Block course “GaAs fabrication”

updated 120929, DM

Our group is pleased to introduce you to the world of GaAs research and in particular, 2D electron gases (2DEGs) in GaAs nanostructures. GaAs is the workhorse material for low dimensional and nanoscale physics. Literally thousands of research articles have been written over the past decades on these topics, and research based on this material compound actively continues today. Hallmark effects such as conductance quantization and the fractional quantum Hall effect, for which the Nobel prize has been awarded in 1998, have been discovered in GaAs 2DEG materials. In addition to scientific investigation, GaAs also finds use in various (high-speed) electronic and, due to the direct bandgap in GaAs, optical applications such as lasers and LEDs. Of particular interest to our group are surface-gate-defined nanostructures in GaAs 2DEGs, which we use to investigate quantum coherence and quantum computation.

In this block course, you will fabricate a gated GaAs Hall bar and perform electrical tests, both at room temperature and at liquid Helium temperature, 4 Kelvin. The main part is the fabrication of a sample, consisting of defining/etching the Hall bar structure (mesa), making contacts to the 2DEG (ohmics) and defining a top gate. The required fabrication procedures are divided into several tasks, which are described in detail on the following pages. You will perform these tasks with the guidance and assistance of the teaching assistant of this course.

The course is organized with a daily schedule as follows:

1 Introduction, preparation: eventually start reading
2 Cleave and clean a GaAs wafer piece
3 Photo lithography: mesa pattern
4 Etch mesa (GaAs etch)
5 Photo lithography: ohmic pattern
6 Deposit ohmics (evaporate Au/Ge/Ni), lift-off
7 Anneal ohmics
8 Photo lithography: gate pattern
9 Deposit gates (Ti/Au) & lift off
10 Au wire bond
11 Test at room temperature
12 Test at 4 Kelvin (ohmic contacts, gates, 2DEG)
13 Density & mobility (optional)

	Mon	Tue	Wed	Thu	Fri
Week 1	#1	read #2-7	#2 & #3	#4 & #5	read #8-13
Week 2	#6	#7 & #8	#9	#10	report
Week 3	SEM	#11 & #12	report	report	report

2 Cleave and clean a GaAs wafer piece

- scratch with diamond scribe
- cleave on edge of a glass slide
- three-solvent-clean: TCE, acetone, methanol (5 min each in ultrasound)
- blow off (N_2 gun)
- inspect with optical microscope (shoot pictures)
- pre-bake (singe) on hot plate 120 ºC, 5 min, let cool 2 min

Reading "Modern GaAs Processing Methods", Ralph Williams

chapter 2) GaAs material and crystal properties - A Tutorial
pages 17-32
pages 32-46 (optional)

chapter 4) Cleaning and Cleanliness, pp. 81-94

3 Photo lithography: Mesa pattern

- spin photoresist (ma-N 415), 6000 rpm, 40 sec, ramp speed 5 (~1.6 um?)
- bake on hotplate 93ºC, 90 sec
- inspect with optical microscope (UV filter)
- expose on mask aligner: CH1, 14 sec exposure, hard contact 5 sec
- develop 60-100 sec in developer (maD 332s), rinse in DI H_2O 20 sec, blow off (N_2 gun)
- inspect with optical microscope

Reading "Nanoelectronics and Information Technology", Rainer Waser

chapter 9) Lithography
9.1) Survey, p. 223
9.2) Optical Lithography, pp. 224 - 230
9.7) Photoresist, pp. 239 - 241

4 Etch mesa

- measure resist thickness (α-step profilometer)
- mix H_2SO_4 (95%) : H_2O_2 : H_2O in ratio 1:8:240 (~ 3 nm/sec), NWIDSSGDU
- etch ~ 40 sec, rinse in DI H_2O
- measure etched depth (α-step profilometer, goal 120-150 nm), etch more if necessary
- remove resist: put the sample in warm NMP (mr-Rem 660, 45-50°C) until all the resist is removed, clean with IPA and blow off
- inspect with optical microscope (shoot photos)

Reading: Modern GaAs Processing Methods, Ralph Williams
chapter 5) Wet Etching, pp. 95 – 106

5 Photo lithography: Ohmic pattern

- three-solvent-clean, N_2 gun, singe hot plate (dito #1 cleaning)
- spin photoresist (ma-N 415), 6000 rpm, 40 sec, ramp speed 5
- bake on hotplate 93ºC, 90 sec
- inspect with optical microscope (UV filter)
- align the sample with ohmic pattern on the mask
- expose on mask aligner: CH1, 14 sec exposure, hard contact 5 sec
- develop 60-100 sec in developer (maD 332s), rinse in DI H_2O 20 sec, blow off
- inspect under optical microscope

6 Deposit ohmics & Lift off

- O_2 plasma: 40 sec at 250 mTorr, 30 W, 16% O_2 (gas #4), 5e-5 p_{base}
- dip the sample in 37% HCl for 5 sec, rinse in H_2O for 15 sec, blow off
- load the sample into evaporator
- evaporate Au:Ge:Ni / 1070:530:400 Å
- let cool, then remove sample from evaporator
- put the sample in warm NMP (mr-Rem 660, 45-50°C) until all the metal over the resist and the resist itself are removed; blow off
- use sonicator if needed (20% power)
- inspect under the optical microscope (shoot photos)

Reading “Nanoelectronics and Information Technology”, Rainer Waser
chapter 8) Film Deposition Methods, pp. 199 - 204
“Mesoscopic Electronics in Solid State Nanostructures”, Thomas Heinzel
chapter 4) Experimental Techniques, pp. 101 – 110 (optional)

7 Anneal ohmics

- load the sample in annealing oven, make sure back of sample is clean to assure good thermal contact
- setup the annealing program (computer: cmd, type az500)
- anneal the sample (see recipe)
- inspect under optical microscope (shoot photos)

Reading “Electrical Characterization of GaAs materials and Devices”, David C. Look
chapter 1.1.7) Contacts , pp. 21-35

8 Photo lithography: Gate pattern

- three-solvent-clean, N_2 gun, singe hot plate (dito #1 cleaning)
- spin photoresist (ma-N 415), 6000 rpm, 40 sec, ramp speed 5
- bake on hotplate 93ºC, 90 sec
- inspect with optical microscope (UV filter)
- align the sample with gate pattern on the mask
- expose on mask aligner: CH1, 14 sec exposure, hard contact 5 sec
- develop 60-100 sec in developer (maD 332s), rinse in H_2O 20 sec, blow off
- inspect under optical microscope

9 Deposit gates (Ti:Au) & Lift off

- O_2 plasma: 40 sec at 250 mTorr, 30 W, 16% O_2 (gas #4), 5e-5 p_{base}
- load the sample in the evaporator, pump down
- evaporate Ti:Au / 50:1000 Å
- let cool, remove sample from evaporator
- put the sample in warm NMP (mr-Rem 660, 45-50°C) until all the metal over the resist and the resist itself are removed; blow off
- inspect under the optical microscope (shoot photos)

10 Au wire bond

- glue the sample to the chip carrier using PMMA
- set the bonding parameters (see recipe) and bond the sample (Au wire)
- inspect the sample under microscope (shoot photos)
- draw a diagram of the bonding scheme, carefully numbering the wires

reading "Mesoscopic Electronics in Solid State Nanostructures", Thomas Heinzel
chapter 4.1.5) Bonding, pp. 110-111

11 Test at room temperature

- check electrical wiring of dip stick with cross-linked carrier (1-2, 3-4, etc.)
- connect everything and ground all wires at the break-out-box
- place the sample in the sample holder, carefully checking orientation, and close the can
- using the battery box (set to some small voltage, e. g. -10 mV) and current preamp, test each ohmic (should be low impedance, < 100 kΩ), and gate (should be high impedance, > 1 MΩ), carefully taking notes

12 Test at 4 Kelvin (ohmic contacts, gates, 2DEG resistance)

- insert the dip stick into the He-dewar to cool to 4K (slowly, to minimize He boil-off)
- measure the ohmic resistances (should be ~200 Ω) and gate resistance (should be > 1 GΩ) using the 2-wire method. Note that the battery box has a finite output impedance, and the dip stick wiring also has a finite resistance.
- perform a 4-wire measurement of the 2DEG resistance using a lock-in amplifier

reading "Mesoscopic Electronics in Solid State Nanostructures", Thomas Heinzel
chapter 4.2) Elements of Cryogenics, pp. 110-120
4.3) Electronic measurements on nanostructures, pp.121-123, 127&128
online tutorial: http://www.allaboutcircuits.com/vol_1/chpt_8/9.html

13 2DEG density & mobility using classical Hall effect (optional)

- cool down dip stick in a dewar with a magnet
- using a Hall bar, measure the Hall voltage $V_{xy} = R_{xy} \cdot I$ and longitudinal resistance R_{xx} in a small magnetic field (+/- 100 mT)
- convert Rxx to resistivity ρ_{xx} based on the Hall bar geometry.
- determine density n (from $R_{xy} = B/(en)$), and then calculate the mobility μ using $1/\rho_{xx} = ne\mu$. Based on the Drude model, estimate the mean scattering time and mean free path of the electrons. Compare the mean free path to the GaAs lattice spacing and interpret.

reading: *notes about classical Hall effect and Drude conductivity (5 pages) available on our web-page*

Report

A report encompassing 2’500 to max. 5’000 words has to be prepared describing the techniques used, the experiments performed and the measurements made. It would be appropriate to have a few pictures of the processed sample at some of the various processing steps. As the language of science generally is English, we highly recommend that your report is written in English. The preferred scientific text processing system for physicists is LaTeX, and we would like to encourage you to prepare your report using LaTeX. Try to structure the report well, if you wish into the following sections:

1) Introduction and Motivation
2) Experiments and Results
3) Conclusion and Discussion

The report will be graded using the published Block course criteria, also available on our webpage.