Appendix 1
Parametric Summary of All DBRTD and QWITT Devices

The following data is a list of all the pertinent MBE runs related to double barrier resonant tunneling diodes and quantum well injection transit diodes. Note that the parameters V_p, ΔV, J_p, J_v, and PVCR are obtained directly from the measurements and therefore have one sigma standard deviations associated with them. The specific negative resistances and $P_{r.f.}$ are also obtained directly from the DC-IV measurements with no standard deviations given for convenience and space in the table. The E_p, E_v, and σ are extracted from the measured DC-IV characteristics, device profile, and specific contact resistance of 3 x 10^{-6} Ω-cm^2 and therefore have no standard deviations associated with them. Note that the values for E_p, E_v, and σ may be misleading if the specific contact resistivity used is significantly off target or if the intrinsic structure of the quantum well is not accurately grown by MBE. Especially for the ELO DBRTDs (after ELO), the backside contact resistances were higher than before ELO and therefore values of E_p, E_v, and σ are misleading. Since all device parameters, such as E_p, E_v, and σ, are extracted with the assumption of a specific contact resistance of $\leq$ 3 x 10^{-6} Ω-cm^2 these values do not accurately represent the intrinsic characteristics of the quantum well and are noted by a "**" or "*".

Appendix 2
AZ5214E Photolithographic Process using the HTG System 3 Aligner

The exposure times given below are highly dependent on the intensity of the UV lamp and the wavelengths that are filtered by two dielectric mirrors. From the most recent lamp and mirror change (10/21/91), the following intensities were measured over a 4 inch by 4 inch exposure area. On the above date, a damaged mid-UV dielectric mirror (part # 70-000-755-0003) was replaced by a 365-405 nm dielectric mirror (part # 70-000-726-0000) which significantly increased the intensity of the system at 405 nm. The measured intensities, using an HTG Model 100 optical powermeter, over the exposure area with the new 365-405 nm dielectric mirror are given below:

C/I Mode

4.94	***5.00***	***5.40***
4.78	***4.86***	***5.30***
5.10	***5.15***	***5.60***

Intensity of the HTG System 3 within a 4 inch by 4 inch exposure area in units of mW/cm^2.

The "intensity/power" meter on the power supply has been calibrated to the external power supply meter. The x,y, and z alignments have already been adjusted, with the following intensities and powers measured:

CP Mode: Intensity = 4.46 mW/cm^2, Power = 265 Watts

CI Mode: Intensity = 4.80 mW/cm^2, Power = 290 Watts

I. IMAGE REVERSAL PATTERNING

1. Spin on primer @ 4000 rpm for 30 sec.
2. Spin on 5214E @ 4000 rpm for 30 sec.
3. Prebake for **70** seconds @ 90°C (on hot metal block in a Blue M bake oven.)
4. Imagewise expose for **21** seconds.
5. Image reversal bake for **70** seconds @ 105°C (on a hot metal block in the Blue M bake oven.) or at 120˚C for **35** seconds.
6. Flood expose for **55** seconds.
7. Develop with AZ 425 MIF developer using slow agitation for **30** seconds. Do not develop for one minute or you may get Saran wrap.

II. NORMAL POSITIVE PATTERN

1. Spin on primer @ 4000 rpm for 30 sec.
2. Spin on 5214E @ 4000 rpm for 30 sec.
3. Prebake for **60** to **90** seconds @ 90°C (on hot metal block in the oven.)
4. Pattern expose for **17** to **23** seconds.
5. Develop with AZ 425 MIF developer for 1 minute.

Appendix 3

General Epitaxial Lift Off Procedure

I. Considerations during epitaxial growth of layer structures for device.

A. Device structures with conductive substrates

1. Insert a n+ AlAs release layer (≈ 100Å - 500Å) between n+ GaAs substrate/buffer layer and the active device layer structure. For p+ GaAs substrates/buffer layers, insert a p+ AlAs release layer (≈100A - 500Å). Doping of the AlAs release layer will allow device testing before epitaxial lift off. Typical growth temperatures for this layer are above 630°C.

2. If the device structure will be mesa isolated, a fairly thick GaAs buffer layer (at least 2500Å) should be grown on top of the AlAs release layer to take into account variations in etch rates.

B. Device structure with semi-insulating substrates

1. Usually, the AlAs release layers are grown undoped.

II. Sample preparation for already processed ELO device structures. (See Figure 3.2)

A. Clean sample with acetone, ethanol, and DI-H_2O.

B. Perform O_2 plasma descum, 1/2 power for 1 minute.

C. Application of Apiezon W black wax to sample.

1. Apiezon W black wax that has been softened by mixing with TCA.

a) Apply wax with dental tool and press wax with teflon press.

b) Slowly bake sample and wax in oven at 85°C for 20 minutes. Raise temperature to 120°C and bake for 3 minutes. Wax should be dome-like in shape with a height of ≤ 0.25 cm of the base of the substrate.(See Fig. 3.4)

2. Apiezon W black wax that is softened by raised temperature.

a) Place Apiezon W wax on sample and heat sample/wax combination on a hot plate set at 90°C using a surface thermometer or an oven set at 125° for 3 minutes.

b) Remove sample from source of heat and before completely cooling press wax with a teflon press. Wax should be dome-like in shape with a height of ≤ 0.25 cm of the base of the substrate. (See Figure 3.4)

D. Make sure that wax covers the mesa isolated structures which contain AlGaAs layers in their active device structures.

E. Expose the AlAs release layer at all edges of the sample.

1. Cleave substrate up to the edge of the black wax carrier.
2. Remove any indium that may be on the edges of the sample.

F. Attach HF resistant teflon or wire to black wax carrier for suspension in 10% HF etchant. Otherwise sample is ready to be inserted into etchant.

III. Etching out AlAs release layer

A. Pour 10% HF etchant. 4.5:1 DI-H_2O:HF, The HF used usually comes as a standard 50% HF mix. Make sure a Nalgene HF resistant beaker is used and not a Pyrex glass beaker.

B. Cool 10% HF etchant to $\approx 0°C$. Although use of a refrigerator or freezer seems tempting, they should not be used due to the lack of fume handling capabilities and the endangerment of others. A useful alternative is "blue" ice and a small cooler which can be placed in a fume hood. With the lid just barely cracked open, the etchant is kept for as long as 12 hours. The AlAs etch rates may vary 50 μm/min to 60 μm/min.

IV. Removing sample from 10% HF etch after complete separation from substrate

A. Dilute 10% HF etchant by gently flowing DI-H_2O into beaker. Dilution will sometimes help free the ELO film from the substrate if it has not already separated from the substrate. Make sure that the sample does not strike the edges of the beaker. If the sample is suspended, it is easier to control the sample. Wear appropriate acid resistant gloves, face shield, and lab coat.

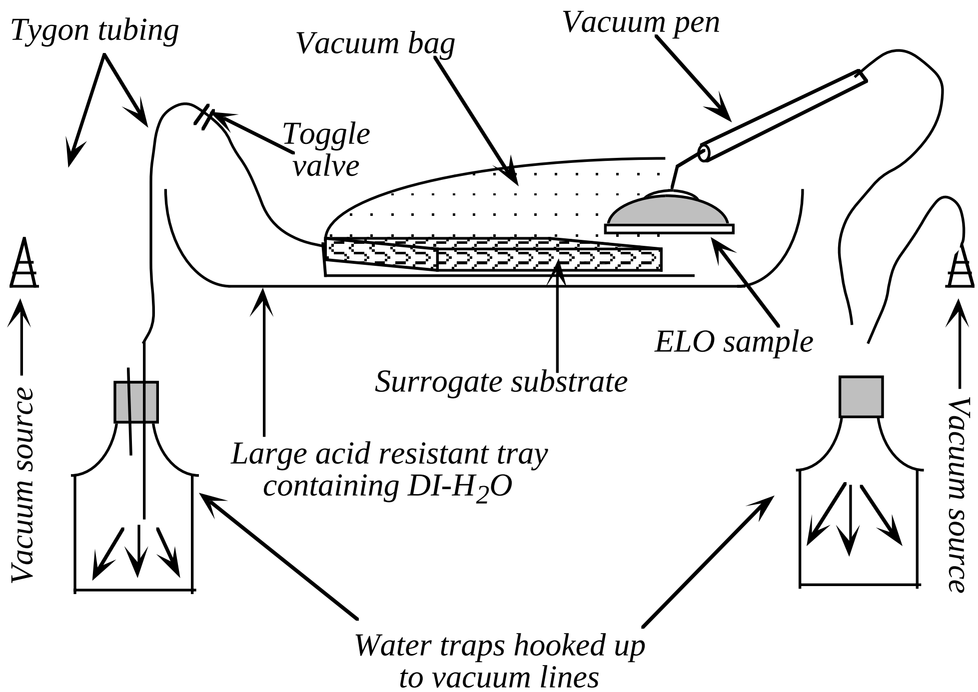
1. Place beaker into a large Nalgene HF resistant tray and allow etchant to overflow into tray. Once the HF etchant has been completely diluted ($\leq$ 0.01% HF), it can be poured down an acid drain.
2. Do not take the ELO sample out of the DI-H_2O environment to prevent particulate contamination of the bare epitaxial film.

B. Have a clean surrogate substrate already at hand for immediate bonding. See Chapter 3, section 3.8

1. The surrogate substrate should have gone through an O_2 plasma.

C. Hook up vacuum pen and vacuum bag for sample transfer and bonding.

1. For bonding under DI-H_2O, water traps and two vacuum lines are required as shown in the figure below. VDW and metal/alloy bonds are usually performed in a DI-H_2O environment.



2. Adhesive bonds do not require a DI-H_2O environment.
3. Apply vacuum pressure and temperature to samples. See Chp. 3.

V. Bonds to alternative substrates.

A. See Chapter 3, sections 3.6 and 3.7 and Chapter 6, sections 6.2, 6.3, and 6.4.

VI. Remove Apiezon W black wax with TCA. Rinse with acetone, ethanol, and DI-H_2O.