III-V Integrated Circuit Fabrication Technology

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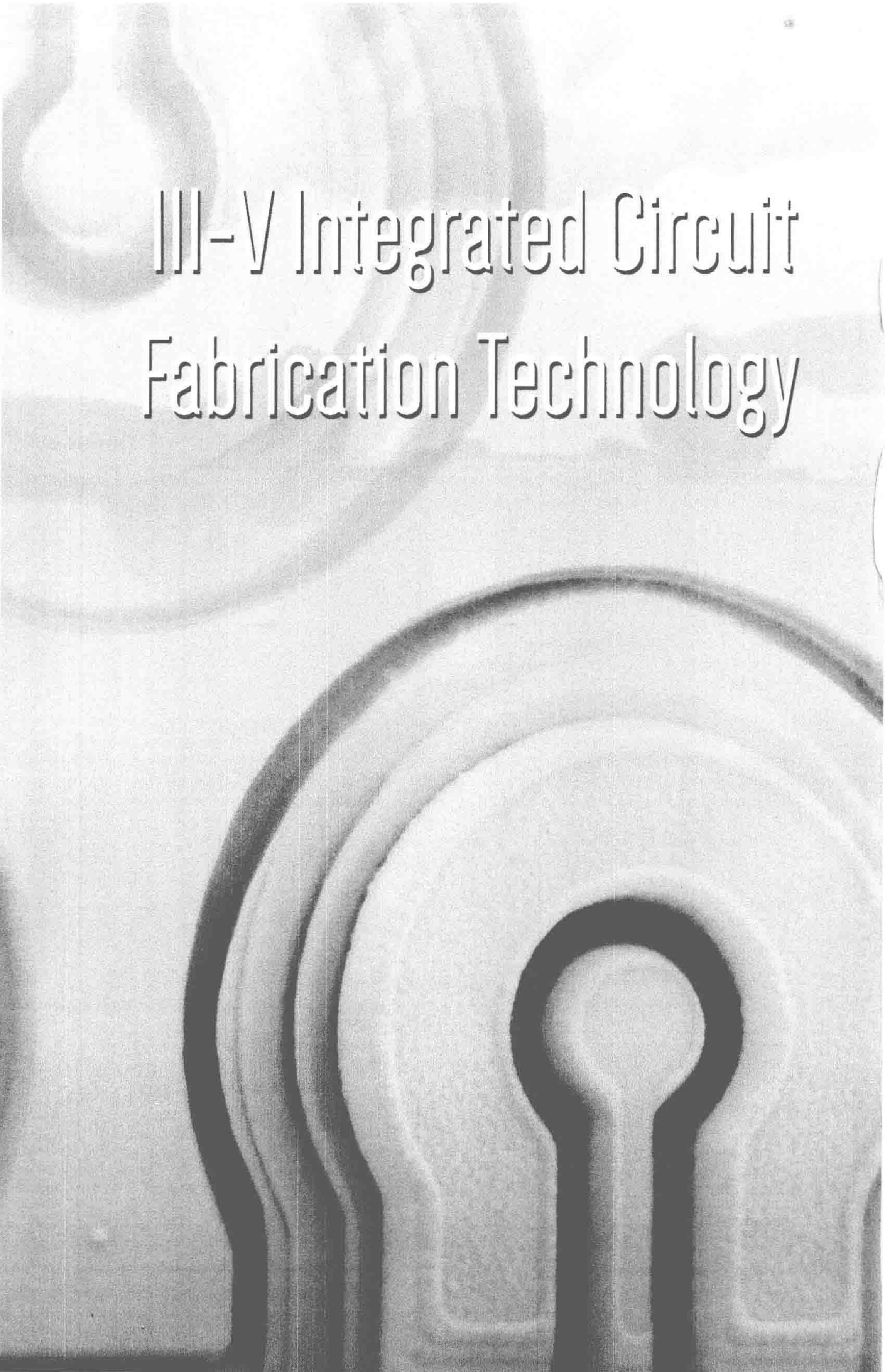

Preface

In this Internet age, practicing engineers still need a book that they can keep on their desk. This book is aimed for them and also graduate students and engineers new to the field of III–V semiconductor integrated circuit (IC) processing. This book specifically addresses the needs of students who know semiconductor theory but lack detailed processing knowledge. The content is chosen on the basis of the needs of students as seen by a teacher and the needs of practicing engineers dealing with processing issues as seen by an experienced process engineer. GaAs processing has reached a mature stage, a long way from a few decades ago, when it was more of an art than a science. New semiconductor compounds are emerging that will dominate future materials and device research; however, the processing techniques used for GaAs will still remain relevant. This book covers all aspects of the current state of the art of III–V processing, with emphasis on heterojunction bipolar transistors (HBTs), the volume leader technology, having grown due to the explosive growth of wireless technology. The book's primary purpose is to discuss processing; only necessary equations are derived and device behavior is discussed for the purpose of understanding device figures of merit and electrical parameters that engineers need to understand and control. All aspects of processing of active and passive devices, from crystal growth to backside processing, including lithography, etching, and film deposition, are covered. New material systems based on GaN are playing a larger role on the development side; although the etching chemistries, deposition materials, and temperature regimes are different, similar principles apply. The most promising structures of these material systems and devices are covered in the book.

The book covers semiconductor material basics, physics of devices used in semiconductor IC processing, and all the processing technologies used in III–V semiconductor fabrication. In the discussion, differences with silicon IC processes are emphasized. Crystal growth and particularly epitaxy are discussed in depth because of the special role played by them and device structures made possible by them. Photolithography, ion implantation, wet and plasma etching, and deposition of films are covered in detail. Thermal processes and diffusion are discussed to the level needed for III–V processing. Schottky and ohmic contact physics and processing are discussed from a practical point of view for controlling these in high-volume production. All the device technologies currently in use in the III–V semiconductor marketplace are discussed in depth, including recently introduced bipolar field-effect transistor (BiFET) and bipolar high-electron-mobility transistor (BiHEMT) technologies. Device types that are emerging and expected to be important in the near future, like metal–oxide–semiconductor field-effect transistors (MOSFETs), are also introduced. Passive devices and interconnects are covered, being integral to monolithic microwave integrated circuit (MMIC) fabrication. Also, backside processing, which is absolutely necessary for high efficiency, is described in detail and wafer-scale bumping is introduced, being critical to future higher-frequency needs. Characterization of films and semiconductor layers, as well as device parameter measurement, is covered in detail. Reliability issues relevant to III–V semiconductors are discussed. Finally, emerging GaN devices and microelectromechanical systems (MEMS) are briefly described.

Most published books on the market emphasize III–V device physics. No new processing book has been published in a decade. Published books are old and cover mostly FET processing. Ralph Williams's book, *Modern GaAs Processing*, is over 20 years old and does not cover processing technologies in detail. S. K. Ghandhi's book, *VLSI Fabrication Principles: Silicon and Gallium Arsenide*, covers processing techniques in detail but IC processing very briefly. This book is also old, published in the 1980s. Fazal Ali's book, *HEMTs and HBTs: Devices, Fabrication and Circuits*, covers fabrication very broadly and was also published in 1991, over 20 years ago. Baca and Ashby's book, *Fabrication of GaAs Devices*, has a narrow focus, specializing in cleaning and passivation; basic IC processing techniques are not covered. It was published in 2005, a decade old now.

This (present) book covers all aspects of processing, from crystal growth to backside processing. It covers the current volume production device types, HBTs, HEMTs, etc. The book is not restricted to GaAs; other emerging III–V materials are covered, too.

Epigrowth, device structure, and processing discussions are connected together through different chapters. Processing techniques relevant to III–V IC fabrication are described as they are used in III–V processing facilities in high-volume production. Process flows are illustrated by step-by-step block diagrams. Scanning electron microscopy (SEM) pictures of actual devices are included, where needed. This is one book to find any topic relevant to III–V processing. Practical process problems and ways to handle these are described.

The current understanding of III–V processing has come a long way from the era when GaAs processing was based on practical knowledge and company trade secrets. This book attempts to connect practice on the fabrication floor to current scientific understanding.

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Acknowledgments

The earlier books on GaAs and III–V semiconductor materials processing were written in an era when GaAs was considered the "technology of the future." This present work, although inspired by those, is aimed at fulfilling the needs of this era in which the technology is well established and perhaps becoming the "technology of the past," while paving the way for future technologies. Many minds and hands have contributed to this work. I am indebted to all my teachers over the years, who left an indelible mark on my life. I also thank the people of India for the almost free education I received.

This book would not have been possible without support from Skyworks Solutions' management, Ravi Ramanathan, Nercy Ebrahimi, and Andy Hunt, and IP council Donald Bollella, who weighed the benefits of contributing to the III–V industry worldwide over the risk of disclosing trade secrets. A lot of data came from my fellow engineers at Skyworks and the CS MANTECH community in general. Early feedback from Martin Brophy (Avago) and Peter Asbeck (UCSD) encouraged me. In particular, help from the following Skyworks colleagues is acknowledged: Heather Knoedler, Jens Riege, Dave Crawford, Ravi Ramanathan, Mike Sun, Jiro Yota, Pete Zampardi, Lance Rushing, Cristian Cismaru, Sam Mony, Lam Luu, and Manjeet Singh. Constant support from my wife, Sushma, and son, Vikram, helped me during difficult times. I am also thankful to Archana Ziradkar of Pan Stanford Publishing for systematic editorial help and to Barron Miller for drafting of many of the figures.

Shiban Tiku

Contents