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 nonequilibrium 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, 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
  o Undergraduate 5-10
  o 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 interconversion of heat and electricity in nanoelectronic devices (a,c)
  iii. Ability to perform quantum analysis of nanoelectronic devices (a,c)

• Methods of Instruction
  o Lecture

• Will/can this course be offered via Distance Learning?
  o 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.

  o 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.

<table>
<thead>
<tr>
<th>Name</th>
<th>Rank</th>
<th>Dept.</th>
<th>Graduate Faculty or expected date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supriyo Datta</td>
<td>Professor</td>
<td>ECEN</td>
<td>Yes</td>
</tr>
</tbody>
</table>

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

- Secondary Reading List

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.
**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.

- [ ] 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

**EXISTING:**

- **Subject Abbreviation:**
- **Course Number:**
- **Long Title:**
- **Short Title:**

**TERMS OFFERED:**

- [ ] Fall  
- [ ] Spring  
- [ ] Summer

**CAMPUS(ES) INVOLVED:**

- [ ] Calumet  
- [ ] Cont Ed  
- [ ] Ft. Wayne  
- [ ] Indianapolis  
- [ ] N. Central  
- [ ] Tech Statewide  
- [ ] W. Lafayette

**CREDIT TYPE:**

1. Fixed Credit: Cr. Hrs.  
   - [ ] 3

2. Variable Credit Range:  
   - [ ] Minimum Cr. Hrs. (Check One)  
     - [ ] Yes
   - [ ] No

3. Equivalent Credit:  
   - [ ] Yes
   - [ ] No

4. Thesis Credit:  
   - [ ] Yes
   - [ ] No

**COURSE ATTRIBUTES:**

1. Pass/Not Pass Only  
2. Satisfactory/Unsatisfactory Only
3. Repeatable  
4. Minimum Repeatable Credit:
5. Credit by Examination
6. Fees
   - [ ] Coop  
   - [ ] Lab  
   - [ ] Rate Request

**SCHEDULE TYPE:**

- **Minutes Per Mgt:**
- **Meetings Per Week:** 50
- **Weeks Offered:**
- **Alotted Credit:**

**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 knowledge of electronics.

**LEARNING OUTCOMES:**

1. Ability to perform semiclassical analysis of charge flow in nanoelectronic devices (a,c)
2. Ability to perform semiclassical analysis of the interconsevation of heat and electricity in nanoelectronic devices (a,c)
3. Ability to perform quantum analysis of nanoelectronic devices (a,c)

**Cross-Listed Courses:**

- [ ]

**OFFICE OF THE REGISTRAR**