# Engineering Tripos Part IIB, 4C3: Advanced Functional Materials and Devices, 2021-22

### Module Leader

Prof. J H Durrell [1]

### Lecturers

Prof. J Durrell, Prof. S Hofmann [2]

### Timing and Structure

Michaelmas term. 14 lectures + 2 Exercise Classes/Practical Demonstrations. Assessment: 100% exam. Will be taught in person with lectures recorded.

## Aims

The aims of the course are to:

- introduce a range of modern functional materials and devices emphasising their processing, properties and limitations.
- introduce principles to describe the origins of the electronic, optical, and magnetic properties of materials, and to explore structure-property relationships for bulk, thin film and nano-materials.
- discuss how these properties can be characterised and engineered for applications ranging from bulk superconductors to piezoelectric sensors, integrated CMOS, solid state lighting, displays and non-volatile memory.
- provide analysis of the key issues shaping the field and the key technologies reshaping society.

## Objectives

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

- appreciate the range and diversity of modern functional materials.
- understand band diagrams and basic implications of quantum mechanics.
- understand qualitatively the origin of ferromagnetic and superconducting order in materials and how this results in useful materials properties.
- understand how extrinsic and intrinsic factors affect the performance of magnetic, superconducting and electrical materials.
- be able to apply their understanding of functional materials to making materials selection decisions.
- understand ferroic, non-linear response materials and the underlying phase transitions.
- understand interface behaviour and basic junctions as the basis for semiconductor device engineering.
- understand size-effects and how materials structure and properties can be controlled from the bulk to thin films and down to the nanoscale.
- understand manufacturing and characterisation requirements of these materials.
- identify current and future materials for a range of state-of-the-art sensor, integrated circuit, lighting, display and memory technologies.

## Content

**Magnetic, Superconducting and Electrical Materials (7L+ 1, Prof. J Durrell)**

- Basics: Recap of magnetic and electrical fields in materials
  (1L – flipped classroom: worksheet to study before lecture)
- Magnetic Materials and Applications (2L);
- Superconducting Materials and Applications (2L);
- Electrical and Multi-ferroic Materials and Applications (2L);
- Guided Classwork Exercise and Superconductivity Demonstration (1L)

**Optoelectronic materials and devices (7L + 1, Prof S Hofmann)**

Setting the scene – Materials for digital technology and modern information society (1L)

***Introduction to Modern Theory of Solids and Opto-Electronic Device Materials***

- Bonds and Bands in Solids (1L)
- Mind the Gap: Semiconductors & Insulators (1L)
- From thin films to emerging nanomaterials (2L)

***Material Challenges in Opto-Electronic Device Applications***

- Interface is the Device: Very large scale integration (VLSI): CMOS technology (1L)
- Let there be light: light emitting diodes, lasers and display technology (1L)

- Guided Classwork Exercise and EE lab/clean room tour (1L)

## Booklists

Coey J.M.D., ‘Magnetism and Magnetic Materials’, CUP (NA166).

Available online to CUED students
[https://www.cambridge.org/core/books/magnetism-and-magnetic-materials/AD... [3]

‘Superconductivity’. Poole (Elsevier)

Available online to CUED students: [https://cam.userservices.exlibrisgroup.com/view/action/uresolver.do?oper... [4]

Braithwaite N. and Weaver G., ‘Electronic Materials’, Butterworths (JA179)

Ohring M., The Materials Science of Thin Films (JA204)

Kasap S.O., ‘Principles of Electronic Materials and Devices’, McGraw-Hill

Useful as a simple guide on quantum mechanics :
Allison J., ‘Electronic Engineering Semiconducting Devices’, McGraw-Hill (NR290)

Campbell S.A., ‘Science and Engineering of Microelectronic Fabrication’ (OUP)

Plummer J. D., Silicon VLSI technology (NQ79)

Dresselhaus et al., Topics in Applied Physics, Carbon Nanotubes, DOI: 10.1007/3-540-39947-X

Avouris et al., 2D Materials: Properties and Devices, https://doi.org/10.1017/9781316681619 [5] (available online via UCam library)

**Reference:**

Kittel C., 'Introduction to Solid State Physics' (Wiley)

Elliott S.R., 'Physics and Chemistry of Solids' (Wiley)

Madou M. J., Fundamentals of Microfabrication (DM.7&8 Folio)

## Examination Guidelines

Please refer to Form & conduct of the examinations [6].

## UK-SPEC

This syllabus contributes to the following areas of the UK-SPEC [7] 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.

#### IA2

Demonstrate creative and innovative ability in the synthesis of solutions and in formulating designs.

#### 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.

#### 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).

**US1**

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

**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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**Links**
[1] mailto:jhd25@cam.ac.uk
[2] mailto:sh315@cam.ac.uk, jhd25@cam.ac.uk
[3] https://www.cambridge.org/core/books/magnetism-and-magnetic-materials/AD3557E2D4538CAA8488A8C1057313BC]
[4] https://cam.userservices.exlibrisgroup.com/view/action/uresolver.do?operation=resolveService&package_service_id=6710588010003606&institutionId=3606&customerId=3605]
[5] https://doi.org/10.1017/9781316681619
[6] https://teaching25-26.eng.cam.ac.uk/content/form-conduct-examinations
[7] https://teaching25-26.eng.cam.ac.uk/content/uk-spec