OPTI (596-009) Semiconductor Lasers
Instructor: **Prof. Garrett D. Cole**
Wyant College of Optical Sciences
The University of Arizona

Credits: 3 units
Level: Graduate

Course Description

This course provides a unified treatment of the physics, design, and performance of semiconductor lasers, integrating foundational concepts with essential dynamic behavior. Topics include semiconductor heterostructures and quantum wells, optical gain and recombination mechanisms, and carrier-photon rate equations describing steady-state and small-signal modulation response. Key device architectures, including Fabry-Pérot, distributed feedback (DFB), distributed Bragg reflector (DBR), and vertical-cavity surface-emitting lasers (VCSELs), are analyzed with an emphasis on their operational principles and design trade-offs. Additional topics include laser linewidth, noise, and fundamental performance limitations. The course prioritizes physical insight and practical relevance to provide a cohesive foundation for modern applications in photonics, communications, sensing, and integrated optical systems.

Prerequisites

OPTI 507 Solid-State Optics OR OPTI 341 Semiconductor Physics & Lasers with instructor's permission. If you do not have these courses, please get permission from the instructor.

Course Learning Objectives

Upon successful completion of this course, students will be able to:

1. Analyze carrier and optical confinement in semiconductor heterostructures and quantum wells.
2. Calculate optical gain, spontaneous emission, and recombination rates in semiconductor materials.
3. Derive and apply laser threshold conditions.
4. Solve carrier-photon rate equations for steady-state and modulated operation.
5. Analyze modulation bandwidth, relaxation oscillations, and dynamic limitations.
6. Evaluate cavity designs including Fabry-Pérot, DFB, DBR, and VCSEL structures.
7. Estimate linewidth, intensity noise, and other key performance metrics.
8. Apply semiconductor laser principles to modern photonic integrated systems.

Suggested Textbooks

Primary Text

Coldren, Corzine, and Mašanović
Diode Lasers and Photonic Integrated Circuits, 2nd Edition, Wiley, 2012.
Details: https://www.wiley.com/en-us/shop/general-introductory-electrical-electronics-engineering/diode-lasers-and-photonic-integrated-circuits-2nd-edition-p-9780470484128).
University of Arizona online textbook: https://arizona-ua.primo.exlibrisgroup.com/discovery/fulldisplay?docid=alma9910486933564038 43&context=L&vid=01UA_INST:01UA&lang=en&search_scope=MyInst_and_CI&adaptor=Local%20Search%20Engine&isFrbr=true&tab=Everything&query=any,contains,Diode%20Lasers%20and%20Photonic%20Integrated%20Circuits&sortby=date_d&facet=frbrgroupid,include,49290710655649924&offset=0

Supplementary References

- Yariv and Yeh, *Photonics: Optical Electronics in Modern Communications*, 6th Edition, Oxford University Press, 2006.
    - Details: https://global.oup.com/ushe/product/photonics-9780195179460?cc=us&lang=en&
    - University of Arizona online textbook: not available
- Saleh and Teich, *Fundamentals of Photonics*, Wiley, 3rd Edition, 2019.
    - Details: https://www.wiley.com/en-us/shop/general-physics/fundamentals-of-photonics-2-volume-set-3rd-edition-p-9781119750819
    - University of Arizona online textbook: https://arizona-ua.primo.exlibrisgroup.com/discovery/fulldisplay?docid=alma9910504825930038 43&context=L&vid=01UA_INST:01UA&lang=en&search_scope=MyInst_and_CI&adaptor=Local%20Search%20Engine&isFrbr=true&tab=Everything&query=any,contains,fundamentals%20of%20photonics&sortby=date_d&facet=frbrgroupid,include,5747838566104928 8&offset=0

Semester Schedule (note that the instructor may update the schedule)

Part I: Semiconductor Laser Foundations

Week 1
- Introduction and applications
- Review of laser fundamentals
- Semiconductor band structure refresher

Week 2
- Carrier statistics
- Density of states
- Optical transitions

Week 3
- Double heterostructures
- Carrier confinement
- Optical confinement

Week 4
- Quantum wells
- Density of states in reduced dimensions
- Gain enhancement

Part II: Gain and Threshold Physics

Week 5
- Radiative and nonradiative recombination
- Spontaneous emission

Week 6
- Optical gain
- Material gain vs. modal gain
- Threshold condition

Week 7
- Internal efficiency
- Power-current characteristics
- Temperature dependence

Midterm Examination

Part III: Laser Dynamics

Week 8
- Carrier-photon rate equations

Week 9

- Steady-state solutions
- Relaxation oscillations

Week 10

- Small-signal modulation
- Modulation transfer function
- Bandwidth limitations

Week 11

- Noise processes
- Relative intensity noise
- Linewidth enhancement factor

Part IV: Laser Structures and Design

Week 12

- Fabry-Pérot lasers
- Longitudinal modes

Week 13

- DBR lasers
- Coupled-cavity concepts

Week 14

- DFB lasers
- Coupled-mode theory
- Single-frequency operation

Week 15

- Surface-emitting lasers (VCSELs, VECSELs, MECSELs, PCSELs, etc.)
- Modern trends:
    - Silicon photonics
    - Integrated lasers
    - Emerging materials
- Final project presentations

Grading Structure

Component	Weight
Homework (8–10 sets)	40%
Midterm	20%
Final Project	20%
Final Exam	20%

The grade will be determined according to the cumulative percentage earned such that 90-100% = A, 80-89% = B, 70-79% = C, 60-69% = D, below 60% = E.

Policies

University-Wide Policies

Links to the following UA policies are provided here, http://catalog.arizona.edu/syllabus-policies:

- Absence and Class Participation Policies
- Threatening Behavior Policy
- Accessibility and Accommodations Policy
- Code of Academic Integrity
- Nondiscrimination and Anti-Harassment Policy
- Subject to Change Statement

Other policies

- Confidentiality: http://www.registrar.arizona.edu/ferpa
- Safety: For a list of emergency procedures for all types of incidents, please visit the website of the Critical Incident Response Team (CIRT): https://cirt.arizona.edu/case-emergency/overview
- Safety video: https://arizona.sabacloud.com/Saba/Web_spf/NA7P1PRD161/common/learningeventdetail/crtfy0000000000003560
- Classroom Behavior: To foster a positive learning environment, students and instructors have a shared responsibility. We want a safe, welcoming, and inclusive environment where all of us feel comfortable with each other and where we can challenge ourselves to succeed. To that end, our focus is on the tasks at hand and not on extraneous activities (e.g., texting, chatting, reading a newspaper, making phone calls, web surfing, etc.).

Additional resources

UA Academic policies and procedures are available at http://catalog.arizona.edu/policies

- **Campus Health**
  - http://www.health.arizona.edu/
  - CH provides medical and mental health care services through virtual and in-person care.
  - Phone: 520-621-9202
- **Counseling and Psych Services (CAPS)**
  - https://health.arizona.edu/counseling-psych-services
  - CAPS provides mental health care, including short-term counseling services.
  - Phone: 520-621-3334
- **The Dean of Students Office's Student Assistance Program**
  - https://deanofstudents.arizona.edu/support/student-assistance
  - Student Assistance helps students manage crises, life traumas, and other barriers that impede success. The staff addresses the needs of students who experience issues related to social adjustment, academic challenges, psychological health, physical health, victimization, and relationship issues, through a variety of interventions, referrals, and follow up services.
  - Email: DOS-deanofstudents@arizona.edu and Phone: 520-621-7057
- **Survivor Advocacy Program**
  - https://survivoradvocacy.arizona.edu/
  - The Survivor Advocacy Program provides confidential support and advocacy services to student survivors of sexual and gender-based violence. The Program can also advise students about relevant non-UA resources available within the local community for support.
  - Email: survivoradvocacy@arizona.edu and Phone: 520-621-5767