Last update: 24-03-2017

# 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: 2017

Degree: DEGREE IN ELECTRONIC ENGINEERING (Syllabus 1992). (Teaching unit Optional)
MASTER'S DEGREE IN TELECOMMUNICATIONS ENGINEERING (Syllabus 2013). (Teaching unit Optional)
MASTER'S DEGREE IN ELECTRONIC ENGINEERING (Syllabus 2013). (Teaching unit Optional)
DEGREE IN TELECOMMUNICATIONS ENGINEERING (Syllabus 1992). (Teaching unit Optional)

ECTS credits: 2,5 Teaching languages: English

## Teaching staff

Coordinator: Juan Miguel López-González

Others: 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.

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## Study load

| | | | |
|---|---|---|---|
| Total learning time: 62h 30m | Hours large group: | 20h | 32.00% |
| | Self study: | 42h 30m | 68.00% |

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## Content

### 1. Introduction of Graphene and CNT

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

Description:
? Course introduction
? Synthesis and characterization techniques
? Graphene

### 2. Quantum mechanics

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

Description:
? Introduction Quantum Mechanics
? E(k) dispersion equation
? Solids crystallography

### 3. Graphene

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

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

### 4. Carbon Nanotubes

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

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

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| 5. Quantum electrical properties of Graphene and CNT | Learning time: 9h<br>Theory classes: 3h<br>Self study : 6h |
|---|---|

Description:
? Conductance, capacitance and inductance
? CNT resistance and transmission line models

| 6. Applications of Carbon Nanotubes | Learning time: 9h<br>Theory classes: 3h<br>Self study : 6h |
|---|---|

Description:
? CNT applications
? CNT Field Effect Transistors, CNTFET

| 7. Applications of Graphene | Learning time: 8h<br>Theory classes: 2h<br>Self study : 6h |
|---|---|

Description:
? Graphene FET
? Graphene electronics
? Graphene optoelectronics
? Graphene transistors review

## Qualification system

Exercises: 100 %

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## Bibliography

### Basic:

Wong, Hon-Sum Philip; Akinwande, Deji. Carbon nanotube and graphene device physics. Cambridge: Cambridge University Press, 2011. ISBN 9780521519052.

Wu,Y ... [et al.]. "Graphene Electronics: Materials, Devices, and Circuits". Proceedings of the IEEE [on line]. Vol. 101, No. 7, July 2013 [Consultation: 07/03/2016]. Available on: <http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=6519298>.

Xia, F.; Yan, H.; Avouris, P. "The interaction of Light and Graphene: Basics, Devices, and Applications". Proceedings of the IEEE [on line]. Vol. 101, No. 7, July 2013 [Consultation: 07/03/2016]. Available on: <http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=6514893>.

### Complementary:

Ferrari, A.C. "Science and technology roadmap for graphene, related two-dimensional crystals, and hybrid systems". Nanoscale [on line]. 2015, núm 7, p. 4598-4810 [Consultation: 07/03/2016]. Available on: <http://pubs.rsc.org/en/results?searchtext=Title%3AScience%20and%20technology%20roadmap%20for%20graphene%2C%20related%20two-dimensional%20crystals%2C%20and%20hybrid%20systems>.

### Others resources:

G.N. Dash, S.R. Pattanaik, S. Behera, ?Graphene for Electron Devices: The Panorama of a Decade?, Journal of the Electron Devices Society, vol. 2 no. 5, September 2014. DOI: 10.1109/JEDS.2014.2328032.

F. Schwierz, ?Graphene Transistors: Status, Prospects, and Problems?, Proceedings of the IEEE, vol. 101, no. 7, July 2013.