INFRARED DETECTORS
MATERIALS AND TECHNOLOGY

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PREFACE

The detection of infrared radiation dates back to 1800 by Sir William Herschel Astronomer Royal to the king of England. He observed a temperature increase in the thermometer as it is moved beyond red end of the visible radiation. Compound semiconductors unlike their elemental counter parts have an excellent technological advantage in band-gap engineering. In particular II-VI compounds such as $Hg_{1-x}Cd_xTe$, whose band-gap can be tuned from 0.0 to 1.6 eV by changing the composition of Cd from 0.17 to 1.0 has tremendous impact on the photodetector applications. Another advantage with this system is the mobility of the charge carriers (electrons) that is quite high (10^5 cm^2/Vs) at liquid nitrogen, which is its normal operating temperature. Technological evolution brought out the quantum well infrared photodetectors that uses the concept of intra-band transitions as the basis for photodetection. This monograph is essentially an introduction to infrared materials, processing and devices. The objective of this monograph is to mitigate the development of IR technology with special reference to defense. The IR detector technology involves a careful material selection, novel device structures and efficient cooling systems. Cooling systems is an important area to reduce the noise in the detection system.

Starting with a brief introduction to the history of IR technology, in Chapter 1, we discuss the propagation of IR through the atmosphere. This discussion sets the stage for the development and optimization of the IR based application systems.

In Chapter 2, we discuss the uncooled infrared focal plane array detectors that are based on resistive bolometer, thermoelectrics, pyroelectrics, and ferroelectrics. These detectors have an advantage over the new generation devices in which there is no requirement of detector cooling. Simple array processing is good enough that is cost effective for non-critical application.

As would be seen from Chapter 2, uncooled infrared devices have limited sensitivity and speed of response that motivates the search for an ultimate true photo detector. A true photo detector is the one that can detect a single photon. Semiconductors have this unique advantage of being able to tune their band gap by engineering materials. In Chapter 3, we discuss Semiconductor photon detectors based on Schottky barrier, photoconductivity, p-n junction photovoltaics and quantum wells.

In Chapter 4, we discuss semiconductor photoconductive detector that work on the principle of introduction of the electrical conduction by optical radiation. We discuss the mechanism of increasing charge carrier generation in the presence of optical excitation, and focus on technology materials like HgCdTe, InSb, InAs alloys that are bandgap engineered systems.

In Chapter 5, we discuss photovoltaic detectors that have the advantage for the speed of response as compared to photoconductive devices. We discuss p-n junction photovoltaic detectors, which have accelerated response time as the charge carriers are generated due to incoming photons are swept across in high electric field in the depletion layer.

In Chapter 6, we focus on the growth of IR materials based on Czochralski, slush growth, traveling heater methods for single crystal. For quantum-well detector more advanced epitaxial methods like LPE, MOCVD and MBE are required. We discussed processing of HgCdTe devices in this chapter. Also, we discuss III-V based materials such as InSb and InAs, which are much more matured in material preparation.

In Chapter 7, we discuss quantum well infrared detectors. Quantum wells are unique in that their band gap can be tailored for use in wide range of IR frequencies. The voltage tenability of these devices makes quantum wells one of the most attractive device technologies. The only drawback being that their material processing and device technology is expensive and quantum efficiencies are poor.

Finally, in Chapter 8, we discuss various mechanisms for the cooling of IR detectors as a radiation shield for effective performance in the presence of noise. We discuss various cooling systems based on Joule-Thompson, one shot cooling, closed cycle cooling, thermoelectric cooling and liquid-solid cryogenic cooling.

We wish that this monograph would serve the purpose of motivating the IR materials and device technology in India.

November 2006

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CHAPTER 1

INTRODUCTION TO INFRARED DETECTORS

1.1 INTRODUCTION

Infrared detectors, which convert infrared radiation into electrical output, form one of the most important group of sensors in weapon system applications. In the civilian area, these sensors play a major role in applications such as medical thermography, fire detection, remote sensing, etc. In this short monograph, the physics and technology of these sensors is discussed. There are a number of textbooks, monographs and reviews dealing with this important topic. However, the emphasis in this monograph is on the technology of detectors with special reference to defence applications. New promising material structures for IR detection; special subsystems such as cooling devices, which are an integral part of IR based sensor systems is also discussed. Before dealing with detector technology in detail, a brief treatment of fundamentals of IR radiation, its transmission through the atmosphere and various expressions, which quantitatively describe the detector performance is given.

1.2 HISTORICAL BACKGROUND

The first experimental observation of invisible radiation beyond the red end of the solar spectrum is credited to Sir William Herschel, Astronomer Royal to the King of England in 1800. He observed a temperature increase in the thermometer as it was moved from the violet end of the spectrum (produced by a prism) towards the red end and beyond the visible region. The invisible radiation beyond the red end was named as infrared radiation.

All bodies, at temperatures greater than absolute zero, emit infrared radiation. The distribution of energy as a function of the wavelength from a black body at any given temperature has been the subject of study by a number of leading scientists in the later part of the 19^{th} and the beginning of the 20^{th} century. Laws such as Rayleigh Jeans law, Wein Displacement law and Planck's law are well known landmarks in physics. Another law, which has importance in system design calculations, is Kirchoff's law. This law establishes the proportionality between the radiant emissivity of the body with its absorption. The radiant emissivity is defined as $e = I / I_b$, where I is the radiant power emitted by a body and I_b is the equivalent emission by a perfect blackbody under similar conditions. The emissivity of a black body is unity and all others have emissivities less than unity. Kirchoff's law also holds good at a particular wavelength interval λ and $\lambda + \delta\lambda$, i.e., the spectral emissivity obeys a similar law, i.e., $e_1 = I_1 / I_{1b}$ at any wavelength. In general, e_1 is a function of wavelength. We will not go further into the details of black body radiation as this is a part of any standard textbook description.

1.3 INFRARED TRANSMISSION THROUGH ATMOSPHERE

A knowledge of the atmospheric absorption of infrared radiation is necessary in understanding the role of the atmosphere through which either the target, which is emitting IR radiation or a source such as a laser beam, which is illuminating a designated target. A monochromatic radiation propagating through the atmosphere has its radiance attenuated exponentially (Bouguer-Lambert law). This attenuation may be due to absorption and scattering and can be expressed as

$$L_\lambda(x) = L_\lambda(0)\exp\{-[\alpha_a(\lambda) + \alpha_s(\lambda)]\} \tag{1.1}$$

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