Chapter 1

Introduction

This work addresses the output power optimization of semiconductor based submillimeter wavelength sources. This wavelength region, from 1 mm to 100 µm (300 GHz to 3 THz), is the least explored portion of the electromagnetic spectrum and one of the most challenging regions for system development. This wavelength region is of great importance in such applications as space-borne radio astronomy, spectroscopy, plasma diagnostics, and atmospheric remote sensing [1]. Remote sensing of the depletion of the ozone layer, in particular, with submillimeter radiometry has added a sense of urgency to developing components operating in this wavelength region [2]. The traditional power sources employed for these applications are gas lasers and backward wave oscillators which are large, unreliable, and consume large amounts of power. The low power and mass requirements of semiconductor devices along with their reliability make them attractive candidates for space applications. The role of such power sources would be to serve as the local oscillator (LO) in a heterodyne receiver system. In this frequency range, the LO power requirement of the Schottky Barrier mixer diode in the receiver is about one milliwatt [3]. Two candidate devices were investigated for their potential as submillimeter wavelength power sources: fundamental oscillation with a double barrier resonant tunneling diode (DBRTD) and frequency multiplication with a heterojunction barrier varactor (HBV) diode.

The devices were fabricated by molecular beam epitaxy (MBE), an ultra-high vacuum deposition technique. We will discuss in chapter 2 the various steps required to optimize the MBE growth conditions for high performance DBRTDs, including the reproducible growth of baseline AlAs/GaAs DBRTDs. The reflection high energy electron diffraction (RHEED) technique is used extensively for calibrating growth rates and growth condition optimization. The influence of growth interruptions on the current - voltage (I - V) characteristics of AlAs/GaAs DBRTDs is studied with the interrupt schedules determined by independent RHEED measurements during prototypical device growth sequences. Then, the MBE techniques required to grow high quality InGaAs lattice-matched to InP are discussed. These layers are characterized by Nomarski optical microscopy, X-Ray crystal diffraction, and Hall-effect measurements.

In chapter 3 we briefly describe the operation of DBRTDs and how to optimize them for maximum output power. Since these devices exhibit negative differential resistance in their I - V characteristics, they can be used as microwave oscillators. For DBRTD oscillators, the output power is proportional to the $\Delta V \Delta J$ power density product, where ΔV is the difference between the peak and valley voltage and ΔJ is the difference between the peak and valley current density. It will be shown why AlAs/$In_{0.53}Ga_{0.47}As$ rather than AlAs/GaAs or AlSb/InAs is the material system of choice for obtaining increased ΔJ. A baseline AlAs/$In_{0.53}Ga_{0.47}As$ DBRTD consisting of a 50Å $In_{0.53}Ga_{0.47}As$ quantum well and 17Å AlAs barriers is developed. The effect of varying the barrier thickness by one monolayer on AlAs/$In_{0.53}Ga_{0.47}As$ DBRTD characteristics will also be presented.

In chapter 4, we show how increase ΔV over that obtained with a baseline DBRTD by modifying the downstream spacer layer profile to take advantage of space-charge effects arising from carriers traversing a space-charge region at a constant saturation velocity. Such a layer modification results in the Quantum Well Injection Transit (QWITT) diode, which was introduced by Kesan *et al.* [4]. The design techniques required for maximizing the output power of QWITT oscillator diodes is discussed. It is shown that by adopting the QWITT design principles, maximum output power can be obtained without sacrificing the frequency response. The current density versus voltage (J - V) characteristics of several types of AlAs/$In_{0.53}Ga_{0.47}As$ QWITT diodes are presented. The effect of the drift region doping, the quantum well conductance, and the saturation velocity on the J - V characteristics is investigated. A novel variation of the QWITT, the depletion edge modulated QWITT (DEMQWITT), is introduced and the J - V characteristic of an AlAs/$In_{0.53}Ga_{0.47}As$ DEMQWITT is presented. Finally, the potential application of QWITTs to submillimeter wavelength power generation is discussed.

An alternative to fundamental oscillation for generating submillimeter wavelength power is frequency multiplication of a high power, lower frequency source with a varactor diode. The dominant device used presently for submillimeter wavelength frequency multiplication is the Schottky barrier diode. However, due to certain limitations of Schottky barrier diodes, there is interest in developing hetero-structure based varactor diodes. One such device is the Heterojunction Barrier Varactor (HBV) diode introduced by Kollberg *et al.* [5]. The major problem with this device currently is its low breakdown voltage and excessive conduction current which leads to low multiplier conversion efficiency. In chapter 5 we address the issue of increasing the breakdown voltage by examining HBV diodes fabricated in the AlAs/$In_{0.53}Ga_{0.47}As$ and AlGaAs/GaAs material systems. The J - V and capacitance - voltage characteristics of these devices will be presented.

In chapter 6, we conclude with a summary and evaluation of DBRTDs and HBV diodes for high frequency power generation and suggest areas for future work.

References

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