230355 - GRACNIF - Graphene and Carbon Nanotubes Introduction and Fundamentals

Coordinating unit: 230 - ETSETB - Barcelona School of Telecommunications Engineering
Teaching unit: 710 - EEL - Department of Electronic Engineering
Academic year: 2015
Degree: DEGREE IN ELECTRONIC ENGINEERING (Syllabus 1992). (Teaching unit Optional)
MASTER'S DEGREE IN ELECTRONIC ENGINEERING (Syllabus 1992). (Teaching unit Optional)
MASTER'S DEGREE IN TELECOMMUNICATIONS ENGINEERING (Syllabus 2013). (Teaching unit Optional)
ECTS credits: 2.5
Teaching languages: English

Teaching staff
Coordinator: Juan Miguel López-González

Degree competences to which the subject contributes

Specific:
CEE12. Ability to use semiconductor devices taking into account their physical characteristics and limitations.
CEE13. Ability to analyze and evaluate the performance at the physical level of the main devices and sensors, the relations between magnitudes in their terminals and their equivalent circuits.
CEE14. Ability to establish a relationship between an electronic device and its fabrication technology, and to understand its design process.
CE13. Ability to apply advanced knowledge in photonics, optoelectronics and high-frequency electronic

Teaching methodology
- Lectures
- Application classes
- Individual work (distance)
- Exercises to strengthen the theoretical knowledge.

Learning objectives of the subject

Learning objectives of the subject:
The aim of Graphene and Carbon Nanotubes Introduction and Fundamentals course is to introduce the basic device physics of carbon nanotubes (CNTs) and graphene necessary to understand the performance of modern electronic devices based on these materials. First, we study basic quantum mechanic of solids. Then we describe the physical and electronic structure and properties of graphene and CNTs. Finally we explained graphene and CNTs applications for: transistors, solar cells, sensors and NEMS.

Learning results of the subject:
- Ability to understand energy bands of solids.
- Ability to understand electrical properties of Graphene.
- Ability to analyse electrical properties of Carbon Nanotubes.
- Ability to understand electrical performance of modern electronic devices based on graphene and CNTs.
# 230355 - GRACNIF - Graphene and Carbon Nanotubes Introduction and Fundamentals

## Study load

<table>
<thead>
<tr>
<th>Total learning time: 62h 30m</th>
<th>Hours large group: 20h</th>
<th>32.00%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Self study:</td>
<td>42h 30m</td>
</tr>
</tbody>
</table>

Last update: 07-07-2015
# 1. Introduction of Graphene and CNT

**Description:**
- Course introduction
- Synthesis and characterization techniques
- Graphene

**Learning time:** 9h 30m  
Theory classes: 3h  
Self study: 6h 30m

---

# 2. Quantum mechanics

**Description:**
- Introduction Quantum Mechanics
- \( E(k) \) dispersion equation
- Solids crystallography

**Learning time:** 9h  
Theory classes: 3h  
Self study: 6h

---

# 3. Graphene

**Description:**
- Lattice of Graphene
- Graphene energy dispersion bands
- Carrier densities
- Nanoribbons

**Learning time:** 9h  
Theory classes: 3h  
Self study: 6h

---

# 4. Carbon Nanotubes

**Description:**
- Chirality and configuration of CNTs
- Metallic and semiconductor CNTs
- CNT energy bands, carrier velocities and density

**Learning time:** 9h  
Theory classes: 3h  
Self study: 6h
### 5. Quantum electrical properties of Graphene and CNT

<table>
<thead>
<tr>
<th>Description:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductance, capacitance and inductance</td>
</tr>
<tr>
<td>CNT resistance and transmission line models</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Learning time:</th>
</tr>
</thead>
<tbody>
<tr>
<td>9h</td>
</tr>
<tr>
<td>Theory classes: 3h</td>
</tr>
<tr>
<td>Self study: 6h</td>
</tr>
</tbody>
</table>

---

### 6. Applications of Carbon Nanotubes

<table>
<thead>
<tr>
<th>Description:</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNT applications</td>
</tr>
<tr>
<td>CNT Field Effect Transistors, CNTFET</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Learning time:</th>
</tr>
</thead>
<tbody>
<tr>
<td>9h</td>
</tr>
<tr>
<td>Theory classes: 3h</td>
</tr>
<tr>
<td>Self study: 6h</td>
</tr>
</tbody>
</table>

---

### 7. Applications of Graphene

<table>
<thead>
<tr>
<th>Description:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graphene FET</td>
</tr>
<tr>
<td>Graphene electronics</td>
</tr>
<tr>
<td>Graphene optoelectronics</td>
</tr>
<tr>
<td>Graphene transistors review</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Learning time:</th>
</tr>
</thead>
<tbody>
<tr>
<td>8h</td>
</tr>
<tr>
<td>Theory classes: 2h</td>
</tr>
<tr>
<td>Self study: 6h</td>
</tr>
</tbody>
</table>

---

### Qualification system

<table>
<thead>
<tr>
<th>Exercises:</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 %</td>
</tr>
</tbody>
</table>
230355 - GRACNIF - Graphene and Carbon Nanotubes Introduction and Fundamentals

Bibliography

Basic:


Complementary:

Ferrari, A.C. "Science and technology roadmap for graphene, related two-dimensional crystals, and hybrid systems". Nanoscale.

Others resources:
