ECE / ChE 613 - Electronic Materials Characterization

Lecture 1: Introduction

Coronavirus (COVID-19)

KEEP CALM AND CARRY ON
Lecture 1

• Electronic Materials Characterization.
• Course Overview.
• Course Logistics.
• Regulations.

Electronic Materials Characterization
ECE / CHE 613

- ECE 613 / CHE 613 is part of a series of graduate level courses on semiconductors and devices.

### Fall 2019
- ECE 611 / CHE 611

### Winter 2020
- ECE 612 / CHE 612

### Spring 2020
- ECE 613 / CHE 613

**Material Processing**
- Silicon growth.
- Processing.
- Layer Deposition.

**Process Integration**
- VLSI.
- Interconnects.
- Multilayer technology.

**Materials Characterization**
- Electronic, optical, structural, chemical properties.

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ECE / CHE 613

- ECE 613 / CHE 613 is part of a series of graduate level courses on semiconductors and devices.

### Fall 2020
- ECE 614

### Winter 2021
- ECE 615

### Spring 2021
- ECE 616

**Semiconductors**
- Energy bands.
- Carrier statistics.
- Transport.

**2 Terminal Devices**
- Diodes.
- Capacitors.
- Schottky Contacts.
- Heterojunctions.

**3 Terminal Devices**
- Bipolar junction transistors.
- Field-effect transistors.
Modern IC Development

Sand to Ingot

Wafer Dicing

https://www.youtube.com/watch?v=d95WNLZvA8y

Modern IC Development

Photolithography

Ion Implantation

https://www.youtube.com/watch?v=d95WNLZvA8y
Modern IC Development

Etching  Deposition

[Image of etching and deposition processes]

https://www.youtube.com/watch?v=d95WNlZvA8y

Modern IC Development

Electrodeposition  CMP

[Image of electrodeposition and CMP processes]

https://www.youtube.com/watch?v=d95WNlZvA8y
Integrated circuit development is the subject of ECE / CHE 611 and ECE 611 / CHE 612.

In ECE / CHE 613, we look at ways to **assess the properties** of electronic materials.

There is an extremely wide range of experimental techniques used in the semiconductor industry and academia.

One can spend an entire degree focusing on a single one of these techniques, so you should think of the course as a series of introductions to different techniques.
My Course Objectives

• The goal for me is the following:
  • Introduce a wide range of different techniques for characterizing electronic materials.
  • Give you an intuition as to what tool / technique you should use if you are presented with a certain problem.
  • A basic grasp of the limitations of the tools and techniques.
  • The basics of how to carry out quantitative analysis.
• The goal is not the following:
  • Get you to memorize a load of formulae, acronyms, etc. you will forget 2 weeks after the final exam.

Course Overview
Course Overview

• Resistivity:

• Resistance Measurements:

Course Overview

• Contact Resistance:
Course Overview

- Dopant Density and Schottky Barriers

1. Defects

\[ E_C \]

\[ E_V \]

\[ C(t, T) \]

\[ C(t_1) - C(t_2) \]
Course Overview

• Carrier Recombination and Lifetime

\[ \frac{1}{\tau_r} = \frac{1}{\tau_{SRH}} + \frac{1}{\tau_{rad}} + \frac{1}{\tau_{Auger}} \]

'thermalizes'

[Diagram of carrier recombination process]

• Hall Mobility

[Diagram of Hall effect]

• Drift Mobility

[Diagram of drift mobility]
Course Overview

• Diodes

![Diode diagram](image)

'normal' case

\( r_s \)-dominated

\( n^+ \)

semiconductor (p-type)

metal (ohmic)

\( n^+ \)

metal (ohmic)

\( E_C \)

\( E_F \)

\( E_V \)

\( I \)

\( V \)

Course Overview

• Metal Oxide Semiconductor Capacitors

![MOS capacitor diagram](image)

\( V_{AC} \)

\( V_{DC} \)

\( C_{OX} \)

\( C_{INV} \)

\( C \)

flatband

accumulation

depletion
inversion

\( V \)

ECE / ChE 613 – Electronic Materials Characterization
Spring 2020 - John Labram
Course Overview

- Field Effect Transistors

![Field Effect Transistor Diagram]

- Optical Characterization

![Optical Characterization Diagram]
Course Overview

• Structural Characterization

Course Logistics
Instructor

- John Labram.
- Assistant Professor, Electrical Engineering and Computer Science.
- Office Location: 3103 Kelley Engineering Center.
- Office Hours: Monday 13:00 – 14:00.
- Email: john.labram@oregonstate.edu.

Course Website

- http://classes.engr.oregonstate.edu/eecs/spring2020/ece613/.
- This will serve as primary source of course information.
- Will be updated frequently (multiple times per week).
- Lecture notes will be uploaded here after each lecture.
- Homework and solutions will be posted here.
Textbook

- The content of the course is heavily based on this book.
- There are also many useful example problems at the end of every chapter.

Lectures

- Until further notice, all lectures will be delivered remotely.
- Lectures will be recorded ahead of time, and a video link made available to the class at the scheduled time of the lecture.
  - The idea is to give you the option to watch the lectures at a time convenient for you.
  - You can also re-watch any lectures / parts of lectures at a later date.
  - Any questions should be emailed to me in written form. I will reply via email.
Lectures

- There will also be a questions and answers page available for each lecture.
- I will update the questions and answers page with each question I receive.
- You can ask questions at any time (e.g. multiple weeks after the lecture).
- The in-person lectures would be compulsory to attend, however I am not implementing any sort of recording of attendance for video lectures.

Lectures

- Videos will be uploaded to YouTube and embedded into the course website.
Lectures

- The slides will be PowerPoint based.
- However, the slides will have significant amounts of text (e.g. paragraphs), and some equations / derivations.
- Should feel like a hybrid between PowerPoint class and traditional whiteboard based class.
- Typically 40-60 slides per lecture.
- If in-person lectures are delivered later in the term, the slides will be printed out and provided before each lecture.

Lectures

- The slides (pdf) will also be uploaded to the course website at the same time as every video.
- The slides are designed to be self-contained and to provide enough information to complete all the homeworks / exams.
- Some lectures will contain examples, but for some subjects I will expect you to consult the textbook if you require examples.
Lecture Schedule

- Lectures will be uploaded at 9 am on:
  - Monday, Wednesday, Friday.
- The lectures are designed to be 50 minutes each.
- However some videos will be longer and some will be shorter.
- This is because some lectures were originally designed to run over multiple slots, and some less than a single slot.
- The total duration will be similar, or perhaps shorter because of the lack of in-person questions.

Lecture Schedule

<table>
<thead>
<tr>
<th>Week</th>
<th>Day</th>
<th>Date</th>
<th>Month</th>
<th>Lecture</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mon</td>
<td>30 Mar</td>
<td>1</td>
<td>Lecture</td>
<td>Introduction</td>
</tr>
<tr>
<td>1</td>
<td>Wed</td>
<td>1 Apr</td>
<td>2</td>
<td>Lecture</td>
<td>Resistivity</td>
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<tr>
<td>1</td>
<td>Fri</td>
<td>3 Apr</td>
<td>3</td>
<td>Lecture</td>
<td>Resistivity Measurements</td>
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<tr>
<td>2</td>
<td>Mon</td>
<td>6 Apr</td>
<td>4</td>
<td>Lecture</td>
<td>Contact Resistance</td>
</tr>
<tr>
<td>2</td>
<td>Wed</td>
<td>8 Apr</td>
<td>5</td>
<td>Lecture</td>
<td>Dopant Density and Schottky Barriers</td>
</tr>
<tr>
<td>2</td>
<td>Fri</td>
<td>10 Apr</td>
<td>6</td>
<td>Lecture</td>
<td>Defects</td>
</tr>
<tr>
<td>3</td>
<td>Mon</td>
<td>13 Apr</td>
<td>7</td>
<td>Lecture</td>
<td>Defects Characterization</td>
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<tr>
<td>3</td>
<td>Wed</td>
<td>15 Apr</td>
<td>8</td>
<td>Lecture</td>
<td>Carrier Lifetime</td>
</tr>
<tr>
<td>3</td>
<td>Fri</td>
<td>17 Apr</td>
<td>9</td>
<td>Lecture</td>
<td>No Lecture - John is Travelling</td>
</tr>
<tr>
<td>4</td>
<td>Mon</td>
<td>20 Apr</td>
<td>10</td>
<td>Lecture</td>
<td>Surface Recombination</td>
</tr>
<tr>
<td>4</td>
<td>Wed</td>
<td>22 Apr</td>
<td>11</td>
<td>Lecture</td>
<td>Charge Carrier Mobility</td>
</tr>
<tr>
<td>4</td>
<td>Fri</td>
<td>24 Apr</td>
<td>12</td>
<td>Lecture</td>
<td>Review Lecture</td>
</tr>
<tr>
<td>5</td>
<td>Mon</td>
<td>27 Apr</td>
<td>13</td>
<td>Lecture</td>
<td>Break to prepare for midterm</td>
</tr>
<tr>
<td>5</td>
<td>Wed</td>
<td>29 Apr</td>
<td>14</td>
<td>Lecture</td>
<td>Midterm Exam</td>
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<tr>
<td>5</td>
<td>Fri</td>
<td>1 May</td>
<td>15</td>
<td>Lecture</td>
<td>Diodes</td>
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<tr>
<td>6</td>
<td>Mon</td>
<td>4 May</td>
<td>16</td>
<td>Lecture</td>
<td>Solar Cells</td>
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<tr>
<td>6</td>
<td>Wed</td>
<td>6 May</td>
<td>17</td>
<td>Lecture</td>
<td>MOS Capacitors 1</td>
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<tr>
<td>6</td>
<td>Fri</td>
<td>8 May</td>
<td>18</td>
<td>Lecture</td>
<td>MOS Capacitors 2</td>
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<tr>
<td>7</td>
<td>Mon</td>
<td>11 May</td>
<td>19</td>
<td>Lecture</td>
<td>Field-Effect Transistors 1</td>
</tr>
<tr>
<td>7</td>
<td>Wed</td>
<td>13 May</td>
<td>20</td>
<td>Lecture</td>
<td>Field-Effect Transistors 2</td>
</tr>
<tr>
<td>7</td>
<td>Fri</td>
<td>15 May</td>
<td>21</td>
<td>Lecture</td>
<td>Field-Effect Transistors 3</td>
</tr>
<tr>
<td>8</td>
<td>Mon</td>
<td>18 May</td>
<td>22</td>
<td>Lecture</td>
<td>Optical Characterization 1</td>
</tr>
<tr>
<td>8</td>
<td>Wed</td>
<td>20 May</td>
<td>23</td>
<td>Lecture</td>
<td>Optical Characterization 2</td>
</tr>
<tr>
<td>8</td>
<td>Fri</td>
<td>22 May</td>
<td>24</td>
<td>Lecture</td>
<td>Optical Characterization 3</td>
</tr>
<tr>
<td>9</td>
<td>Mon</td>
<td>25 May</td>
<td>25</td>
<td>Lecture</td>
<td>No Lecture - Memorial Day</td>
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<tr>
<td>9</td>
<td>Wed</td>
<td>27 May</td>
<td>26</td>
<td>Lecture</td>
<td>No Lecture - Memorial Day</td>
</tr>
<tr>
<td>9</td>
<td>Fri</td>
<td>29 May</td>
<td>27</td>
<td>Lecture</td>
<td>Ion Beam Techniques</td>
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<tr>
<td>10</td>
<td>Mon</td>
<td>1 Jun</td>
<td>28</td>
<td>Lecture</td>
<td>X-Ray &amp; UV Techniques</td>
</tr>
<tr>
<td>10</td>
<td>Wed</td>
<td>3 Jun</td>
<td>29</td>
<td>Lecture</td>
<td>Surface Imaging Techniques</td>
</tr>
<tr>
<td>10</td>
<td>Fri</td>
<td>5 Jun</td>
<td>30</td>
<td>Lecture</td>
<td>Review Lecture</td>
</tr>
</tbody>
</table>

Lecture Schedule

ECE / Che 613 – Electronic Materials Characterization
Spring 2020 - John Labram
Assessment

• The final grade will consist of the following contributions:

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Percentage of Final Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homework</td>
<td>50</td>
</tr>
<tr>
<td>Mid-Term Exam</td>
<td>25</td>
</tr>
<tr>
<td>Final Exam</td>
<td>25</td>
</tr>
</tbody>
</table>

Grade Boundaries

<table>
<thead>
<tr>
<th>Lower Bound (%)</th>
<th>Upper Bound (%)</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>93</td>
<td>100</td>
<td>A</td>
</tr>
<tr>
<td>90</td>
<td>92</td>
<td>A-</td>
</tr>
<tr>
<td>87</td>
<td>89</td>
<td>B+</td>
</tr>
<tr>
<td>83</td>
<td>86</td>
<td>B</td>
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<tr>
<td>80</td>
<td>82</td>
<td>B-</td>
</tr>
<tr>
<td>77</td>
<td>79</td>
<td>C+</td>
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<tr>
<td>73</td>
<td>76</td>
<td>C</td>
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<td>70</td>
<td>72</td>
<td>C-</td>
</tr>
<tr>
<td>67</td>
<td>69</td>
<td>D+</td>
</tr>
<tr>
<td>63</td>
<td>66</td>
<td>D</td>
</tr>
</tbody>
</table>

• Percentages will be rounded-off to the nearest whole percent to determine letter grade.
Homework

- There will be a total of 5 homeworks.
- Each homework carries equal weight.
- The homeworks are designed to test your understanding of the concepts covered in the lectures.
  - Sometimes you will be expected to apply knowledge obtained in the lectures to new (previously unseen) situations.
- The homeworks overall contribute 50% of the course grade.
  - 10% each.

Homework

- You will be assessed via a mixture of:
  - **Text-based answers.** I.e. you will be expected to describe a process or phenomenon in words.
  - **Analytical problems.** Derivations and/or calculations that can be solved with just pen, paper, and calculator.
  - **Data analysis.** You will be provided with some simple numerical data (e.g. in .csv format) and expected to process it to extract parameters / draw conclusions.
Homework

• Homework will be set on Wednesdays or Fridays, and due **1 week later at 9:00 am.**
• Please send an electronic copy of the homework to me (john.labram@oregonstate.edu) on the due date.
  • Can be a Word document, pdf, or series of scanned images.
  • Please make the document as easy as possible to follow. E.g. circle / make a box around final answer.
  • If you scan / photograph your homework please ensure the resolution is high!
• Please use your OSU address (not Gmail etc.)

Homework

• The homeworks will be returned to you one week after they are submitted.
• The solutions will be posted when the homeworks are returned.
• The homeworks will be returned electronically to your OSU email address.
Homework

- The homework schedule is as follows:

<table>
<thead>
<tr>
<th>#</th>
<th>Set</th>
<th>Due</th>
<th>Returned</th>
<th>Lectures Covered</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Wed 04/08/20</td>
<td>Wed 04/15/20</td>
<td>Wed 04/22/20</td>
<td>2, 3, 4, 5</td>
</tr>
<tr>
<td>2</td>
<td>Wed 04/15/20</td>
<td>Wed 04/22/20</td>
<td>Wed 04/22/20</td>
<td>5, 6, 7, 8</td>
</tr>
<tr>
<td>3</td>
<td>Fri 05/08/20</td>
<td>Fri 05/15/20</td>
<td>Fri 05/22/20</td>
<td>12, 13, 14, 15</td>
</tr>
<tr>
<td>4</td>
<td>Fri 05/15/20</td>
<td>Fri 05/22/20</td>
<td>Fri 05/29/20</td>
<td>16, 17, 18</td>
</tr>
<tr>
<td>5</td>
<td>Fri 05/22/20</td>
<td>Fri 05/29/20</td>
<td>Fri 05/29/20</td>
<td>19, 20, 21</td>
</tr>
</tbody>
</table>

- Late homework will be deducted 10% per day late for a maximum of 5 days, after which the homework grade will be zero.
- E.g. if you scored 85% on a homework, but you hand it in 2 days late, you will receive a grade of 65%.

Exams

- There will be two exams: one midterm and one final.
- They will carry equal weight to the final course grade: 25% each.
- The midterm will examine content covered in Lectures 2-11 (inclusive).
- The final exam will examine content covered in Lectures 12-25 (inclusive).
- The exams will consist of optional questions. For example, you may be expected to complete 2 out of 3 questions.
Exams

• The exams are designed to test your ability to apply knowledge acquired during the exams to new situations.
• Both exams will be closed book and closed notes.
• Besides a small number of well-known equations, most equations will be provided at the start of the exam.
• All physical constants and parameters will also be provided.

Exams

• Details of exams will be made known nearer the time.
• However it is likely that at least the mid-term examination will be carried out remotely.
• You will be made aware of the plan for examinations with at least 2 weeks notice.
• The schedule for exams is subject to change:

<table>
<thead>
<tr>
<th>Exam</th>
<th>Week</th>
<th>Date</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midterm</td>
<td>5</td>
<td>Wed 04/29/20</td>
<td>09:00 am</td>
</tr>
<tr>
<td>Final</td>
<td>F</td>
<td>Tue 06/09/20</td>
<td>12:00 pm</td>
</tr>
</tbody>
</table>
Exam Style Example

- Taken from 611, but style will be similar.
- Most equations will be given:

\[ P = \frac{N}{V} \]

\[ T = \frac{N}{2N} \]

Exam Style Example

- Taken from 611, but style will be similar.
Exam Style Example

- Taken from 611, but style will be similar.
- Most constants will also be given:

<table>
<thead>
<tr>
<th>Name</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant of Coulomb's Law</td>
<td>k</td>
<td>1.38</td>
</tr>
<tr>
<td>Specific Heat Capacity of Water</td>
<td>c</td>
<td>4187</td>
</tr>
<tr>
<td>Latent Heat of Vaporization of Water</td>
<td>h</td>
<td>2257</td>
</tr>
<tr>
<td>Latent Heat of Condensation of Water</td>
<td>h</td>
<td>583</td>
</tr>
<tr>
<td>Latent Heat of Fusion of Water</td>
<td>h</td>
<td>407</td>
</tr>
<tr>
<td>Specific Heat Capacity of Solid Air</td>
<td>c</td>
<td>1004</td>
</tr>
<tr>
<td>Specific Heat Capacity of Liquid Air</td>
<td>c</td>
<td>1300</td>
</tr>
<tr>
<td>Specific Heat Capacity of Solid Carbon</td>
<td>c</td>
<td>1358</td>
</tr>
<tr>
<td>Specific Heat Capacity of Liquid Carbon</td>
<td>c</td>
<td>2375</td>
</tr>
<tr>
<td>Specific Heat Capacity of Solid Oxygen</td>
<td>c</td>
<td>287</td>
</tr>
<tr>
<td>Specific Heat Capacity of Liquid Oxygen</td>
<td>c</td>
<td>44</td>
</tr>
<tr>
<td>Specific Heat Capacity of Solid Nitrogen</td>
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<td>c</td>
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<td>c</td>
<td>1865</td>
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<td>c</td>
<td>1995</td>
</tr>
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<td>c</td>
<td>1631</td>
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<td>Specific Heat Capacity of Solid Neon Antimony</td>
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<td>Specific Heat Capacity of Liquid Neon Antimony</td>
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<td>Specific Heat Capacity of Liquid Neon Tellurium</td>
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<td>Specific Heat Capacity of Solid Neon Selenium</td>
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<td>Specific Heat Capacity of Solid Neon Tellurium</td>
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<td>1303</td>
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<tr>
<td>Specific Heat Capacity of Liquid Neon Tellurium</td>
<td>c</td>
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</tr>
<tr>
<td>Specific Heat Capacity of Solid Neon Tellurium</td>
<td>c</td>
<td>1503</td>
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<tr>
<td>Specific Heat Capacity of Liquid Neon Tellurium</td>
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</tbody>
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Regulations
Cheating and Student Conduct

• Academic dishonesty is defined as an intentional act of deception in one of the following areas:
  • **Cheating** - use or attempted use of unauthorized materials, information or study aids.
  • **Fabrication** - falsification or invention of any information.
  • **Assisting** - helping another commit an act of academic dishonesty.
  • **Tampering** - helping another commit an act of academic dishonesty.
  • **Plagiarism** - representing the words or ideas of another person as one's own.

When evidence of academic dishonesty comes to the instructor's attention, the instructor will document the incident, permit the accused student to provide an explanation, advise the student of possible penalties, and take action.

The instructor may impose any academic penalty up to and including an "F" grade in the course after consulting with his or her department chair and informing the student of the action taken.
Disruptive Behavior

- While the University is a place where the free exchange of ideas and concepts allows for debate and disagreement, all classroom behavior and discourse should reflect the values of respect and civility.
- Behaviors which are disruptive to the learning environment will not be tolerated.
- As your instructors, we are dedicated to establishing a learning environment that promotes diversity of race, culture, gender, sexual orientation, and physical disability.

Disruptive Behavior

- Anyone noticing discriminatory behavior in this class, or feeling discriminated against should bring it to the attention of the instructors or other University personnel as appropriate.
Next Time...

- Resistivity.
  - Calculating Resistivity.

  \[ \rho = \frac{1}{\sigma} \quad \rho = \left[ q(\mu_e n + \mu_h p) \right]^{-1} \]