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Defect Characterization of Molecular Beam Modular Epitaxially Grown HgCdTe Samples

by Ian Olver

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14. ABSTRACT
This report provides an overview of defect characterization techniques of epitaxially grown mercury cadmium telluride (HgCdTe) wafers. The development of good HgCdTe based detectors requires high quality semiconductor material. Growth conditions, choice of substrate, and overall cleanliness of the entire procedure all have a major impact on material quality. The types of defects that can be observed include craters, surface hillocks, dislocations, precipitates, bumps, and post-growth scratches due to human error. While high quality, low dislocation density (<105 cm^{-2}) HgCdTe can be grown on lattice matched cadmium zinc telluride (CdZnTe) substrate, these substrates are expensive and have limited area. Lattice-mismatched silicon substrates are available in large area and low cost, but result in higher dislocation density (>106 cm^{-2}). These defects hinder device performance. The goal of epitaxial growth is to have the least amount of defects possible. The project objective was to characterize various defects in HgCdTe films grown on Si substrates and recognize their importance.

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1. Introduction

Mercury cadmium telluride (Hg1-xCdxTe) is a very important material for infrared detection applications. When Cd mole fraction is equal to zero, we get mercury telluride (HgTe), which is a semi-metal with a band gap of zero. When the Cd mole fraction is equal to one, we get cadmium telluride (CdTe), which has a band gap of 1.56 eV. Hence, the alloy HgCdTe is tunable within the infrared spectrum and is especially useful for mid-wavelength (3–5 μm) and long-wavelength (8–12 μm) infrared purposes. Additionally, it can be used for near infrared (1.5–1.8 μm and 2.2–2.4 μm) to very long wavelength infrared (>15 μm) applications. HgCdTe is unrivaled among infrared materials, such as silicon and indium antimonide; however, HgCdTe/Si suffers from high defect densities that makes it difficult to reproduce high quality reliably. As a result, defect counting is an important tool for improving the quality of these materials.

Equipment Used

1. Nomarski Microscope
2. Scanning Electron Microscope
3. Atomic Force Microscope
4. Resist Spinner
5. Profilometer
6. Etching Materials

2. Experimental Procedures and Results

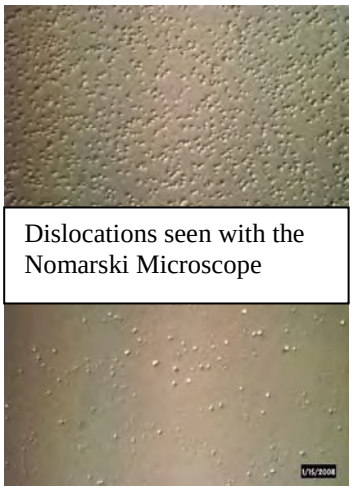
In order to look at the sample under the microscopes, the HgCdTe sample had to be prepared. The sample was cleaned with a spray acetone and then isopropyl alcohol. These chemicals remove any dirt or organic contaminants that can reside on the wafer.

After cleaning, the sample was blown dry with nitrogen gas. Defects are observed through microscopes, either optical or electron based. Optical Microscopes have limited magnification, on the order of 200 times. The sample was first examined under the Nomarski Microscope and images of the defects were taken (figure 1). After the Nomarski microscope, I observed the HgCdTe under the Scanning Electron Microscope. Finally, I used the Atomic Force Microscope to examine the defects. Many of the images taken with the different microscopes were of the same defect. After observing the HgCdTe with the three microscopy techniques, the sample was etched in methanol bromine to exaggerate the defects such as scratches and craters. This etch

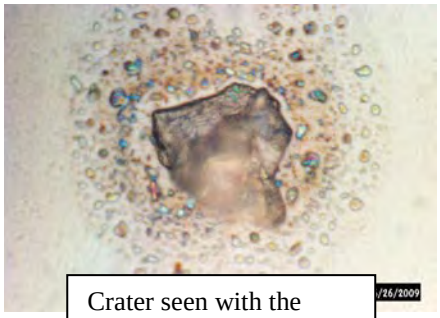
does not reveal dislocations, however. A dislocation etch would need to be performed to further reveal dislocations. The sample was etched in a .25%Br solution for three 60-s periods. The sample was examined under the Nomarski Microscope after each 60 s etch (figure 2).

By examining a sample of HgCdTe, various surface defects were identified. These include dislocations, scratches, craters, voids, bumps, and precipitates. Dislocations occur when planar molecules grow out of alignment. This is caused by lattice mismatches. Scratches are caused by human error if the sample is not properly handled or if tweezers are scraped across the sample. Craters in HgCdTe samples are caused by Hg deficiency during growth. Craters happen more often when the growth temperature is slightly high

The Nomarski is an optical microscope that acquires very fine color images that illustrate details of defects very well. It works by polarizing a light source into two beams which take different paths through the sample. The beams are later recombined, giving the appearance of a three-dimensional sample, emphasizing lines and edges.



Dislocations seen with the Nomarski Microscope



Crater seen with the Nomarski Microscope

Nomarski Microscope

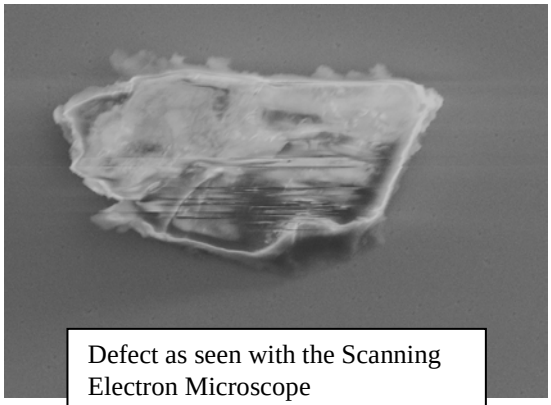
Figure 1. Sample examined under the Nomarski Microscope.

Crater before etch seen with a Nomarski Microscope

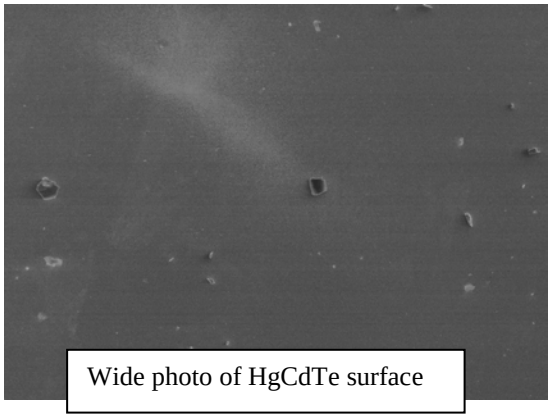
Crater after etch seen with Nomarski Microscope (~ 1 micron etch)

Figure 2. The crater before and after etches examined under the Nomarski Microscope.

A Scanning Electron Microscope has a higher resolution than the Nomarski Microscope and can magnify an image to several thousand times its normal size. This type of microscope requires a small sample because the microscope is focusing on a very small area and it becomes hard to orient a large sample quickly. The Scanning Electron Microscope images a sample's surface by scanning it with a high-energy beam of electrons. The electrons produce signals that show the sample's surface topography, composition and other properties. The HgCdTe sample under the Scanning Electron Microscope is shown in figure 3.



Defect as seen with the Scanning Electron Microscope

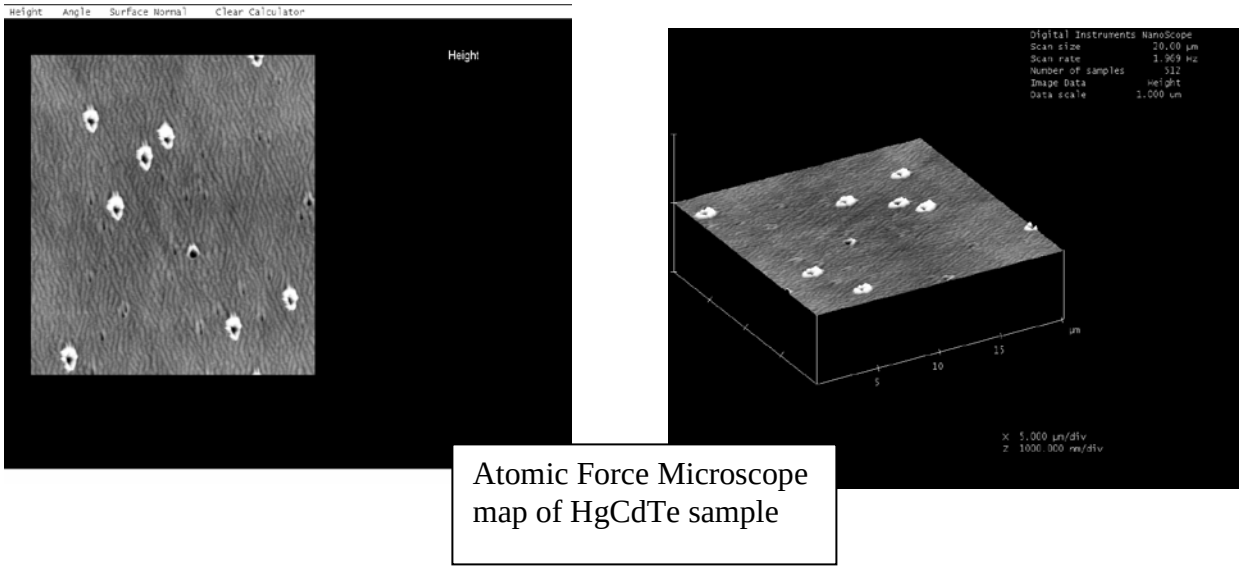


Wide photo of HgCdTe surface

Scanning Electron Microscope

Figure 3. The HgCdTe sample examined under the Scanning Electron Microscope.

The Atomic Force Microscope has the highest resolution and magnification of the three microscopes. This microscope is very good at mapping the topography of a sample. The Atomic Force Microscope uses a tiny probe mounted on a cantilever to “scan” the surface of an object. The probe is extremely close to but does not touch the surface. As the probe moves across the surface, forces between it and the atoms on the surface induce forces on the probe that bend the cantilever. The amount of bending is measured, providing a map of the topography of the surface. The HgCdTe sample examined under Atomic Force Microscope is shown in figure 4.



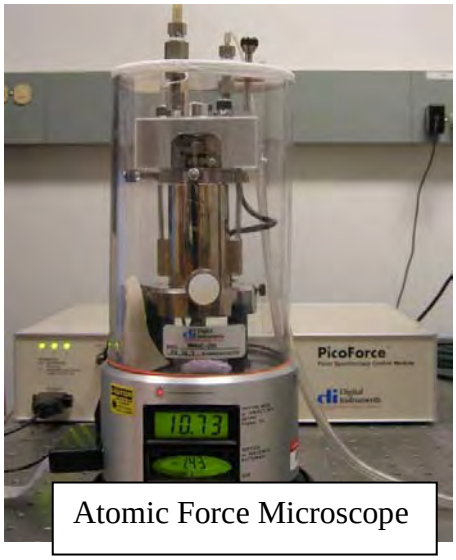


Figure 4. The HgCdTe sample examined under Atomic Force Microscope

In addition to working on the original project, I was able to access Class 100 and Class 10 cleanrooms to use some specialized equipment. This included but was not limited to, the resist spinner, profilometer, and mask aligner. A cleanroom is an environment or series of rooms with very low levels of contaminants. A Class 1000 cleanroom has more airborne contamination than a Class 100 or Class 10 cleanroom. For the spinning process, an excess amount of a resist is placed on the substrate, which is being held down on a vacuum chuck, and is then rotated at high speed in order to spread the fluid by centrifugal force. A *Profilometer* is a measuring tool used to

measure a profile, or height, and is used to accurately measure the thickness of the resist that is applied. It works much like a record player. It moves a very small stylus across the surface of the sample and calculates the height and general irregularity of the sample's surface.

3. Procedure for Spinning Resist onto the HgCdTe Sample

1. Set desired program in the spinner computer and set the required temperature on the hot plate.
2. Test program with a sample wafer
3. Place your sample onto the spinner
4. Use an eyedropper to put the resist onto the wafer. Make sure there are no air bubbles in the dropper.
5. Start the spinning program.
6. When the spinning stops, place the wafer onto the hot plate and using a stopwatch, bake the resist for the time specified for that resist.
7. After baking, place the wafer into the sample holder.

4. Conclusion

The development of good HgCdTe based detectors requires high quality semiconductor material. Growth conditions, choice of substrate, and overall cleanliness of the entire procedure all have a major impact on material quality. Defects in the semiconductor material reduce the performance of fabricated devices and therefore must be minimized.

5. References

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