UNIVERSITÀ DEGLI STUDI DI PALERMO

DEPARTMENT	Ingegneria
ACADEMIC YEAR	2023/2024
MASTER'S DEGREE (MSC)	ELECTRONICS ENGINEERING
SUBJECT	NANOELECTRONICS
TYPE OF EDUCATIONAL ACTIVITY	C
AMBIT	20925-Attività formative affini o integrative
CODE	20519
SCIENTIFIC SECTOR(S)	ING-INF/01
HEAD PROFESSOR(S)	MACALUSO ROBERTO Professore Associato Univ. di PALERMO
OTHER PROFESSOR(S)	
CREDITS	6
INDIVIDUAL STUDY (Hrs)	102
COURSE ACTIVITY (Hrs)	48
PROPAEDEUTICAL SUBJECTS	
MUTUALIZATION	
YEAR	2
TERM (SEMESTER)	1° semester
ATTENDANCE	Not mandatory
EVALUATION	Out of 30
TEACHER OFFICE HOURS	**MACALUSO ROBERTO** Tuesday 13:00 15:00 DEIM

DOCENTE: Prof. ROBERTO MACALUSO

PREREQUISITES	In order to attend proficiently the course, the student must posses a wide knowledge of MOSFET devices.
LEARNING OUTCOMES	Knowledge and understanding. The student at the end of the course will have full knowledge of the most advanced design and materials for the realization of scaled-down MOSFET devices . In particular, the student will be able to understand, starting from the physical and technological limits of the CMOS technology, which is currently dominating the market of integrated electronic circuits, which technologies and alternative materials will be used to get more and more dense, fast, and low power consuming devices. Capability of applying knowledge and understanding. The student will be able to apply his/her acquired knowledge for the study and design of short channel MOSFET devices, and for the growth and the characterisation of new nanostructured materials and new nanoelectronic devices. Independent judgment. During the course, particular emphasis is given to stimulate the ability of independent judgment of the student in assessing technology strategies, economic advantages, quality and efficiency associated to the studied manufacturing processes and devices. The student will acquire skills such as to be able to compare both from a technical and scientific point of view and from an economic point of view, different materials, technologies and devices for micro and nanoelectronics, correlating them to the particular applications considered from time to time. This ability to compare, together with the knowledge of the basic physics which lies behind the studied devices, will allow him/her to be able to deal with the design of new nanodevices. Communication skills. The student will acquire the ability to communicate effectively with both written and oral on topics and issues concerning the object of the course also in an international context: in particular, a special attention will be paid to the English terminology. The student, in addition, will be able to hold conversations on issues regarding the choice of nano-structured materials and nano-devices for specific purposes, to highlight problems related to the limits of their functioning and to offer solutions. Learning ability. The student will learn the interactions between the physics of the nanodevices and their use in the most common applications. This will allow him/her to be competitive in a field in constant growth and nowadays extremely strategic for all advanced economies, which embraces a wide range of applications. The student can then work in the design and fabrication of innovative and high scientific content products in all industrial sectors and applied research based on nanotechnology.
ASSESSMENT METHODS	The assessment will be based on an oral exam, which will range on the main topics of the course with a minimum of 3 questions, which can in turn develop into further sub-questions, depending on the preparation shown by the student. The purpose of the oral test is to verify that the student has full mastery of all the topics covered during the course. The questions will tend to verify that the student possesses adequate presentation skills, be able to correlate the various contents of the course on his/her own, understands the applications or implications of the various contents covered by the course, has acquired adequate command of the technical language, especially with refer to the English technical terminology. The assessment is out of thirty (maximum mark: 30/30). The pass mark will be reached when the student will show, at least in general terms, knowledge and understanding of the topics, and minimal application skills for the resolution of specific cases. The student must also posses presentation and argumentative skills that enable the transmission of his knowledge to the examiner. Below this threshold, the examination will result insufficient. The more, however, the examinee with its argumentative and presentation skills will interact with the examiner, and the more his/her knowledge and application capabilities will go into details, the more the assessment will be positive. More in details, the assessment will be based on the following scheme: 30-30 cum laude: Excellent. Full knowledge and understanding of concepts and methods of the discipline, excellent analytical skills even in solving original problems; excellent communication and learning skills; excellent ability to connect the various topics discussed during the course. 27-29: Very good. Very good knowledge and understanding of concepts and methods of the discipline; very good communication skills; the student is able to apply his/her knowledge to solve the proposed problems and to range comfortably between one subject and another.

	24-26: Good. Good knowledge of main concepts and methods of the discipline; discrete communication skills; limited autonomy for applying concepts and methods for solving original problems; limited ability to link the various topics dealt with during the course. 21-23: Satisfactory. Partial knowledge of main concepts and methods of the discipline; satisfactory communication skills; scarce judgment autonomy. 18-20: Acceptable: Minimal knowledge of concepts and methods of the discipline; minimal communication skills; very poor or null judgement autonomy. Unacceptable: Insufficient knowledge and understanding of concepts and methods of the discipline.
EDUCATIONAL OBJECTIVES	The course provides, together with the state of the art CMOS technology, currently dominating the market of integrated circuits, and the issues related to the scaling of these devices, specific knowledge on properties and technology of novel materials such as graphene, carbon nanotubes, as potential building blocks for realizing a new generation of dense, fast, and low power consuming integrated circuits. The course will cover also advanced fabrication and characterisation techniques of nanodevices and nanostructures, and includes both theoretical exercises and laboratory visits. The latter aim to highlight practical aspects in the use of some of the characterization techniques (e.g. scanning or transmission electron microscopy and atomic force microscopy) studied during the course.
TEACHING METHODS	Frontal lectures, numerical exercises, laboratory visits, seminars.
SUGGESTED BIBLIOGRAPHY	Testi di riferimento/Reference texts: • R. S. Muller, T. I. Kamins: "Device electronics for integrated circuits", Wiley, 2003. ISBN: 978-0-471-59398-0. Testo reperibile gratuitamente in formato elettronico presso il Sistema Bibliotecario di Ateneo / e-book available through UniPa Discovery Service. • Zheng Cui: “Nanofabrication - Principles, Capabilities and Limits”, 2° Edition, Springer, 2017. ISBN 978-3-319-39359-9. Testo reperibile gratuitamente in formato elettronico presso il Sistema Bibliotecario di Ateneo / e-book available through UniPa Discovery Service. • Y. Leng: Materials characterization: introduction to microscopic and spectroscopic methods – Wiley, 2009. ISBN: 978-3-527-33463-6. Testo non reperibile gratuitamente in formato elettronico presso il Sistema Bibliotecario di Ateneo / e-book not available through UniPa Discovery Service. • Note e dispense del docente reperibili attraverso il portale studenti dagli studenti iscritti al corso /Material (projected slides) provided by the professor and available through the student portal by students enrolled in the course. Testi consigliati per approfondimento/Recommended texts for further study: • V. Mitin, V. Kochelap, M. Stroscio: Introduction to Nanoelectronics – Cambridge University Press, 2008. ISBN 978-1-107-40376-5. Testo reperibile gratuitamente in formato elettronico presso il Sistema Bibliotecario di Ateneo / e-book available through UniPa Discovery Service. • H.-S. P. Wong, D. Akinwande: Carbon Nanotube and graphene device physics – Cambridge University Press, 2011. ISBN 978-0-521-51905-2. Testo reperibile gratuitamente in formato elettronico presso il Sistema Bibliotecario di Ateneo / e-book available through UniPa Discovery Service.

SYLLABUS

Hrs	Frontal teaching
4	Introduction to Nanoelectronics: toward the nanoscale. Properties of nanostructured materials and relative sensing applications.
2	Moore's law. The International Roadmap for Devices and Systems (IRDS): latest technological trends. More Moore and more than Moore paradigms.
2	Down-scaling of MOSFET devices: constant field scaling, constant voltage scaling, quasi-constant voltage scaling, empirical scaling.
4	Short-channel effects: threshold voltage roll-off, subthreshold current effects, punch-through, gate leakage, mobility degradation, velocity saturation, drain current variation. Hot electrons effects.
3	Gate oxide: tunnelling leakage currents components, gate depletion, high-k dielectrics and metal gate. Gate induced drain leakage (GIDL).
3	Reliability of short-channel MOSFETs: hot carrier degradation in both n-MOS and p-MOS, impact ionization, gate-oxide degradation and breakdown, electromigration, junction spiking.
1	Techniques to control short-channels effects: light-doped drain technology, shallow junctions, silicide source/ drain contacts, raised source/drain, halo implants, retrograde channel profiles.
6	Advanced MOSFET structures: ultra-thin body MOSFET, silicon-on-insulator (SOI) physics and technology, double gate MOSFET, bulk and SOI FinFET. Basic concepts of strained-silicon technology. Nanowire-FET.
2	Scaling of interconnections: Cu/low-k dielectrics interconnections, single and dual damascene process.
5	Fabrication techniques of micro and nanodevices: optical lithography and its limits, deep-UV lithography, immersion lithography, extreme-UV lithography, electron beam lithography. Soft lithography and nanoimprint lithography (NIL). 7 nm technological node.

SYLLABUS

Hrs	Frontal teaching
10	Characterization techniques of nanomaterials and nanostructures: scanning electron microscope (SEM), transmission electron microscope (TEM), scanning tunneling microscope (STM), atomic force microscope (AFM).
3	Novel materials for nanoelectronics and their properties: graphene, carbon nanotubes (CNTs). Possible applications in nanoelectronics and photonics, growth techniques.
1	Carbon nanotubes-based devices: back-gated and top-gated CNT-FETs: comparison with Si-MOSFETs. CNTs-based gas sensors.

Hrs	Practice
2	Exsercises on short-channel MOSFETs.