Department of Materials
Imperial College London

Materials Science and Engineering (MEng)
Biomaterials and Tissue Engineering (MEng)
Materials with Nuclear Engineering (MEng)
Materials Science and Engineering (BEng)
Materials with Management (BEng)

YEAR 2 MODULE AND ASSESSMENT STUDENT HANDBOOK

2018-19

Introduction

This handbook contains specific information for the Year 2 students in the 2018-2019 cohort, including the module details and assessment deadlines and year composition for this academic year. It is to be used in conjunction with the General Handbook for all students for full regulations and guidance on the undergraduate programmes in the Department of Materials.

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1. Programme Information

Key dates 2018 - 19

Term dates

Autumn term:	29 September - 14 December 2018
Spring term:	5 January - 22 March 2019
Summer term:	27 April - 28 June 2019

Closure dates

Christmas/New year:	24 December 2018 - 1 January 2019
	(College reopens on 2 January 2019)
Easter holiday:	18 April – 23 April 2019
	(College reopens on 24 April 2019)
Early May bank holiday:	6 May 2019
Spring bank holiday:	27 May 2019
Summer bank holiday:	26 August 2019

Year structure

2nd year comprises 6 modules: 5 which are primarily lectures courses, 1 of which has a significant lab component and 1 which is around engineering essential skills. These modules are listed below along with the relative module weighting in the year structure.

MSE.201	Mathematics and Computing (17%)
MSE.202	Materials Chemistry and Polymer Science (14%)
MSE.203	Mechanical Behaviour (14%)
MSE.204	Microstructure (14%)
MSE.205	Electronic Properties of Materials (14%)
MSE.206	Materials Engineering (26%)

Progression

Progression criteria for Year 2 are:

- passing every module with a minimum of 40%
- passing the combined coursework from all modules with a minimum of 40%

Additional progression criteria for students on the MEng

- passing with a year total of at least 60%

The combined coursework mark is calculated by summing the module and coursework item weighting.

MSE 201
Mathematics and Computing

Course Co-ordinator: Dr P. Tangney
Status: Second Year Core
Prerequisites: MSE 101 Mathematics and Computing

Aims
This course is a continuation of the first year course MSE 101, and aims to give students a firm foundation in the aspects of Mathematics and Computing of most relevance to Materials Science and Engineering, especially the topics required in subsequent years of study. The missions of Mathematics and Computer Programming are to provide tools, and sufficient knowledge to use them safely, for the purpose of understanding and applying the quantitative methods of Materials Science and Engineering.

Learning outcomes

By the end of the course, students should know and understand the following and be able to apply them in solving problems.

Vector calculus (Dr J Lischner)
Preliminaries: cylindrical and spherical polars; double and triple integrals. Vector calculus: gradient, divergence, curl and Laplacian in cylindrical and spherical polars; line, surface and volume integrals, proof and application of divergence and Stokes' theorems; Maxwell's equations leading to Gauss's Law and Ampère's Law.

Fourier methods (Dr A Mostofi)
Orthogonality of functions; periodic functions; orthogonality relations of sine and cosine; Fourier series; discontinuous functions; use of symmetry; Parseval's theorem for Fourier series. Fourier transform: definition, relation to Fourier series, simple properties; bandwidth theorem; Parseval and convolution theorems for Fourier transforms; applications to diffraction and partial differential equations (e.g., heat diffusion).

Cartesian tensors (Dr A Mostofi)
Basic properties and rules of tensor algebra; transformation laws; isotropic tensors; symmetric and anti-symmetric tensors; suffix notation and Einstein summation convention; Kronecker and Levi-Civita symbols; representation of grad, div and curl; principal axes and diagonalisation; matter tensors and Neumann's Principle; applications to elasticity, anisotropic dielectrics, conductivity.

Partial differential equations (Dr M Foreman)
Skills to construct a PDE from a given problem in solid mechanics, diffusion or heat conduction in 1-3 dimensions. Separation of variables; Laplace, Poisson, diffusion and wave equations, equations from simple problems in linear elasticity; initial conditions and boundary conditions. Green functions.

Mathematics of Electromagnetism (Dr P Tangney)
Application of vector calculus and partial differential equations to problems in electromagnetism; Maxwell's equations. Electrostatics –applying Gauss' Law to calculate capacitances. Currents –applying Stokes' Theorem to calculate magnetic field strengths and inductances. Dynamics: Oliver Heaviside and his formulation of Maxwell's Equations. Plane-wave solutions, in both dielectric and conducting media; concept of skin-depth. Poynting 's Vector: energy density and power flow. Cables, Waveguides and Modes – both radio frequency and optical.

Probability theory and Statistics (Dr P Tangney)

Venn diagrams and set theory notation; basic definitions and rules of probability; Bayes' theorem; combinations and permutations; discrete random variables; probability distributions; Properties of distributions: mean, mode and median, variance, higher moments, probability generating functions; Poisson and binomial distributions; Continuous random variables; probability density functions, moment generating functions; Gaussian and exponential distributions; central limit theorem; parameter estimation, error estimation.

Computer Programming (Prof A Horsfield)

Systematic programming in MATLAB. Vector programming, Write a molecular dynamics program for simulations in 1-D. Creating a simple graphical interface, and writing code for Arduino boards.

Recommended textbooks A = required, B = recommended but not essential, C = background reading

Mathematics

A *Mathematical Methods for Physicists and Engineers*, K. F. Riley, M. P. Hobson and S. J. Bence, CUP 2006

B *Engineering Mathematics Through Applications*, K. Singh, Palgrave Macmillan 2003
Mathematical Methods in the Physical Sciences, M. Boas, Wiley 2006

C *Mathematical Methods for Physicists*, G. Arfken and H. Weber, Academic Press 1995
Practical Physics, G. Squires, CUP 2001

Computer Programming

A *Getting Started with MATLAB*, Rudra Pratap, Oxford University Press 2009

Structure, teaching and learning methods

Mathematics

48 lectures: Autumn and Spring terms
10 tutorials: Autumn and Spring terms

Computer Programming

5 practical classes: Spring term

Assessment

Mathematics

Examination

The course is examined in the Summer term. The examination paper, duration 3 hours, is in two sections. Section A is compulsory and consists of short answer questions on all parts of the course. Section B contains 4 questions of which students must answer 3.

Coursework

There are 10 tutorials for which students need to prepare answers to problem sets.

Progress Tests

There will be two tests, one at the start of the Spring term and one at the start of the Summer term.

Computer Programming

Coursework

At the start of each laboratory session the students do a short multiple-choice quiz on a homework assignment, each worth 3 marks.

MSE 202
Materials Chemistry

Course Co-ordinator: Prof Julian Jones

Status: Second Year Core

Prerequisites: A-level Chemistry or Introduction to Materials Chemistry, MSE 102

Aims

This course is designed to (i) give students a fundamental understanding of materials stability and the implications for corrosion and protection of engineering materials, (ii) develop students understanding of polymer synthesis, characterisation, structure and properties, and (iii) to develop an understanding of how macromolecules arrange themselves in polymer solids and how that arrangement affects the macroscopic properties. The module also covers how polymers are processed into useful products and how macroscopic properties can be controlled through processing. The course content follows on directly from the first year 102 and 104 courses and develops many of the concepts of thermodynamics, kinetics and polymers applied to materials systems.

Learning outcomes

Glasses and their degradation (Prof J R Jones)

On successfully completing this course unit, students will be able to:

- Define a glass
- Describe glass production by the melt-quench and sol-gel chemistry routes
- Describe the structure of glasses
- Describe and explain the evolution of atomic and nanostructure of glasses
- Explain the differences in synthesis, structure and properties of melt and sol-gel derived silicate glasses
- Describe the properties needed for window glass, nuclear waste glass and bioactive glass for medical implants
- Explain the corrosion/ degradation mechanisms of glasses for window glass, nuclear waste glass and bioactive glass for medical implants

Degradation of Polymers (Prof J R Jones)

- On successfully completing this course unit, students will be able to:
- Describe the molecular structure of degradable polymers
- Explain the degradation of common degradable polymers such as polyesters
- Describe the advantages and disadvantages of degradation mechanisms with respect to applications such as medical implants and packaging

Phase Stability Diagrams and High Temperature Oxidation (Dr I Stephens)

On successfully completing this course unit, students will be able to:

- Describe how free energy concepts can be used to understand material and phase stability in a range of systems.
- Construct and use and Ellingham Diagrams
- Construct and use Phase Predominance and Vapour Species Diagrams
- Give examples of the use of thermodynamic diagrams for industrial processes (e.*g.* metal extraction).

- Describes the main types of high temperature oxidation and understand the implications of each in terms of materials stability and selection
- Describe the role of defects in oxidation processes and give examples of defect formation in semi-conducting oxides
- Derive equations that relate defect concentration with oxygen partial pressure
- Describe Wagner's theory of oxidation and use a simplified model to derive the parabolic rate law.

Aqueous Corrosion and Protection (Dr I Stephens)

At the end of this part of the course the student will be able to:

- Construct thermodynamic diagrams (Pourbaix) for simple systems and use them in a predictive manner
- Understand the factors that affect corrosion rates and write down electrochemical equations that describe them.
- Calculate thickness loss from electrochemical data
- Explain the concept of passivity and its breakdown
- Describe the main types of corrosion
- Discuss the synergistic effects of dissolution and mechanical stress
- Describe the main physical, chemical and electrochemical methods of corrosion protection and give appropriate examples of their industrial use.
- Explain the concept of risk-based management of corrosion inspection and maintenance.

Polymers (Dr Cecilia Mattevi)

At the end of the module, the students should be able to:

- understand relevant polymer structure-property-processing interrelationships,
- know which factor influence polymer solidification/crystallization,
- understand concepts that lead to higher order in macromolecular structures,
- are familiar with the crystallization kinetics of polymer solidification, and why this is of importance when processing this class of materials into functional architectures,
- understand what influences the melting of (semi-)crystalline polymers (including effects of diluents – i.e. Flory Huggins equation)
- understand how processing and solidification conditions influence the properties of the final structures (mechanical, optical as well as electronic characteristics).

Recommended textbooks A = required, B = recommended but not essential, C = background reading.

A *Introduction to the High Temperature Oxidation of Metals,* Birks, Meier, Pettit, CUP 2006

Principles and Prevention of Corrosion, D.A. Jones, Macmillan 1991

Introduction to Polymer Science, RJ Young and PA Lovell, Chapman And Hall 1991

B *Basic Chemical Thermodynamics,* EB Smith, ICP 2004

Polymer Chemistry and Physics of Modern Materials JMG Cowie, Billings and Son London.

Textbook of Polymer Science, FW Billmeyer, Wiley Interscience.

C *Physical Chemistry* 8th edition, PW Atkins and J De Paula, OUP 2006

Electrochemical Methods: Fundamentals and Applications, 2nd edition, AJ Bard and LR Faulkner, Wiley 2001

Corrosion Mechanisms in Theory and Practice, P Marcus, CRC 2002

Structure, teaching and learning methods

40 lectures: Autumn and Spring terms

8 tutorials: Autumn and Spring terms

MSE 203
Mechanical Behaviour

Course Co-ordinator: Dr Finn Giuliani

Status: Second Year Core

Prerequisites: 101, 103, 104 (matrices, calculus, statics, dislocations, deformation and phase metallurgy)

Aims

To understand mechanical behaviour of materials in terms of microstructure and continuum mechanics.

Learning outcomes

Dislocations and Hardening (Dr F Giuliani)

The aim of the course is to examine how defects, crystal structure and microstructure affects mechanical properties, particularly strength. A range of length scales are addressed, from the atomic (nm), such as the effect of solute atoms, through dislocations (10's of nm), grain boundaries (mm) to second phases (nm to mm). This develops an insight into the range of strengthening mechanisms and defects which give rise to strength and lead to fracture. By the end of the course, students will be able to work mathematically with the following problems;

- Stress-Strain Curves. True vs Engineering stress and strain. General features of stress-strain curves.
- Micro-mechanisms of deformation: slip systems, Schmid law. Ideal Shear vs Dislocations; types, motion.
- Stress and strain fields, dislocation multiplication, forces between dislocations.
- Strengthening mechanisms: grain boundary hardening; solution hardening, ordering; second phase hardening; work hardening; thermal activation; athermal and thermal obstacles.
- Further plasticity phenomena; twinning, textures.

Fracture and yield (Dr M-S Pham)

This aspect of the course examines mechanical behaviour in terms of macro and micromechanisms. The aim is to develop understanding of the mechanics of fracture and the influence of microstructure on mechanical behaviour. The course covers:

- Brittle and ductile fracture and its transition
- Extension of Griffith to small scale plasticity; the strain energy release rate
- The stress intensity approach to fracture in plane stress and plane strain
- Crack tip plasticity and plastic zone size and the effect of sample thickness
- Measurement of fracture toughness
- Weibull statistics for brittle materials

- Ductile failure: yield and plasticity
- The instability condition in uniaxial and multiaxial stress
- Mechanistic basis of ductile fracture
- The J-integral approach for ductile cracking
- Introduction to mechanistic basis of fatigue crack nucleation and growth

States of Stress (Prof D Dye)

This course aims to develop the ability to set up and manipulate descriptions of the state of stress in a material and to understand and apply yield criteria. By the end of the course, students will have leaned;

- To derive equations for the normal and shear stresses in multiaxial stress situations from the forces within a component.
- To be able to write these as a stress matrix.
- To introduce the concepts of principle stress and strain and maximum shear stress including Mohr's circle.
- To recognize the principle stresses / strains as the eigenvalues of the stress / strain matrix.
- To be able to rotate a stress or strain matrix and find the orientation of the principal axes.
- To be able to analyse the stress and strain state for the cases of a rotating shaft, a pressure vessel.
- To be able to use Nye's convention for calculating stresses in anisotropic media from the stiffness constants and strain tensor, and vice-versa; to be able therefore to calculate directional moduli and applied shear stresses on slip systems.
- To be able to determine the stress tensor from diffraction data.
- To be able to use the Von Mises and Tresca Yield Criteria, and understand the pi-plane convention.

Continuum Aspects of Deformation (Prof T C Lindley)

Students will develop an understanding of the macro-aspects of fracture, fatigue and creep behaviour leading to the ability to quantitatively assess the different types of failure including plastic collapse, brittle fracture, fatigue and creep. Students will encounter different types of failure, macroplasticity, fracture, fatigue and creep including the following:

- Types of failure - plastic, fracture, fatigue and creep
- Plasticity - tensile instability (necking) and the effect of work hardening and strain rate dependence, bending beams including initiation of plasticity, plastic collapse, residual stresses, springback.
- Torsion of rotating shafts.
- Fracture - Gc from load/displacement diagrams, fracture toughness in plane strain and plane stress with effect of thickness, stress concentrations, principal stresses and fracture, leak before break.
- Fatigue - HCF, LCF and crack growth, stages of development of fatigue cracks including persistent slip band formation, striations, S-N curves-Basquin's, Goodman's and Miner's laws, Low cycle fatigue-Coffin-Manson law, fatigue crack growth-Paris law.
- Creep - including creep and rupture data and design requirements, isothermal and isochronal displays, parametric representations-Larson-Miller, Sherby-Dorn, Manson-Haferd, creep curves and modern design procedures, empirical versus physical models of creep curves, Monkman-Grant and life fraction laws, strain hardening versus time hardening, combined creep and fatigue damage.
- Understand the statistical approach to failure (Weibull)

Recommended textbooks A = required, B = recommended but not essential, C = background reading.

B	D Hull and DJ Bacon. Introduction to Dislocations, 4th ed., Butterworth-Heinemann, Oxford UK, 2001.
B	GE Dieter. Mechanical Metallurgy, 3rd Ed., McGraw-Hill, London, UK, 1988.
B	TL Anderson, Fracture Mechanics, Fundamentals and Applications. Taylor and Francis, 2005.
B	AH Cottrell, An Introduction to Metallurgy, 2nd Ed., Institute of Materials, 1995.
B	AH Cottrell. Mechanical Properties of Matter.
B	Le May. Principles of Physical Metallurgy.
B	RW Hertzberg. Deformation and Fracture of Engineering Components

Assessment

Examination

The course is examined in the summer term in a single 3-hour examination paper composed of eight questions, which will reflect the balance of lectures across the course. The exam is split into two sections; one on mechanisms and one on stress states, with four questions in each section. Students answer 5 questions from the 8 available, with a minimum of two from each section; each question is worth 20 marks giving a total of 100 for the paper.

MSE 204
Microstructure

Course Co-ordinator: Dr Chris Gourlay

Status: Second Year Core

Prerequisites: MSE 102 Materials Chemistry, MSE 104 Structure and Properties of Materials

Aims

This course is designed to allow students to progress in their understanding of thermodynamics and kinetics so as to allow them to investigate, explain and quantify the formation of microstructures by either solidification or by solid state phase transformations. It introduces them to a wide range of solid state phase transformations and through detailed analysis equips them with an insight into the scientific concepts underpinning the control of microstructures in primarily metals but also to some extent ceramics. This course also aims to: show how equilibrium phase diagrams can be used to predict the solidification process and the microstructure of materials that have been crystallised from a melt under equilibrium conditions; consider the effect of non-equilibrium solidification processes; and introduce examples from alloy, ceramic and glass-ceramic systems.

Learning outcomes

Solid state phase transformations:

At the end of this part of the course the student will be able to

- develop simple models for free energy of ideal and regular solutions
- define the chemical potential and derive the phase diagram from information about the free energy versus composition
- discuss diffusion and the relation between activation energy, temperature and diffusion rate
- derive Fick's first law, be aware of Fick's second law and realise that diffusion is driven by chemical potential gradients
- discuss a range of interfaces in solids (solid vapour, various types of grain boundaries, coherent, semi-coherent and incoherent interfaces)
- develop a simple model to explain the energy of solid-vapour surfaces, and use it to predict the shape of crystals (Wulff plot), and argue why solid-solid boundaries have a lower energy than solid-vapour interfaces
- explain how boundaries move through a material (diffusion and glissile dislocations)
- describe how surface energy drives the densification during sintering of powder compacts
- discuss homogeneous and heterogeneous nucleation of precipitates and derive the equations controlling the free energy changes upon nucleation and a model for the nucleation rate variations with temperature.
- explain what precipitate free zones are and how they can be avoided.
- discuss growth of precipitates under interface or diffusion control and show that thermodynamically microstructures with precipitates are unstable and evolve towards larger precipitates
- use their theoretical knowledge to discuss precipitate hardening in Al-Cu alloys
- discuss spinodal decomposition and argue why ordering in materials occurs
- outline the difference between first order and second order transformations.
- understand the different processes and energy changes involved in recovery and recrystallisation of deformed microstructures and be able to derive a kinetic model for recrystallisation (JMAK).

- explain why grains grow and derive an expression for Zener drag
- recognize and explain carbon steel microstructures and cast iron microstructures with reference to the iron-carbon phase diagram
- be aware of the different forms of ferrite and by extension of precipitates (Widmanstatten, massive, grain boundary allotriomorphs)
- explain the formation of pearlite and by extension of eutectoid decomposition
- explain the differences between reconstructive and displacive phase transformations
- list macroscopic observations about martensite formation
- discuss the crystallography of the austenite to martensite transformation
- describe the sequence of events during tempering of martensite and how it influences the properties
- distinguish conceptually between upper and lower bainite formation
- discuss and use TTT and CCT diagrams
- explain the mechanisms underpinning shape memory alloys (SMA)
- quantify the contribution of the martensitic transformation to toughening in zirconia

Liquid-solid transformations:

At the end of this part of the course a student should be able to:

- explain the physical basis of the barrier to nucleating a crystal in a liquid, and compare this with nucleating a solid in a solid sample.
- derive the size of a critical nucleus as a function of melt supercooling and heterogeneous nucleating substrate size / type.
- predict the effect of nucleation difficulties of phase α on: (i) the growth of existing phase β, and (ii) the subsequent growth of α.
- list the differences between atomically smooth and atomically rough S-L interfaces.
- understand why the dimensionless entropy of fusion can be used to predict whether phases will have rough or smooth S-L interfaces.
- sketch the mechanisms of faceted crystal growth with the aid of a Kossel crystal, and explain why crystal defects are important in faceted crystal growth.
- sketch the mechanisms of nonfaceted (nf) crystal growth, explain why non faceted growth requires lower growth undercooling, and why non faceted interfaces are more likely to develop curvature than faceted interfaces.
- derive the solidification path of a binary alloy assuming zero diffusion in the solid: the Scheil equation.
- derive the condition for constitutional supercooling during unidirectional solidification of a binary alloy. understand how interface velocity alters the diffusion profile in the liquid.
- discuss the interplay between the curvature of a S-L interface and the diffusion of heat and solute from the interface in determining the shape of growing non faceted crystals. Qualitatively apply this to nucleation, interface stability, dendrite growth and eutectic growth.
- understand why the liquid becomes supersaturated in dissolved gas during solidification. Predict the hydrogen concentration in the liquid as a function of solid fraction in Al alloys.
- derive the shape of the shrinkage pipe formed in a pure metal solidifying in a cylindrical mould.
- explain the influence of the solidification mode of an alloy on the distribution of porosity.
- describe the origin of common types of macrosegregation.

Liquid-solid transformations:

At the end of this part of the course a student should be able to:

- interpret all the features of a ternary liquidus projection and isothermal sections for systems containing solid phases that exhibit partial or complete solid solubility, three phase reactions, and binary and ternary compounds.

• use ternary phase diagrams to describe and quantify each stage of the solidification process for a three component system that may contain binary and ternary invariant reactions. • appreciate and understand that full equilibrium may not be achieved in the actual processing of molten material, and that phenomena such as segregation and constitutional supercooling can play important roles in determining the microstructure of solidified materials.
Recommended textbooks A = required, B = recommended but not essential, C = background reading. A DRF West and N Saunders, Ternary phase diagrams in materials science, 3rd edition, Maney Publications, 2002 Phase transformations in Metals and Alloys, 2nd Edition, D.A. Porter and K.E. Easterling, Stanley Thornes B Steels : microstructure and properties, Honeycombe, R. W. K., Edward Arnold Recrystallization and releated annealing phenomena, F.J. Humphreys, M. Hatherly, Pergamon C WD Kingery, HK Bowen and DR Uhlmann, Introduction to ceramics, 2nd edition, Wiley Interscience, 1976.
Assessment *Examination* The course is examined in the summer term. The examination paper, duration 3 hours, is in three sections. Section A is compulsory and consists of a range of short answer and multiple choice questions on all parts of the course (20 marks) and a compulsory question on the use of ternary phase diagrams to predict solidification (20 marks). Section B is one question and is also compulsory. Section C contains 4 questions of which students must answer 3 (20 marks per question).

MSE 205
Electronic Properties of Materials

Course Co-ordinator: Prof Norbert Klein

Status: Second Year Core

Prerequisites: all 1st year courses, in particular MSE 105 Materials Physics

Aims

This course is designed to:

(a) Give students an understanding of the quantum free electron theory of metals and the transport and optical properties, discuss the occurrence of band gaps within the nearly free electron model by Bragg reflection and describe the electrical properties of n and p type doped semiconductors.
(b) Describe the physics of some important semiconductor devices used in very large scale integration, in optoelectronics and in photovoltaic cells.
(c) Introduce the concepts of functional dielectric materials and to explore their use in selected devices
(d) Provide the theoretical background to the experiments performed in the second year electrical materials laboratory
(e) Strengthen the student's preliminary knowledge of magnetism through a quantum mechanical analysis of the origins of magnetism, introduce techniques for measuring magnetic properties, give examples of magnetic materials and applications and explain the magnetic properties of superconductors.

Learning outcomes

Part A Quantum theory of metals and semiconductors (Prof N Klein)

- The students will be able to set out the working assumptions involved in the quantum theory of the free electron gas.
- The students will be able to solve the 3-dimensional Schroedinger equation for zero potential (free electron gas approximation) under consideration of Pauli's exclusion principle.
- The students will be able to explain the concept of reciprocal space or k space, and explain the meaning of the Fermi wave vector, the Fermi energy, and the Fermi velocity.
- The students will be familiar with the Fermi Dirac distribution and the density of states.
- The student will be able to explain the specific heat of a free electron gas and its deviation from the classical expectation.
- The student will be able to discuss the electrical and thermal conductivity of a metal in the free electron approximation, its relation to the electron mean free path and the Fermi velocity and its temperature dependence.
- The students will be able to explain the optical response of a metal in the free electron gas approximation and explain the role of the plasma frequency.
- The students will be able to explain the meaning of Bloch waves and illustrate the one dimensional dispersion relation within the nearly free electron model and the effect of Bragg reflection.
- The students will be able to explain the origin of bandgaps within the nearly free electron model and illustrate the difference between insulators, semiconductors and metals based on the value of the Fermi energy.
- The students will be able to explain the effects of doping by the existence of acceptor and donor levels.

- The students will be able to explain the concept of effective mass and hole conductivity by the 1D dispersion relation of the free electron gas.
- The students will be able to explain the concept of reciprocal space and construct the Brillouin zone.
- The students will be able to explain the difference between direct and indirect semiconductors based on their band structure.
- The student will be able to discuss the properties of the most important semiconductors.

Electronic devices (Dr Anna Regoutz)

- The students will understand key electronic concepts in semiconducting materials including band diagrams, Fermi distribution, and carrier types, and relate these to their application and behavior in fundamental semiconductor devices.
- The students will understand fundamental semiconductor devices including p-n junctions, bipolar junction transistors and MOS capacitors. They will be able to explain the basic physical concepts of these devices, illustrate them using band structure diagrams, and give relevant examples of their application.
- The students will be able to describe and calculate fundamental device parameters of p-n junctions, bipolar junction transistors and MOS capacitors, as well as describe their operation modes.
- The students will be able to explain very large scale integration, and explain its relationship to integrated circuits, miniaturization, and MOSFET/CMOS technology.
- The students will be able to explain the structure, the basic device parameters, and the operational regions of a MOSFET. They will be able to calculate the threshold voltage and give details on optimization strategies for the threshold voltage
- The students will be able to describe a static CMOS inverter and its operation. They will be able to outline a general CMOS process flow and describe all major fabrication steps involved. They will be able to draw a simple CMOS structure.
- The students will understand the fundamentals of optoelectronics, including radiative transitions and optical absorption in semiconductors.
- The students will be able to describe the structure, function, and operation principles of LEDs, OLEDs, infrared LEDs, and fiber optics.
- The students will be able to explain the fundamentals of semiconductor lasers and give examples of laser materials and device structures.
- The students will be able to explain the fundamentals of photodetectors, including photoconductors, photodiodes, and p-i-n photodiodes.
- The students will understand the function, structure, and device layout of photovoltaic cells.

Magnetism and superconductivity (Prof N Klein)

- The students will be able explain the meaning of the physical quantities related to magnetism, magnetic field, magnetic induction, magnetic moment, magnetization, magnetic susceptibility, and discuss their interrelations.
- The students will be able to explain the fundamentals of electromagnetism: Lorentz force, induction law, Ampere’s law.
- The students will be able to explain the Hall effect and derive an expression for the Hall voltage
- The student s will be able to explain the quantum mechanical properties of an atom in a magnetic field, in particular the roles of the quantum numbers for spin and angular momentum.
- The student will be able to explain the origin of diamagnetism by induced magnetic moments and calculate the diamagnetic susceptibility of atoms based on the classical Langevin result.

- The students will be able to discuss the interaction of a quantum mechanical angular momentum with a magnetic field and describe the Bohr magneton, the Landee factor and the Zeeman energy level splitting.
- The students will be able to explain the temperature dependence of the magnetic susceptibility of a paramagnetic material by the thermal occupation of the Zeeman energy levels.
- The students will be able to explain and illustrate the magnetic properties of a superconductor, in particular the Meissner effect and the London penetration depth.
- The students will be able to draw and explain the magnetization curves for type I and type 2 superconductors and explain the magnetic microstructure in the Shubnikov phase.
- The students will be able to explain how pinning by impurities can result in an increase of the critical current density.
- The students will be able to name and describe the properties of the important superconducting materials for high power and magnet applications.
- The students will be able to draw and explain the hysteresis curve of a ferromagnetic material and explain the relevant quantities.
- The students will be able to explain the difference between hard and soft magnetic materials, and to give and illustrate examples for materials and applications.
- The students will be able to derive the Curie – Weiss law by employing mean-field theory and the Curie law for the paramagnetic susceptibility.
- The students will be able to explain the most common methods for imaging of ferromagnetic domains.
- The students will be able to discuss the two competing energy terms at a Bloch wall (exchange and anisotropy energy) and their implications for the magnetic properties.
- The student will be able to explain the (giant) magnetoresistance and its application in information technology.

Dielectric Materials (Dr M Oxborrow)

- The students will be able to define the terms piezo-, pyro- and ferro- and anti-ferroelectric and explain the interrelationships between these properties.
- The students will be able to describe the polarisation behaviour of a ferroelectric material as a function of temperature and of applied stress. This will include an understanding of the Curie temperature which will link to the experiment performed as part of the second year electrical materials laboratory.
- The students will be able to sketch a P-E loop for a ferroelectric materials, label the important features, discuss poling and the origins of this hysteresis effect in terms of the domain structure of the material.
- The students will be able to describe the phenomenological theory of ferroelectricity in BaTiO3.
- The students will be able to sketch the phase diagram for PbZrO3-PbTiO3 (PZT's) and use it as guide to materials selection for practical applications.
- The students will be able to describe the construction and operation of some simple devices based on ferroelectric ceramics, such as the spark igniter, intruder alarm, and FRAM devices.
- The students will understand the role that phonons play in determining the optical properties of materials
- The students will be able to understand the concept of a solid ionic conductor and relate this to considerations of the defect structure of the materials.
- The students will be able to derive an expression for the ac impedance of a parallel R-C circuit and plot the frequency response of this circuit on an ac- impedance plot. They will also be able to use this plot to interpret the ac response of ceramic ionic conductor and relate this to the experiment performed in the second year electrical materials laboratory.

Recommended textbooks A = required, B = recommended but not essential, C = background reading.

A R. Waser (editor), “Nanoelectronic and Information Technology”, Chapter 2

J.R. Hook and H.E. Hall, “Solid State Physics”, John Wiley and sons.

C. Kittel, “Introduction to solid state physics”, John Wiley and sons.

S. Sze, M.-K. Lee, “Semiconductor Devices. Physics and Technology”, John Wiley and Sons.

B S. M. Sze, K.K. Ng, “Physics of Semiconductor Devices”, John Wiley and Sons.

S. Dimitrijev, “Principles of Semiconductor Devices”, OUP.

L. Solymar and D. Walsh, “Lectures on the Electrical Properties of Materials”, OUP.

J.D. Plummer, M. Deal, P.B. Griffin, “Silicon VLSI Technology. Fundamentals, Practice and Modeling”, Prentice Hall.

R.G. Chambers, Electrons in metals and semiconductors, Chapman and Hall.

E. M. Purcell, Electricity and Magnetism, McGraw Hill.

S.M. Sze, “VLSI Technology” McGraw Hill.

Braithwaite and Weaver, Electronic Materials, OUP press, (1990)

Moulson and Weaver, Electroceramics (2^{nd} edition), Wiley Interscience (2003)

Chiang, Birnie and Kingery, Physical ceramics : principles for ceramic science and engineering, Wiley VCH, (1996).

C Any standard textbook on Physics, for example Tipler

C. Kittel, “Introduction to solid state physics”, John Wiley and sons.

Tilley & Tilley, “ Superfluidity and Superconductivity”, Chapter 1 and 6.

R. Waser (editor), “Nanoelectronic and Information Technology”, Chapter 4

MSE 206

Materials Engineering – Process Principles

Course Co-ordinator: Martyn McLachlan

Status: Second Year Core

Prerequisites: 1st Year Core Courses

Aims

The aim of the module is to provide the students with a fundamental understanding of mass and fluid flow, and of plasma physics and how it can be applied in nanofabrication processes.

Learning outcomes

Mass and heat flow (Dr K Rhazaoui)

By the end of the course, students should know and understand the following concepts and methods and be able to apply them to practical materials problems:

- To understand and apply the fundamental heat transfer and mass transfer equations to the processing and production of materials
- To quantitatively and qualitatively predict materials processing and materials behaviour for simplified classical examples
- To apply the knowledge to process optimization

The specific objectives are:

- Understand Fourier's laws, Fick's laws and Diffusion-Convection equations
- Solve the heat and mass transfer governing equations in simplified boundary conditions
- Derive the heat and mass transfer equation from the irreversible thermodynamic law
- Familiar with the available numerical methods in solving the heat-mass transfer equations
- Understand the physical basis of the fluid mechanics
- Explain how flow develops in a pipe, and discuss the effect of the Reynolds number (laminar, transition and turbulent flow)
- Derive and apply the Hagen Poiseuille equation for fluid flow down a pipe
- Define Bernoulli's equation as an energy balance and then expand it to account for pressure and minor losses, using friction factors
- Apply the Mechanical Energy Balance to steady state and non-steady state pipe flow problems, including non-circular pipes and ducts
- For flow over solid object (e.g. aircraft wings), calculate Friction and Pressure Drag and the effect of Reynolds number, define and apply Drag Coefficients, deriving Terminal Velocity
- Understand the Carman Kozeny equation and how it is amended to produce the Ergun Equation
- Understand the Navier-Stokes Equations

Plasma in nanofabrication (Dr P Petrov)

At the end of this part of the course the student will be able to:

- Explain what plasma is and how it is generated.
- Describe plasma's basic parameters and classification.
- Understand plasma behaviour (incl. plasma-matter interactions).
- Discuss the application of plasma in industrial processes.

Recommended textbooks A = required, B = recommended but not essential, C = background reading

B "Plasma Electronics: Applications in Microelectronic Device Fabrication" by T Makabe and Z Petrovic, (Taylor & Francis Group 2006), ISBN 0-7503-0976-8

Introduction to plasma physics, Goldston, Robert J. Rutherford, Paul H., Bristol : Institute of Physics Publishing 1995

M. White, "Fluid Mechanics", McGraw-Hill Book Company, 1986.

C.A. Long, "Essential Heat Transfer", Pearson Edn Ltd, 1999.

J. K. Vennard & R. L. Street, "Elementary Fluid Mechanics", John Wiley, 1982,

J. Szekely & N.J. Themelis, "Rate Phenomena In Process Metallurgy", Wiley Interscience, 1971. Pages 639-654

J.M. Coulson & J.F. Richardson, "Chemical Engineering Volume 2" Pergamon Press, 1991. Pages 132-137 & 224-229.

"Transport Phenomena", by R. B. Bird, W. E. Stewart and E. N. Lightfoot (Wiley 1960).

3. Assessments

Coursework, tests and laboratory exercises make up the coursework mark that is used in the calculation of the year mark. The tables in this section will help you to be able to plan your study and revision timetable based on the due dates for the various elements. Each of the items here have a corresponding assessment description sheet that is included at the end of the handbook. This also includes a rough rubric for each assessment that can be used to guide the preparation of the item.

Coursework elements (excluding ad-hoc laboratory exercises)

Module	Due Date	% Contribution to Module
MSE 206: Case Study Report	Mon, 14/01/2019	9.8%
MSE 206: Case Study Presentation	17-18/01/2019	9.8%
MSE 206: Process Principles Abstract	Tues, 05/03/2019	4.9%
MSE 206: Process Principles Poster Submission	Tues, 12/03/2019	-
MSE 206: Process Princples Poster Presentation	Tues, 19/03/2019	4.9%
MSE 206: Heat Flow Coursework	Tues, 19/03/2019	4.9%
MSE202;203;204;205: Long Labs	Thurs, 07/03/2019	13%++
MSE206: BPES Management Project	Fri, 22/03/2019	24.4%**

Coursework tests

Module	Due Date	% Contribution to Module
MSE201: Maths Progress Test 1	11/01/2019	7.4%
MSE201: Maths Progress Test 2	30/04/2018	7.4%
MSE206: Characterisation Test	12/12/2018	2.4%
MSE206: BPES Project Management	22/03/2019	24.4%**

++ The mark from this exercise is split evenly between the 4 listed modules, irrespective of which module it forms a part of. Therefore it contributes 13% to each of the listed modules.
*** The weighting ratio of these components are decided by Business School and are not confirmed however together they constitute 50% of the MSE206 module*

Your academic performance in the laboratory sessions from autumn term will be used to determine your lab groups for the Spring Term. However your lab group will not affect your personal tutorial group, nor will it affect the afternoon on which you do a lab in the Spring term.

Autumn term Ad-hoc laboratory deadlines

	Monday					Tuesday				
Experiment	15/10	22/10	29/10	05/11	12/11	16/10	23/10	30/10	06/11	13/11
AC impedance	A1	A5	A4	A3	A2	B1	B5	B4	B3	B2
Infra-Red (IR) Spectroscopy (Big report)	A2	A1	A5	A4	A3	B2	B1	B5	B4	B3
Scanning Electron Microscopy (SEM)	A3	A2	A1	A5	A4	B3	B2	B1	B5	B4
XRD	A4	A3	A2	A1	A5	B4	B3	B2	B1	B5
DSC	A5	A4	A3	A2	A1	B5	B4	B3	B2	B1

	Thursday					Friday				
Experiment	18/10	25/10	01/11	08/11	15/11	19/10	26/10	02/11	09/11	16/11
AC impedance	C1	C5	C4	C3	C2	D1	D5	D4	D3	D2
Infra-Red (IR) Spectroscopy (Big report)	C2	C1	C5	C4	C3	D2	D1	D5	D4	D3
Scanning Electron Microscopy (SEM)	C3	C2	C1	C5	C4	D3	D2	D1	D5	D4
XRD	C4	C3	C2	C1	C5	D4	D3	D2	D1	D5
DSC	C5	C4	C3	C2	C1	D5	D4	D3	D2	D1

Ad-hoc Lab Module Contribution

Module	Experiment name	Wt
MSE.206	AC Impedance	3%
MSE.206	Infra-Red (IR) Spectroscopy (Big Report)	3%
MSE.206	Scanning Electron Microscopy (SEM)	3%
MSE.206	XRD	3%
MSE.206	DSC	3%

4. Assessment forms and rubrics

Individual Coursework Information form

Module code	MSE 206
Year of Study	2ND Year
Assignment Name	MSE 206: Process Principles Abstract
Academic in Charge	Dr Peter Petrov
Marker	GTAs
When the assignment is presented to the students	1st week of lectures (spring term) – 30 January
Method of submission	Blackboard Learn
Student's self-study hours	5-10 hours of self-study required

Assignment details

Students are required **individually** to write and submit (via blackboard) an abstract (300 – 500 words) of their poster presentation. The abstract will be of the format as per a conference proceedings book.

Other requirements

A template for the abstract will be available on blackboard. This will be completed and submitted without formatting change to Blackboard.

Guideline marking rubric

The abstract is graded out of 10.

Individual Coursework Information form

Module code	MSE 206
Year of Study	2ND Year
Assignment Name	MSE 206: Process Principles Poster
Academic in Charge	Dr Peter Petrov
Marker	Posters judging panel, chaired by Dr PK Petrov
When the assignment is presented to the students	1st week of lectures (spring term) - 30 January 2019
Method of submission	Blackboard Learn
Student's self-study hours	15-20 hours of self-study required

Assignment details

Students are required to divide themselves into **groups of four**, to prepare and present a poster describing an application, discussed during the lecture course. The poster details will include an introduction to the application, the principles of the application, the materials properties that are necessary for the application and the processing methods for making those materials.

Other requirements

The poster should be size A1 and should be submitted in .pdf format. It should be designed according to good poster design principles. Poster design is one of the topics included as a personal tutor item for 2018/2019 with your tutor.

Guideline marking rubric

The posters are adjudicating by multiple academics who will walk around and discuss the poster contents with the students. Marks are awarded to the presentation, content, depth of research and individual contributions.

Individual Coursework Information form

Module code	MSE 206
Year of Study	2ND Year
Assignment Name	MSE 206: Heat Flow Coursework
Academic in Charge	Dr Khalil Rhazaoui
Marker	GTAs and Dr Rhazaoui
When the assignment is presented to the students	Tuesday 19th February
Method of submission	Hardcopy via Student Office
Student's self-study hours	5-10 hours of self-study required

Assignment details

Students are expected to understand and apply the fundamental heat transfer and mass transfer equations to the processing and production of materials in the context of real-world quantitative problems. Some derivation is to be expected, to test the fundamental understanding of equations describing heat and mass transfer under various conditions.

Other requirements

No specific format is required from the students when submitting their coursework – although students are encouraged to be as neat as possible. Printed work is always preferred although can be time-consuming seen as there is a lot of Maths involved.

Guideline marking rubric

Category	**Mark**
Question 1	/20
Question 2	/20
Question 3	/20
Question 4	/20
Question 5	/20
Total	**/100**

Individual Coursework Information form

Module code	MSE 206
Year of Study	2nd Year
Assignment Name	Case Study Presentation
Academic in Charge	Dr Martyn McLachlan
Marker	Panel
When the assignment is presented to the students	5th/6th week of autumn
Method of submission	Oral Presentation in groups of 4
Student's self-study hours	10 hours attending presentations

Assignment details

The presentation is a 12-minute (plus 3 minutes for questions) talk. All students from the group are expected to be present for the presentation, and all students assigned to an afternoon are expected to be present for the full afternoon.
The talk should include a brief introduction to the artefact and discussion of some of the key components. **You will not have time to describe everything so you need to be selective but detailed.**
Scientific content, detail, understanding, presentation skills and personal contribution are all assessed for each person in the group. Questions will probe deeper understanding of the analytical techniques used, particularly focussing on your understanding of limitations of the techniques or unusual determinations made from the technique.

Other requirements

A Powerpoint style presentation is suggested, but not prescriptive

Guideline rubric for Case Study Presentation Mark

Quality of slides/layout/presentation 15%

Data presentation/clarity 15%

Quality and clarity of explanations 20%

Demonstration and understanding of technical content 30%

Time 10%

Questions 10%

Individual Coursework Information form

Module code	MSE 206
Year of Study	2nd Year
Assignment Name	Case study Report
Academic in Charge	Dr Martyn McLachlan
Marker	Academic assigned to group
When the assignment is presented to the students	9 November 2018
Method of submission	Blackboard Learn
Student's self-study hours	10 hours for report preparation

Assignment details

The report details the findings of the group and should include the following elements.

- Include details of all laboratory investigations, giving a description of the preparation and analytical techniques used and the reason for your choice of each one.
- Identify the component's function and then deduce the required property characteristics which should be ranked according to their importance.
- Discussion of why the determined particular materials and processing route were selected for each component that is analysed.
- Characteristics should be expressed in **quantitative** terms where possible – this may involve simple stress analysis, heat transfer calculations, analysis of electrical properties *etc*

The report has a joint component and then individual components. The joint reflects the combined input from all team members, while the individual reflects the contribution you have made to the overall effort.

Other requirements

Should be written in a report format. **Each student will need to submit an individual copy of the report complied in their groups.**

The upper limit is 6000 words regardless of group size, but shorter, concise reports are encouraged. This refers to the main body of text and excludes references or captions. Appendices may be included and should include raw data only with limited captioning but no text.

Combined Grading Rubric for Case Study

Marks are awarded using the following criteria:

1. **20% for the report as a joint effort**
   Can your contribution to the written report be seen, what role did you have in preparing the final report, did you work as part of a team (lab sessions, project meetings), how did you assist in preparing the report (typesetting, preparing figures, formatting)?
2. **20% for the individual section of the report**
   Is your section well written, is it concise, is your data well formatted, are figures clear, have you used references appropriately, does it fit logically into the report with the work of your group?
3. **20% for the data analysis, quality of characterisation, interpretation of data**
   Have appropriate analytical techniques been used, is the analytical data well interpreted, is the analysis convincing, is the analysis correct, have you presented the data in a way it can be checked by the marker, have you been able to combine data from complimentary techniques?
4. **20% for effort, initiative, log book, *etc*. on an individual basis (supervisor)**
   How did you work within your team, was the log book well maintained and easy to interpret, did you support others in the group, did you attend project meetings, did you generate ideas,
5. **20% for the *individual* contribution to the seminar**
   To obtain these marks you must present at the seminar, did you keep to time, could you be understood by the audience, did you effectively communicate your data and its interpretations, were your slides legible, did your section integrate into the team presentation?