Flipped Classroom Approach in Optoelectronics Course for Electronic and Information Engineering Students

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ABSTRACT

Optoelectronics is one of the core courses for first year graduate students major in communication engineering and electronic and information engineering at Fudan University. The conventional approach to teach students from a diverse academic background is challenging. In 2022, we introduce flipped classroom approach in optoelectronic course. The course is organized under 15 topics in optoelectronics. Students will take the lead in presentation, topic discussion and case study. We find that by introducing the flipped classroom approach, students are able to master the course materials with better efficiency.

Keywords: Optoelectronics, Information science, Graduate education, Flipped classroom, Communication engineering.

1. INTRODUCTION

Optoelectronics is one of the core courses for first year graduate students major in communication engineering and electronic and information engineering at Fudan University. The students are from a diverse academic background, such as those major in electrical engineering, physics, chemistry, material science and engineering, mechanical engineering, computer science, communication engineering, automation etc. Conventionally, the professor gives lectures and assign homework. However, it is challenging to balance the needs between students who have already learnt related topics and those who have little background knowledge. We have to spend the first 4 sessions in fundamental semiconductor physics and related materials to align students' background. Since 2022, we introduce flipped classroom approach in optoelectronic course. The flipped classroom approach has been gaining substantial momentum worldwide including in Asia [1]. Recent studies suggest that the students had a positive perception about the flipped classroom during the COVID-19 pandemic [2]. In our case, we have identified 15 topics in optoelectronics. In the introductory, we detail the key concepts, reference materials, and important messages to be covered in each topic. Additionally, for each topic, we provide 3 questions to be answered and 2 research papers that is related for case study. Students are required to read the reference materials and the research papers before the class while in class, they take turns in presentation, topic discussion and case study. We find that by introducing the flipped classroom approach, students are able to fill the knowledge gap and master the class with better efficiency.

2. COURSE DESIGN

The course "Optoelectronics" is 3 credits, which means 3 hours per week. The course schedules are shown in Table 1. After the first 2 introductory session, the students are grouped to work on topics selected. In week, the first hour would be a presentation on the topic. The second hour would be the discussion of questions from the audience and the questions raised by the instructors. The third hour would be the presentation and discussion of the research papers related to the topic. At the end of this course, each student is requested to submit a course paper, which could be a mini-review of a topic discussed or a detailed discussion about a question covered in the course. The scoring criteria are 25% topic presentation, 20% discussion involvement, 20% case study, 35% course paper.

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Seventeenth Conference on Education and Training in Optics and Photonics: ETOP 2023,
edited by David J. Hagan, Mike McKee, Proc. of SPIE Vol. 12723, 1272317
 · doi: 10.1117/12.2670578

Table 1. Course Schedule

Week	Arrangement
1	Introduction and Fundamentals of Optoelectronics
2	Fundamentals of Semiconductor Devices
3	Topic 1: Basic knowledge of optoelectronics
4	Topic 2: Optical fibers and optical waveguides
5	Topic 3: Semiconductor optoelectronic materials
6	Topic 4: Principle of light emitting diode
7	Topic 5: Properties, structures and applications of light emitting diodes
8	Topic 6: Fundamentals of laser diode
9	Topic 7: The key parameters of laser diode
10	Topic 8: Optical cavity in a laser diode
11	Topic 9: Transient response of laser diode
12	Topic 10: Distributed feedback laser diode
13	Topic 11: Fabrication, packaging and reliability of optoelectronic devices
14	Topic 12: Polarization and modulation of light
15	Topic 13: Fundamentals of light detection
16	Topic 14: Photodetectors
17	Topic 15: Photonic integrated circuit
18	Final: Course Paper Presentation

The key points and questions to be answered and discussed in each topic are as follows.

Topic 1: Basic knowledge of optoelectronics Margins

Key points:
1. Band gap in semiconductor
2. Direct and indirect band gaps
3. Compound semiconductor materials and Vegard's Law
4. Review of basic concepts of optics, including refractive index and group velocity
5. Snell's Law and total reflection
6. Fresnel equation
7. Antireflective coating and dielectric film mirror
8. The coherence of light

Questions:
1. Why it is difficult to make a silicon LED?
2. How is a beam splitter being made?
3. What is a DBR mirror?

Topic 2: Optical fibers and optical waveguides

Key points:
1. Single mode and multiple mode
2. Dispersion
3. Dielectric optical waveguide
4. Structure and characteristics of optical fibers
5. Loss in an optical fiber
6. Numerical aperture
7. Dispersion and compensation in a single mode fiber
8. Step index fiber
9. Optical fiber communication

Questions:
1. What is the loss of light in the fiber?
2. What is the typical structure of single mode fiber? What are the common core sizes?

3. What determines the number of modes that can be transmitted in a fiber?

Topic 3: Semiconductor optoelectronic materials

Key points:
1. Lattice constants, strains and defects
2. Fermi-Dirac distribution function in semiconductors
3. State density
4. Doping, P type semiconductor and N type semiconductor
5. Degenerate semiconductors and non-degenerate semiconductors
6. PN junction formation, space charge region and depletion region
7. Carrier drift and diffusion
8. Voltammetry characteristics of diodes
9. Carrier recombination
10. Positive bias and inverse bias
11. Junction resistance and capacitance

Questions:
1. How does doping affect the characteristics of the diode?
2. Where might the leakage current from the diode come from?
3. What are the factors that limiting the operation speed of a diode?

Topic 4: Principle of light emitting diode

Key points:
1. Quantum well
2. Common LED structure
3. Radiation recombination
4. Bimolecular rate equation
5. Nonradiative recombination: Shockley-Read-Hall and Auger recombination
6. ABCCD model in LED
7. The ideality factor of LED
8. Ohmic contact

Questions:
1. How is the wavelength of the LED determined?
2. Is the probability of nonradiative recombination related to material growth and device fabrication?
3. What are the possible origins of Auger recombination?

Topic 5: Properties, structures and applications of light emitting diodes

Key points:
1. Carrier transport in heterojunction LEDs
2. The introduction of the electron blocking layer
3. Typical structure of a blue LED
4. Internal quantum efficiency, external quantum efficiency and light extraction efficiency
5. The luminous flux of LED
6. How to make white LED
7. Color rendering index and color temperature
8. Current spreading in LED
9. Efficiency droop

Questions:
1. What is the relationship between the wall-plug efficiency and EQE of LED ?
2. What is the relationship between the energy band and the wavelength of the LED?
3. How to improve the luminous efficiency of LED under high power?

Topic 6: Fundamentals of laser diode

Key points:
1. Review of carrier generation and recombination in the active region
2. Spontaneous radiation process
3. Photon generation and loss in laser resonators

4. Carrier and photon rate equation
5. The threshold of the laser
6. Internal loss and mirror loss
7. I-V characteristics and P-I characteristics of laser diodes
8. Slope efficiency
9. Gain

Questions:

1. What is spontaneous radiation? What is stimulated radiation?
2. How to evaluate the performance of a laser?
3. What is the difference between the optical power - current curve of a laser and an LED?

Topic 7: The key parameters of laser diode

Key points:

1. Typical parameters of F-P cavity lasers
2. Typical parameter analysis of VCSEL
3. Luminous efficiency
4. Thermal properties of lasers and temperature effects
5. Characteristics of cavity surface coating devices
6. Transparent current density

Questions:

1. How to design a set of lasers to measure internal parameters?
2. How is internal quantum efficiency measured?
3. How to get the transparent current density?
4. What is the difference between transparent current density and threshold current density?

Topic 8: Optical cavity in a laser diode

Key points:

1. Fabry - Perot cavity
2. Ridge waveguide
3. Optical longitudinal mode
4. Optical transverse mode
5. TE and TM modes
6. Several effective waveguide designs

Questions:

1. Why does the spectrum of laser emission have a narrower linewidth than that of LED?
2. What is the side mode suppression ratio (SMSR)?
3. What information can the laser gain spectrum give?

Topic 9: Transient response of laser diode

Key points:

1. Frequency response of a laser diode
2. Measurement of small signal modulation
3. Resonance frequency
4. Damping factor
5. The relationship between resonant frequency and injection current
6. Photon lifetime
7. Modulation bandwidth
8. Parasitic capacitance
9. Large signal modulation

Questions:

1. Which is faster, LED *vs.* laser diode, and why?
2. What limits the modulation bandwidth of a semiconductor laser?
3. What are the differences between small signal and large signal modulation?

Topic 10: Distributed feedback laser diode

Key points:

1. Significance of single wavelength devices
2. Grating
3. Bragg reflector
4. Structure of the DFB
5. Distributed feedback structure design principles
6. DFB phase regulation

Questions:

1. What is the structure difference between F-P laser, DFB laser, DBR laser and VCSEL?
2. What are the advantages of DFB laser over VCSEL?
3. Why the F-P laser and DFB laser are sensitive to the temperature?

Topic 11: Fabrication, packaging and reliability of semiconductor optoelectronic devices

Key points:

1. Epitaxial growth: MBE, MOCVD
2. Lithography and mask plate
3. Dry etching and wet etching
4. Deposition: PVD, CVD
5. Key steps and processes in chip manufacturing
6. The main process of photoelectric device manufacturing
7. Common forms of packaging for optoelectronic devices
8. Materials commonly used in optoelectronic device packaging
9. Reliability, failure and aging

Questions:

1. What is planar craft? Why do micro and nano processing choose such a processing idea?
2. What is yield?
3. How to evaluate device reliability?

Topic 12: Polarization and modulation of light

Key points:

1. The polarization properties of light
2. Propagation of light in anisotropic crystals
3. Dichroism
4. Birefringent effect
5. Electro-optical effect
6. Pockels Effect
7. Kerr Effect
8. Liquid crystal
9. Mahzender modulator
10. Acousto-optic modulator
11. Optical isolator

Questions:

1. Which is more suitable for high-speed modulation? lithium niobate electro-optic modulator or liquid crystal modulator?
2. What is the principle of electro-optic amplitude modulator?
3. What is the Photoelastic Effect?

Topic 13: Fundamentals of light detection

Key points:

1. Principle of semiconductor photodetector
2. Light absorption in semiconductor materials
3. Photocurrent
4. Quantum efficiency of photodetectors
5. Responsivity
6. Structure of PIN photodetector
7. Frequency response of PIN photodetector

Questions:

1. What are the differences between photodiodes and solar cells?
2. Why use the P-I-N structure?
3. How to design a high-speed photodetector?

Topic 14: Photodetectors

Key points:

1. APD: avalanche photodiode
2. Heterojunction photodiode
3. Schottky junction photodiode
4. Phototransistor
5. Photoconductive detector
6. Detector noise and NEP
7. Signal to noise ratio of optical receiver

Questions:

1. How to improve the responsiveness of photodetector?
2. What materials are used for UV detector and infrared detector?
3. What are the advantages of APD and PIN PD?

Topic 15: Photonic integrated circuit PIC

Key points:

1. Photon integration and photoelectric integration
2. Coherent optical communication
3. Semiconductor optical amplifier
4. Waveguide photodetector
5. Wavelength converter
6. Fabrication of photonic integrated circuits
7. Application of photonic integrated circuits

Questions:

1. What are the similarities and differences between photon integration and electronic integration
2. Why is it necessary to integrate laser, modulator and SOA on chip?
3. What are the characteristics and uses of waveguide photodetector?

3. CONCLUSION

This paper presents the course development of optoelectronics for graduate students in school of information science and technology. The course design for a flipped classroom approach is discussed. With this approach, we find that the chances that a student being distracted from the class is reduced compared with conventional approach of lecturing.

ACKNOWLEDGEMENTS

The authors acknowledge the funding support from Natural Science Foundation of Shanghai (21ZR1406200); Major Key Project of PCL; The joint project of China Mobile Research Institute & X-NET; The Key Research and Development Program of Jiangsu Province (BE2021008-5).

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