters 12–15 are devoted to discussions of a number of discrete and continuum models of MBE. Chapter 16 is a review and summary of the experimental studies of surface growth in MBE, using the dynamic scaling approach and fractal concepts. The authors critically review the available results and correctly conclude that much work remains to be done in this field from both theoretical and experimental points of view.

The discussion in the remaining chapters in Part 4 turns to microscopic modeling of MBE, sputtering, and other ion-assisted processes. In particular, the authors show that the concept of dynamic scaling of the island size distribution, developed originally for describing the distribution of clusters in colloidal aggregation and droplets in vapor-deposited thin films, can be used to describe the early stages of the growth in MBE. The important point that the authors make is that in contrast to previous examples, in these processes it is necessary to include nonlocal effects due to diffusion and shadowing. It has been much harder to develop theories of nonlocal models, such as the diffusion-limited aggregation model, and this promises to continue to be an active area of research in the future.

Perhaps one of the most important parameters in surface growth is noise, because the evolution and morphology of surfaces are governed by an interplay between stochastic processes or noise, which tends to roughen the surface, and relaxational processes, which tend to smoothen it. Part 5 is devoted to a discussion of special types of noise, such as spatially and temporally correlated noise and power-law noise, that are often generated by processes which exhibit extreme or rare dynamical events. This type of noise has been observed in an experiment on two-fluid displacement in porous media and may exist in many nonequilibrium processes. Although the origin of these rare events is not clear, their effect on simple surface growth models is discussed in Chapter 23.

Finally, Part 6 consists of three chapters dealing with advanced topics. The most important of these chapters is Chapter 26 in which the connection between scaling properties of directed polymers and certain types of surface growth equations is discussed. This is an important theoretical connection which has been exploited extensively in the literature.

Overall this timely and beautifully produced book provides an excellent overview of some of the most important developments in the application of dynamic scaling concepts to surface growth. This has been a rapidly developing field and the authors have done an excellent job of distilling a decade's worth of work into a readable book that provides the background needed to delve into recent literature in this field. I recommend this book strongly to students studying surface and interface growth phenomena, because it provides an excellent background needed in order to enter this field. I also recommend it to researchers seeking a comprehensive review of a particular surface growth problem, because the authors have covered most of the important surface growth areas in which scaling and fractal concepts have been used. To nonspecialists, this book will also be quite useful as a general introduction to the application of scaling and fractals to nonequilibrium surface growth phenomena.

Despite the overall excellent quality of the book, there are a few comments and suggestions that I would like to make. I find the treatment of the linear equation in Chapter 5 too sketchy and not as thorough as the original Edwards–Wilkinson paper. Although experts would say that the linear equation is *trivial* to solve, I believe readers who are not familiar with the topic and are trying to solve a Langevin equation and calculate correlation functions for the first time would have found a fuller treatment of the linear equation quite educational. I also would have liked to see a discussion of equilibrium surface roughening in earlier chapters so that the reader would be able to contrast it with nonequilibrium surface growth in later chapters. For this reason, I would recommend that the reader study the discussion of the roughening transition in Chapter 18 right after reading the linear theory. Also, the discussion of some of the topics that are under current investigation might mislead the reader into thinking that these topics are as firmly established as the rest of the material in the book. In particular, the reader should be aware of the fact that the topics of continuum modeling of MBE and the problem of diffusion bias have already undergone considerable refinement since this book was completed. However, these materials are quite clearly presented and should serve as a nice background for studying more recent papers on these subjects.

In 1991 Tamás Vicsek and I put together a book (*Dynamics of Fractal Surfaces*, World Scientific, Singapore) containing a small collection of some of the most important papers in the study of growing surfaces. At that time we had appreciated the richness of this field, which a group of us had been working on since 1985, and we wanted to provide new researchers with a collection of some of the basic ideas that had emerged from the original papers. Altogether, however, we could not find more than three experimental papers to support our idea! But the pace and the quality of the activity in this field made it clear to us that great progress was imminent. In many ways the present book is proof that in fact considerable advances have been made in our understanding of the dynamics of growing surfaces and interfaces in the past decade. This timely and excellent book should serve the growing community of researchers well in the coming years.

Fereydoon Family
Department of Physics
Emory University
Atlanta, Georgia 30322