NOTICES

Disclaimers

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Citation of manufacturer’s or trade names does not constitute an official endorsement or approval of the use thereof.

DESTRUCTION NOTICE—For classified documents, follow the procedures in DoD 5220.22-M, National Industrial Security Program Operating Manual, Chapter 5, Section 7, or DOD 5200.1-R, Information Security Program Regulation, C6.7. For unclassified, limited documents, destroy by any method that will prevent disclosure of contents or reconstruction of the document.
Defect Characterization of Molecular Beam Epitaxially Grown HgCdTe Samples

Ian Olver
Sensors and Electron Devices Directorate, ARL

Approved for public release; distribution unlimited.
REPORT DOCUMENTATION PAGE

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302.

Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE (DD-MM-YYYY) September 2009
2. REPORT TYPE Summary
3. DATES COVERED (From - To)
4. TITLE AND SUBTITLE Defect Characterization of Molecular Beam Epitaxially Grown HgCdTe Samples

5a. CONTRACT NUMBER
5b. GRANT NUMBER
5c. PROGRAM ELEMENT NUMBER
5d. PROJECT NUMBER
5e. TASK NUMBER
5f. WORK UNIT NUMBER

6. AUTHOR(S) Ian Olver

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
ATTN: RDRL-SEE-I
Adelphi MD 20783-1197

8. PERFORMING ORGANIZATION REPORT NUMBER
ARL-TN-0372

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
The George Washington University
Science & Engineering Apprentice Program
1776 G. Street Ste 171
NW Washington DC 20052

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

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.

15. SUBJECT TERMS
Defect characterization

16. SECURITY CLASSIFICATION OF:
   a. REPORT Unclassified
   b. ABSTRACT Unclassified
   c. THIS PAGE Unclassified

17. LIMITATION OF ABSTRACT
   UU

18. NUMBER OF PAGES
   14

19a. NAME OF RESPONSIBLE PERSON
     Kim Olver

19b. TELEPHONE NUMBER (Include area code)
     (301) 394-2048

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18
## Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acknowledgments</td>
<td>iv</td>
</tr>
<tr>
<td>1. Introduction</td>
<td>1</td>
</tr>
<tr>
<td>2. Experimental Procedures and Results</td>
<td>1</td>
</tr>
<tr>
<td>3. Procedure for Spinning Resist onto the HgCdTe Sample</td>
<td>6</td>
</tr>
<tr>
<td>4. Conclusion</td>
<td>6</td>
</tr>
<tr>
<td>5. References</td>
<td>7</td>
</tr>
<tr>
<td>Distribution List</td>
<td>8</td>
</tr>
</tbody>
</table>
Acknowledgments

I would like to thank the following scientists for their help in learning how to use the equipment and for their help in understanding key concepts about mercury cadmium telluride: Dr. Priyalal Wijewarnasuriya, Mrs. Kimberley Olver, Dr. John Little, Dr. Fred Semendy, Dr. Yuanping Chen, Dr. Greg Brill, and Dr. Unchul Lee.
1. Introduction

Mercury cadmium telluride (Hg$_{1-x}$Cd$_x$Te) 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.

Figure 1. Sample examined under the Nomarski Microscope.
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.
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.
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


<table>
<thead>
<tr>
<th>No. of Copies</th>
<th>Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ADMNSTR</td>
</tr>
<tr>
<td>ELEC</td>
<td>DEFNS TECHL INFO CTR</td>
</tr>
<tr>
<td></td>
<td>ATTN DTIC OCP</td>
</tr>
<tr>
<td></td>
<td>8725 JOHN J KINGMAN RD STE 0944</td>
</tr>
<tr>
<td></td>
<td>FT BELVOIR VA 22060-6218</td>
</tr>
<tr>
<td>1 CD</td>
<td>US ARMY RSRCH LAB</td>
</tr>
<tr>
<td></td>
<td>ATTN RDRL CIM G T LANDFRIED</td>
</tr>
<tr>
<td></td>
<td>BLDG 4600</td>
</tr>
<tr>
<td></td>
<td>ABERDEEN PROVING GROUND MD 21005-5066</td>
</tr>
<tr>
<td>13 HCs</td>
<td>US ARMY RSRCH LAB</td>
</tr>
<tr>
<td>3 CDs</td>
<td>ATTN IMNE ALC HRR MAIL &amp; RECORDS MGMT</td>
</tr>
<tr>
<td></td>
<td>ATTN RDRL CIM L TECHL LIB</td>
</tr>
<tr>
<td></td>
<td>ATTN RDRL CIM P TECHL PUB</td>
</tr>
<tr>
<td></td>
<td>ATTN RDRL SEE I F SEMENDY</td>
</tr>
<tr>
<td></td>
<td>ATTN RDRL SEE I K OLVER (7 copies)</td>
</tr>
<tr>
<td></td>
<td>ATTN RDRL SEE I P UPPAL</td>
</tr>
<tr>
<td></td>
<td>ATTN RDRL SEE I U LEE</td>
</tr>
<tr>
<td></td>
<td>ATTN RDRL SEE I Y CHEN</td>
</tr>
<tr>
<td></td>
<td>ATTN RDRL SEE M A SAMPATH</td>
</tr>
<tr>
<td></td>
<td>ATTN RDRL SEE I P WIJEWARNASURIYA</td>
</tr>
<tr>
<td></td>
<td>ADELPHI MD 20783-1197</td>
</tr>
</tbody>
</table>

TOTAL: 18 (13 HCs, 4 CDs, 1 ELECT)