Preface

Although it was already well known that the energy-level spacing in a quantum well (QW) structure can be tailored to the infrared photon energy, the early attempt of using QWs in infrared detection was based on free electron absorption in QWs to bring the electrons over the top of the barriers. The energy level structure and the large dipole moment of the envelope QW wavefunctions have not been utilized. The sensitivity of the detectors is expected to be low.

In 1985, West and Eglash observed strong intersubband (envelope wavefunction) transition in GaAs/Al$_x$Ga$_{1-x}$As multiple quantum wells (MQW) that initiated serious investigations in using MQWs as infrared photodetectors. In 1987, Choi *et al.* and Levine *et al.* published a series of papers illustrating the basic operating principles of the detector, and demonstrating sensitive infrared detection based on this transition. In these MQW structures, the final QW state of transition was placed either slightly above or below the top of the barriers to obtain optimum sensitivity. However, since the barriers in these structures were relatively thin, the sensitivity of the detectors did not improve significantly at a lower operating temperature. By increasing the barrier thickness to suppress the tunneling current, Levine *et al.* in 1990 improved the low-temperature sensitivity, and at these temperatures, the detector is suitable for detector array applications. The detectors are formally referred to as quantum well infrared photodetectors (QWIPs). In 1991, only four years after the basic detector demonstration, Bethea *et al.* obtained the first infrared image using a 10-element linear scanning array.

So far, the detectors have to be illuminated at an oblique angle at the edge of the mesa, since intersubband transition is only initiated by the perpendicular electric field in the radiation relative to the material layers. Additional light-coupling scheme has to be devised to create normally incident absorption, which is crucial in the 2-dimensional detector array format. In 1991, Andersson and Lundqvist proposed using diffraction gratings for this application. According to their calculations, large quantum efficiency can be obtained using proper grating parameters. Based on this coupling scheme, Bethea *et al.* and others have fabricated QWIPs into 2-dimensional staring arrays, and produced high-quality and high-resolution thermal imageries. Despite these exciting achievements, the measured quantum efficiency is well below expectation, and research on an efficient light-coupling scheme continues. Currently, there are several approaches under investigation. They can be divided into three basic approaches: the diffractive approach (e.g. the random scattering reflector and the enhanced-QWIP), the reflective approach (e.g. the corrugated-QWIP), and the refractive approach (e.g. using microlens).

Besides the light-coupling issue, there is a more serious drawback in the quantum well technology: the large thermal dark current observed at the elevated temperatures, which prevents the array to be operated at the standard temperature. In order to lower the detector dark current, Choi *et al.* proposed a detector structure, (referred as an infrared hot-electron transistor (IHET)), to preferentially filter out the dark current. With a proper filter design, the current level can be reduced arbitrarily, thus dissociating its current level from the detector cutoff wavelength. However, the detector cannot be operated with the standard photoconductor readout circuit, so a compatible readout circuit must be developed. In addition to detector applications, an IHET structure is also very useful in studying the opto-electronic properties of a QWIP. Based on these studies, detectors with better performance can be achieved.

The year of 1997 marks the tenth anniversary of the QW infrared technology. In this ten-year period, much has been learned about this technology, although some detector properties still need further studies. Since this technology reaches a certain degree of maturity, it is a suitable time to review its status. This book is designed to give a detailed and systematic discussion on the physics and the technology relevant to QWIPs. The book is organized into three parts. The first part discusses the fundamental aspects of infrared detection, and the relationship between the detector band structure and its optical absorption characteristics; the second part discusses the transport properties of the QWIP; and the third part discusses detector performance. Infrared detection is a multi-disciplinary subject, it is difficult to treat each topic with equal vigor. Nevertheless, I hope to give readers with enough background on each topic of QW infrared technology.

In addition to their impact on infrared technology, one can also witness the prevalence of quantum effects in these MQW structures. Basic premises of quantum mechanics, such as quantization in a box, quantum mechanical transmission, dipole transition, and miniband structure in superlattice, are beautifully displayed. They are, in fact, good examples of basic quantum mechanics. The ability of placing an electron with precise energy in an otherwise empty miniband can also be useful in studying several branches of physics, including band theory, theory of electron transport, hot-electron energy relaxation, noise in quantum structures, and new materials. Therefore, the study of QWIP should not be confined to infrared engineers, but should also be of interest to physicists in general. This book can serve as a resource for a course on QWIPs or as a reference in the areas of quantum or solid state physics.

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K. K. Choi
Adelphi, MD