ANTIMONIDE-BASED INFRARED DETECTORS

A New Perspective

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Preface

Among the many materials investigated in the infrared (IR) field, narrow-gap semiconductors are the most important in the IR photon detector family. Although the first widely used narrow-gap materials were lead salts (during the 1950s, IR detectors were built using single-element-cooled PbS and PbSe photoconductive detectors, primarily for anti-missile seekers), this semiconductor family was not well distinguished. This situation seems to have resulted from two reasons: the preparation process of lead salt photoconductive polycrystalline detectors was not well understood and could only be reproduced with well-tried recipes; and the theory of narrow-gap semiconductor bandgap structure was not well known for correct interpretation of the measured transport and photoelectrical properties of these materials.

The discovery of the transistor stimulated a considerable improvement in the growth and material purification techniques. At the same time, rapid advances were being made in the newly discovered III-V compound semiconductor family. One such material was InSb from which the first practical photovoltaic detector was fabricated in 1955 [G. R. Mitchell, A. E. Goldberg, and S. W. Kurnick, *Phys. Rev.* **97**, 239 (1955)]. In 1957, P. W. Kane [*J. Phys. Chem. Solids* **1**, 249 (1957)] using a method of quantum perturbation theory (the so-called **k·p** method), correctly described the band structure of InSb. Since that time, the Kane band model has been of considerable importance for narrow-gap semiconductor materials.

The end of the 1950s saw the introduction of narrow-gap semiconductor alloys in III-V (InAsSb), IV-VI (PbSnTe, PbSnSe), and II-VI (HgCdTe) material systems. These alloys allowed the bandgap of the semiconductor and hence the spectral response of the detector to be custom tailored for specific applications. Discovery of variable bandgap $Hg_{1-x}Cd_xTe$ (HgCdTe) ternary alloy in 1959 by Lawson and co-workers [*J. Phys. Chem. Solids* **9**, 325 (1959)] triggered an unprecedented degree of freedom in infrared detector design. Over the next five decades, this material system successfully fought off major challenges from different material systems, but despite that, it has more competitors today than ever before. It is interesting, however, that none of these competitors can compete in terms of fundamental properties. They may promise to be more manufacturable, but never to provide higher performance or, with the exception of thermal detectors, to operate at higher temperature.

Recently, there has been considerable progress towards III-V antimonide-based, low-dimensional solids development, and device design innovations. Their development results from two primary motivations: the perceived challenges of reproducibly fabricating high-operability HgCdTe focal plane arrays (FPAs) at reasonable cost and theoretical predictions of lower Auger recombination for type-II superlattice (T2SL) detectors compared to HgCdTe. Lower Auger recombination translates into a fundamental advantage for T2SL over HgCdTe in terms of lower dark current and/or higher operating temperature provided other parameters such as Shockley–Read–Hall lifetimes are equal.

In fact, investigations of antimonide-based materials began at about the same time as HgCdTe—in the 1950s, and the apparent rapid success of their technology, especially low-dimensional solids, depends on the previous five decades of III-V materials and device research. However, the sophisticated physics associated with the antimonide-based bandgap engineering concept started at the beginning of the 1990s gave a new impact and interest in development of infrared detector structures within academic and national laboratories. In addition, implementation of barriers in photoconductor structures, in so-called barrier detectors, prevents current flow in the majority carrier band of a detector's absorber but allows unimpeded flow in the minority carrier band. As a result, this concept resurrects the performance of antimonide-based focal plane arrays and gives a new perspective in their applications. A new emerging strategy includes antimonide-based T2SLs, barrier structures such as the nBn detector with lower generation-recombination leakage mechanisms, photon trapping detectors, and multi-stage/cascade infrared devices.

This book describes the present status of new concepts of antimonide-based infrared detectors. The intent is to focus on designs having the largest impact on the mainstream of infrared detector technologies today. A secondary aim is to outline the evolution of detector technologies showing why certain device designs and architectures have emerged recently as alternative technologies to the HgCdTe ternary alloy. The third goal is to emphasize the applicability of detectors in the design of FPAs. This is especially addressed to the InAsSb ternary alloys system and T2SL materials. It seems to be clear that some of these solutions have emerged as real competitors of HgCdTe photodetectors. Special efforts are directed on the physical limits of detector performance and the performance comparison of antimonide-based detectors with the current stage of HgCdTe photodiodes. The reader should gain a good understanding of the similarities and contrasts and the strengths and weaknesses of a multitude of approaches that have been developed over two last decades as an effort to improve our ability to sense infrared radiation.

The level of this book is suitable for graduate students in physics and engineering who have received preparation in modern solid-state physics and electronic circuits. This book will be of interest to individuals working with aerospace sensors and systems, remote sensing, thermal imaging, military imaging, optical telecommunications, infrared spectroscopy, and lidar, as well. To satisfy all these needs, each chapter first discusses the principles needed to understand the chapter topic as well as some historical background before presenting the reader with the most recent information available. For those currently in the field, this book can be used as a collection of useful data, as a guide to literature in the field, and as an overview of topics in the field. The book also could be used as a reference for participants of educational short courses, such as those organized by SPIE.

The book is divided into ten chapters. The introduction (Chapter 1) gives a short historical overview of the development of IR detectors with antimonide-based materials and describes the detector classification and figures of merit of infrared detectors. The main topics in crystal growth technology, both bulk materials and epitaxial layers, as well their physical properties are given in Chapter 2. Special emphasis is paid to the modern epitaxy technologies such as molecular beam epitaxy and metalorganic chemical vapor deposition. Chapter 3 provides similar information about type-II superlattices. The next two chapters concern technology and performance of both bulk as well as superlattice antimonide-based infrared detectors. New classes of infrared detectors called barrier detectors, trapping detectors, and cascade detectors are covered in three succeeding chapters: Chapters 6, 7, and 8. An overview of antimonide-based FPA architectures is given in Chapter 9. Finally, remarks are included in the last chapter.

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