Module Handbook Photovoltaics Northumbria

| Fakultät 5: Mathematik und Naturwissenschaften Institut für Physik | Category: |
| Subject: European Master in Renewable Energy | - Master Module |
| Summer Term 2017 | Degree award: |
| | - Master |

| Emphases: | Sections: |
| - | |

| Module reference number/Title: |
| pre351 - Photovoltaic Cell and Module Technology |

| Duration: 1 semester | Type of program: |
| Cycle: once a year | - |
| Type of module: mandatory | Lectures, Laboratories |
| Level: MM (master module) | Language: English |
| This module should be taken in 2nd semester | Attainable credit points: 10,00 CP |

| Person responsible for the programme: | Person responsible for this module: |
| Professor N. Pearsall | Dr. I. Forbes |

| Alternative person(s) responsible for this module: |
| Dr. V. Barrioz |

| Examiner(s): |
| Another member of staff from the Department (not teaching on the module) and the external examiner (from another UK University) appointed for the course. |

| Objective of the module / skills: |
| After completing the module, the student will |
| - have a critical understanding of the physical principles relating to the operation and design of photovoltaic cells. |
| - be able to compare and analyse the design and operation of the main types of photovoltaic cells. |
| - have a critical understanding of the effect of material purity and crystallinity on the device performance. |
| - be able to compare and evaluate different methods for the fabrication of photovoltaic cells in terms of device properties and manufacturing issues. |
| - have a critical understanding of the principles of operation and design of photovoltaic modules. |
| - be able to compare and evaluate methods for the fabrication of photovoltaic modules, including performance and manufacturing issues. |

| Content of the module: |
| 1. Physics of Solar Cell Devices: |
- Solar spectrum, solar constant and air mass.
- Important semiconductors. Important solar cell devices.
- Drude theory. Breakdown of classical theory. Quantum theories of conduction: E-k curves, energy bandgap and effective masses, direct and indirect transitions.
- Carrier statistics in equilibrium - intrinsic and extrinsic behaviour.
- Carrier transport, mobilities and diffusion coefficients, scattering mechanisms. Hall effect.
- Non-equilibrium behaviour: direct, indirect and surface recombination, carrier lifetime and diffusion length.
- Current density and continuity equations, examples of solutions.
- Optical and thermal properties of semiconductors. Antireflection coatings. p-n junction in equilibrium: built in voltage, depletion region and depletion capacitance. Derivation of I-V characteristics in the dark.
- Variations of photocurrent and open circuit voltage with incident light intensity. Optimum energy bandgap of a solar cell.
- Loss mechanisms. Introduction to tandem/ multijunction concepts.
- Real diodes: recombination and generation in the depletion region, effects of series and leakage resistance on ideal behaviour. Schottky diodes and Ohmic contacts. Interface states.
- Heterojunctions: Anderson model, current transport models, heterojunction window effect.
- Effects of temperature and radiation on solar cell performance.

2. Solar Cell Fabrication Technologies
- Introduction: Important semiconductors and solar cell devices.
- Important semiconductor parameters. Effects of lattice vibrations, impurity atoms and other crystal imperfections on these parameters.
- Purification of silicon: chemical, zone refining and gettering. Segregation coefficient.
- Crystal growth: Bridgmann methods, Czochralski method and Floating Zone Methods.
- Advanced epitaxial growth methods: MBE, MOCVD, LPE AND VPE.
- Low cost thin film deposition methods: thermal evaporation methods, sputtering methods and wet chemical methods, e.g electrodeposition, autocatalytic deposition, spray pyrolysis and screen printing.
- Compensation doping: alloying, solid state diffusion and ion implantation. Dielectric deposition - thermal oxidation of silicon, LPCVD and PECVD silicon oxide and nitrides.
- Photolithography. Etching - wet and dry methods.
- Overview of characterisation techniques for semiconductor materials and cells.
- Overview of design of silicon, III-V and thin film solar cells for terrestrial and space applications and the design and fabrication of photovoltaic modules made from these cells.

Suggested reading:
Proceedings of IEEE Photovoltaic Specialist Conferences.

Comments:  
Helpful previous knowledge:
| - | Core module of European Master on Solar Energy |
| - | Associated with the module(s): |

| Prerequisites for admission: | - |

| Maximum number of students / selection criteria: | - |

| Types of examinations: | - |
| Written exam (60%, 3 hours) | - |
| Laboratory Reports (40%) | - |

| Examination periods: | - |
| At the end of the semester | - |

| Registration procedure: | - |
### European Master in Renewable Energy

**Subject:** European Master in Renewable Energy  
**Category:** Master Module  
**Degree award:** Master  
**Summer Term 2017**

### Module reference number/Title:

**pre352 - Advanced Photovoltaic Cell Design**

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<thead>
<tr>
<th>Duration</th>
<th>Type of program</th>
<th>Type of module</th>
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<tbody>
<tr>
<td>1 semester</td>
<td>-</td>
<td>mandatory</td>
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<tr>
<th>Cycle</th>
<th>Language</th>
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<tr>
<td>once a year</td>
<td>English</td>
<td>MM (master module)</td>
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<tr>
<th>This module should be taken in 2nd semester</th>
<th>Workload</th>
<th>Required attendance</th>
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<tr>
<td></td>
<td>100 hours</td>
<td>24 hours</td>
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### Person responsible for the programme:

- Prof. N. Pearsall

### Person responsible for this module:

- Dr. R. Fu

### Alternative person(s) responsible for this module:

- Examiner(s):

### Objective of the module / skills:

After completing the module, the student will be able to:
- Critically appraise the choice of semiconductors used and the design and fabrication methods used to produce an advanced PV device.
- Critically appraise the characterisation methods used with semiconductor materials and with PV devices.
- Perform a literature review on advanced PV devices to a professional standard.
- Present data and information both verbally and in the written form to a professional standard.

### Content of the module:

1. **Introduction**
   - Flat plate modules. Concentrator solar cells. Multijunction concepts.
   - Overview of types of solar cell developed - status of the technologies.

2. **Advanced Devices**
   - Polycrystalline silicon.
   - Space applications. Physics of multijunction cells. Quantum well devices.
- Thermophotovoltaic devices.

3. Advanced Characterisation Methods
- Material characterisation: X-ray diffraction, electron and ion beam characterisation methods, optical characterisation, Van der Pauw length.
- Device Characterisation: DLTS, photoluminescence and PAS.
- Solar simulators.
- Measurement of fill-factor, solar conversion efficiency and spectral response.
- I-V-T and C-V-f measurements. Radiation damage.

4. Literature Review
This will be undertaken for one of the following topics: crystalline silicon devices, III-V devices or thin film devices.

Suggested reading:
Proceedings of IEEE Photovoltaic Specialist Conferences.

Comments:
- 
Weblink:
- 
Prerequisites for admission:
- 

Helpful previous knowledge:
Core module of European Master on Solar Energy

Associated with the module(s):
- 

Maximum number of students / selection criteria:
- 
Types of examinations:
Written report (literature review): The module assessment is in the form of a review of approximately 3,000 words, chosen by the student from a list of PV device categories.

Examination periods:
At the end of the semester
Registration procedure:
- 

Subject: European Master in Renewable Energy
Summer Term 2017

Module reference number/Title:
**pre353 – Photovoltaics, Economics, Policy and Environment**

| Duration: | 1 semester |
| Cycle: | once a year |
| Type of module: | mandatory |
| Level: | MM (master module) |
| This module should be taken in 2nd semester |

**Type of program:**
- Lectures, seminars

**Language:**
- English

**Attainable credit points:**
- 5,00 CP

**Workload:**
- 100 hours

**Required attendance:**
- 24 hours

**Person responsible for the programme:**
- Prof. N. Pearsall

**Person responsible for this module:**
- Prof. N. Pearsall

**Examines:**
- -

**Objective of the module / skills:**
After completing the module, the student will be able to:
- Critically analyse the international policies relating to photovoltaics and other energy technologies focusing on the strategic, environmental and economic implications of these policies
- Perform an economic and/or environmental analysis of a photovoltaic system.

**Content of the module:**
1. Economic Analysis
   - Economic theory - net present value, effect of interest rates, definition of capital and recurrent costs
   - Production economics - definition of production costs, economies of scale, projected manufacturing costs
   - Subsidies and tariff issues - effect of electricity supply costs on system viability
   - Financing mechanisms - review of international financing mechanisms for purchase and operation of systems
2. Policy Issues
   - Market development and projections
   - Review and appraisal of government policies and market development schemes
   - Security of supply
   - Climate change issues
   - Energy for development - role of photovoltaics
<table>
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<tr>
<th>3. Environmental Impact Assessment</th>
<th>Helpful previous knowledge:</th>
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<tbody>
<tr>
<td>- Process definition for module production</td>
<td>Core module of European Master on Solar Energy</td>
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<tr>
<td>- Hazard assessment</td>
<td>Associated with the module(s):</td>
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<td>- EC environmental directives</td>
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<td>- Embodied energy calculations</td>
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<td>- Energy payback times and ratios</td>
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<td>- Calculation of associated CO2 and other emissions</td>
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Suggested reading:
- Journal of "Progress in Photovoltaics"
- Proceedings of European Photovoltaic Solar Energy Conferences
- Proceedings of IEEE Photovoltaic Specialist Conferences
- IEEEXplore database
- Environmental data sources
- Government literature (including European Commission and international) on renewable energy promotion
- IEA Photovoltaic Power Systems Programme reports

Comments:
- 
Weblink:
- 
Prerequisites for admission:
- 
Maximum number of students / selection criteria:
- 
Types of examinations:
  - Written report (essay, approximately 3,000 words) and Presentation (10 minutes)
Examination periods:
  - At the end of the semester
Registration procedure:
-
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<tr>
<th>Fakultät 5: Mathematik und Naturwissenschaften</th>
<th>Category:</th>
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**Emphases:**

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**Sections:**

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**Module reference number>Title:**

**pre354 - Photovoltaic System Technology**

| Duration: 1 semester | Type of program: |
| Cycle: once a year | - |
| Type of module: mandatory | Lectures, seminars |
| Level: MM (master module) | Language: English |
| This module should be taken in 2nd semester | Attainable credit points: 10,00 CP |
|  | Workload: 200 hours |
|  | Required attendance: 48 hours |

**Person responsible for the programme:**

Prof. N. Pearsall

**Person responsible for this module:**

Prof. N. Pearsall

**Alternative person(s) responsible for this module:**

- 

**Examiner(s):**

another member of staff from the Department (not teaching on the module) and the external examiner (from another UK University) appointed for the course.

**Objective of the module / skills:**

After completing the module, the student will be able to:

- Assess the system requirements for both grid connected and stand alone applications.
- Design and develop a PV system by evaluating complex customer needs in relation to an application.
- Critically evaluate the performance of a PV system in comparison to a theoretical model of such a system, calculating yields and efficiencies.
- Analyse the main system losses and compare methods for minimising these for various system designs.

**Content of the module:**

1. Basic systems design
   - Photovoltaic (PV) arrays, support structures
   - Electrical Connections and wiring issues
   - BOS components
   - Stand alone and grid connected systems
   - System sizing
2. Stand-alone systems
   - Applications
- Performance assessment and sizing
- Standards and regulations

3. Grid connected systems - electrical
- Inverter systems and electrical supply issues
- Grid connection regulations
- Harmonic content, reactive power, and wiring issues

4. Grid connected systems - large scale
- Design of large scale systems
- Case studies

5. Grid connected systems - building integrated
- System design and sizing
- Energy in buildings and building components
- Installation and operation
- Case studies

6. Concentrator systems
- Design of concentrator systems
- Operation and maintenance

7. Monitoring and performance analysis
- Monitoring specifications
- Yield and performance ratio, and MTBF
- Operational issues and maintenance

8. Standards and regulations
- Standards for construction and operation
- Regulations governing system design and operation
- Health and safety issues

9. Space systems
- Array configurations
- Quality control and assessment
- Design of systems
- BOL and EOL design tradeoffs

Suggested reading:

Journals:
- Progress in Photovoltaics
- Renewable Energy
- Various IEEE journals relating to electrical engineering

Databases and Websites
- IEA PV Power Systems Programme (www.iea-pvps.org)
- European Photovoltaic Industries Association (http://www.epia.org/home/)
- PVGIS web site (http://re.jrc.ec.europa.eu/pvgis/)

Other Resources
- Measurement data from system trials
- PVSyst software
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<td>Written report (40%, design assignment): Feasibility report, maximum of 10 pages plus technical appendices</td>
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