Infrared Detectors

Second Edition

Antoni Rogalski

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SECOND EDITION

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Preface

Progress in infrared (IR) detector technology has been mainly connected to semiconductor IR detectors, which are included in the class of photon detectors. They exhibit both perfect signal-to-noise performance and a very fast response. But to achieve this, the photon detectors require cryogenic cooling. Cooling requirements are the main obstacle to the more widespread use of IR systems based on semiconductor photodetectors making them bulky, heavy, expensive, and inconvenient to use.

Until the 1990s, despite numerous research initiatives and the appeal of room temperature operation and low cost potential, thermal detectors have enjoyed limited success compared with cooled photon detectors for thermal imaging applications. Only the pyroelectric vidicon received much attention with the hope that it could be made practical for some applications. Throughout the 1980s and early 1990s, many companies in the United States (especially Texas Instruments and Honeywell's Research Laboratory) developed devices based on various thermal detection principles. In the mid-1990s, this success caused DARPA (Defense Advanced Research Projects Agency) to reduce support for HgCdTe and attempt a major leap with uncooled technology. The desire was to have producible arrays with useful performance, without the burden of fast (*f*/1) long-wavelength infrared optics.

In order to access these new changes in infrared detector technology, there was need for a comprehensive introductory account of IR detector physics and operational principles, together with important references. In 2000, the first edition of *Infrared Detectors* was published with the intention of meeting this need. The last decade has seen considerable changes with numerous breakthroughs in detector concepts and performance. It became clear that the book needed substantial revision to continue to serve its purpose.

In this second edition of *Infrared Detectors*, about 70% of the contents have been revised and updated, and much of the materials have been reorganized. The book is divided into four parts: fundaments of infrared detection, infrared thermal detectors, infrared photon detectors, and focal plane arrays. The first part provides a tutorial introduction to the technical topics that are fundamental to a thorough understanding of different types of IR detectors and systems. The second part presents theory and technology of different types of thermal detectors. The third part covers theory and technology of photon detectors. The last part concerns IR focal plane arrays (FPAs) where relations between the performance of detector arrays and infrared system quality are considered.

The short description below mainly concerns differences between the original edition and this revision. I have added a discussion of radiometry and flux-transfer issues needed for IR detector and system analysis in the first part. In the next two parts, in addition to updating traditional issues described in the previous book, I have included new achievements and trends in the development of IR detectors, most notably:

- novel uncooled detectors (e.g., cantilever detectors, antenna and optically coupled detectors);
- type II superlattice detectors; and
- quantum dot infrared detectors.

In addition, I have highlighted new approaches to terahertz (THz) arrays and a new generation of infrared detectors—so-called third-generation detectors. THz technologies are now receiving increasing attention, and devices exploiting this wavelength band are set to become increasingly important in a diverse range of human activity applications (e.g., security, biological, drugs and explosion detection, gases fingerprints, imaging, etc.). Today, researchers are developing third-generation systems that provide enhanced capabilities such as a larger number of pixels, higher frame rates, better thermal resolution, multicolor functionality, and other on-chip functions.

This book is written for those who desire a comprehensive analysis of the latest developments in infrared detector technology and basic insight into fundamental processes important to evolving detection techniques. Special attention has been given to the physical limits of detector performance and comparisons of performance in different types of detectors. The reader should gain a good understanding of the similarities and contrasts, the strengths and weaknesses of a multitude of approaches that have been developed over a century to improve our ability to sense IR radiation.

The level of presentation is suitable for graduate students in physics and engineering who have received standard preparation in modern solid-state physics and electronic circuits. This book is also of interest to individuals working with aerospace sensors and systems, remote sensing, thermal imaging, military imaging, optical telecommunications, infrared spectroscopy, and light detection and ranging (LIDAR). To satisfy the needs of the first group, many chapters discuss the principles underlying each topic and some historical background before bringing the reader the most recent information available. For those currently in the field, the book can be used as a collection of useful data, as a guide to the literature, and as an overview of topics covering a wide range of applications. The book could also be used as a reference for participants of relevant workshops and short courses.

This new edition of *Infrared Detectors* gives a comprehensive analysis of the latest developments in IR detector technology and basic insight into the fundamental processes important to evolving detection techniques. The book covers a broad spectrum of IR detectors, including theory, types of materials and their physical properties, and detector fabrication.

Antoni Rogalski

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The author has benefited from the kind cooperation of many scientists who are actively working in infrared detector technologies. The preparation of this book was aided by many informative and stimulating discussions with the author's colleagues at the Institute of Applied Physics, Military University of Technology in Warsaw. The author thanks the following individuals for providing preprints, unpublished information, and in some cases original figures, which were used in preparing the book: Drs. L. Faraone and J. Antoszewski (University of Western Australia, Perth), Dr. J. L. Tissot (Ulis, Voroize, France), Dr. S. D. Gunapala (California Institute of Technology, Pasadena), Dr. M. Kimata (Ritsumeikan University, Shiga, Japan), Dr. M. Razeghi (Northwestern University, Evanston, Illinois), Drs. M. Z. Tidrow and P. Norton (U.S. Army RDECOM CERDEC NVESD, Fort Belvoir, Virginia), Dr. S. Krishna (University of New Mexico, Albuquerque), Dr. H. C. Liu (National Research Council, Ottawa, Canada), G. U. Perera (Georgia State University, Atlanta), Professor J. Piotrowski (Vigo System Ltd., Ożarów Mazowiecki, Poland), Dr. M. Reine (Lockheed Martin IR Imaging Systems, Lexington, Massachusetts), Dr. F. F. Sizov (Institute of Semiconductor Physics, Kiev, Ukraine), and Dr. H. Zogg (AFIF at Swiss Federal Institute of Technology, Zürich). Thanks also to CRC Press, especially Luna Han, who encouraged me to undertake this new edition and for her cooperation and care in publishing this second edition.

Ultimately, it is the encouragement, understanding, and support of my family that provided me the courage to embark on this project and see it to its conclusion.

About the Author

Antoni Rogalski is a professor at the Institute of Applied Physics, Military University of Technology in Warsaw, Poland. He is a leading researcher in the field of IR optoelectronics. During the course of his scientific career, he has made pioneering contributions in the areas of theory, design, and technology of different types of IR detectors. In 1997, he received an award from the Foundation for Polish Science (the most prestigious scientific award in Poland) for achievements in the study of ternary alloy systems for infrared detectors—mainly an alternative to HgCdTe new ternary alloy detectors such as lead salts, InAsSb, HgZnTe, and HgMnTe. In 2004, he was elected as a corresponding member of the Polish Academy of Sciences.

Professor Rogalski's scientific achievements include determining the fundamental physical parameters of InAsSb, HgZnTe, HgMnTe, and lead salts; estimating the ultimate performance of ternary alloy detectors; elaborating on studies of high-quality PbSnTe, HgZnTe, and HgCdTe photodiodes operated in 3–5 μm and 8–12 μm spectral ranges; and conducting comparative studies of the performance limitation of HgCdTe photodiodes versus other types of photon detectors (especially QWIP and QDIP IR detectors).

Professor Rogalski has given about 50 invited plenary talks at international conferences. He is author and co-author of over 200 scientific papers, 11 books, and 13 book chapters. He is a fellow of the International Society for Optical Engineering (SPIE), vice president of the Polish Optoelectronic Committee, vice president of the Electronic and Telecommunication Division at the Polish Academy of Science, editor-in-chief of the journal *Opto-Electronics Review*, deputy editor-in-chief of the *Bulletin of the Polish Academy of Sciences: Technical Sciences*, and a member of the editorial boards of *Journal of Infrared and Millimeter Waves* and *International Review of Physics*.

Professor Rogalski is an active member of the international technical community. He is a chair and co-chair, organizer and member of scientific committees of many national and international conferences on optoelectronic devices and material sciences.

Table of Contents

PART I

FUNDAMENTS OF INFRARED DETECTION