Quantum Cascade Laser Material Growth and Characterization

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Introduction

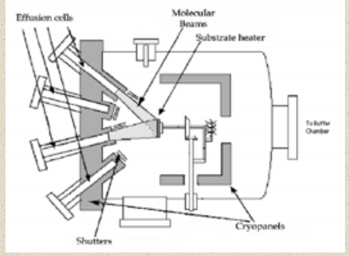
During my participation in the MIRTHE (Mid-InfraRed Technologies for Health and the Environment) program, I was involved in the growth and characterization of the semiconductor materials used to create QCLs. I assisted in the actual growing procedure, I conducted an experiment to characterize the semiconductor material, and I created a computer program to automate the process used to characterize the samples.

Growth Setup

MBE Machine:

1.) Load Lock Chamber
2.) Buffer Chamber
3.) Growth Chamber

The semiconductor materials are grown using a Molecular Beam Epitaxy (MBE) machine. A sample of Indium Phosphide substrate is cleaved to the appropriate size depending on the particular growth setup and inserted into the load lock chamber (1). This is the first of three chambers that make up the MBE. Using a series of vacuum pumps we can achieve ultra high vacuum in the growth chamber (3), or a pressure of about 10^{-10} torr, down from room pressure of 760 torr. The sample is transferred from the load lock chamber, through the buffer chamber, and into the growth chamber, where material growth takes place.



Inside view of the growth chamber. Liquid nitrogen is pumped through the cryopanels to remove excess heat from the cells and to absorb residual gas molecules from the chamber to improve the vacuum. The substrate holder is heated during the growth process so when the elements condense on the substrate, they bond to the crystal lattice. Shutter systems control the layers of each element that is released into the chamber.

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Growth Process

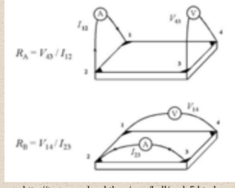
Once ultra high vacuum is achieved, the growth process can begin. Within the growth chamber are a number of effusion cells, each containing ultra pure elements such as gallium and arsenic. These cells are heated individually until they evaporate. These evaporated elements are controlled by a shutter system. When a shutter is open for a particular cell, that element is released into the chamber and is shot towards the substrate. Due to the ultra high vacuum, the evaporated elements do not interact with each other or residual vacuum chamber gasses until they reach the wafer. Once these particles condense on the wafer, they may react with the other elements and become incorporated into the substrate's crystal lattice. A computer controls the shutter operation, allowing for precise control of the thickness of each layer.

Characterization Setup:

Top Left: Picoammeter
Measure current through two contacts
Make sure measured current is about equal to input current
Bottom Left: Multimeter
Measure voltage difference
Top Right: Current Source
Supply input current to the contacts
Bottom Right: Switch System
Rotate current through different contacts

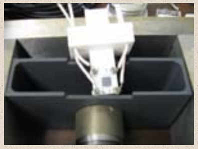
Van der Pauw Method

A technique used to measure the resistivity of a semiconductor. The sample is cleaved into a square and contacts are attached to the four corners. Current is run through two contacts while the voltage across the other two contacts is measured. Once this process is finished, we apply a magnetic field perpendicular to the flow of current.



http://tau.nanophys.kth.se/cmp/hall/node5.html

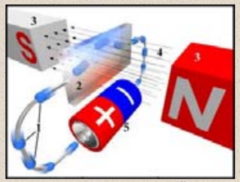
Van Der Pauw setup for characterization testing on a semiconductor. 1, 2, 3, and 4 are the contacts to the sample, I is the current, V is the voltage. Current is run through 1 and 2 while the voltage is measured across 3 and 4. Then the current runs through 2 and 1 and the voltage is measured. The current gets rotated and the voltage is measured repeatedly until there are eight values for the voltage difference. These values are averaged together and the result is used for characterization calculations.



Cleaved sample ready to be tested. Contacts are made to the four corners and gold wire is used to connect to the experimental apparatus. Measurements are taken outside of the magnet as well as inside of the magnet facing both forward and backward. The white wires are connected to the switch system used in the characterization setup.

Hall Effect

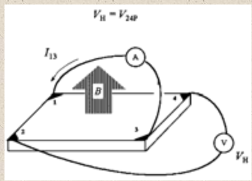
When a conductor has an electric current flowing through it and a magnetic field is applied perpendicular to the current flow, a potential difference is created. Using this measured potential, called the Hall Voltage, and the Van der Pauw voltage, we calculate the free charge carrier density and mobility of the sample. The density depends on the amount of silicon doping, and the mobility is a measure of the electron scattering. Once characterization tests are analyzed, new samples can be made with minor adjustments to doping levels and effusion cell temperatures to optimize the semiconductor material. These tests are also done at liquid nitrogen temperatures to see how low temperatures affect the characteristics of the semiconductor.



http://www.answers.com/topic/hall-effect

Hall effect diagram, showing electron flow.
1. Electrons
2. Semiconductor
3. Magnets
4. Magnetic field
5. Power source
The semiconductor takes on a negative charge at the top edge (blue color) and positive at the lower edge (red color).

Van der Pauw setup used for Hall Effect characterization testing on the semiconductor sample. 1, 2, 3, and 4 are the contacts to the sample, B is the magnetic field, I is the current, V_H is the Hall voltage. Current is run through 1 and 3, and the voltage is measured across 2 and 4. The current is reversed and the voltage is measured again. The current and voltage gets rotated around the sample again and averaged together to get one value for the Hall voltage.



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Semiconductor structure once growth is completed. Alternating layers of indium gallium arsenide and indium aluminum arsenide on an indium phosphide substrate.

Results:

The current MBE machine is very new, so growth and characterization is just getting off the ground. However, we found that in general, at liquid nitrogen temperatures, mobility increases and density decreases. For a specific sample of InGaAs, the mobility increased by over 200% of the mobility at room temperature, from about 6,620 to 14,500 $cm^2/V{\cdot}s$. The carrier density decreased slightly, from 1.72×10^{16} to 1.18×10^{16} cm^{-3}.