An Interdisciplinary Lecture Course for Microelectronics Fabrication

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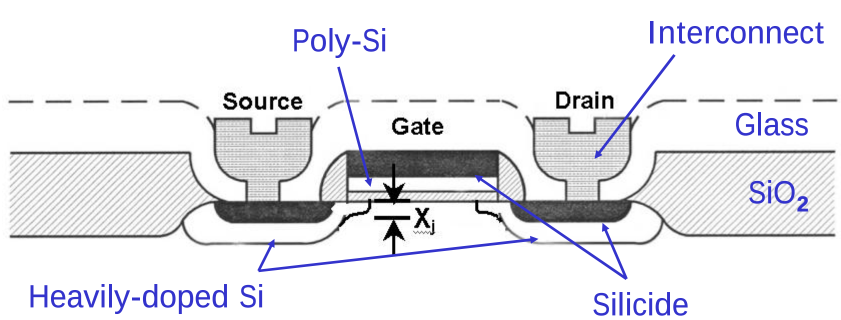
MOSFET Schematic



- Hundreds of process steps
- Many materials
- Some components are nanoscale: finite-size effects

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International Technology Roadmap for Semiconductors

	1999	2001	2004	2007	2010	2013
DRAM half-pitch (nm)	180	130	90	65	45	32
Transistors/chip at production (millions)	61	97	193	386	773	1546
MPU cost/function (μcents/transistor)	120	60	30	15	5.3	1.9

- Rapid scaling requires skilled workforce for processing
  - Interdisciplinary, flexible

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Employment Patterns

- Typical US fab employs:
  - 25-30% chemical engineering
  - 25-30% electrical engineering
  - Remainder: materials science, mechanical eng, physics...
- Distribution of training differs outside US
- Fast-moving but high capitalization
  - Profit margins squeezed, patterns shifting
  - Market cycles
  - Time-to-market critical
- Technical staff must have working knowledge beyond their formal disciplinary training

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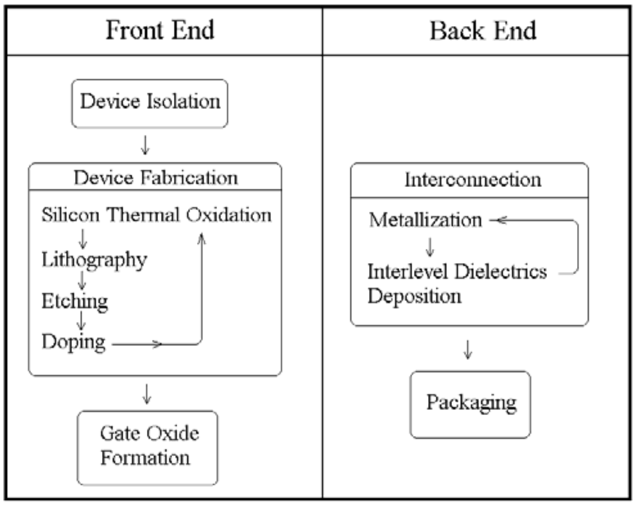
Process Flow Schematic



- Hundreds of steps
- Unit-ops concepts:
  - Lithography
  - Doping
  - Deposition
  - Etching
  - Cleaning/polishing
- Much chemistry, transport

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Student Enrollment

- Advantages of mixed course enrollment
  - Gives tast of work environment in fab
  - Broadens student base to justify large investment
- Two dimensions to mixed enrollment:
  - Multiple disciplines
    - Electrical/microelectronics engineering
    - Chemical engineering
    - Materials science
    - Chemistry
    - Physics
  - Multiple degree levels
    - MS, PhD
    - Upper-level undergraduate

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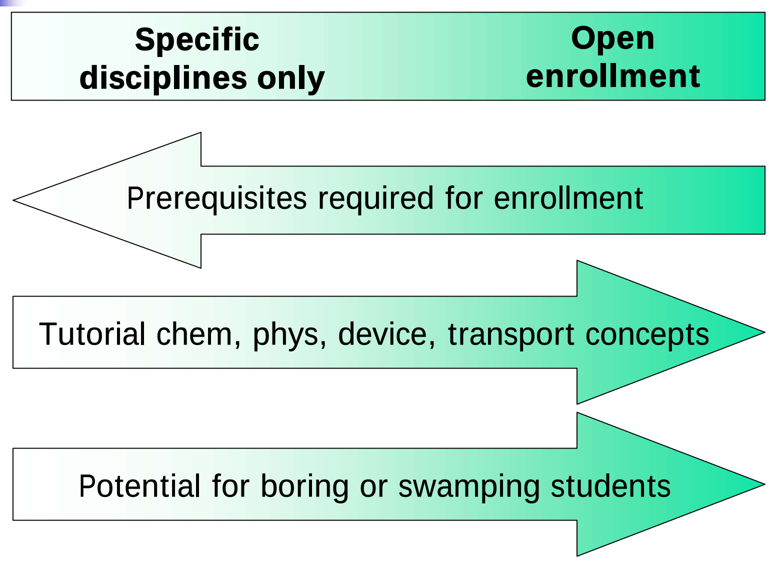
Conceptual Trends for Mixed-Enrollment Courses



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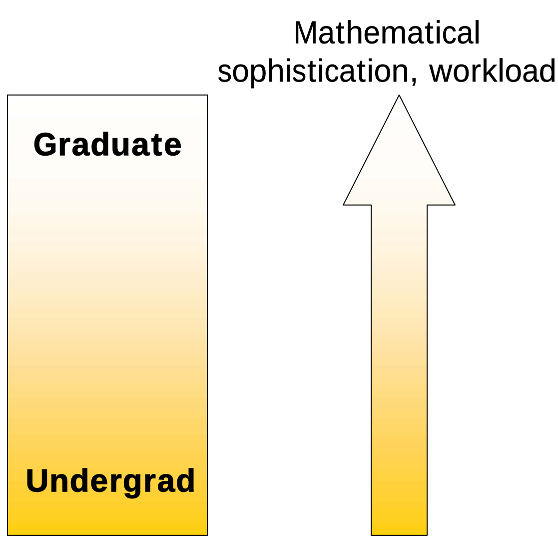
Conceptual Trends for Mixed-Enrollment Courses



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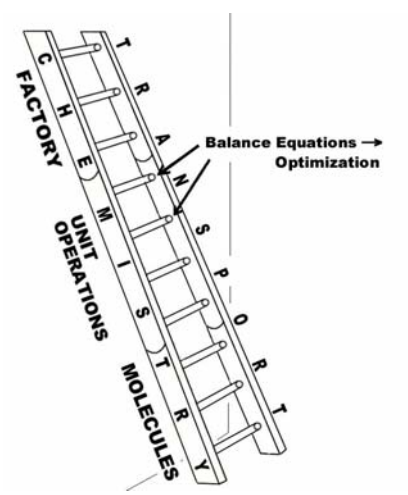
"Chemistry & Transport in Semiconductor Materials Synthesis"

- Broad audience
  - ChE, EE, Chemistry, Materials Sci
  - Grad & Undergrad
- ~24 students per offering
  - Eight groups of 3 (mixed-discipline)
- Limited number of in-depth experiments
  - Closely coupled to computational modeling
- Original course funded by AMAT, Intel, Illinois Board of Higher Education, 4 campus units

Purposes of Lecture Courses



- Transfer specific facts
  - Technology details
  - Mathematical methods
- Offer an ordered framework for facts: knowledge
  - Unit operations ↔ process flow
  - Unity of form for balance eqns in mass, energy, momentum

Rev Chem Eng, **18** (2001) 1.

UIUC: “Chemistry & Transport in Microelectronic Processing”

- Lecture course, 70+ students per offering
- Broad audience
  - ChE, EE, Chemistry, Materials Sci
  - Grad & Undergrad
- 2-week intro to semiconductor physics, devices
- Subjects ordered by increasing sophistication of mathematical governing equations

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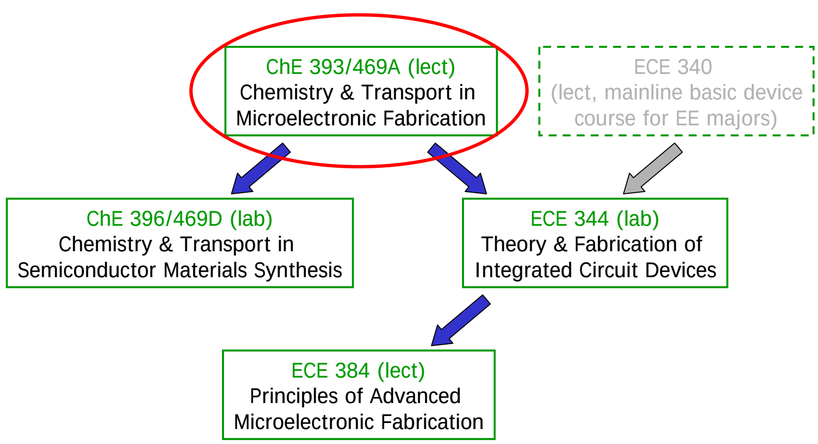
Informal Option in Processing at UIUC

- Up to 4 elective courses in chem eng, electrical eng
- Prerequisites kept minimal



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Course Structure

- Begin with 2 weeks of semiconductor device physics
  - More than this bores EE students
- Continue with lithography physics/chemistry
- Order remaining processing subjects by increasing sophistication of:
  - Mathematics
  - Conceptual difficulty of balance equations

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Conceptual Ordering of Processing Topics

Chemistry only

↓

Overall mass balances (1-D, steady-state)

↓

Overall mass balances (1-D, transient)

↓

Differential mass balances (1-D, steady-state)

↓

Differential mass balances (populations)

↓

Differential energy balances (1-D, steady-state)

↓

Differential energy balances (1-D, transient)

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Lectures 1-9

Lect. No.	Topics	Underlying Concepts
1 2	• Industry history • SIA Roadmap • Semiconductor materials	Overall perspective
3 4 5	• Semiconductor physics • pn junctions • Field effects	Solid state physics
6 7	• Lithography	Optics
8 9	• Etching (wet)	Buffers Electrochemistry

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Lectures 10-13

Lect. No.	Topics	Underlying Concepts
10	• Etching (dry)	Plasma phenomena
11	• Etching (dry)	Plasma phenomena
12	• Physical vapor deposition	Sputtering physics Process control
13	• Rapid thermal processing	Rate selectivity Process control
	Microelec. Lab Tour	

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Lectures 14-18

Lect. No.	Topics	Underlying Concepts
14 15 16 17	• Chemical vapor deposition	Surface kinetics Kinetics/gas transport Boundary layers Case study: $TiSi_2$
18	• Si oxidation	Rate-limiting steps Diffusion-rxn (differential mass balances, 1-D)

Lecturs 19-22

Lect. No.	Topics	Underlying Concepts
19 20	• Si refining	Well-stirred reactors Differential mass balances on distributions
21	• Czochralski growth	Separations by crystallization Differential energy balances (1-D)
22	• Diffusional doping	Defect thermodynamics Transient diffusion equations

Lectures 23-26

Lect. No.	Topics	Underlying Concepts
23	• Diffusional doping	Defect thermodynamics Transient diffusion equations
24	• Ion implantation • Transient enhanced diffusion	Implantation physics Diffusion-rxn (3-D PDE's)
25	• Packaging	Electrochemistry 1-D heat transfer
26	• Factory-level issues	Process integration

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Role of Modeling

- Simple, unsophisticated
  - Simple analytical
    - Rate selectivity
    - Deal-Grove model of oxidation
  - Easy-to-use software packages
  - For undergraduate, graduate students
- Sophisticated
  - Complex analytical
    - Transient enhanced diffusion
    - Spin coating
    - CVD with viscous flow
    - Dry etching with flow
  - For graduate students only

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Lecture Course Challenges

- Initial investment of time (several years)
- Experienced staffing
- Setting proper pace, depth
- Creating faculty, student constituency

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Techniques to Mitigate Challenges

- Engage faculty from several disciplines
  - Adds depth to presentation
  - Helps set appropriate pace, depth
  - Expands pool of students likely to enroll
  - Aids in staffing

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Summary

- Lecture courses relatively easy to set up
  - Helps to have interdiciplinary faculty constituency
- Begin with a little device background
- Introduce processing concepts in order of increasing mathematical, conceptual difficulty
  - Balance between qualitative, mathematical content