



[Home](#) | [Blog](#) | [Lithography](#) | [Published Works](#) | [For Profit](#) | [About Chris](#) | [Gentleman](#) | [Scientist](#)

CHE 323, Chemical Processes for Micro- and Nanofabrication, Chris Mack

Lectures recorded in the Fall of 2013 in Austin, Texas

Course materials, by class date for the [Fall 2015](#) semester

(Have all lectures watched, material read, and homework done by the indicated date.)

Friday, August 28

Read chapter 1 of the Campbell text

Lecture 1: [Semiconductor Overview](#) (18 min) – hardcopy of the slides: [Lecture1.pdf](#)

After watching lecture 1, watch the first 5 minutes of [Properties of Semiconductors](#) (by Nobel Prize winner Walter Brattain, co-inventor of the transistor)

Optional: Watch William Shatner explain how chips are made in 1976: [Microworld](#) (14 min)

Lecture 2: [Moore's Law](#) (22 min) – hardcopy of the slides: [Lecture2.pdf](#)

Additional reading material for Lecture 2:

G. E. Moore, "[Cramming More Components onto Integrated Circuits](#)", *Electronics*, Vol. 38, No. 8 (Apr. 19, 1965) pp. 114–117.

G. E. Moore, "[Progress in Digital Integrated Electronics](#)", *IEDM Technical Digest* (Washington, D.C.: 1975) pp. 11–13.

Monday, August 31

Lecture 3: [Semiconductor Economics](#) (20 min) – hardcopy of the slides: [Lecture3.pdf](#)

Additional reading material for Lecture 3:

G. E. Moore, "[Lithography and the Future of Moore's Law](#)", *Optical/Laser Microlithography VIII, Proc.*, SPIE vol. 2440, pp. 2–17, 1995.

Chris A. Mack, "[Fifty Years of Moore's Law](#)", *IEEE Transactions On Semiconductor Manufacturing*, Vol. 24, No. 2 (May, 2011) pp. 202–207.

Chris A. Mack, "[The Multiple Lives of Moore's Law](#)", *IEEE Spectrum*, pp. 30–37 (Apr. 2015).

Read chapter 2 of the Campbell text (skip section 2.5)

Lecture 4: Single-Crystal Silicon (14 min) – hardcopy of the slides: Lecture4.pdf

A couple of short (2 and 4 min) video animations of the process for making wafers:

<http://www.youtube.com/watch?v=LWfCgpJzJYM>, <http://www.youtube.com/watch?v=AMgQ1-HdEIM>

Wednesday, September 2

Homework #1: Problems; Solutions

Lecture 5: Doping (20 min) – hardcopy of the slides: Lecture5.pdf

Lecture 6: P-N Junctions (21 min) – hardcopy of the slides: Lecture6.pdf

Friday, September 4

Homework #2: Problems; Solutions; Spreadsheet Data; Spreadsheet Solution

Read chapter 16 of the Campbell text

Lecture 7: The Junction Diode (13 min) – hardcopy of the slides: Lecture7.pdf

Lecture 8: Transistors (21 min) – hardcopy of the slides: Lecture8.pdf

Lecture 9: CMOS Process Flow (13 min) – hardcopy of the slides: Lecture9.pdf

Optional introductory video (a bit dated, but not bad): The Fabrication of Integrated Circuits (11 min)

Monday, September 7

No class – Happy Labor Day!

Wednesday, September 9

Read chapter 4 of the Campbell text (skip sections 4.4, 4.7, 4.8, and 4.10)

Lecture 10: Thermal Oxidation, part 1 (20 min) – hardcopy of the slides: Lecture10.pdf

Lecture 11: Thermal Oxidation, part 2 (19 min) – hardcopy of the slides: Lecture11.pdf

Optional Reading: Deal-Grove 1965 paper

Friday, September 11

Lecture 12: Thermal Oxidation, part 3 (35 min) – hardcopy of the slides: Lecture12.pdf

Graphs and Table of Deal-Grove Model Parameters: Deal-Grove Data Sheet.pdf

BRIGHAM YOUNG UNIVERSITY: Oxide growth time calculator

Monday, September 14

Homework #3 (oxidation): Problems; Solutions

Read chapter 3 of the Campbell text, reread section 4.6

Lecture 13: [Diffusion, part 1](#) (17 min) – hardcopy of the slides: [Lecture13.pdf](#)

Review of Fick's Law (if you need it, 12 min): [Khan Academy Video](#)

Lecture 14: [Diffusion, part 2](#) (20 min) – hardcopy of the slides: [Lecture14.pdf](#)

Wednesday, September 16

Lecture 15: [Diffusion, part 3](#) (35 min) – hardcopy of the slides: [Lecture15.pdf](#)

Friday, September 18

Homework #4 (diffusion): [Problems](#); [Solutions](#)

Read chapter 5 of the Campbell text (skip sections 5.2, 5.5, 5.6, and 5.7)

Lecture 16: [Ion Implantation, part 1](#) (20 min) – hardcopy of the slides: [Lecture16.pdf](#)

Optional: Applied Materials video, [Ion Implantation 101](#) (13 min)

Monday, September 21

Lecture 17: [Ion Implantation, part 2](#) (19 min) – hardcopy of the slides: [Lecture17.pdf](#)

Lecture 18: [Ion Implantation, part 3](#) (14 min) – hardcopy of the slides: [Lecture18.pdf](#)

Wednesday, September 23

Homework #5 (ion implantation): [Problems](#); [Solutions](#)

Read chapter 6 of the Campbell text (skip section 6.4)

Lecture 19: [Rapid Thermal Processing](#) (26 min) – hardcopy of the slides: [Lecture19.pdf](#)

Friday, September 25

Read chapter 12 of the Campbell text

Lecture 20: [Evaporation, part 1](#) (15 min) – hardcopy of the slides: [Lecture20.pdf](#)

Lecture 21: [Evaporation, part 2](#) (27 min) – hardcopy of the slides: [Lecture21.pdf](#)

Georgia Tech [e-beam evaporation animation](#) (1.5 min)

Monday, September 28

Exam #1 (covers all material through RTP, lecture 19)

Data Sheet for Exam 1 (you will be given this during the exam): [Exam1_formulas_data_constants.pdf](#)

Review Material:

Review Questions: [Exam1_Review.pdf](#)

Formulas lectures 1–19: [Formulas 1–19.pdf](#) (black&white: [Formulas 1–19_B&W.pdf](#))

Practice Exam: [Exam1_Practice.pdf](#)

One final video to help you prepare for taking the exam [here](#).

Wednesday, September 30

Lecture 22: [Sputtering, part 1](#) (15 min) – hardcopy of the slides: [Lecture22.pdf](#)

Lecture 23: [Sputtering, part 2](#) (24 min) – hardcopy of the slides: [Lecture23.pdf](#)

Norfolk State University [YouTube video on sputtering](#) (watch first 4.5 minutes, more if you like)

Friday, October 2

Homework #6 (PVD): [Problems](#); [Solutions](#)

Read chapter 13 of the Campbell text (skip 13.3, 13.9 and 13.10)

Lecture 24: [CVD, part 1](#) (21 min) – hardcopy of the slides: [Lecture24.pdf](#)

Lecture 25: [CVD, part 2](#) (23 min) – hardcopy of the slides: [Lecture25.pdf](#)

Monday, October 5

Lecture 26: [Deposition Processes](#) (19 min) – hardcopy of the slides: [Lecture26.pdf](#)

Optional: [animation of atomic layer deposition](#) (2 min)

Read sections 15.1 – 15.3 of the Campbell text

Lecture 27: [Device Isolation](#) (19 min) – hardcopy of the slides: [Lecture27.pdf](#)

Wednesday, October 7

Homework #7 (CVD): [Problems](#); [Solutions](#)

Read sections 15.9 – 15.11 of the Campbell text

Lecture 28: [Device Interconnect, part 1](#) (23 min) – hardcopy of the slides: [Lecture28.pdf](#)

Lecture 29: [Device Interconnect, part 2](#) (26 min) – hardcopy of the slides: [Lecture29.pdf](#)

Friday, October 9

Read section 11.2 of the Campbell text

Lecture 30: [Chemical Mechanical Polishing \(CMP\)](#) (18 min) – hardcopy of the slides: [Lecture30.pdf](#)

Read section 15.10 of the Campbell text

Lecture 31: [Copper Dual Damascene](#) (17 min) – hardcopy of the slides: [Lecture31.pdf](#)

Monday, October 12

Lecture 32: [Semi Manufacturing: Yield and Defects](#) (22 min) – hardcopy of the slides: [Lecture32.pdf](#)

Lecture 33: [Semi Manufacturing: Process Control](#) (18 min) – hardcopy of the slides: [Lecture33.pdf](#)

Wednesday, October 14

Homework #8 (interconnect and manufacturing): [Problems](#); [Solutions](#)

Read chapter 11 of the Campbell text

Lecture 34: [Etch, part 1](#) (18 min) – hardcopy of the slides: [Lecture34.pdf](#)

Lecture 35: [Etch, part 2](#) (14 min) – hardcopy of the slides: [Lecture35.pdf](#)

Friday, October 16

Lecture 36: [Etch, part 3](#) (23 min) – hardcopy of the slides: [Lecture36.pdf](#)

Lecture 37: [Etch, part 4](#) (20 min) – hardcopy of the slides: [Lecture37.pdf](#)

Monday, October 19

Homework #9 (etch): [Problems](#); [Solutions](#)

Read section 7.1 of the Campbell text

Lecture 38: [Lithography: Introduction](#) (23 min) – hardcopy of the slides: [Lecture38.pdf](#)

Read [Semiconductor Lithography \(Photolithography\) – The Basic Process](#) from my website

Read section 8.6 of the Campbell text

Lecture 39: [Lithography: Process Overview](#) (27 min) – hardcopy of the slides: [Lecture39.pdf](#)

A couple of 30 – 40 s videos on photoresist spin coating:

<https://www.youtube.com/watch?v=3m4WmYObxzY>

<https://www.youtube.com/watch?v=1iZ5XzF6hEo>

Wednesday, October 21

Exam #2 (covers all material from evaporation, lecture 20, to etch, lecture 37)

Review Material:

Formulas lectures 20–37: [Formulas 20–37.pdf](#) (black&white: [Formulas 20–37_B&W.pdf](#))

Review Questions: [Exam2_Review.pdf](#)

Practice Exam: [Exam2_Practice.pdf](#)

Friday, October 23

Read sections 7.4, and 7.5 of the Campbell text

Lecture 40: [Lithography: Imaging Tools](#) (24 min) – hardcopy of the slides: [Lecture40.pdf](#)

Additional video: [ASML scanner](#)

Read section 7.2 of the Campbell text

Lecture 41: [Lithography: Diffraction, part 1](#) (31 min) – hardcopy of the slides: [Lecture41.pdf](#)

A few videos on diffraction by an isolated slit:

Experiment (5 min): <https://www.youtube.com/watch?v=AXaZc-VQzWk>

Simulation (15 s): https://www.youtube.com/watch?v=uPQMI2q_vPQ

A more detailed set of lectures and animations on diffraction (optional):

<http://www.animations.physics.unsw.edu.au/light/diffraction/>

Monday, October 26

Optional: If you need some extra help on Fourier transforms, here are a couple of videos:

(13 min) <http://www.youtube.com/watch?v=1JnayXHhjlq>

(9 min) <http://www.youtube.com/watch?v=sCCLrSGPmhE>

Optional: From the Khan Academy, some very basic topics on [Light Waves](#)

Lecture 42: [Lithography: Diffraction, part 2](#) (34 min) – hardcopy of the slides: [Lecture42.pdf](#)

Optional: [Laboratory Experiment – measure pitch using a laser pointer](#) – Due on Monday, Nov. 2

(Required: read this [laser pointer safety sheet](#) if you plan to do the lab)

Wednesday, October 28

Homework #10 (litho 1): [Problems](#); [Solutions](#)

Read section 7.6 of the Campbell text

One-page handout on Fourier transforms: [Fourier Transforms.pdf](#)

Lecture 43: [Lithography: Projection Imaging, part 1](#) (28 min) – hardcopy of the slides: [Lecture43.pdf](#)

Lecture 44: [Lithography: Projection Imaging, part 2](#) (19 min) – hardcopy of the slides: [Lecture44.pdf](#)

Friday, October 30

Lecture 45: [Lithography: Illuminating the Mask](#) (37 min) – hardcopy of the slides: [Lecture45.pdf](#)

Lecture 46: [Lithography: Defocus and DOF](#) (32 min) – hardcopy of the slides: [Lecture46.pdf](#)

Monday, November 2

Read section 7.8 of the Campbell text

Lecture 47: [Lithography: Standing Waves/Swing Curves](#) (29 min) –hardcopy of the slides: [Lecture47.pdf](#)

Lecture 48: [Lithography: Resolution and Immersion](#) (20 min) – hardcopy of the slides: [Lecture48.pdf](#)

Wednesday, November 4

Homework #11 (litho 2): [Problems](#); [Solutions](#)

Read sections 8.1–8.3 and 8.7 of the Campbell text

Lecture 49: [Lithography: DNO Photoresists](#) (25 min) – hardcopy of the slides: [Lecture49.pdf](#)

Lecture 50: Lithography: Photoresist ABCs (28 min) – hardcopy of the slides: Lecture50.pdf

Friday, November 6

Read section 8.8 of the Campbell text

Lecture 51: Lithography: CAR, part 1 (21 min) – hardcopy of the slides: Lecture51.pdf

Lecture 52: Lithography: CAR, part 2 (30 min) – hardcopy of the slides: Lecture52.pdf

Monday, November 9

Read section 8.4 of the Campbell text

Lecture 53: Lithography: Development (22 min) – hardcopy of the slides: Lecture53.pdf

Lecture 54: Lithography: Resist Contrast (34 min) – hardcopy of the slides: Lecture54.pdf

Wednesday, November 11

Homework #12 (litho 3): Problems; Solutions

Lecture 55: Lithography: Linewidth Control (24 min) – hardcopy of the slides: Lecture55.pdf

Lecture 56: Lithography: Lithographic Quality (25 min) – hardcopy of the slides: Lecture56.pdf

Friday, November 13

Lecture 57: Lithography: RET, part 1 (25 min) – hardcopy of the slides: Lecture57.pdf

Lecture 58: Lithography: RET, part 2 (30 min) – hardcopy of the slides: Lecture58.pdf

Monday, November 16

Read section 9.7 of the Campbell text

Lecture 59: Lithography: Double Patterning (25 min) – hardcopy of the slides: Lecture59.pdf

Optional: ASML on Double Patterning (5 min) – <https://www.youtube.com/watch?v=k062oh-K2zM>

Lecture 60: Lithography: Extreme Ultraviolet (21 min) – hardcopy of the slides: Lecture60.pdf

Optional: Cymer video on EUV Sources (7 min) – <https://www.youtube.com/watch?v=8xJEs3a-1QU>

Optional: Dow video on EUV Resists (5 min) – <https://www.youtube.com/watch?v=tTej1bw76bs>

Wednesday, November 18

Homework #13 (litho 4): Problems; Solutions

Read sections 9.1–9.3 and 9.9 of the Campbell text

Lecture 61: Electron Beam Lithography, part 1 (23 min) – hardcopy of the slides: Lecture61.pdf

Lecture 62: Electron Beam Lithography, part 2 (28 min) – hardcopy of the slides: Lecture62.pdf

Optional: E-beam litho in a research lab (5 min) – <https://www.youtube.com/watch?v=25AsHRgBJDM>

Friday, November 20

Exam #3 (covers all material from lithography intro, lecture 38, to EUV Lithography, lecture 60)

Review Material:

Formulas lectures 38–60: [Formulas 38–60.pdf](#) (black&white: [Formulas 38–60_B&W.pdf](#))

Review Questions: [Exam3_Review.pdf](#)

Practice Exam: [Exam3_Practice.pdf](#)

Monday, November 23

Read section 9.11 of the Campbell text

Lecture 63: [Nanoimprint Lithography, part 1](#) (14 min) – hardcopy of the slides: [Lecture63.pdf](#)

Lecture 64: [Nanoimprint Lithography, part 2](#) (16 min) – hardcopy of the slides: [Lecture64.pdf](#)

Wednesday, November 25

Lecture 65: [Line-Edge Roughness, part 1](#) (32 min) – hardcopy of the slides: [Lecture65.pdf](#)

Friday, November 27

No class – Happy Thanksgiving!

Monday, November 30

Lecture 66: [Line-Edge Roughness, part 2](#) (20 min) – hardcopy of the slides: [Lecture66.pdf](#)

Lecture 67: [Line-Edge Roughness, part 3](#) (20 min) – hardcopy of the slides: [Lecture67.pdf](#)

Optional: Dow video on LER (7 min) – <https://www.youtube.com/watch?v=utjk82k6Lrc>

Wednesday, December 2

Homework #14 (litho 5): [Problems](#); [Solutions](#)

Lecture 68: [Directed Self Assembly, part 1](#) (29 min) – hardcopy of the slides: [Lecture68.pdf](#)

Lecture 69: [Directed Self Assembly, part 2](#) (22 min) – hardcopy of the slides: [Lecture69.pdf](#)

Optional: Dow video on DSA (5 min) – <https://www.youtube.com/watch?v=7Dp6EFyROT4>

George Whitesides paper: [Self-Assembly at All Scales](#)

Friday, December 4

Last Day of Class!

Additional Review Questions for the Final: [Exam4_Review.pdf](#)

The final will be comprehensive, covering all material: Lectures 1 – 69.

Practice Final Exam: [Final_Practice.pdf](#), Solutions: [Final_Practice_solutions.pdf](#)

Final exam date and time: TBA.

Bonus Lectures!

Here are some additional lectures related to the topic of semiconductor manufacturing. While not an official part of the course, the interested student may enjoy these additional topics.

Bonus Lecture 1: [Mask Making, part 1](#) (33 min) – hardcopy of the slides: [Bonus Lecture1.pdf](#)

Bonus Lecture 2: [Mask Making, part 2](#) (25 min) – hardcopy of the slides: [Bonus Lecture2.pdf](#)

Bonus Lecture 3: [Mask Making, part 3](#) (21 min) – hardcopy of the slides: [Bonus Lecture3.pdf](#)

The lighter side of mask making: [having fun at the Bacus conference](#).

Working in the semiconductor industry has its downsides...

[A music video](#).

© 2006–2020 Chris A. Mack | [Back to top](#)