PREFACE

The modern science of solidification began in the 1940's, when engineers began to use analytical methods and models to describe solidification processes. In 1940, Chvorinov applied the analysis of heat flow to predict solidification patterns and defects in sand castings. In the 1950's Chalmers and co-workers analyzed the heat and solute balance at the moving solid-liquid interface to understand why planar interfaces become unstable during unidirectional growth. This body of work culminated in a seminal text, *Principles of Solidification*, written by Chalmers in 1964.

In the 1960's, Mullins and Sekerka put Chalmers' analysis on a firmer mathematical footing by performing a formal stability analysis. Later in the 1960's and in the 1970's, Flemings and co-workers developed models for segregation and other microstructural features by applying heat and solute balances at the scale of the microstructural features themselves. Flemings followed Chalmers' text with *Solidification Processing* in 1974, presenting this next generation of achievements.

The next decade saw a great deal of activity in the study of microstructure as a pattern selection problem through the competition between the transport of heat and solute and inherent length scales in the material owing to surface energy. This body of work was summarized in 1984 in *Fundamentals of Solidification*, by Kurz and Fisher.

Kurz and Fisher's book appeared just at the beginning of a revolution in modeling of solidification, when low-cost powerful computers became available. Computational approaches allowed more accurate and detailed models to be constructed, shedding light on many important phenomena. Today, industrial users regularly model the solidification of geometrically complex parts ranging from directionally solidified turbine blades to automotive engines. At the microscopic scale, computational models have been used to great effect to understand the pattern selection process in ways that were only hinted at using the analytical techniques available earlier. In the 1990's, methods were developed to combine these microscopic and macroscopic views of solidification processes.

Although there have been a few specialty texts written in the intervening time between Kurz and Fisher's book and the present, none of them provides a comprehensive presentation of the fundamentals, analytical models, and computational approaches. Also in the 1990's and 2000's, a short course on solidification was developed in collaboration with

Ecole des Mines de Nancy, EPFL and Calcom, that incorporated both the fundamental aspects described earlier and the developing computational techniques. Through teaching this course, and at our respective universities, we felt that there was a need for a new text, which led us to write the book you now hold in your hands. The subject is presented in three parts: *Fundamentals*, which provides the basics of thermodynamics, phase diagrams, and modeling techniques. *Microstructure* then uses these techniques to describe the evolution of the solid at the microscopic scale, from nucleation to dendrites, eutectics and peritectics to microsegregation. This section concludes with a chapter on coupling macro- and micro-models of solidification. The final part, *Defects*, uses the same principles to describe porosity, hot tearing and macrosegregation. We have striven to present this wide range of topics in a comprehensive way, and in particular to use consistent notation throughout.

Additional remarks for the second edition

The second edition of this book makes a number of changes from the first:

- Corrections of typographical errors in the first edition.
- Introduction of Key Concepts within the chapters to assist the reader in understanding and referring to some of the most important aspects of the text.
- Additional material, especially in Parts II and III, highlighting advances in the various topics since the first edition was published in 2009.
- Many of the figures, as well as the Key Concepts and Examples, are now in color.

ACKNOWLEDGMENT

This work represents the culmination of our education, training and practice over the last 25 years. We have had many mentors, colleagues and friends who have helped us along the way, too numerous to name them all. We would particularly like to express our gratitude to our mentors, Wilfried Kurz, Stephen Davis and Robert Pond, Sr. In addition to the authors mentioned above, we would like to acknowledge the very fruitful discussions we have had over the years with many esteemed colleagues: William Boettinger, Martin Glicksman, John Hunt, Alain Karma and Rohit Trivedi, to name just a few. Much of the structure of this text derived from the short course described above, and we would like to thank our colleagues and fellow teachers in that course, past and present, in particular Philippe Thévoz and Marco Gremaud who organize the course. Special thanks are due to Christoph Beckermann, Hervé Combeau, Arne Dahle and Mathis Plapp for their helpful comments and contributions to the manuscript, and to Sébastien Rappaz for the design of the cover. We also owe a special debt of gratitude to our students, postdocs and coworkers, whose contributions made this book possible. We would also like to thank our many colleagues and friends who graciously allowed us to use figures and movie sequences that appear throughout the book.

Most importantly, we would like to thank our families for their love and support.

Jonathan A. Dantzig and Michel Rappaz
Lausanne, 2009, 2016