Introduction

EECS 320

Introduction to Semiconductor Devices

Why Should I Take EECS 320

- Almost 100% of Electrical Engineering Ultimately Depends on Non-linear Devices to
  - Control/Rectify Electric Power
  - Amplify Analog Signals
  - Multiply Analog Signals
  - Perform Computation
  - Transmit and Receive Information (analog and digital)
  - Detect Light (including imaging)
  - Turn Light into Energy (solar cells)

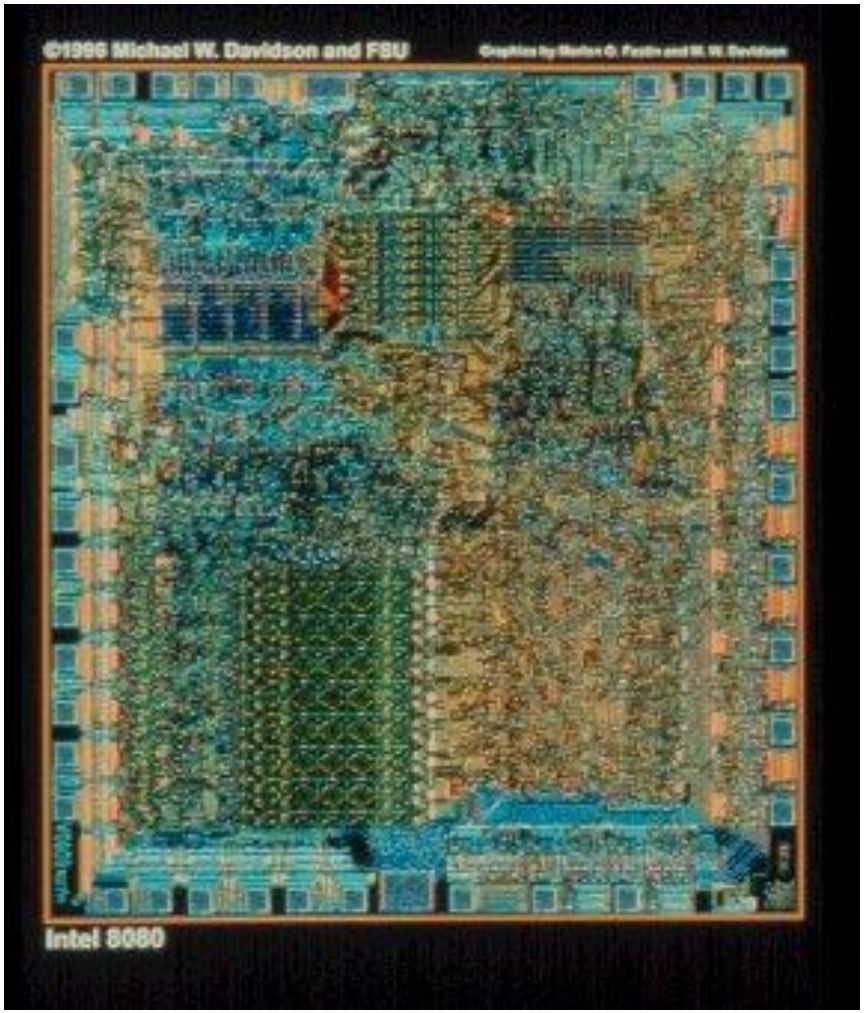
Semiconductors

- These work and are still used for some limited applications
- Semiconductors are the answer for speed, power efficiency, integration

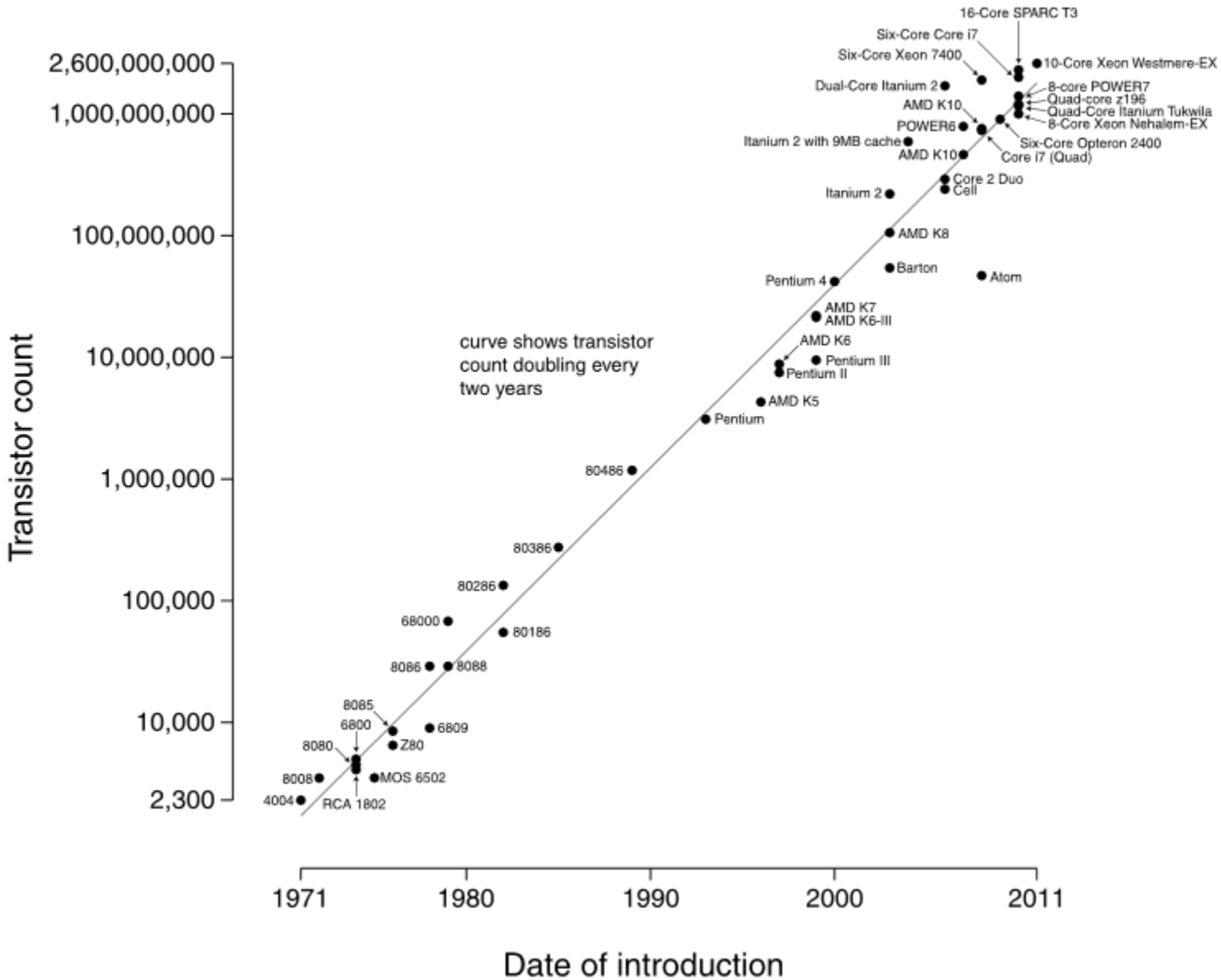
Integrated Circuits

Integrate billions of transistors in small area

Amazing capabilities for information processing and storage!



Microprocessor Transistor Counts 1971-2011 & Moore's Law

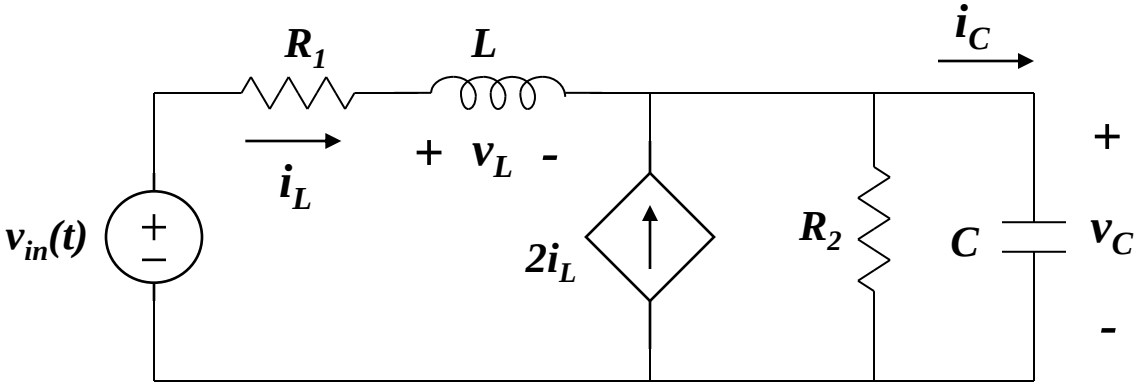


Why take 320?

- Without semiconductor devices, almost nothing you want to do in EE/CE would be possible
- Understanding this core enabling technology is of relevance to every EE, CE

Linear Circuits

In EECS 215 you learned about *linear* devices and circuits

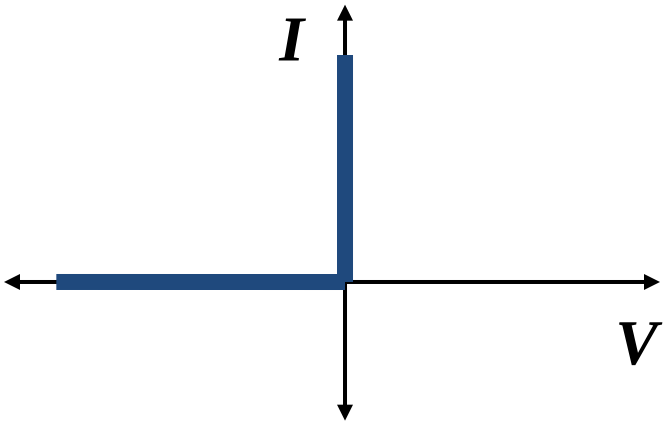


In EECS 320, you will learn of important *nonlinear* devices: *Diodes* and *transistors*

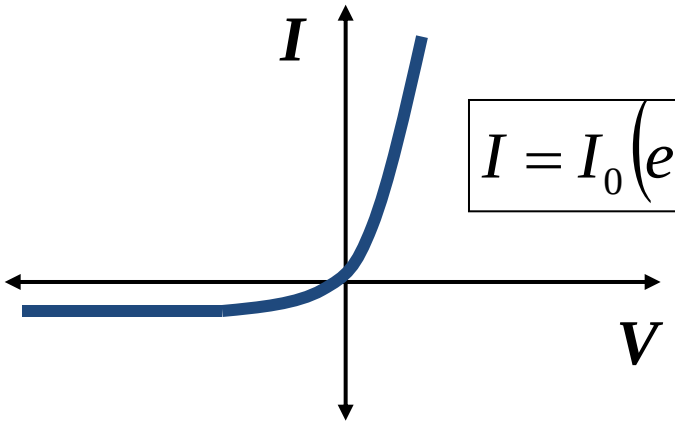
Diode

A one way valve for current flow

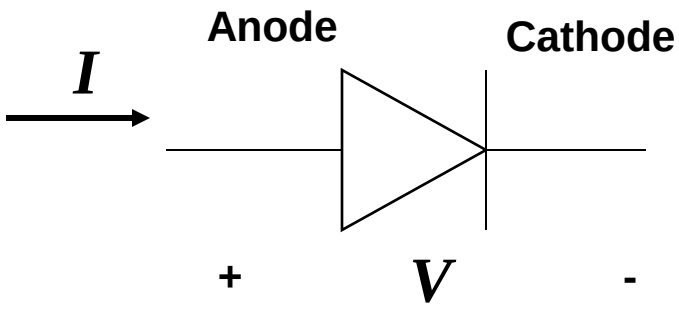
Ideal

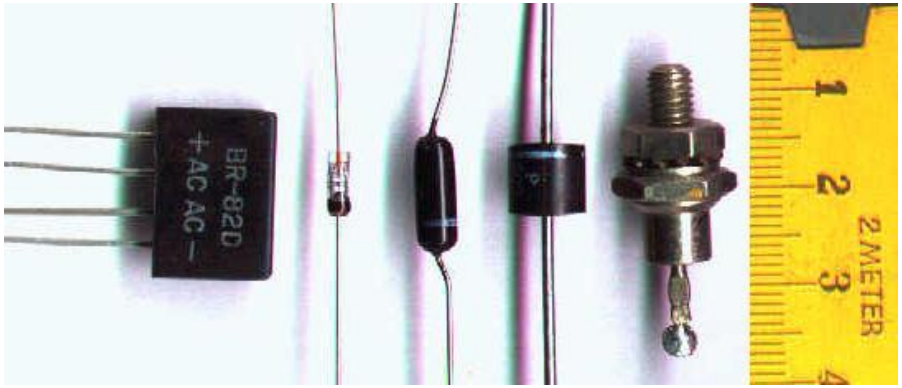


Actual



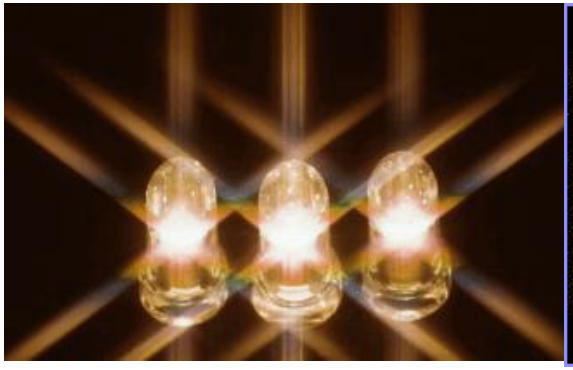
$$I = I_0\left(e^{qV/kT} - 1\right)$$

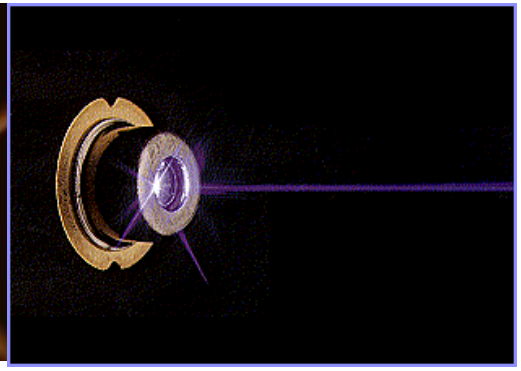




Diode Applications

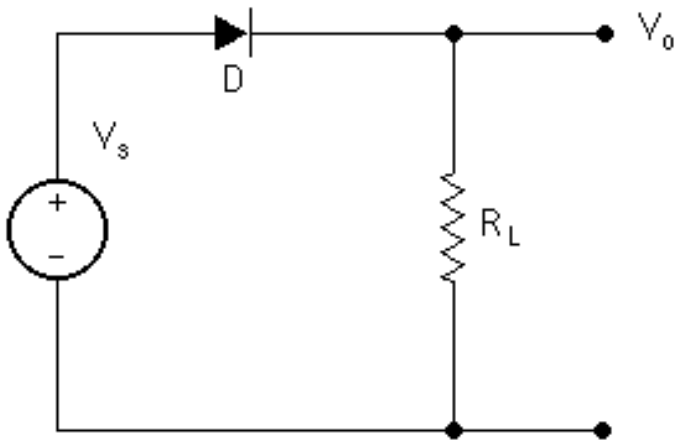
- Rectifier
  - Power conversion
- Over-voltage protection
- Light emitter (light emitting diode LED)
- Light detector (photodiode, solar cell)

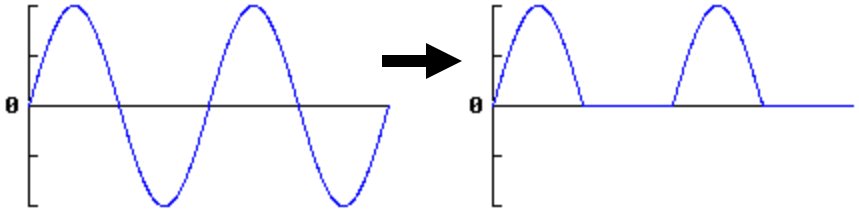




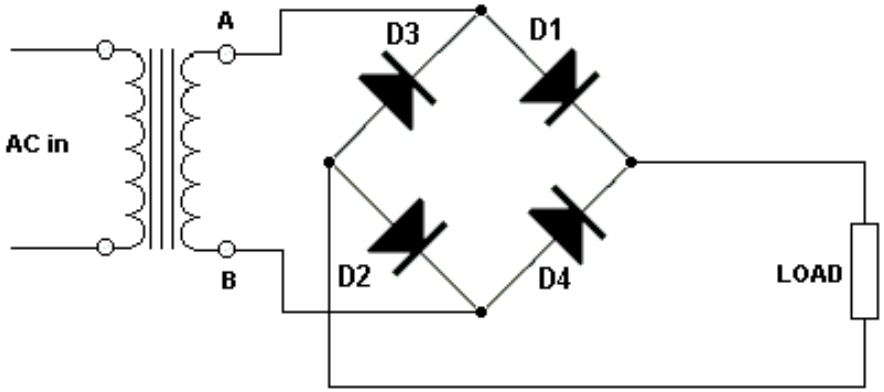
Diode Rectifiers

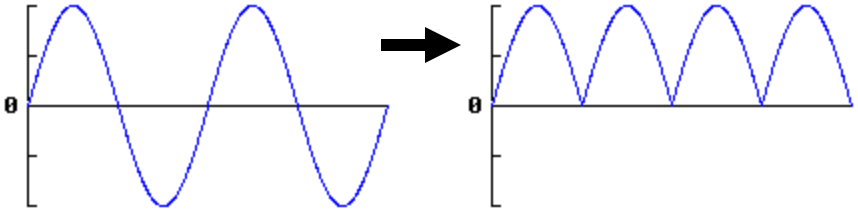
Half-wave rectifier



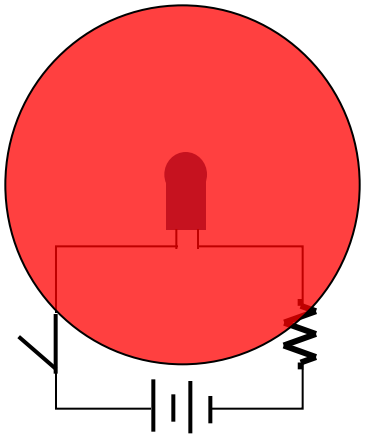


Full-wave rectifier

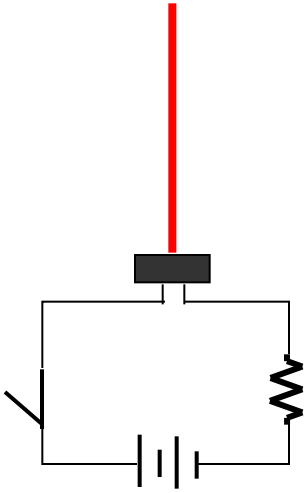




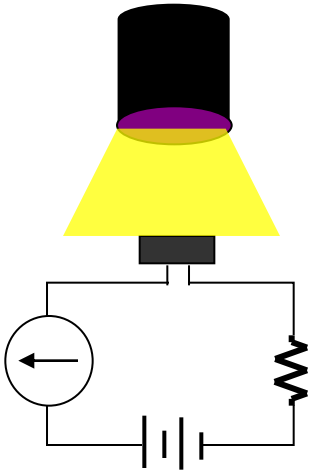
Light Sensitive Diodes



Light-emitting Diode



Semiconductor Laser



Visible Light Sensor

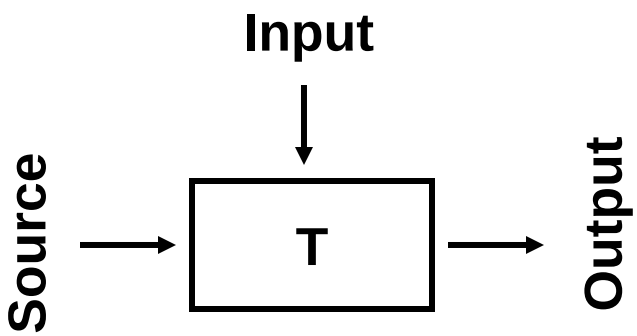
Transistor

tran•sis•tor (trán-zìs’ter)

A solid-state electronic device that is used to control the flow of electricity in electronic equipment and consists of a small block of a semiconductor with at least three electrodes

Trans(fer) + (res)istor

Idea: control large output with small input



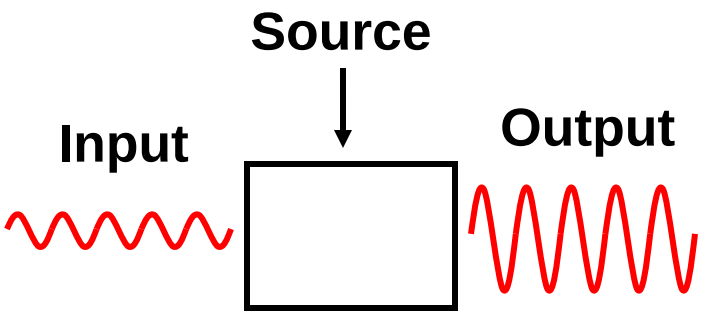
This device should exhibit *gain*

What Is A Transistor Used For?

Analog

Gain: Signal amplification

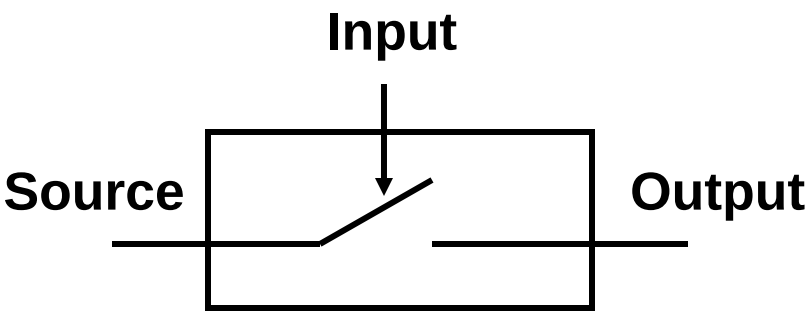
Realization of signal processing electronically



Digital

Switch: on or off

Realization Of Boolean logic electronically

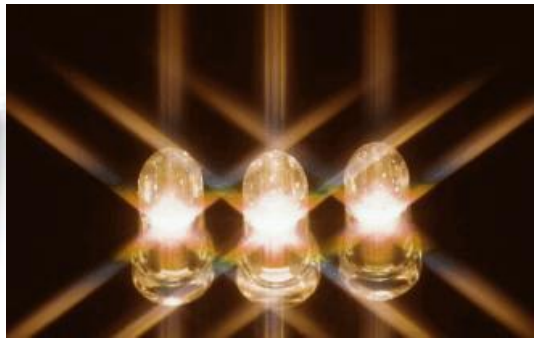


Integrate many devices into a circuit

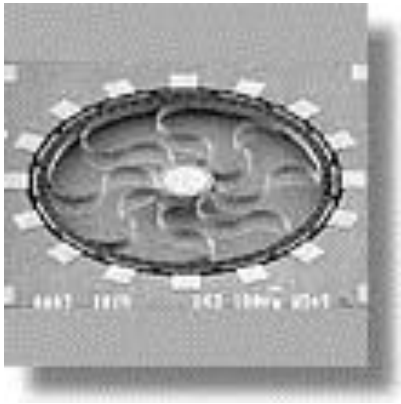
Semiconductor Devices: Other Phenomena

Electronic devices may also interface with physical phenomena including light, pressure, temperature, etc

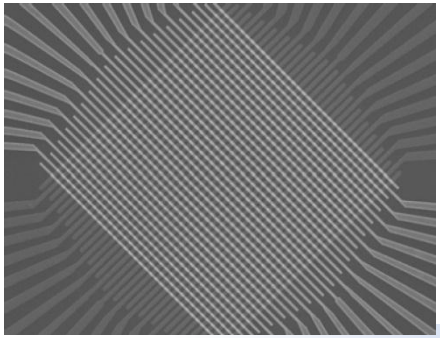
Optoelectronics

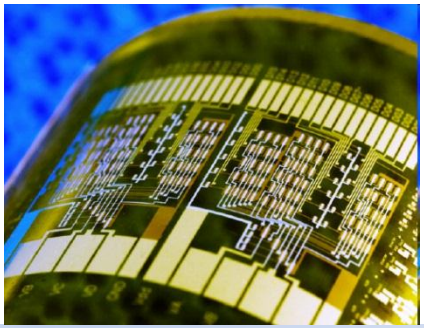


Sensors



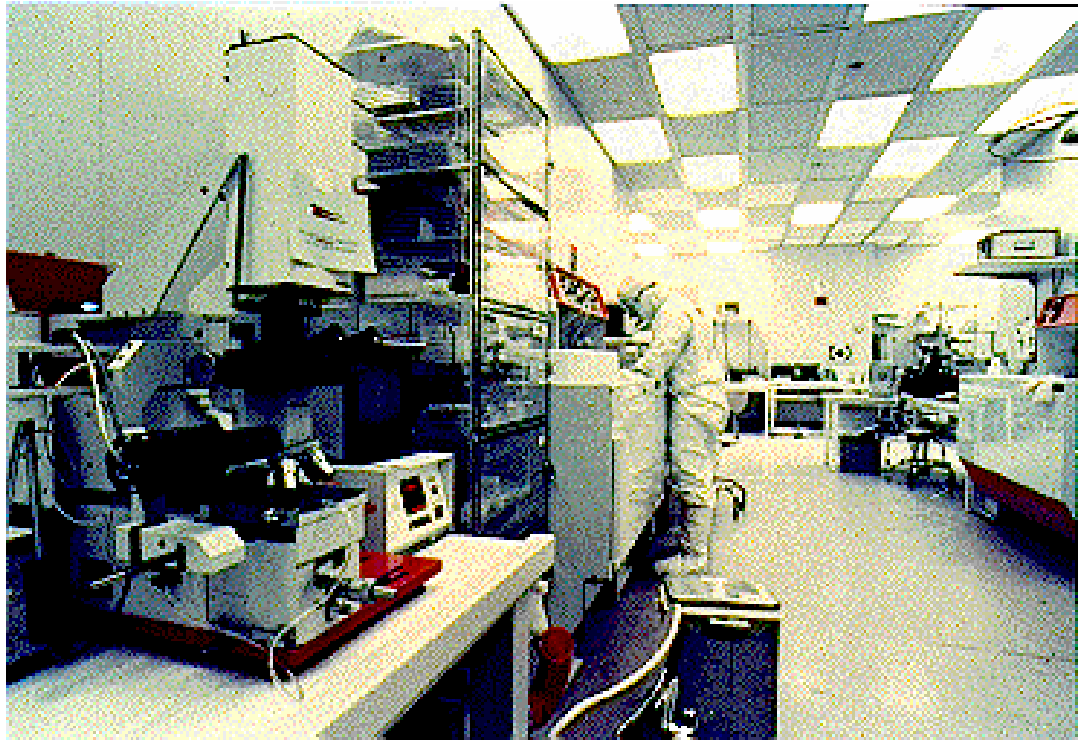
Nanotechnology





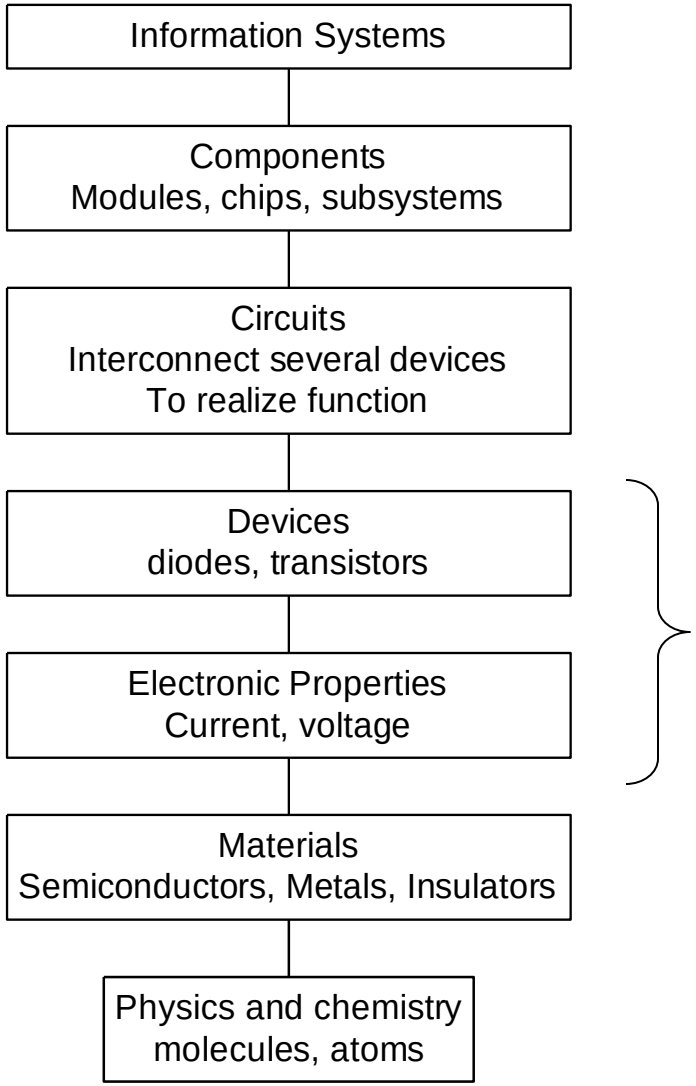
Lurie Nanofabrication Facility

We are fabricating such devices here as we speak!



The "clean room" – fabricate solid state devices and systems at the micro and nanoscale

Why should I take EECS 320?



Systems, CE, CS

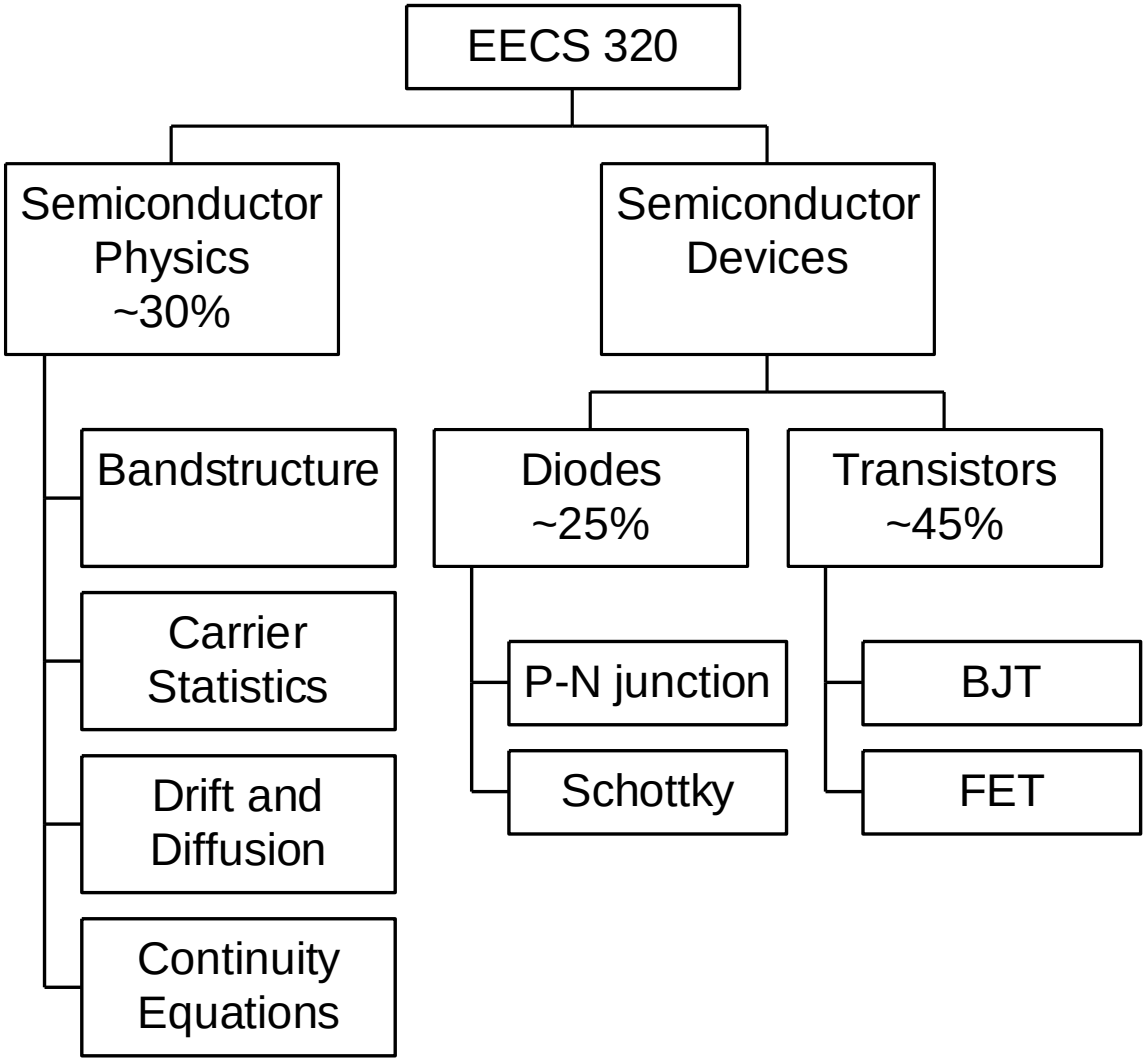
Systems, Circuits

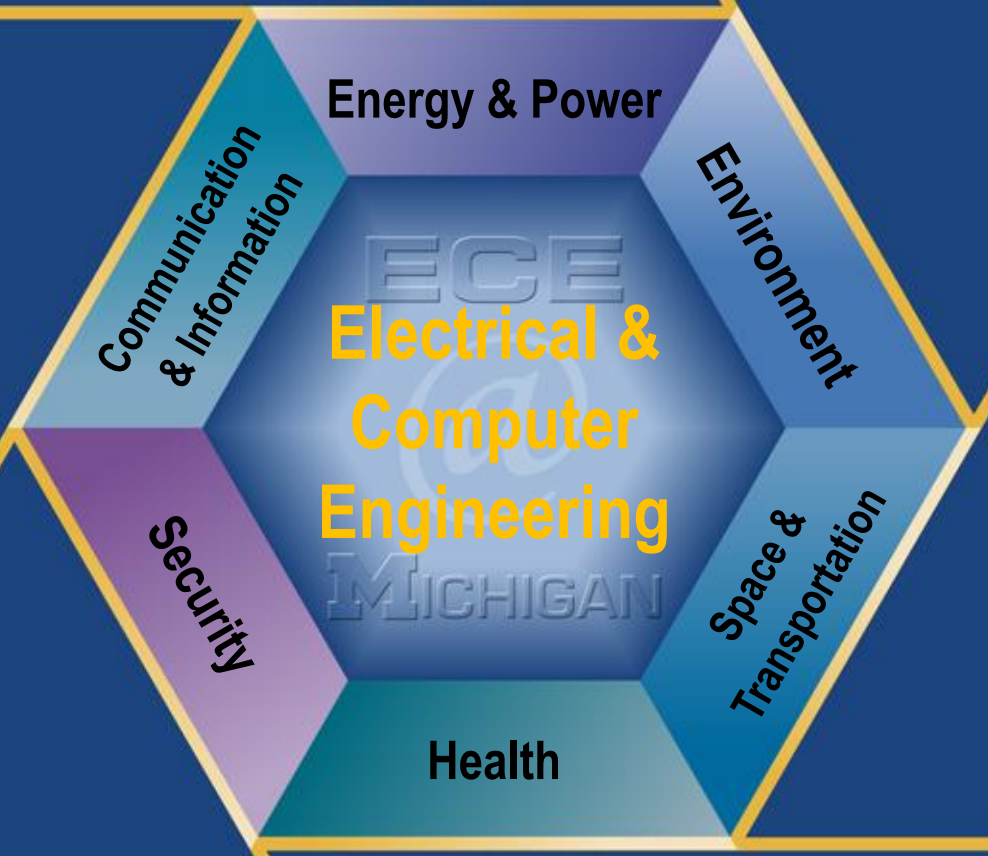
Circuits; analog, digital, VLSI

Solid state, EECS 320

Electromagnetics and optics require knowledge of devices and circuits

EECS 320 Course Overview




Energy & Power
Environment
Space & Transportation
Health
Security
Communication & Information
ECE
Electrical & Computer Engineering
@
MICHIGAN

ECE
@
MICHIGAN
(thin slice)
Hospital
1 cm
Double-clad
Optical Fiber

Great Job Outlook & Top Salaries!

Engineering Major	# Jobs	Salary (# reporting)
Electrical/Electronics	301,500	$59,074 (79)
Civil Engineering	278,400	$52,605 (56)
Mechanical	238,700	$58,392 (139)
Industrial/Manufacturing	214,800	$57,734 (36)
Computer Hardware	74,700	$60,879 (24)
Aerospace/Aero- and Astronautical	71,600	$57,231 (12)
Chemical	31,700	$65,142 (50)
Materials	24,400	$59,125 (4)
Nuclear	16,900	$58,650*
Bioengineering & Biomedical	16,000	$62,125 (4)

"The Need for Electrical Engineers"

2010 IEEE Spectrum web podcast

Congress sees a weakness in the lack of electrical engineers (only 2) and software engineers (0) on staff overseeing vehicle safety. Future hiring is anticipated in these areas.

Future Job Outlook
BLS (Bureau of Labor Statistics)

The occupation of electrical and computer engineers engineering is projected to grow as fast as the average for all occupations, or faster.

Source for Salaries: Winter 2010 Salary Survey, National Association of Colleges and Employers. [*Nuclear from Jan 2009 data] These are salaries for new graduates with their undergraduate degrees.
Source for Job Numbers: Bureau of Labor Statistics – Occupational Outlook Handbook, 2010-11 Edition (#'s from 2008

Job Prospects Remain Strong for EE/CE!

Wall Street Journal (4/8/10)
When comparing starting salaries of new graduates with last year's graduates, electrical engineers saw the largest increase in salary, around three percent, followed by chemical and civil engineering graduates. Graduates with computer-related degrees increased by almost six percent. For all graduates, however, average starting salaries actually fell by 1.7%.

The Consumerist (5/10/10)
Engineering majors were in 7 of the 10 categories for top average salaries, both starting and mid-career salaries (9 if you include related degrees in physics and computer science). CE and EE were in the top 4.

2010 News Reports

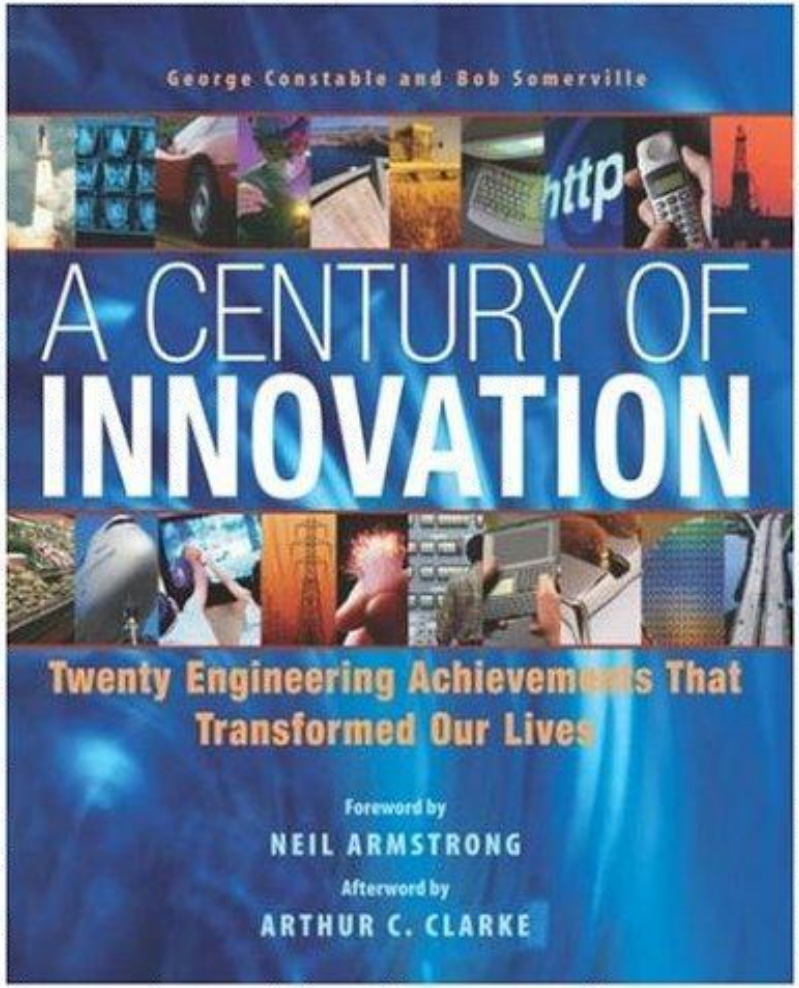
CNN Money (4/8/10) "
"College students gearing up to graduate this spring are likely to make less on their first job than those who got their degree last year," a report from the National Association of Colleges and Employers indicates."

"For engineering students, initial pay offers are 1.2% higher at $59,149. Electrical engineering majors' salaries have jumped the most, by 3% to $59,326."

Wall Street Journal (5/10/10)
25% of all soon-to-be alumni had a job offer before graduating. For engineering majors, that number was between 39-43%.

EE and CE Majors are Game Changers

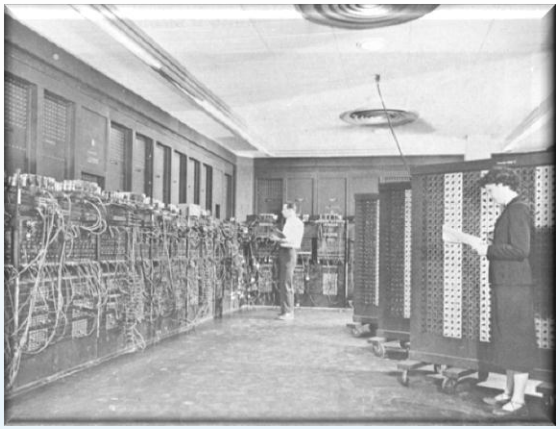
Innovation and Accomplishment

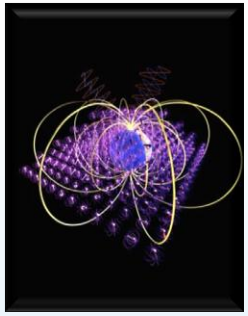


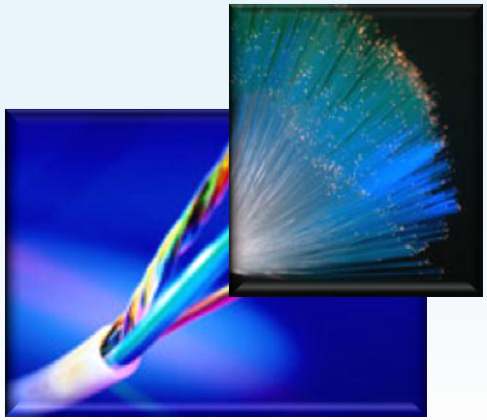
The 20 Engineering Achievements That Transformed Our Lives – mostly made possible through electrical and computer engineers!

Electrification
Electronics
Radio and Television
Computers
Telephony
Internet (fiber optic technology)
Imaging
Spacecraft
Lasers and Fiber Optics
Health Technologies
Household Appliances
High Performance Materials
Automobile
Airplane
Air Conditioning and Refrigeration
Highways
Agricultural Mechanization
Water Supply and Distribution
Nuclear Technologies
Petroleum and Petrochemical Tech.

EE and CE Connects the World







Job Growth in Green Energy!

The Bureau of Labor Statistics forecasts that green jobs will increase in number for at least the next decade.

Solar panels hooked up to electric grid in NJ – right now!

The U.S. plan to reduce dependence on foreign oil hinges on new energy sources and more efficient lighting

Communications box

Solar Cell Technology

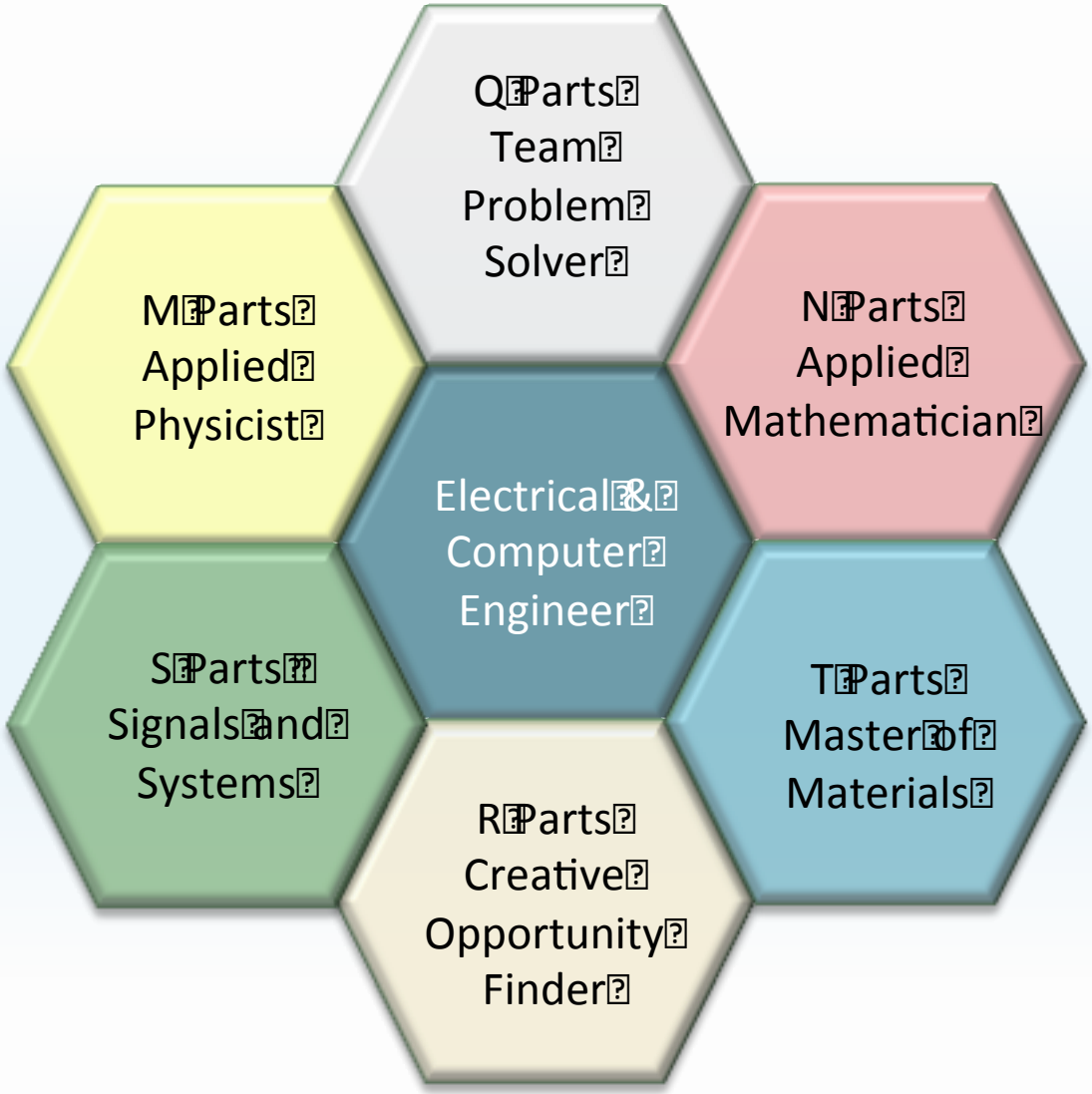
Electric Vehicle Technology

Careers in Electrical and Computer Engineering

Sample Activities

- Design, development, and implementation of electronic devices or systems, such as power generators, computer systems, space systems and satellites, lighting systems, medical technology
- Design and improve systems for automobiles, including sensors, anti-lock brakes, etc.
- Design and improve wireless communication provided by cell phone systems and GPS devices
- Work on the electronic and systems areas of cars, robots, cell phone systems, lighting and wiring in buildings, radar and navigation systems
- Research and development
- Teach the next generation!

Electrical / Computer Engineer



Undergraduate Degrees in EECS

EECS Department

Electrical and Computer Engineering

- Electrical Engineering
- Computer Engineering
- Minor in EE

Computer Science and Engineering

- Computer Science (Engineering and LS&A)
- Minor in CS

Areas of Research in EECS

EECS Department

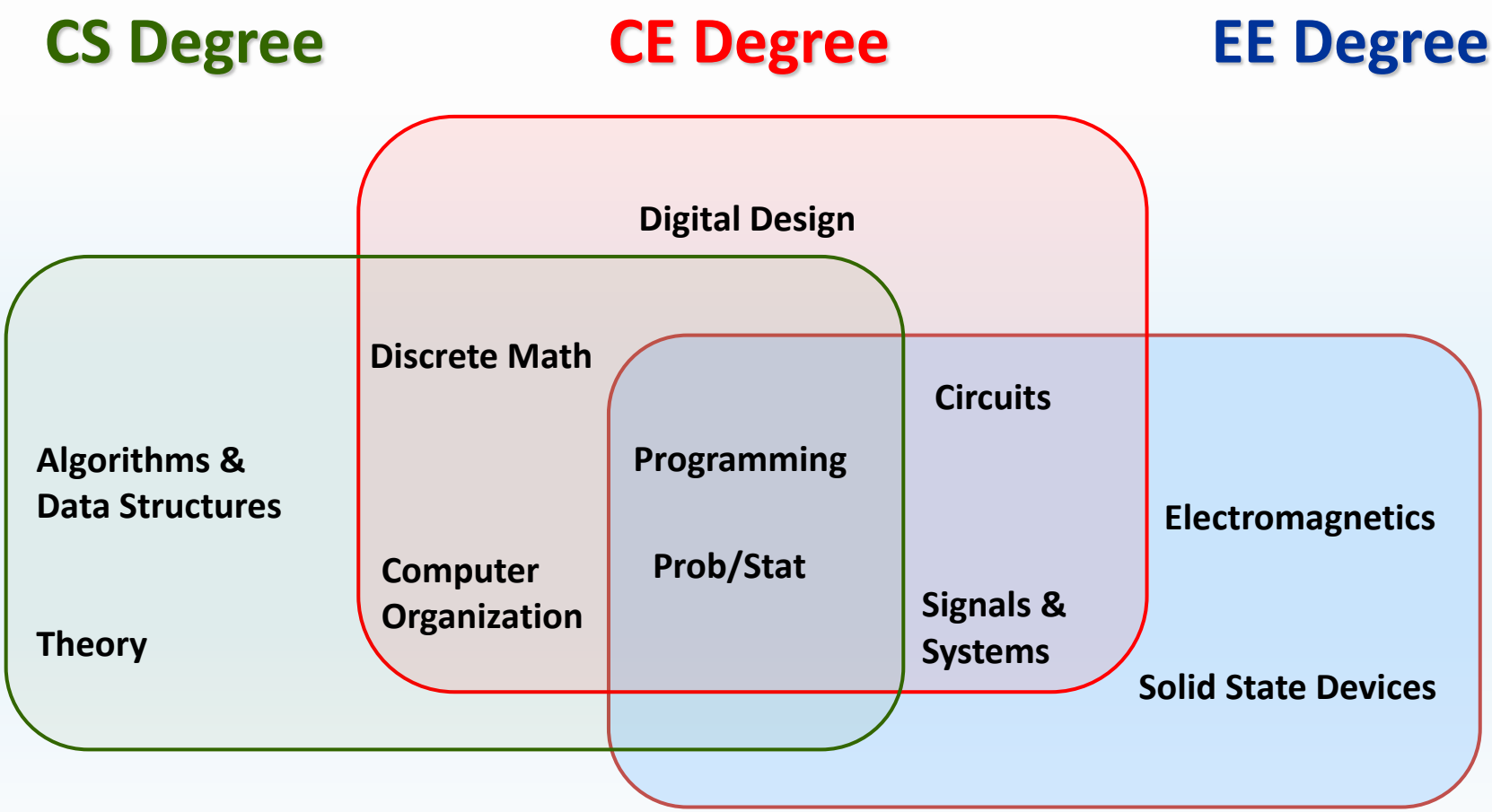
Electrical and Computer Engineering

Applied Electromagnetics
Communications
Computer Vision
Control Systems
Energy & Power
Integrated Circuits & VLSI
MEMS & Integrated Microsystems
Nanotechnologies & Nanodevices
Optics and Photonics
Plasma Science
Quantum Science & Devices
Robotics
Signal & Image Processing
Solid-State Devices

Computer Science and Engineering

Artificial Intelligence
Bio & Health Informatics
Cloud Computing
Computer & Device Architectures
Database Management Systems
Embedded Systems
High-Performance Computing
Human-Computer Interaction
Low Power & Green Computing
Mobile Computing & Applications
Multiplayer Games & Environments
Operating Systems & Compilers
Performing Arts Technologies
Security & Privacy

EECS Undergraduate Degree Programs



All 3 programs also require EECS 496 (Professionalism, 2 credits)
teaming, entrepreneurship, ethics, …

BSE in Electrical (EE) and Computer (CE) Engineering Major Areas of Concentration

- Circuits and Microsystems
- Applied Electromagnetics and RF Circuits
- Optics and Photonics
- Solid-State Electronics
- VLSI and Computer Engineering
- Control Systems
- Communications
- Signal Processing
- Power/Energy

Solid-State Devices and Nanotechnology
MEMS and Microsystems
Applied Electromagnetics
Signal and Image Processing
Communications
Control Systems
Robotics and Computer Vision
Plasma Science
Optics and Photonics
Quantum Science and Devices
Integrated Circuits and VLSI
Energy and Power
ECE @ MICHIGAN
Research

ECE @ Michigan

MEMS and Microsystems

Biomedical Implantable and Health-Care Microsystems

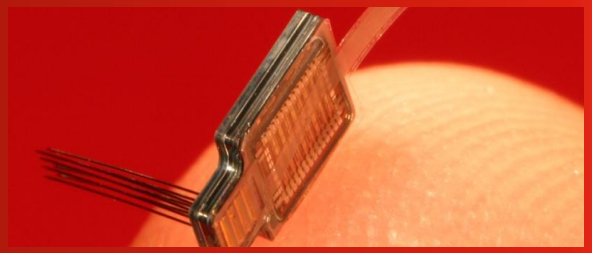
NEMS, Nanosensors and Nanomaterials

Env. Microsystems, Microfluidics and Gas/Chemical Sensors

Micromachining, Packaging, Microplasma-Based MEMS

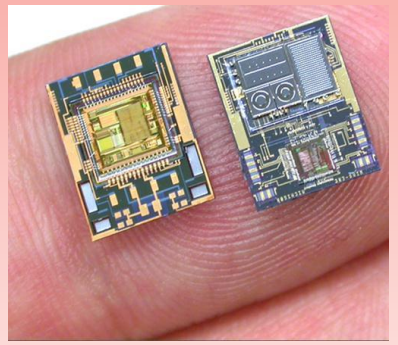
Power Sources & Energy Harvesting

RF-MEMS and Wireless Interfaces



An Integrated Hybrid Recording Array

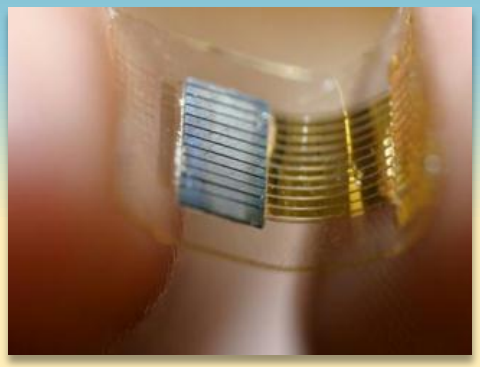
K. Wise/WIMS



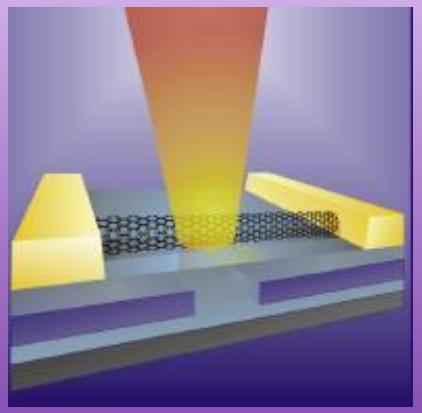
K. Wise/WIMS

A fully integrated microsystem for autonomous data gathering

Fabricated micro thermoelectric power generator from environmental sources

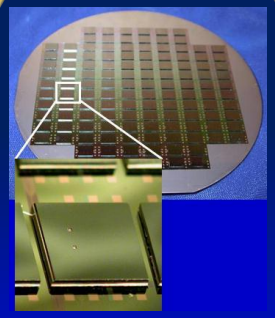


K. Najafi



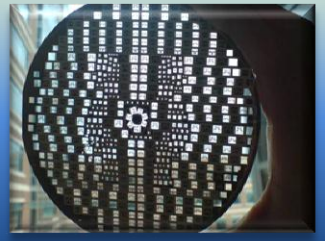
Improving solar cells at a nanolevel: terahertz electrical characterization in nanomaterial photovoltaics

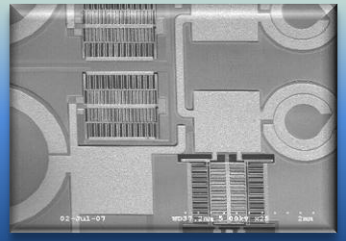
Z. Zhong



AU-SI eutectic vacuum packaging

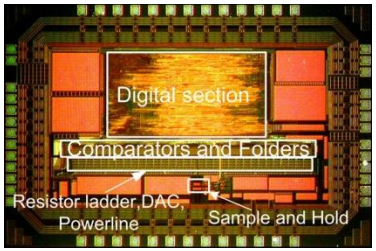
K. Najafi





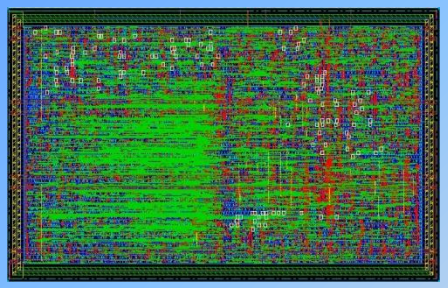
Resonators and integrated circuits

M. Rais-Zadeh



An 8 bit 500MS/S calibrated folding analog-to-digital converter

M. Flynn



UWB for short-range wireless communication

D. Wentzloff

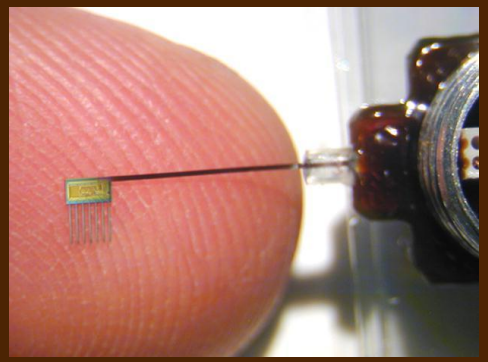
Integrated Circuit Design and VLSI

ECE @ MICHIGAN

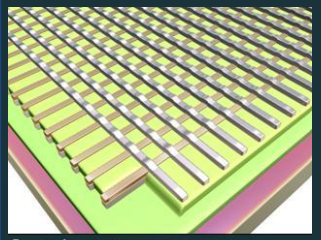
- Analog Electronics and ICs
- RF and Wireless Communication Circuits
- Circuits for MEMS and Microsystems
- VLSI and Digital Circuits & Systems
- Extreme Low-Power Circuits
- Nanoelectronics

A neural interface containing integrated circuitry on the probe

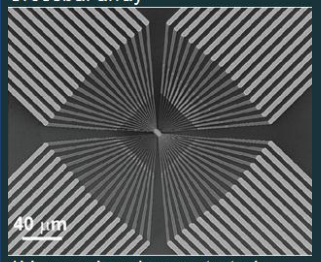
K .Wise, WIMS



Non-transistor based memory and logic devices beyond the end of the roadmap



Crossbar array



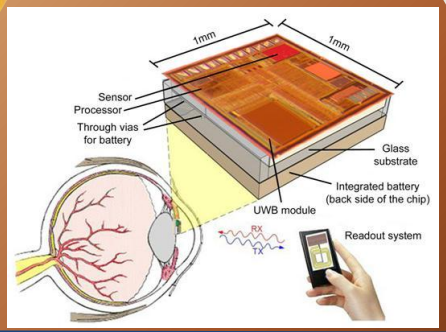
1kb crossbar demonstrated

Crossbar arrays

W. Lu

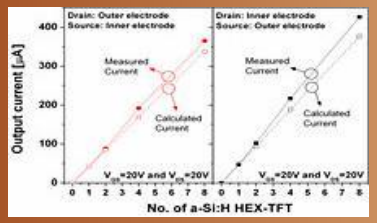
Phoenix: A 30pW platform for sensor applications

D. Blaauw, D. Sylvester



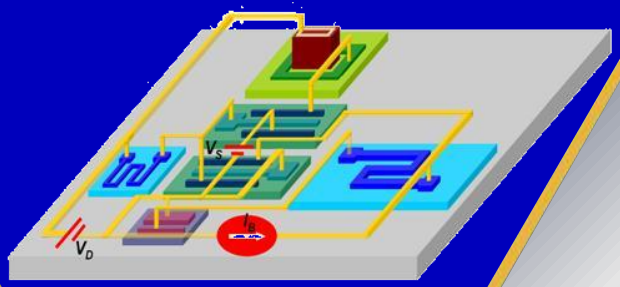
Prototype wire-wrap circuit board measures pollutants using a distributed social network of embedded systems

R. Dick

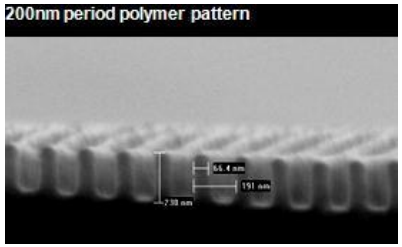


Hexagonal a-Si:H TFTs, a new advanced technology for flat panel displays

J. Kanicki



Magneto-opto-electronic integrated circuits



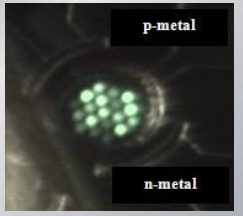
Roll-to-roll nano-imprinting on a flexible plastic web

J. Guo

Solid-State Devices and Nanotechnology

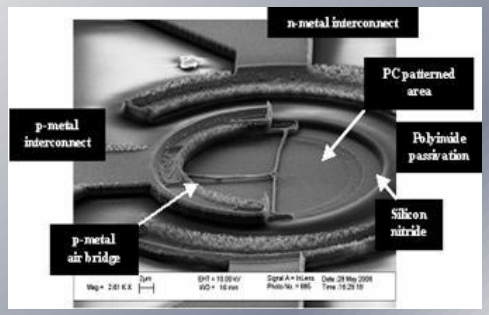
ECE @ MICHIGAN

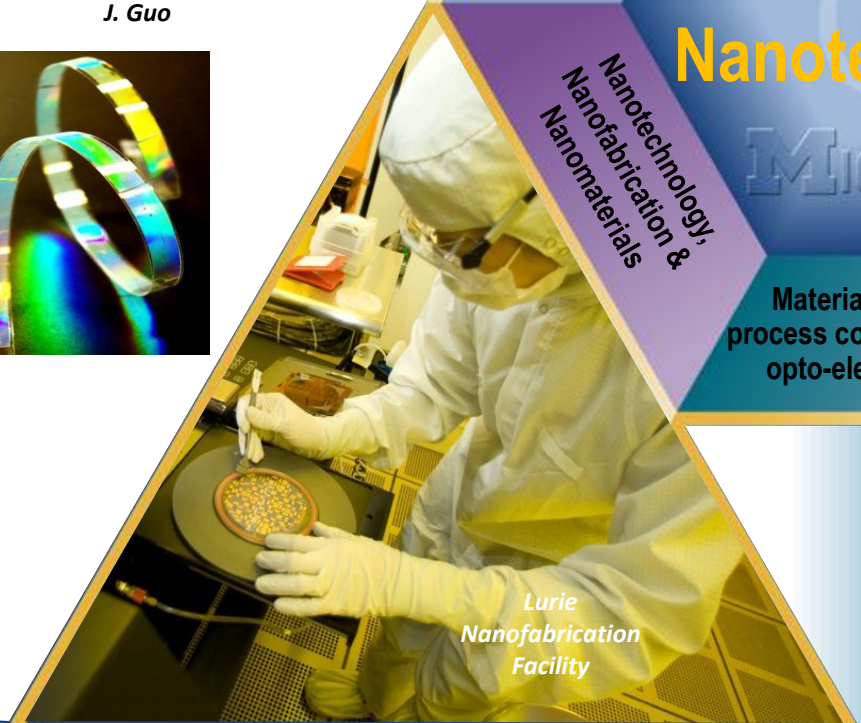
- Displays and Detectors
- High Frequency Devices and Circuits
- Integrated Photonics & Optoelectronics
- Materials, metrology & process control for nano- and opto-electronic devices
- Nanotechnology, Nanofabrication & Nanomaterials
- Polymer and Organic Devices and Circuits



Electrically-driven quantum dot photonic crystal lasers

P. Bhattacharya

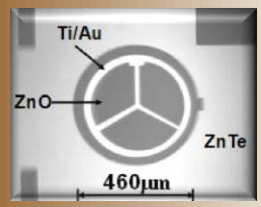




Lurie Nanofabrication Facility

Material Synthesis

Material Properties



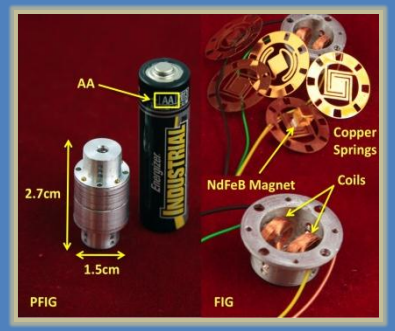
Devices

J. Phillips

PHEV and the grid

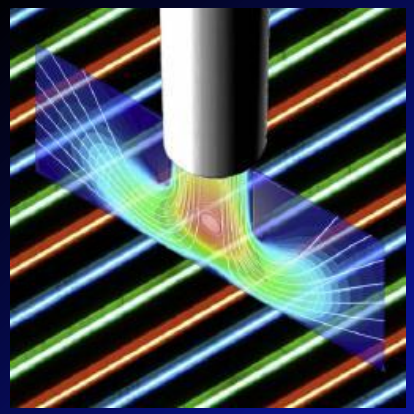
HEV and fuel economy

J. Grizzle, I. Hiskens



Scavenging Power from Low-frequency Vibrations

K . Najafi



White Lighting: Saving energy with organics

S. Forrest

Electric Vehicles

Solid-State Lighting

Electromechanical Energy Conversion

ECE

Energy and Power

@ MICHIGAN

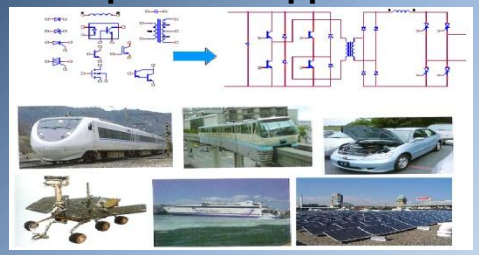
Power Electronic Systems

Power System Analysis and Control

Renewable Energy (wind and solar cells)

New courses in energy

Flow of electrical energy in industrial, residential, and transportation applications

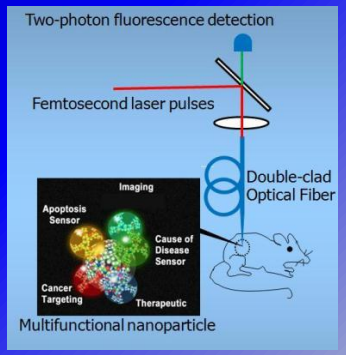


"Smart" Grid

I. Hiskens

I. Hiskens, S. Forrest, J. Phillips, Z. Zhong

HERCULES: Record breaking high intensity laser

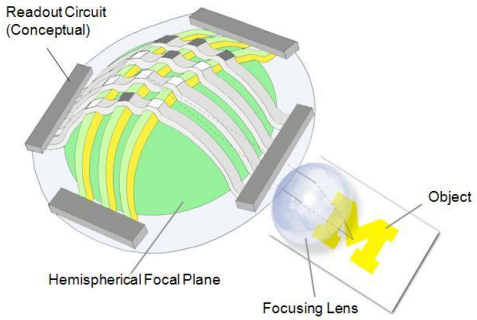


Targeting cancerous tumors for treatment

T. Norris

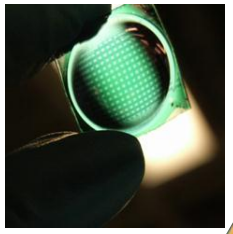
Lasers to manipulate quantum bits, to store and process information

D. Steel



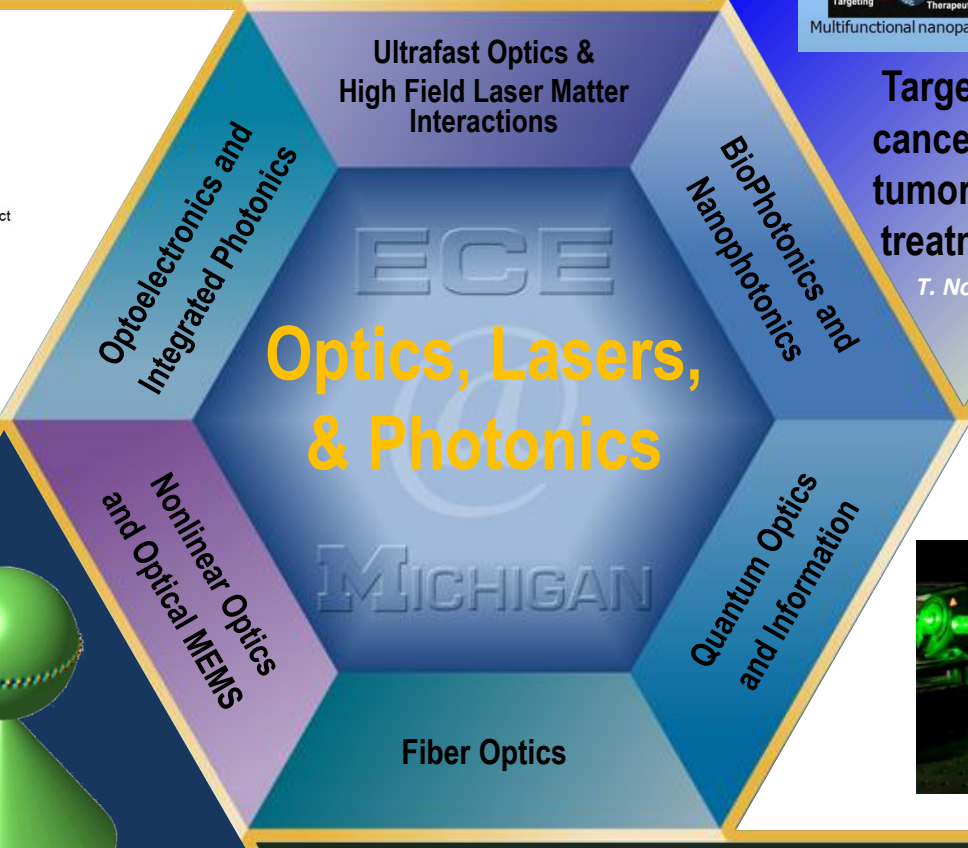
Hemispherical organic photodetector focal plan imaging arrays

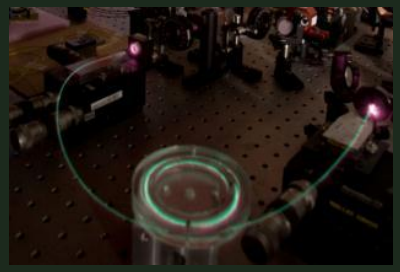
S. Forrest



Highest frequency demonstrated in any type of MEMS – 10GHz

T. Carmon

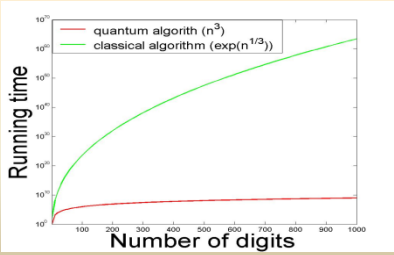




Ultrafast laser pulse generation in optical fibers for next-generation lithography and optical scanning

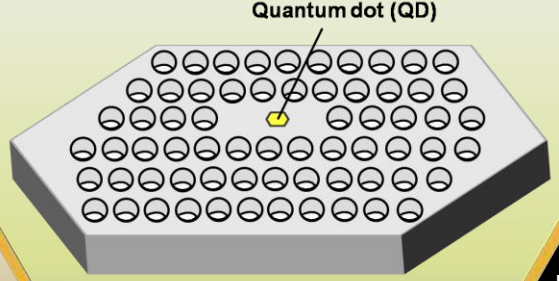
A. Galvanauskas

Quantum Science and Devices: After the End of Moore's Law



Determining the power and limits of quantum computation. Applications to cryptography, new paradigm for Moore's Law

J. Hayes, I. Markov, Y. Shi



Single Photon Control

Future quantum information processing requires manipulation of single photon and electron

PC Ku

Optically driven quantum bits for ultra low-power quantum computers

Spin polarized lasers to study proteins and vitamins, and for secure communication

P. Bhattacharya

Quantum Algorithm Development

Quantum Design Automation

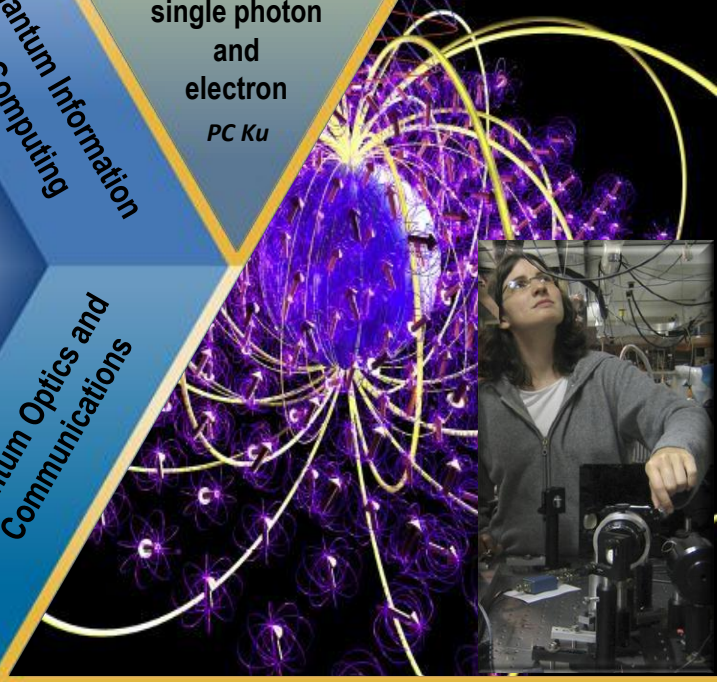
Quantum Spin Devices (Spintronics)

Quantum Information & Computing

Quantum Electronics & Low Dimensional Transport

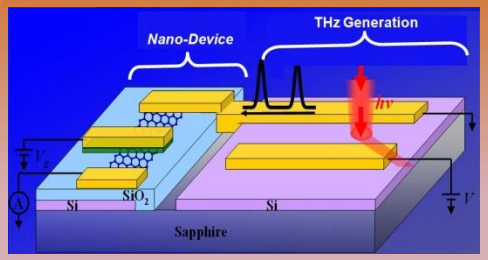
Quantum Optics and Communications

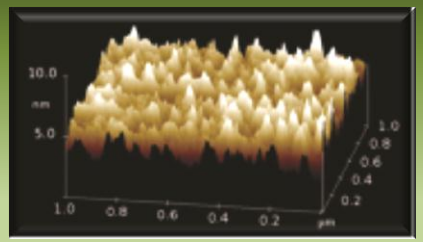
Quantum Optoelectronics

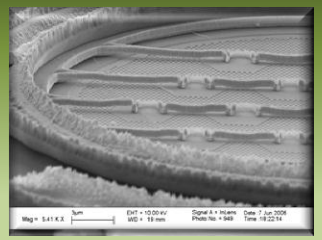


Ultra-fast (THz) Electrical Measurement on Nanoscale Devices

Z. Zhong





MBE quantum dots and photonic crystal nanoscale lasers

P. Bhattacharya