Quantum Cascade Laser Material Growth and Characterization

Billy Mozet[1,2], Jianxin Chen[1], Claire Gmachl[1]
[1]Princeton University, Princeton, NJ 08544
[2]Permanent address: Gettysburg College, Gettysburg, PA 17325
Email: mozewi01@gettysburg.edu

Quantum Cascade Laser (QCL) materials are produced through the growth of a thinly layered semiconductor using a Molecular Beam Epitaxy (MBE) machine. We grow InGaAs and InAlAs heterostructures on InP substrates. The substrates are introduced into a growth chamber through a load lock chamber, where the different layers are added in an alternating layered structure with thicknesses varying in the tens of angstroms scale (Figure 1A). The thicknesses of these layers determine the properties of QCLs, such as the emission frequency. This process is done in an ultra high vacuum to ensure material quality. Once the semiconductor material is tested and approved, it can be used as a QCL to emit a customized frequency of light.

We characterize the samples of semiconductor material using Hall Effect measurements and Van der Pauw geometry methods (Figure 1B). We send a current between contacts 1 and 2 and measure the voltage across contacts 3 and 4. Then we rotate the system so current flows between 2 to 3 and we measure the voltage across 1 and 4. We continue this process and average all of the voltages together to get one voltage value. Then we apply a magnetic field and measure the voltage from 2 to 4 with a current running from 1 to 3. Rotating this system and measuring the voltages gives us the Hall Voltage. We can then calculate the free charge carrier density and the mobility of these samples. The amount of Silicon doping included in the semiconductor controls the density. Free carrier absorption occurs when the doping level is too high, and the excess carriers absorb the light that the sample emits, which decreases the efficiency of the QCL. However, if there are not enough carriers, miniscule flaws in the sample that are unavoidable will prevent electrons from flowing through the material and emitting light. This causes a buildup of electrons and electrical charge, which creates an electric field and thus blocks other electrons from flowing. We found an optimal value for the carrier density to be around 3×10^{16} cm^{-3}.

The mobility of a semiconductor is a measure of the scattering of electrons within the material. The less scattering that occurs, the higher the mobility, and vice versa. If the growth chamber can attain a vacuum of about 10^{-10} Torr, then impurities will be minimal and the mobility will increase. If these conditions are not met, then impurities will infest the sample and lower the mobility. The process of layer accumulation also affects the mobility. If the process is run efficiently, then the defects in the layers and the alloy scattering will be minimized, and the mobility will increase. But if the layered structure is not grown properly, then more electron scattering will occur, and the mobility will decrease. We aim for a value of around 6000 $cm^2/V\cdot s$ for InGaAs and 800 $cm^2/V\cdot s$ for InAlAs.

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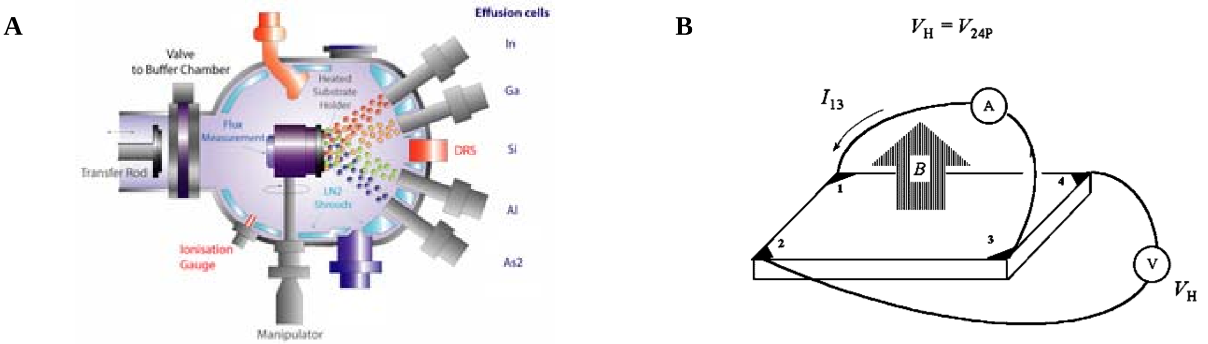

Fig. 1 **(A)** Main growth chamber interior: shows how different substances are grown onto the substrate to form the semiconductor material. http://www.photonics.ethz.ch/research/core_competences/technology/epitaxial_growth/mbe **(B)** Van Der Pauw setup for characterization testing on the semiconductor. 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. http://electron.mit.edu/~gsteele/vanderpauw/