Engineering Tripos Part IIA, 3B6: Photonic Technology, 2021-22

Module Leader

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Timing and Structure

Lent term. 16 lectures.

Aims

The aims of the course are to:

- Introduce key aspects of photonics technology and its applications in fields such as communications, storage, medicine, environmental sensing and solar power.
- Introduce both optical fibres and photonic components including light emitting diodes, lasers, photodiodes and solar cells.
- Introduce photonic sub-systems including transmitters and receivers for use in applications such as wide area, metropolitan and local area networks.

Objectives

As specific objectives, by the end of the course students should be able to:

- Know of the main applications of optoelectronics.
- Choose appropriate transmission media with reference to bandwidth and physical environment.
- Know which semiconductors are used for what optoelectronic tasks and why.
- Be familiar with the construction of LEDs, and be able to estimate their linewidth, speed and external quantum efficiency.
- Be familiar with the construction of Fabry-Perot and grating based diode lasers, and how this relates to their spectra and light-current characteristics
- Estimate the response of semiconductor lasers to changes in their drive current or operating environment.
- Be familiar with the construction of junction photodiodes, and hence be able to estimate the capacitance and responsivity, and know how to operate them for best sensitivity and speed.
- Be familiar with the relationship in construction and operation between junction photodiodes, avalanche photodiodes, solar cells and photoconductors.

- Perform noise calculations for typical optoelectronic circuits.
- Be aware of the design of typical receiver circuits with reference to the physical characteristics of photodetectors.
- Be familiar with the construction of fibres as well as the causes of attenuation and dispersion.
- Perform calculations of link budgets, dispersion and attenuation limits.

Content

Photonic Technology

- How and why optoelectronics fits within electronics: Outline of major applications areas within engineering, science and medicine. Examples of optoelectronic subsystems, solar cells, lighting, Communication transceivers.
- Optical processes in semiconductors: Direct and indirect band structures, comparison of Silicon, Germanium, GaAs based and InP based materials. Optical absorption, Optical emission, non-radiative transitions
- Light emitting diodes**:** Quantum efficiency, wavelength, optical line width, visible devices, modulation limits, device structures, materials.
- Laser diodes: Stimulated emission, optical gain. Laser as a feedback amplifier of spontaneous emission, Fabry-Perot laser cavities. Rate equations, modulation characteristics, dynamic linewidth. Examples of common diode laser types.
- Optical transmitter circuits: LED based circuits, LED types, transmitter power, bandwidth. Laser based circuits, laser types, biassing, feedback circuits. Noise in optical systems, shot noise, thermal noise, noise bandwidths, circuit effects.
- Photodetectors: PN junction photodiodes, photoconductors, solar cells, avalanche photodiodes, capacitance, transit time, leakage currents, avalanche gain and noise.
- Optical receiver circuits; Transimpedance amplifiers.
- Fibres and transmission: Multimode and single mode fibres: Attenuation, dispersion, interfaces to fibre.
- Transmission systems in a real environment: Power budgets, error rates, monitoring, power penalties, margins for temperature and ageing. Emerging technologies.

Examples papers

Three examples papers are provided during the course.

Coursework

Laser Experiment

Students are provided with two types of semiconductor lasers and are asked to perform basic electrical and optical measurements to characterise their operation. The measurements are used to derive the basic properties of these laser devices and understand the underlying fundamental physical mechanisms that govern their operation.

<u>Learning objectives</u>:

After completing this coursework students should be able to

- Be familiar with the basic operation of LEDs and lasers,
- Generate light-current and current-voltage curves for a semiconductor device,
- Find the laser threshold and stray series resistance of a laser,
- Characterise the spectrum of light emitted from LEDs and lasers,
- Estimate the refractive index of the laser.

<u>Practical information</u>:

- Sessions will take place in EIETL, during weeks 3-8 in Lent term and weeks 1-2 in Easter term.
- This activity involves preliminary work (~ 2 h): you should read the related lecture notes and experiment information sheet with the appendices, to gain some knowledge background on semiconductor devices and error analysis prior to experiments.

Full Technical Report:

Students will have the option to submit a Full Technical Report.
Students are asked to i). expand on their experimental results based on the feedback provided at the marking session, ii.) perform the Haaki-Paoli analysis to obtain the gain spectrum of a semiconductor laser and iii.) provide an analysis of the effects of temperature on the operation of laser devices.

Booklists

Please refer to the Booklist for Part IIA Courses for references to this module, this can be found on the associated Moodle course.

Examination Guidelines

Please refer to Form & conduct of the examinations [1].

UK-SPEC

This syllabus contributes to the following areas of the UK-SPEC [2] standard:

Toggle display of UK-SPEC areas.

GT1

Develop transferable skills that will be of value in a wide range of situations. These are exemplified by the Qualifications and Curriculum Authority Higher Level Key Skills and include problem solving, communication, and working with others, as well as the effective use of general IT facilities and information retrieval skills. They also include planning self-learning and improving performance, as the foundation for lifelong learning/CPD.

IA1

Apply appropriate quantitative science and engineering tools to the analysis of problems.

KU1

Demonstrate knowledge and understanding of essential facts, concepts, theories and principles of their engineering discipline, and its underpinning science and mathematics.

KU2

Have an appreciation of the wider multidisciplinary engineering context and its underlying principles.

E1

Ability to use fundamental knowledge to investigate new and emerging technologies.

E2

Ability to extract data pertinent to an unfamiliar problem, and apply its solution using computer based engineering tools when appropriate.

E3

Ability to apply mathematical and computer based models for solving problems in engineering, and the ability to assess the limitations of particular cases.

P1

A thorough understanding of current practice and its limitations and some appreciation of likely new developments.

P3

Understanding of contexts in which engineering knowledge can be applied (e.g. operations and management, technology, development, etc).

P8

Ability to apply engineering techniques taking account of a range of commercial and industrial constraints.

US1

A comprehensive understanding of the scientific principles of own specialisation and related disciplines.

US2

A comprehensive knowledge and understanding of mathematical and computer models relevant to the engineering discipline, and an appreciation of their limitations.

US3

An understanding of concepts from a range of areas including some outside engineering, and the ability to apply them effectively in engineering projects.

US4

An awareness of developing technologies related to own specialisation.

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