The University Of Sheffield.

Electronic & Electrical Engineering.

EEE6215 NANOSCALE ELECTRONIC DEVICES

Credits: 15

Course Description including Aims

The course aims to provide students with an understanding of the science and technology which underpins modern electronic device technology, with an emphasis on integrated electronic devices at the nanoscale. The course begins with a discussion on the need for advanced electronic devices and systems, the present-day commercial application sectors and future perspectives. Following a short resume on semiconductor electronic properties the course will introduce basic transistor device types including the bipolar junction transistor, the metal-semiconductor FET and the metal-oxide FET; describing their structure, fabrication method and electronic characteristics. The high speed/high power performance capabilities of these approaches will be described. The use of semiconductor heterojunctions to create advanced bipolar and FET devices will be discussed. The course goes on to describe integrated circuits based on CMOS technology, discussing the historical scaling of device size, the current state of the art in device structure and properties and the challenges faced for future high speed IC developments. The course finishes with a discussion of the present state of the art in advanced devices including the physical properties, technological realization and potential future developments for semiconductor devices at the nanoscale.

Course Objectives

On successful completion of this module the students should be able to:

1. Understand the major application areas of modern electronic devices and have knowledge of the present market and future technological needs.
2. Have knowledge of the basic structural, electronic and optical properties of semiconductor materials of relevance to transistor operation
3. Describe the basic structure, physical operation and the device characteristics of various transistor types
4. Demonstrate an understanding of the performance, systems capability and limitations advanced electronic devices
5. Gain knowledge on how advanced materials and advanced device geometries may be used to create high speed or high power electronic devices.
6. Have knowledge of the principles behind Integrated Circuit development and of device scaling, including an understanding of the key scientific and technological issues at present.
7. Understand modern CMOS technology and its application in different sectors (eg: CPU, MCU, memory, image sensors)
8. Discuss other types of semiconductor electronic devices used in high performance circuits.
9. Gain knowledge on how photonic devices may play a role in future high speed electronic systems
10. Have an understanding of the current state of the art and of future trends in high-speed electronic device development.

Detailed Syllabus

- Introduction: Overview of semiconductor materials and devices, applications of semiconductor devices, current state of the art, industry trends
- The junction transistor (BJT): operating principles, equivalent circuits, performance including figures of merit.
- Field-effect transistors (MOSFET, MESFET): operating principles, equivalent circuits, performance including figures of merit Advantages and disadvantages compared to the BJT. High speed FET devices. Application to high speed circuits. Application to power electronics
- Heterojunction transitors: HEMT, HBT: Types of heterojuction, semiconductor heteroepitaxy, electrons in heterojunctions, device operating principles, equivalent circuits, performance including figures of merit , advantages over basic devices, heteroepitaxial integration.
- Integrated circuits: integration of active and passive devices, scaling of circuits, Moore's law of device integration, CMOS technology, CMOS performance issues, applications: CPU, MCU, CMOS memory, imaging arrays
- Limitations to device scaling: physical effects; tunneling, hot electron effects, impact ionization. Technological limitations; device nanotechnology, lithography, epitaxy, interconnects
- New materials and technologies for high speed devices: III-V/ Si integration. nanowires and quantum dots, carbon nanotubes, graphene and related materials, molecular electronics, single electron transistor, spin transistor, optical interconnects, optical processing.

Recommended Previous Courses

Students are required to have a background which covers basic semiconductor device properties together with some elements of semiconductor technology. Previous knowledge of the basic properties of semiconductor materials such as the crystal structure, doping control of conduction, electron mobility, optical band gap and of the operation of simple devices such as pn-diodes, bipolar transistors and field effect transistors is important for this course. Students should have either taken the previous modules EEE118 "Electronic Devices" and EEE225 "Analogue and Digital Devices" or have taken external courses with equivalent learning outcomes.

Assessment

3 Hour Examination the end of semester 2. Candidates must choose any four out of six questions. Examination represents 85% of the total marks. (75% total marks)
The coursework elements of this module are a written assignment on the future of Moore's law in December (7%) and an extended problem sheet on transistor fundamentals and equivalent circuits in March (8%).

Recommended Books

S.M.Sze and M.J Lee	*Semiconductor Devices: Physics and Technology*	Wiley
D.L.Pulfrey	*Understanding Modern Transistors and diodes*	Cambridge
B.G. Streetman and S. Banerjee	*Solid state electronic devices*	Prentice Hall
Y.Taur and T.H Ning	*Fundamentals of modern VLSO devices*	Cambridge

UK-SPEC/IET Learning Outcomes

Outcome	Supporting Statement
SM1m / SM1fl	Students will develop a comprehensive understanding of the underlying scientific principles behind the development of modern day transistors and integrated circuits. Assessed by examination.
SM2m	The course will introduce mathematic models used to describe transistor operation which the students will apply to predict device performance. A critical element of this course is to indentify and calculate key figures of merit with which to compare performance and to seek ways to improve it through a change of materials or device parameters. Assessed by examination and by assignment.
SM4m	The students will develop an awareness of the current state of the art and future trends in advanced nanoscale electronic devices, including future device scaling approaches, new materials and emerging device technologies. Assessed by examination and by assignment.
SM6m	During the course, the students will be introduced to the fundamental physical and chemical concepts behind semiconductor device manufacture and operation, the development of new materials and the application of new technological approaches to achieve the net generation of device schemes. Assessed by examination and by assignment..
SM2fl	The students will develop an awareness of the current state of the art and future trends in advanced nanoscale electronic devices, including future device scaling approaches, new materials and emerging device technologies. Assessed by examination and by assignment
SM3fl	During the course, the students will be introduced to the fundamental physical and chemical concepts behind semiconductor device manufacture and operation, the development of new materials and the application of new technological approaches to achieve the net generation of device schemes. Assessed by examination and by assignment.
EA1p / EA1m	A major theme within this course is the continuous development of semiconductor integrated circuits, which has been achieved through an analysis of key device parameters and their optimisation. The students will develop an understanding of what has been done to achieve smaller, faster and more efficient devices and what needs to be done in the future. Assessed by examination and by assignment.
EA2p / EA2m	The performance of different types of transistor device is described and contrasted in terms of both analytical methods and practical device performance characteristics. Assessed by examination and by assignment.
D1fl	The students will be asked to investigate current thinking on the future of integrated circuit development it faces unprecedented technological and commercial challenges. In particular, students will be directed towards several recent contrasting articles on the future of Moores law, some of which describe the future as healthy and others which suggest it is dead. Students will be asked to interpret this contrasting information and perform independent research before forming their own opinion. Assessed by assignment.
D2m / D2fl	The fundamental physical and materials limitations of device scaling are discussed, as well as the social and economic factors, which are driving ever increasing integrated circuit performance. Limitations in terms of materials sustainability and the ever-increasing cost of manufacture are discussed. Assessed by examination and by assignment.
D3m	The students will be asked to investigate current thinking on the future of

integrated circuit development it faces unprecedented technological and commercial challenges. In particular, students will be directed towards several recent contrasting articles on the future of Moore’s law, some of which describe the future as ‘healthy’ and others which suggest it is ‘dead’. Students will be asked to interpret this contrasting information and perform independent research before forming their own opinion. Assessed by assignment.

ET2m / ET2fl Students will develop knowledge of the commercial and societal importance of integrated circuit technology and its direct and indirect economic value. Key future developments and their impact on the industry will also be discussed including the viability of the Moore’s law when faced with both technological and economic challenges. Assessed by examination and by assignment.

EP1fl The course seeks to describe past developments and the current state of the art in terms of the materials, equipment, processes and end products used enabled by the integrated circuit industry. Assessed by examination and by assignment.

EP2m The course seeks to describe past developments and the current state of the art in terms of the materials, equipment, processes and end products used /enabled by the integrated circuit industry. Assessed by examination and by assignment.