PHYSICS OF SEMICONDUCTOR DEVICES AND MEMORIES (AY 17–18)

Massimo Rudan

These slides are available in pdf format at the link entitled *Teaching Activity* of the website

http://www.micro.deis.unibo.it/cgi-bin/user?rudan

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TO WHOM IS THIS COURSE ADDRESSED?

- In the Academic year 2017–2018 the Students attending the course belong to the first year of the Electronic technologies for Big-Data and Internet of Things program (934, mandatory), to the second year of the Ingegneria elettronica program (934, elective[1]), and to the second year of the Ingegneria chimica e di processo program (929, elective[1]).

- The course may be attended by Students different from the above who choose it on a case-by-case basis.

[1] Here the course is called “Solid State Electronics M”.

MORE DETAILS ABOUT THE ABOVE

- The lessons in the agenda will be given in the period from Tuesday, September 19, through Monday, December 18, 2017. The weekly hours shown in the Faculty's schedule are sufficient to complete the maximum of 60 hours.

Note:

- The classrooms may be changed if necessary.
- The agenda may also be changed if necessary. Hours may be swapped with those of other teachers.
- **Changes in the agenda will be sought in order to balance the needs of the different groups of Students.**

SCHEDULE 2017-2018

- The initial schedule is: Mondays 11–14 in classroom 7-4 (whose address is Via Saragozza 8), Fridays 11–13 in classroom 5-2.
- It may happen that a few hours are added to the schedule if a need of recovery arises. In any case the total number of hours will not exceed 60.
- Due to national or local holidays the Faculty will be closed on
  - Wednesday, October 4.
  - Wednesday, November 1.
  - Friday, December 8.

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AIMS OF THE COURSE

- First part: to provide the basic physical and mathematical concepts that are necessary to understand the transport phenomena in solid-state materials.
- Second part: to describe the fundamental physical properties of semiconductors, and give the derivation of the mathematical model for solid-state devices.
- To apply the model to the description of the basic devices, sensors, and memories, and illustrate some examples of innovative research activities in the field.
- The course is a prerequisite to *Advanced solid-state sensors M*, given in the second semester of the same year.

PREREQUISITES

- Basic concepts of mathematics and physics acquired from earlier courses.
- Basic concepts about the electron devices.
- In this course further mathematical and physical concepts, not necessarily elementary, will be used. They will be explained as necessary during the lessons. The use of such concepts can not be dispensed with, they actually constitute the cultural basis of the course itself.

EXAMS

- The exams are oral.
- To register for the exam it is necessary to use the electronic lists that will be made available on the website

https://almaesami.unibo.it

The Students that have access to the e-lists are kindly asked to use this method only

- The electronic lists will carry the indication of the meeting point for the examinations' scheduling.
- DEI: second floor of the "Aule Nuove" building.

REFERENCES (I)

- Solid-State Electronics

  - 1-1. D. A. Neamen, *Semiconductor Physics and Devices*, IRWIN, 1992.
  - 1-2. M. Rudan, *Tavole di Microelettronica*, Pitagora Tecnoprint, 3ª Ed., 2001 (in English).
  - 1-3. M. Rudan, *Physics of Semiconductor Devices*, Springer, 2015; second edition, 2017.
  - 1-4. S. M. Sze, *Semiconductor Devices — Physics and Technology*, Wiley, 1985.
  - 1-5. E. De Castro, *Fondamenti di Elettronica — Fisica elettronica ed elementi di teoria dei dispositivi*, UTET, 1975.
  - 1-6. E. De Castro, *Teoria dei dispositivi a semiconduttore*, Pàtron, 1983.
  - 1-7. N. Ashcroft, N. Mermin, *Solid State Physics*, Saunders, 1976.
  - 1-8. Standard textbooks on Quantum Mechanics (A. Messiah, L. Landau, D. Bohm).

REFERENCES (II)

- The textbooks listed above are given as references.
- The book *Tavole di Microelettronica* is written in English and is the collection of most of the transparencies used by M. Rudan in his courses. It is meant as a teaching aid providing drawings, schemes, and calculations, not as a "replacement" of the lessons. Richer explanations are in the 2015/2017 textbook *Physics of Semiconductor Devices* published by Springer.
- During the lessons further transparencies not included in the collection may be used. Those that are not subjected to copyright will be posted on M. Rudan's website (many are actually posted there already).

WARNING !!!!

- The page numbering of the version of *Tavole di Microelettronica* available from bookstores is <u>different</u> from that of the transparencies used by M. Rudan in class. In the latter, many more pages have been added since the book's publication. For this reason,

WHEN TAKING NOTES, REFER TO THE TITLE AND CONTENT OF THE PAGE, NOT TO ITS NUMBER….

CONTENTS (I)

- Introduction to Quantum Mechanics.
- Semiconductor devices.
  - Introduction to device physics.
  - Mathematical model of semiconductor devices.
  - Models for the equations' coefficients.

CONTENTS (II)

- Semiconductor devices, sensors, and memories.
  - Structure of the elementary devices.
  - Steady-state regime.
  - Dynamic regime.
- Scaling rules.
- Measuring techniques for a number of semiconductor parameters.
- Discretization methods for the numerical solution of the device model.

CONTACTING THE TEACHER/TUTOR

- The official agenda for contacting the teacher is:
  - Thursdays 11:30–13:30
  - Fridays 11:30–13:30

- However, it is advisable to ask for an appointment (not limited to the above agenda) during a class, or by calling 051-209-3016 (93016 when using the internal telephones of the Faculty), or by sending a message to

massimo.rudan@unibo.it

THESIS (I)

- Possible subjects for a thesis in the area of semiconductor devices or materials are:
  - Advanced physical models for carrier transport in solids: through the BTE or the Schrödinger equation (coupled with the Poisson eq.), using different solution methods, among which the NEGF (Non-Equilibrium Green Function).
  - Quantum computation.
  - Carbon nanotubes, silicon nanowires.
  - Electronic nose (design and characterization of integrated sensors for volatile compounds using polymers).
  - MEMS for applications to radio-frequency circuits.
  - Advanced memory architectures, e.g., Phase-change memories (chalcogenide materials).
- Depending on the time left, some of the above research activities may be illustrated in seminars held within the course's schedule.

THESIS (II)

- All the thesis subjects shown above are carried out by M. Rudan, or by Colleagues of his, working at the (*)

Advanced Research Center on Electronic Systems (ARCES)

- The Professors of Electronics of the Faculty of Engineering belonging to ARCES are: G. Baccarani, G. Masetti, M. Rudan, R. Guerrieri, A. Gnudi, E. Franchi, R. Rovatti, C. Metra, S. Reggiani, N. Speciale.

ARCES is a Research Center of the University of Bologna, not a private Company.

(*) In Italian: ***Centro di Ricerca sui Sistemi Elettronici per l'Ingegneria dell'Informazione e delle Telecomunicazioni "Ercole De Castro" (ARCES).***

IEEE

- IEEE means *Institute of Electrical and Electronic Engineers* (pron. "I triple E").
- IEEE is an international Institute made of a large number of Technical Societies: *Electron Devices, Circuits and Systems, Quantum Electronics, Antennas, Telecommunications, Computers, Power Electronics,* and so on.
- Becoming an IEEE member gives access to one or more Societies and to the related Journals.
- In the University sites where IEEE is present, a Student Branch is present as well. Registration fees for Students are lower than the regular ones.

The information provided here about IEEE has no relation with the official teaching activity. It is only meant to inform the Students about the existence of the Student membership.

WARNING NO 2:

- The concepts illustrated in this class must be understood and "well digested"; a qualitative description is just the starting point: it must be followed by a thorough, quantitative analysis (i.e., using math at the appropriate level).
- In other terms, math is not the object of the class, it is the necessary tool for describing the concepts; same as being able to read music to the purpose of performing a sonata.
- Conclusion: do not consider the exam as a moment where formulas must just be written down one after the other by a strenuous effort of memory. This attitude leads invariably to a disaster… If you've problems, ask questions early enough!!

WARNING NO 3:

- The recording of the audio part of the 2017-2018 lessons will be posted in the Teacher's website on a day-by-day basis.
- This is made to help the students, not as an encouragement not to come to class….