

HUBBUB 2013 September 5-6, 2013

The nanoHUB-U Initiative

Mark Lundstrom and Supriyo Datta

Network for Computational Nanotechnology
Birck Nanotechnology Center
Purdue University, West Lafayette, Indiana USA



21st Century Electronics

Moore's Law may end soon. What then?

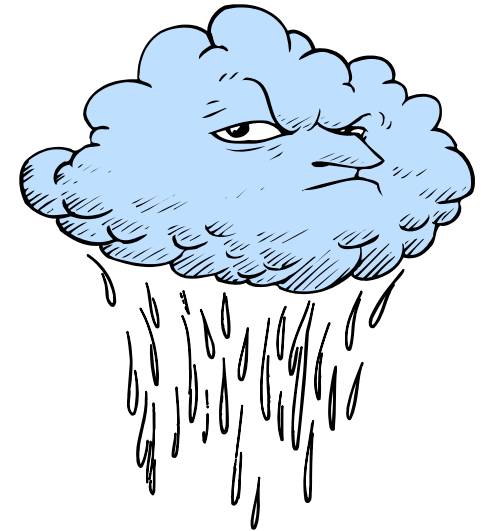
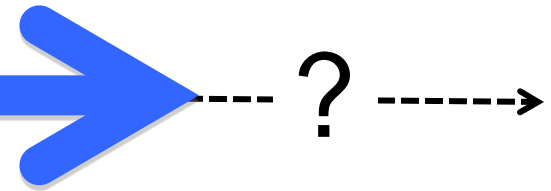
faster, smaller, cheaper....

Vacuum
tubes
~ 1900

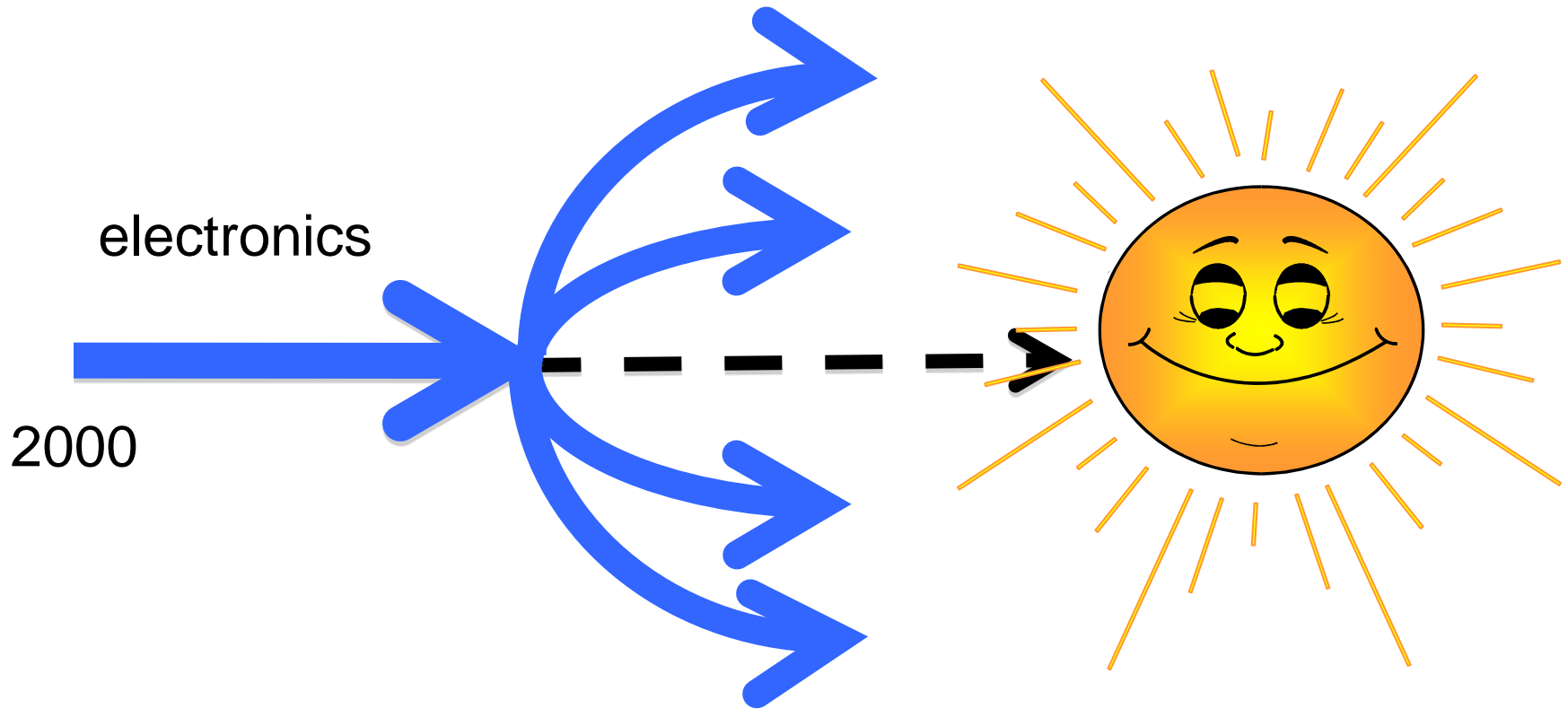
transistor
~ 1947

IC
~ 1959

CMOS
~ 1980's



The “Era of Accelerated Technology Innovation”



More diverse, less predictable
rapidly changing, problem-driven

21st Century Electronics

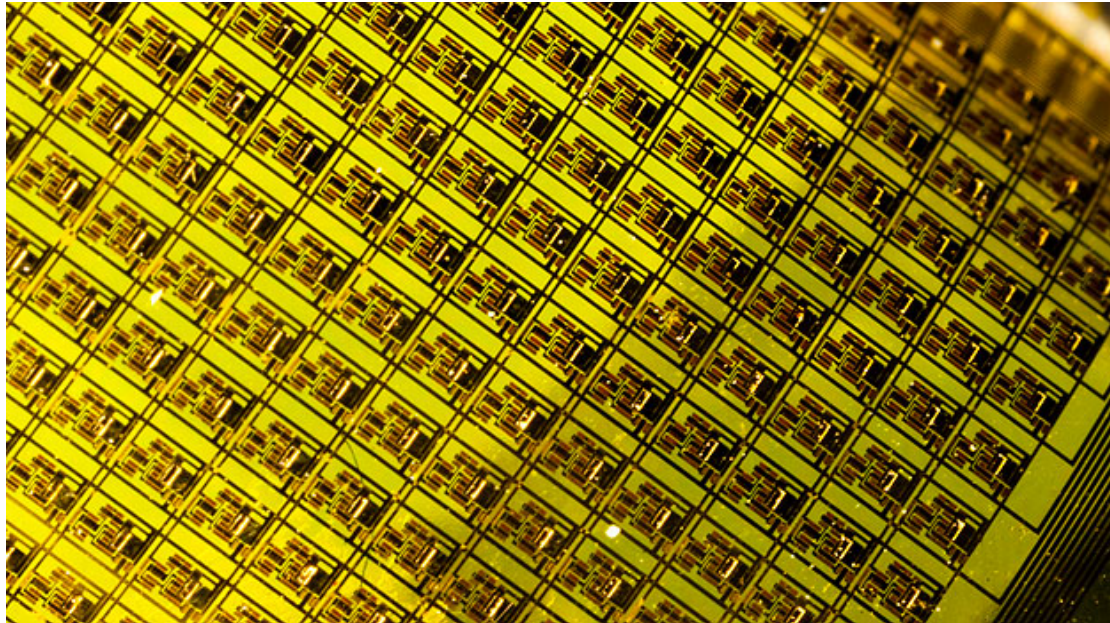
CMOS transistors for logic
III-V transistors for RF
A/D and D/A convertors
Digital Signal processor
Microprocessor
ROM and FLASH memory



www.apple.com

CMOS imager
Gyroscope
MEMS devices
Magnetometer
Microphone, speaker
LCD display and touch screen

21st Century Electronics



Bio-integrated electronics for cardiac therapy

This flexible, waterproof circuit can wrap the surface of the heart...

John Rogers Research Group: <http://rogers.matse.illinois.edu>

needed today: technology maestros

society's grand challenges



technology maestros:

- Are deep in their field
- Understand related disciplines and technologies
- Able to learn, adapt, and contribute (quickly)

an opportunity

SEEC

*Semiconductor Electronics
Education Committee*

R.B. Adler, et al., 1960-1967



1960's

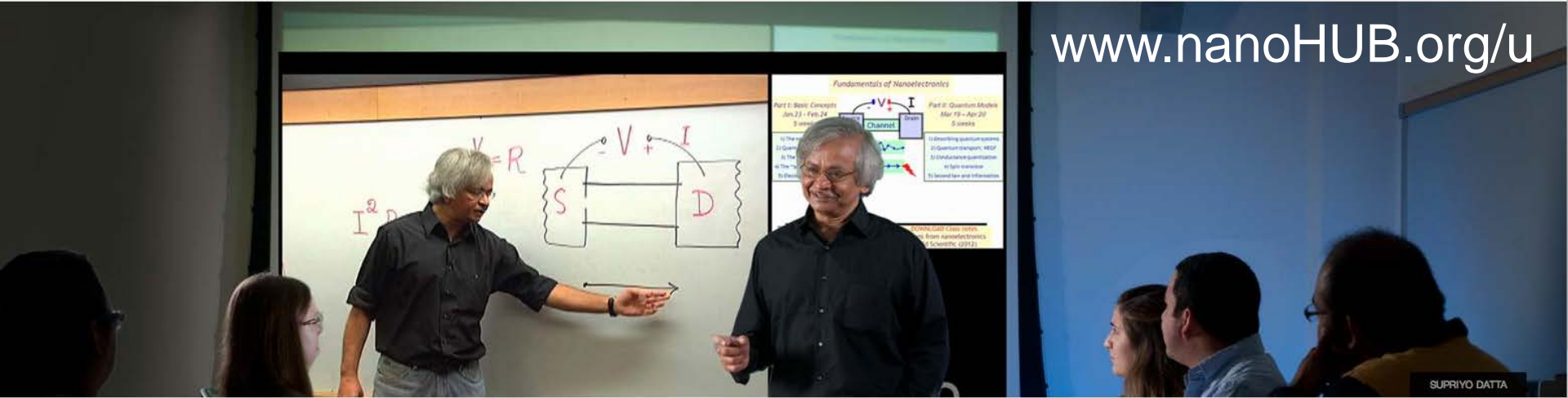


<http://nanohub.org/u>

2010's

Truly a fabulous learning experience."

— past nanoHUB-U student



Welcome to nanoHUB-U

Transcending disciplines with short courses accessible to students in any branch of science or engineering.

Cutting-edge topics distilled into short lectures with quizzes, homework, practice exams.

SELF-PACED COURSES FOR FREE

Learn at your own pace.

LIVE SHORT COURSES FOR \$30

Interact with nanoHUB-U profs

Coming Fall 2013: "Thermoelectric Science and Technology" and "Electronic Biosensors"

EDUCATORS

Use nanoHUB-U on your campus

CERTIFICATES, BADGES, CREDIT

Learn more about receiving credit and/or recognition

Nano-tuts

Short tutorials taught succinctly by our award-winning professors.

Topics based on your suggestions!



Lessons from Nanoscience

Low-cost lecture notes from World Scientific Publishing Co.



LECTURES

L5.1: The Ultimate MOSFET and Beyond - Fundamental Limits

[Play video](#) [YouTube](#) [Download](#) [L5.1 Slides](#) [Quiz](#)

L5.2: The Ultimate MOSFET and Beyond - Heterostructure FETs

[Play video](#) [YouTube](#) [Download](#) [L5.2 Slides](#) [Quiz](#)

L5.3: The Ultimate MOSFET and Beyond - Heterostructure BJTs

[Play video](#) [YouTube](#) [Download](#) [L5.3 Slides](#) [Quiz](#)

L5.4: The Ultimate MOSFET and Beyond - The CMOS Inverter

[Play video](#) [YouTube](#) [Download](#) [L5.4 Slides](#) [Quiz](#)

L5.5: The Ultimate MOSFET and Beyond - CMOS Logic Performance

[Play video](#) [YouTube](#) [Download](#) [L5.5 Slides](#) [Quiz](#)

L5.6: The Ultimate MOSFET and Beyond - Analog/RF CMOS

[Play video](#) [YouTube](#) [Download](#) [L5.6 Slides](#) [Quiz](#)

DISCUSSION FORUM

[Week 5 discussion](#)

HOMEWORK

[Week 5 homework](#)

[Submit Week 5 homework here](#)

[Load VSspice](#)

[VS Model 45nm CMOS.txt](#)

****Special Thanks to Professors Dimitri Antoniadis and Jacob White of MIT for the HW exercises and and the SPICE like circuit simulation tool.**

[Extended Homework Problem Set](#)

[Solutions](#)

[Extended Homework Problem Set Solutions](#)

Tutorial: The Ultimate MOSFET and Beyond - Homework Solution

[Play video](#) [YouTube](#) [Download](#)

EXAM

[Week 5 exam](#)

[Retake \(optional\)](#)

[For more details, see the Course Exam Policies on the FAQ Page](#)

REFERENCES AND SUPPLEMENTAL MATERIALS

[Comments about Digital Circuits](#)

about nanoHUB-U

- Rethinking traditional topics.
- A forum for evolving viewpoints.
- Short (5 weeks) but not superficial.
- Designed to “transcend disciplines” and be broadly accessible.
- Focus on seniors, beginning grad students, working engineers.

nanoHUB-U numbers

- Launched in Spring 2012
- 7 courses offered by 6 instructors
- More than 2500 students:
 - 65 countries represented
 - 318 universities represented
 - 72 companies represented
- Increasing use on-campus in “blended courses”

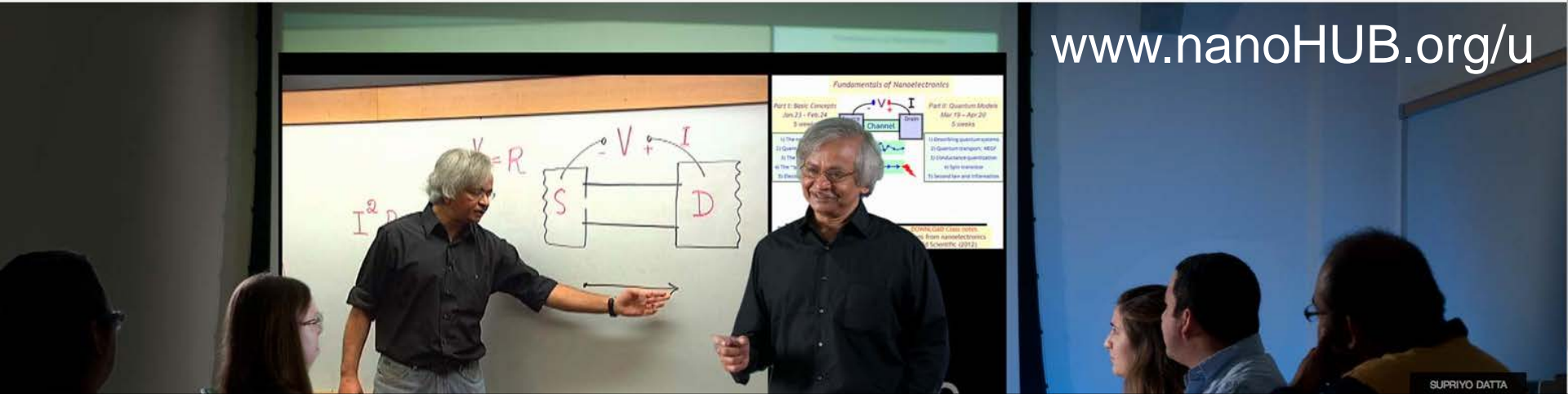


<http://nanohub.org/u>

driven by research (seeded by Intel)

Truly a fabulous learning experience."

— past nanoHUB-U student



www.nanoHUB.org/u

SUPRIYO DATA

“Thanks to your team ... for introducing courses on subjects that are **never to be found anywhere** -- accessible for all students worldwide.

While the concept of MOOC from other platforms...are just catching up... nanoHUB saw it's potential way before others and stands out as a unique one from others for its quality content .. delivery format...above all choice of subject titles. Thanks!”

-nanoHUB-U student in Australia

plans, directions, goals

- Expand curriculum, engage other faculty, other universities, industry partnerships, figure out certification and credit, sustainability, etc.

Goals:

- 1) Become a major, global forum for the developing the **new** educational resources needed for 21st Century electronics.
- 2) Learn how to use these technologies to transform on-campus education.

The first nanoHUB-U offering

Fundamentals of Nanoelectronics

Part I: Basic Concepts

Jan.23 – Feb.24, 2012

~ 600 registered

Part II: Quantum Models

Mar.19 – Apr.20, 2012

~ 400 registered

- 1) The new Ohm's law
- 2) Quantum of resistance
- 3) The nanotransistor
- 4) The "spinning" electron
- 5) Electricity from heat

- 1) Describing quantum systems
- 2) Quantum transport: NEGF
- 3) Conductance quantization
- 4) Spin transistor
- 5) Second law and information

WEEK 1

The new "Ohm's law" for nanoscale resistors

Posted

LECTURES

M1.1 The New Ohm's Law - Change in Paradigm

[Play video](#) [YouTube](#) [Download](#) [Quiz](#)

M1.2 The New Ohm's Law - Two Key Concepts

[Play video](#) [YouTube](#) [Download](#) [Quiz](#)

M1.3 The New Ohm's Law - Why Electrons Flow

[Play video](#) [YouTube](#) [Download](#) [Quiz](#)

M1.4 The New Ohm's Law - Generalized Ohm's Law

[Play video](#) [YouTube](#) [Download](#) [Quiz](#)

M1.5 The New Ohm's Law - Conductivity and Ballistic Conductivity

[Play video](#) [YouTube](#) [Download](#) [Quiz](#)

M1.6 The New Ohm's Law - Where is the Heat?

[Play video](#) [YouTube](#) [Download](#) [Quiz](#)

LECTURE NOTES

[Week 1 Slides](#)

DISCUSS

[Week 1 discussion](#)

HOMEWORK

[Week 1 homework](#)

[Solutions](#)

Problem 1 tutorial

[Play video](#) [YouTube](#) [Download](#)

Problem 2 tutorial

[Play video](#) [YouTube](#) [Download](#)

Problem 3 tutorial

[Play video](#) [YouTube](#) [Download](#)

Problem 4 tutorial

[Play video](#) [YouTube](#) [Download](#)

EXAM

[Week 1 exam](#)

[Retake \(optional\)](#)

http://www.youtube.com/watch?v=gFRll8phF_M

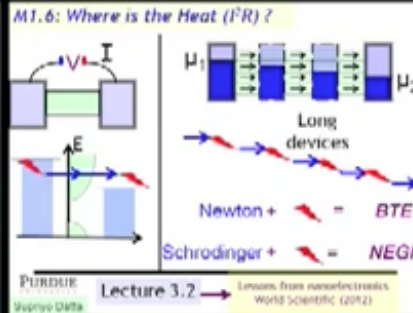


FUNDAMENTALS OF
NANOELECTRONICS: BASIC CONCEPTS

The New Ohm's Law
Module 1.6: Where is the Heat?



Supriyo Datta
Electrical Engineering
Purdue University, West Lafayette, IN



Supriyo Datta

The New Ohm's Law:
Module 1.6
Where is the Heat?



Uploaded on Dec 18, 2011

Table of Contents:

00:09 Recap

04:30 Joule heating

06:30 How contacts get heated

09:25 Elastic resistors are conceptually simpler

16:40 Elastic resistors in series

21:15 Mechanics and thermodynamics

nanoHUB-U Fundamentals of Nanoelectronics I: M

• 2.5 hours of video lecture
in six 25-minute modules (M)

• 4 problems with solutions
and video tutorials (T)

LECTURES

M1.1 The New Ohm's Law - Change in Paradigm

> Play video > YouTube > Download > Quiz

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Problem 3 tutorial

> Play video > YouTube > Download

Problem 4 tutorial

> Play video > YouTube > Download

EXAM

> Week 1 exam

> Retake (optional)

“ Flipped Syllabus “

Syllabus

	<u>Video Lectures</u>	<u>Text (LNE)</u>
Exam 1 (8/29): The new Ohm's law	Part I: M1.1-1.6, T1.1-1.4	L1-4
Exam 2 (9/12): Quantum of conductance	Part I: M2.1-2.6, T2.1-2.4	L5
Exam 3 (9/26): Nanotransistor	Part I: M3.1-3.6, T3.1-3.4,	L6-8
Exam 4 (10/10): Spin valve	Part I: M4.1-4.6, T4.1-4.4	L14
Exam 5 (10/24): Thermoelectricity, Entropy Law of equilibrium	Part I: M5.1-5.5, T5.1-5.4 Part II: M5.1-5.3	L10,11 L16
Exam 6 (11/7): Quantum systems	Part II: M1.1-1.6, T1.1-1.4	L18
Exam 7 (11/21): Quantum transport	Part II: M2.1-2.6, 3.1 T2.1-2.4,	L19,20