Chapter 6

Summary and Conclusion

In this work we have presented data on the electrical characteristics of DBRTDs and HBV diodes.

A reproducible MBE process was developed for the growth of AlAs/$In_{0.53}Ga_{0.47}As$ and AlAs/GaAs DBRTDs. RHEED was used extensively for calibrating growth rates and growth condition optimization. The influence of growth interruptions on the I - V characteristics of AlAs/GaAs DBRTDs was studied with the interrupt schedule determined by independent RHEED measurements during prototypical device growth sequences. Our data suggests that interface roughness at inverted and normal interfaces does not play a significant role in determining the transport characteristics of high current density DBRTDs. To further improve device performance, the MBE growth of lattice-matched InGaAs on InP was carried out. The techniques required to grow lattice-matched InGaAs and strained AlAs on InP were discussed. The InGaAs epitaxial layers were characterized by Nomarski optical microscopy, X-Ray crystal diffraction, and Hall-effect measurements.

We have also shown that 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. Varying the barrier thickness of thin barrier AlAs/$In_{0.53}Ga_{0.47}As$ DBRTDs is shown to have dramatic effects on the J - V characteristics; changing the barrier thickness by one monolayer changes the peak current density by a factor of two. This extreme sensitivity to layer dimensions highlights the precise layer thickness required for reproducible DBRTD characteristics.

The DBRTD oscillator output power is proportional to the $\Delta V \Delta J$ power density product. By employing AlAs/$In_{0.53}Ga_{0.47}As$ QWITTs, both ΔV and ΔJ are increased over that obtained with AlAs/GaAs devices. It was shown that an optimum drift region length exists and depends on the quantum well injection conductance and the drift region saturation velocity. The effect of the drift region doping on AlAs/$In_{0.53}Ga_{0.47}As$ QWITTs was investigated and found that to avoid destructive breakdown, the drift region doping must be higher than the peak current density. Low sigma AlAs/$In_{0.53}Ga_{0.47}As$ QWITTs were also fabricated with ΔV's as high as two volts. These devices, when placed in microstrip resonator circuits, produced 20 mW output power at 1 GHz, a record for DBRTD oscillators. Also, a DC-to-RF power conversion efficiency as high as 50% was achieved. This is the highest efficiency reported for CW operation of a two terminal semiconductor device. The W_{opt} for these low sigma devices is approximately 1.2 µm, a distance too large to deplete with conventional quantum well and spacer layer design. In an effort to fabricate devices with large ΔV, a novel variation of the QWITT was developed, the DEMQWITT, which is designed to provide a W_{opt} at each point in the NDR region of the quantum well injector characteristic. An AlAs/$In_{0.53}Ga_{0.47}As$ DEMQWITT was fabricated and a valley region as large as 10 volts was achieved.

The development of QWITT oscillators has been driven by the need to power optimize DBRTD performance. The role of such an oscillator would be to function as a LO for the Schottky diode mixer, preferably at terahertz frequencies. The LO power required in this frequency range is approximately one mW. It was concluded that given the constraints of external circuit matching and power coupling, generation of useful amounts of power by fundamental oscillation with DBRTDs is not presently viable and alternative techniques must be pursued. However, a promising area for high speed DBRTDs may be switching applications where the stringent requirement of circuit impedance matching is removed. Maximizing ΔJ and reducing the device capacitance is of prime concern for such applications and DBRTDs appear to be well suited for such a purpose.

An alternate approach for generating submillimeter-wavelength radiation is by frequency multiplication with a varactor diode. The HBV diode is a potential replacement for submillimeter-wavelength Schottky diode varactors that are currently employed for such applications. The major problem with this type of device has been its low breakdown voltage and excessive conduction current which leads to low multiplier power conversion efficiency. We have presented results on AlGaAs/GaAs and AlAs/$In_{0.53}Ga_{0.47}As$ HBV diodes which exhibit record breakdown voltages as high as 12 V and capacitance modulation ratios as high as 6. The AlAs/$In_{0.53}Ga_{0.47}As$ HBV diodes, in particular, are extremely attractive candidates for submillimeter wavelength frequency multipliers.