TO: The Faculty of the College of Engineering

FROM: School of Electrical and Computer Engineering of the College of Engineering

RE: New Graduate Course, ECE 50653 Fundamentals of Nanoelectronics

The faculty of the School of Electrical and Computer Engineering has approved the following new course. This action is now submitted to the Engineering Faculty with a recommendation for approval.

ECE 50653 Fundamentals of Nanoelectronics
Sem. 1, Lecture 3, Cr. 3.

Prerequisite: MA266 & MA265 or MA262

Prerequisite by Topic: Familiarity with matrix algebra, MATLAB, Elementary differential equations.

Description: The modern smartphone is enabled by a billion-plus nanotransistors, each having an active region that is barely a few hundred atoms long. Interestingly the same amazing technology has also led to a deeper understanding of the nature of current flow on an atomic scale. The aim of this course is to make the fundamentals of nanoelectronics accessible to anyone in any branch of science or engineering, assuming very little background beyond linear algebra and differential equations, although we will be discussing advanced concepts in non-equilibrium statistical mechanics that should be of interest even to specialists.
We first introduce a new perspective connecting the quantized conductance of short ballistic conductors to the familiar Ohm's law of long diffusive conductors, along with a brief description of the modern nanotransistor. We then address fundamental conceptual issues related to the meaning of resistance on an atomic scale, the interconversion of electricity and heat, the second law of thermodynamics and the fuel value of information. Finally we introduce the concepts of quantum transport as applied to modern nanoscale electronic devices.

Reason: This course presents a new perspective that has emerged in the last two decades provides a powerful approach to new questions at the frontier of modern nanoelectronics. To our knowledge, there is no other course at any level addressing these topics. We believe this new perspective is of general interest, not just for electrical engineers, but for anyone interested in an atomic level understanding of everyday processes, like the flow of heat and electrical current.

Michael R. Melloch

Michael R. Melloch, Associate Head
School of Electrical and Computer Engineering

Approved for the faculty of the Schools
of Engineering by the Engineering
Curriculum Committee

ECC Minutes 14 Date 3-1-16
Chairman ECC

Supporting Document to the Form 40G
for a New Graduate Course

To: Purdue University Graduate Council

From: Faculty Member: Supriyo Datta

Department: Electrical and Computer Engineering

Campus: West Lafayette

Date:

Subject: Proposal for New Graduate Course

Contact for information if questions arise:
Name: Matt Golden
Phone: 494-3374
Email: goldenm@purdue.edu
Address: EE Building, Room 135

Course Subject Abbreviation and Number: ECE 50653

Course Title: Fundamentals of Nanoelectronics

Course Description: The modern smartphone is enabled by a billion-plus nanotransistors, each having an active region that is barely a few hundred atoms long. Interestingly the same amazing technology has also led to a deeper understanding of the nature of current flow on an atomic scale. The aim of this course is to make the fundamentals of nanoelectronics accessible to anyone in any branch of science or engineering, assuming very little background beyond linear algebra and differential equations, although we will be discussing advanced concepts in non-equilibrium statistical mechanics that should be of interest even to specialists.

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Semesters Offered:

For the benefit of graduate student plan of study development, how frequently will this prototype be offered? Which semesters?

Each Fall

A. Justification for the Course:

Provide a complete and detailed explanation of the need for the course (e. g., in the preparation of students, in providing new knowledge/training in one or more topics, in meeting degree requirements, etc.), how the course contributes to existing majors and/or concentrations, and how the course relates to other graduate courses offered by the department, other departments, or interdisciplinary programs.

Justify the level of the proposed graduate course (500- or 600-level) including statements on, but not limited to: (1) the target audience, including the anticipated number of undergraduate and graduate students who will enroll in the course; and (2) the rigor of the course.

Use the following criteria:
Graduate Council policy requires that courses at the 50000 level in the Purdue system should be taught at the graduate level and meet four criteria: a) the use of primary literature in conjunction with advanced secondary sources (i.e., advanced textbooks); b) assessments that demonstrate synthesis of concepts and ideas by students; c) demonstrations that topics are current, and; d) components that emphasize research approaches/methods or discovery efforts in the course content area (reading the research, critiquing articles, proposing research, performing research). Such courses should be taught so that undergraduate students are expected to rise to the level of graduate work and be assessed in the same manner as the graduate students.

This course presents a new perspective that has emerged in the last two decades provides a powerful approach to new questions at the frontier of modern nanoelectronics. To our knowledge, there is no other course at any level addressing these topics. We believe this new perspective is of general interest, not just for electrical engineers, but for anyone interested in an atomic level understanding of everyday processes, like the flow of heat and electrical current.

With this in mind, we have developed this course, assuming very little background beyond linear algebra and differential equations. But we discuss very advanced concepts involving non-equilibrium statistical mechanics, and that is why graduate level maturity is necessary. We normally have a majority of graduate students enroll for this course with 5-10 advanced undergraduate students.

- Anticipated enrollment
    - Undergraduate 5-10
    - Graduate 15-20

B. Learning Outcomes and Method of Evaluation or Assessment:

ECE Graduate Learning Outcomes:

a. Knowledge and Scholarship (thesis/non-thesis)
b. Communication (thesis/non-thesis)
c. Critical Thinking (thesis/non-thesis)
d. Ethical and Responsible Research (thesis) or Professional and Ethical Responsibility (non-thesis)

- List Learning Objectives for this course and map each Learning Objective to one or more of the ECE Learning Outcomes (a-d, listed above):

    i. Ability to perform semiclassical analysis of charge flow in nanoelectronic devices (a,c)
    ii. Ability to perform semiclassical analysis of the interconcersion of heat and electricity in nanoelectronic devices (a,c)
    iii. Ability to perform quantum analysis of nanoelectronic devices (a,c)

- Methods of Instruction

    - Lecture

- Will/can this course be offered via Distance Learning?

    - The course will not be offered via Distance Learning though it could be if necessary.

- Grading Criteria

Grading criteria (select from checklist); include a statement describing the criteria that will be used to assess students and how the final grade will be determined. Add and delete rows as needed.

- exams and/or quizzes

► Describe the criteria that will be used to assess students and how the final grade will be determined:
Six Exams and a Final Exam

C. Prerequisite(s):

List prerequisites and/or experiences/background required. If no prerequisites are indicated, provide an explanation for their absence. Add bullets as needed.

- MA266 & MA265 or MA262

Prerequisite by Topic: Familiarity with matrix algebra, MATLAB, Elementary differential equations.

D. Course Instructor(s):

Provide the name, rank, and department/program affiliation of the instructor(s). Is the instructor currently a member of the Graduate Faculty? (If the answer is no, indicate when it is expected that a request will be submitted.) Add rows as needed.

Name	Rank	Dept.	Graduate Faculty or expected date
Supriyo Datta	Professor	ECEN	Yes

E. Course Outline:

Provide an outline of topics to be covered and indicate the relative amount of time or emphasis devoted to each topic. If laboratory of field experiences are used to supplement a lecture course, explain the value of the experience(s) to enhance the quality of the course and student learning. For special topics courses, include a sample outline of a course that would be offered under the proposed course. **(This information must be listed and may be copied from syllabus).**

Weeks	*Principal Topics*
1-2	The new Ohm's law, from ballistic to diffusive conductors
3-4	Conductance quantization, density of states and density of modes, the nanotransistor
5-6	What and where is the resistance?
7-9	Thermoelectricity, Second Law, Fuel value of information
10-11	Bandstructure
12-14	Quantum transport: NEGF
15	Future Directions

F. Reading List (including course text):

A primary reading list or bibliography should be limited to material the students will be required to read in order to successfully complete the course. It should not be a compilation of general reference material.

A secondary reading list or bibliography should include material students may use as background information.

- Primary Reading List
  - S.Datta, "Lessons from Nanoelectronics," World Scientific (2012), ISBN 978-981-4335-29-4. Manuscript version is made freely available to students.
- Secondary Reading List
  - S.Datta, Quantum Transport: Atom to Transistor, Cambridge University Press (2005), ISBN 0-521-63145-9.
  - MatLab: Student Version, Current Edition, The MathWorks, Inc.

G. Library Resources

Describe any library resources that are currently available or the resources needed to support this proposed course.

This course has been taught as a two-part online course, first on nanoHUB-U (Purdue-led online course platform) in 2012.
https://nanohub.org/courses/fon1
The second Edition of the online course was just offered on edX (the MIT-led online course platform).

The on-campus course covers the same topics and all course material including *video lectures, notes, quizzes and practice exams* are available online for easy reference.

https://nanohub.org/courses/ECE595

H. Course Syllabus

(While not a necessary component of this supporting document, an example of a course syllabus is available, for information, by clicking on the link below, which goes to the *Graduate School's Policies and Procedures Manual for Administering Graduate Student Program.*
See Appendix K.
http://www.purdue.edu/gradschool/faculty/documents/Graduate_School_Policies_and_Procedures_Manual.pdf

Office of the Registrar
FORM 40G REV. 4/13

PURDUE UNIVERSITY
REQUEST FOR ADDITION, EXPIRATION, OR REVISION OF A GRADUATE COURSE (50000-60000 LEVEL)

DEPARTMENT: Electrical and Computer Engineering
EFFECTIVE SESSION: Fall 2016

INSTRUCTIONS: Please check the items below which describe the purpose of this request.

- [x] 1. New course with supporting documents (complete proposal form)
- [ ] 2. Add existing course offered at another campus
- [ ] 3. Expiration of a course
- [ ] 4. Change in course number
- [ ] 5. Change in course title
- [ ] 6. Change in course credit/type
- [ ] 7. Change in course attributes
- [ ] 8. Change in instructional hours
- [ ] 9. Change in course description
- [ ] 10. Change in course requisites
- [ ] 11. Change in semesters offered
- [ ] 12. Transfer from one department to another

PROPOSED:
Subject Abbreviation: ECE
Course Number: 50653
Long Title: Fundamentals of Nanoelectronics
Short Title: Fundamentals of Nanoelectronics
Abbreviated title will be entered by the Office of the Registrar if omitted. (30 CHARACTERS ONLY)

EXISTING:
Subject Abbreviation:
Course Number:

TERMS OFFERED
Check All That Apply:
- [x] Fall
- [ ] Spring
- [ ] Summer

CAMPUS(ES) INVOLVED
- [ ] Calumet
- [ ] Cont Ed
- [ ] Ft. Wayne
- [ ] Indianapolis
- [ ] N. Central
- [ ] Tech Statewide
- [x] W. Lafayette

CREDIT TYPE
1. Fixed Credit: Cr. Hrs. 3
2. Variable Credit Range:
   Minimum Cr. Hrs
   (Check One) To [ ] Or [ ]
   Maximum Cr. Hrs
3. Equivalent Credit: Yes [ ] No [x]
4. Thesis Credit: Yes [ ] No [x]

COURSE ATTRIBUTES: Check All That Apply
1. Pass/Not Pass Only [ ]
2. Satisfactory/Unsatisfactory Only [ ]
3. Repeatable [ ]
   Maximum Repeatable Credit:
4. Credit by Examination [ ]
5. Fees [ ] Coop [ ] Lab [ ] Rate Request
   Include comment to explain fee
6. Registration Approval Type
   Department [ ] Instructor [ ]
7. Variable Title [ ]
8. Honors [ ]
9. Full Time Privilege [ ]
10. Off Campus Experience [ ]

Schedule Type	Minutes Per Mtg	Meetings Per Week	Weeks Offered	% of Credit Allocated
Lecture	3	50	16	100
Recitation				
Presentation				
Laboratory				
Lab Prep				
Studio				
Distance				
Clinic				
Experiential				
Research				
Ind. Study				
Pract/Observ				

Cross-Listed Courses

COURSE DESCRIPTION (INCLUDE REQUISITES/RESTRICTIONS):
The modern smartphone is enabled by a billion-plus nanotransistors, each having an active region that is barely a few hundred atoms long. Interestingly the same amazing technology has also led to a deeper understanding of the nature of current flow on an atomic scale. The aim of this course is to make the fundamentals of nanoelectronics accessible to anyone in any branch of science or engineering, assuming very little

*COURSE LEARNING OUTCOMES:
i. Ability to perform semiclassical analysis of charge flow in nanoelectronic devices (a,c)
ii. Ability to perform semiclassical analysis of the interconcersion of heat and electricity in nanoelectronic devices (a,c)
iii. Ability to perform quantum analysis of nanoelectronic devices (a,c)

Calumet Department Head	Date	Calumet School Dean	Date	Calumet Director of Graduate Studies	Date
Fort Wayne Department Head	Date	Fort Wayne School Dean	Date	Fort Wayne Director of Graduate Studies	Date
Indianapolis Department Head	Date	Indianapolis School Dean	Date	IUPUI Associate Dean for Graduate Education	Date
North Central Department Head	Date	North Central School Dean	Date	North Central Director of Graduate Studies	Date
[signature] West Lafayette Department Head	11/30/15 Date	[signature] West Lafayette College/School Dean	3/1/16 Date	Date Approved by Graduate Council	Date
Graduate Area Committee Convener	Date	Graduate Dean	Date	Graduate Council Secretary	Date
				West Lafayette Registrar	Date

OFFICE OF THE REGISTRAR