UTSA | Electrical & Computer Engineering

EE 1322: Intro to Electrical & Computer Engineering

Module 10: Electronic Materials and Devices

Dr. Ethan C. Ahn
Assistant Professor of Electrical Engineering, UTSA
Concentration Chair for Electronic Materials and Devices

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Know Your Instructor

Dr. Ethan C. Ahn

Email: ethan.ahn@utsa.edu, *Phone*: (210) 458 – 4491
Lab: https://utsanano.wixsite.com/nano

Assistant Professor, Dept. of Electrical & Computer Engineering (2016 to present)

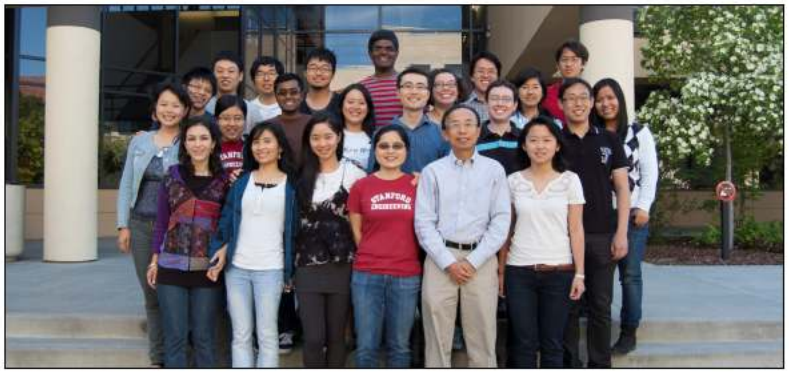
Research Area (not limited to)

- Nanoelectronics
  ; novel nanomaterials and nanodevices for future computing (neuromorphic, quantum)
  ; both computational (30%) and experimental (70%)
- Energy harvesting and storage solutions (piezoelectric, thermoelectric, supercapacitor)
- MEMS sensor and actuator for biomedical and other applications

Sr. Panel Process Engineer
Apple Inc., Cupertino, CA

Ph.D. in Electrical Engineering
Post-Doctoral Researcher
Stanford University, Palo Alto, CA

IBM imec SAMSUNG



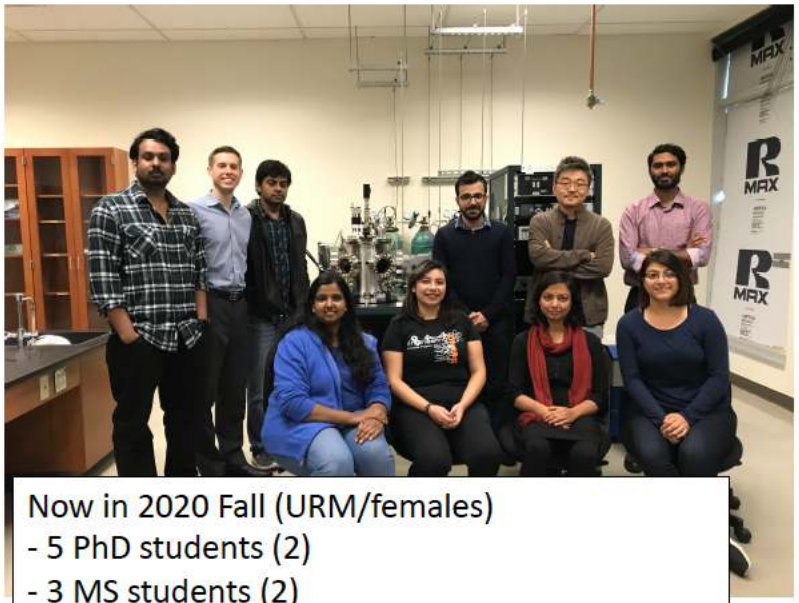
PhD Thesis at Stanford
- CNT, Graphene
- Emerging Nonvolatile Memory

Know Your Instructor

UTSA Nanoelectronics Laboratory (UNL)
located at the thriving UTSA downtown campus!

Know Your Instructor

April 2019
"UTSA harnesses spin of electrons to power tech devices "
- YouTube
- Voice of America, WOAI radio, In Compliance Magazine
- Phys.org, Nanowerk, LongRoom, Interference Technology



Now in 2020 Fall (URM/females)
- 5 PhD students (2)
- 3 MS students (2)
- 2 UG students (1)
- Other visitors, interns, sabbatical leave faculty

PhD (5)

J. Anam (PCM)

P. Gopalakrishnan (Graphene)

A. Sebastian (2D materials)

A. Zaman (Memristor)

H. Cherian (Spin devices)

MS (3)

D. Espinoza (Energy-storage)

C. Carley (Supercapacitor)

N. Huynh (Hardware Security)

UG (2)

L. Munoz

S. Palmer (Energy/biomedical)

Module 10 Outline

1. **Introduction**
   - What study area is Materials and Devices?
2. Opportunities in Education
3. Opportunities in Research

What's This?

What's This?

A laptop computer

It is a specific type of computing system (other types: desktop, phone, server, etc.)

The subject (area) of study:

System (= A unified whole that have a specific purpose)

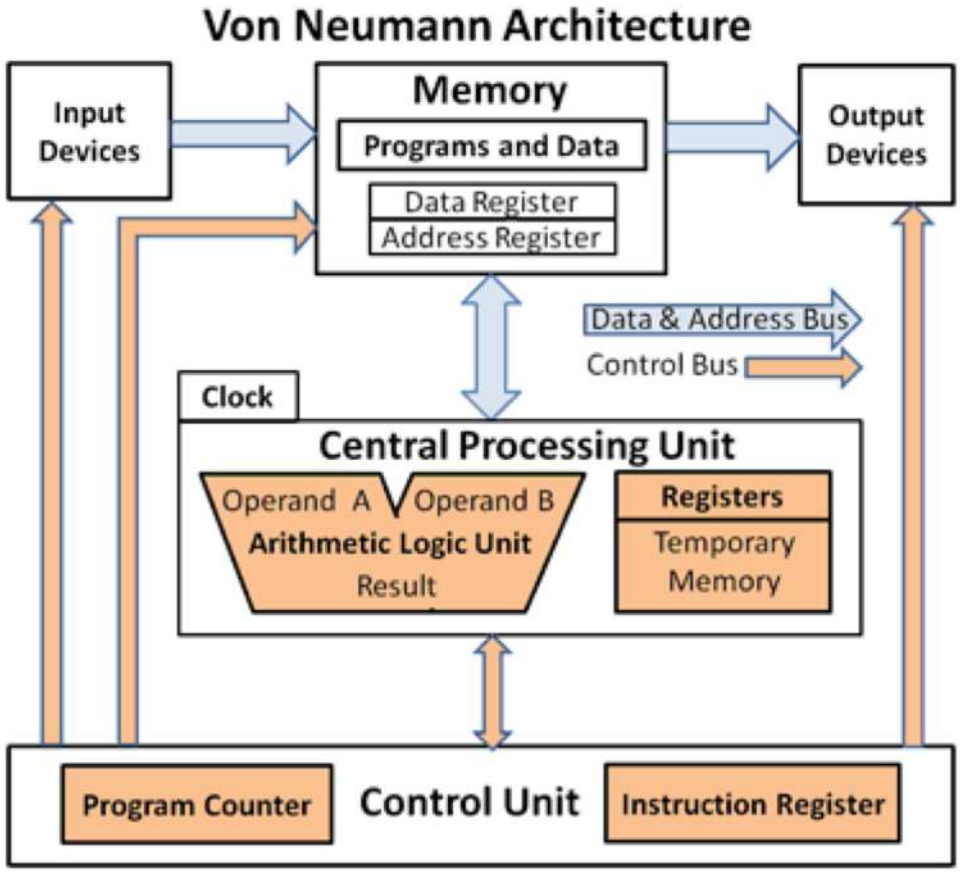
What's Inside?

What's Inside?

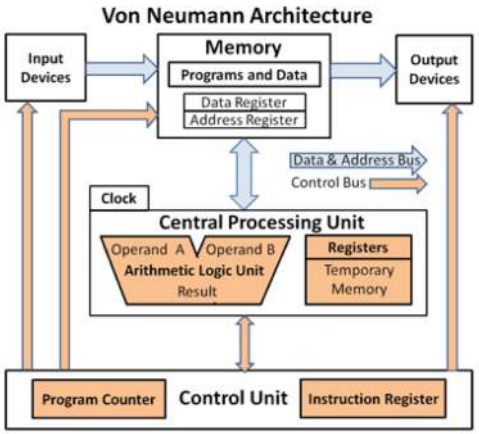
The subject (area) of study:

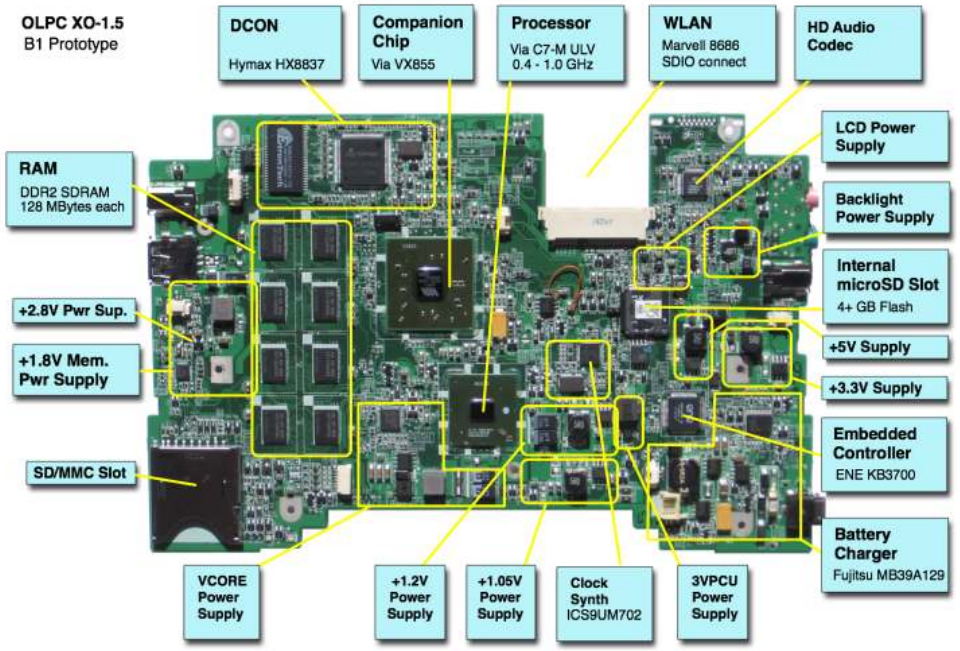
Architecture

(= planning, designing, and constructing a structure)



What's Inside?



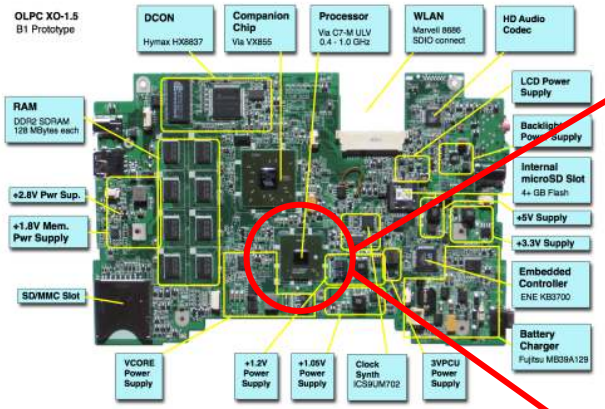


The subject (area) of study:

Electrical Circuit

(= interconnection of electrical components)

What's Inside?



Xeon Broadwell-E5 v4 (2016)

- **7.2 billion transistors**

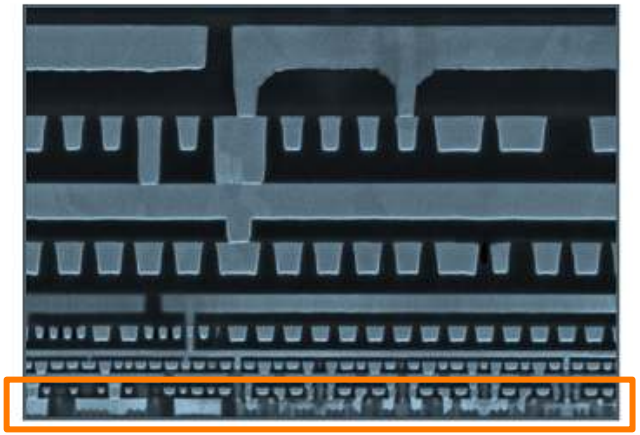
*only 4 transistors in 1960

- F (technology node) = 14 nm

The subject (area) of study:

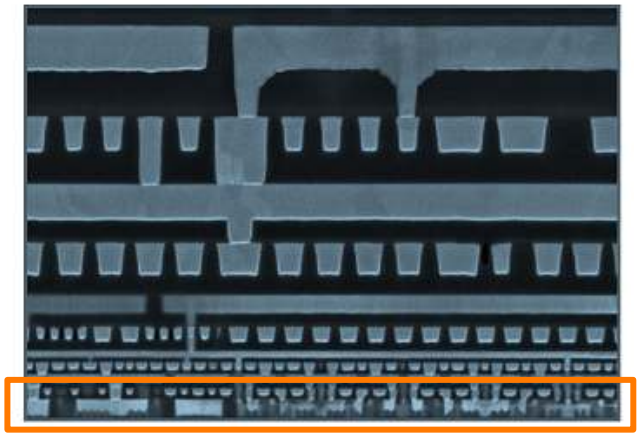
Devices

(= electrical components, such as transistors, resistors, inductors, etc.)

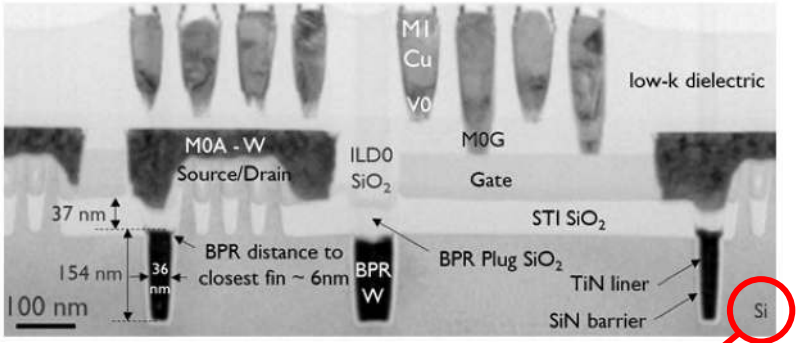


Transistors (devices)

What's Inside?



Transistors (devices)



FinFET CMOS Device

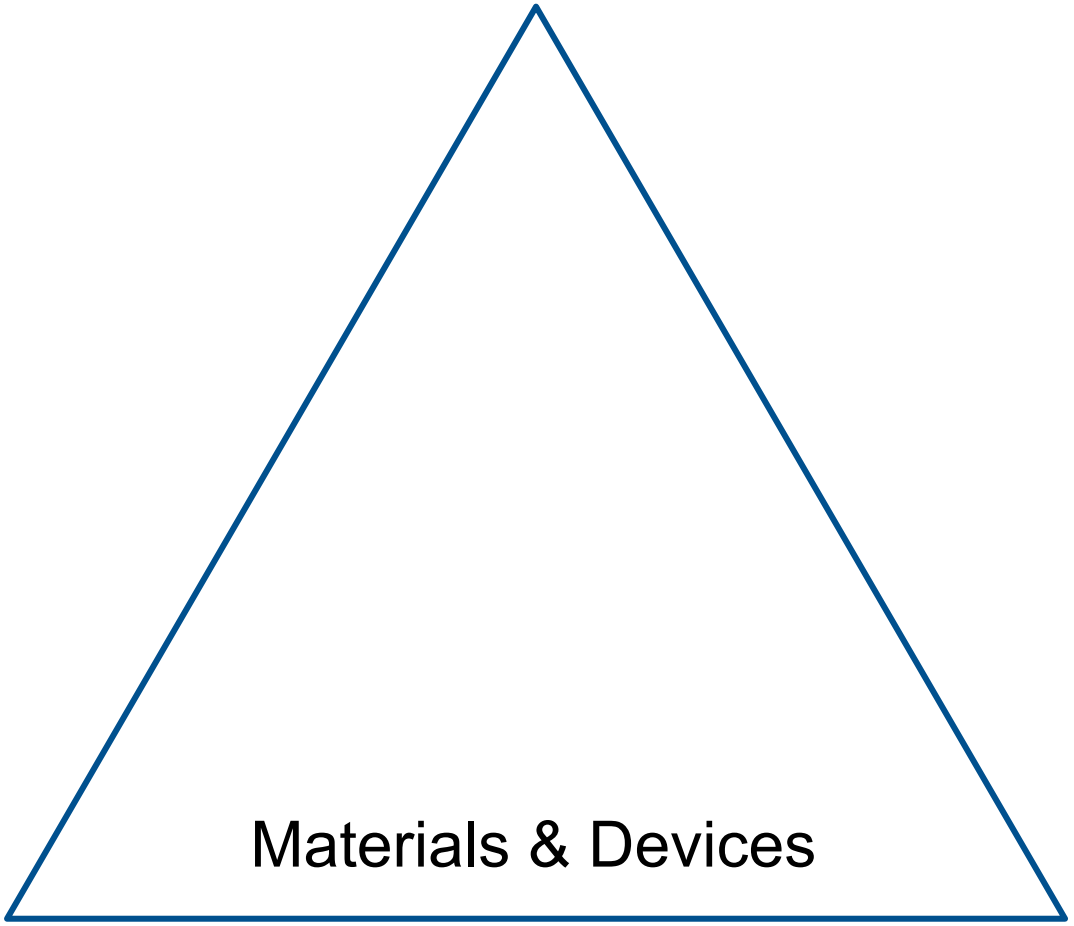
The subject (area) of study:

Materials

(= semiconductors, metals, oxides, etc.)

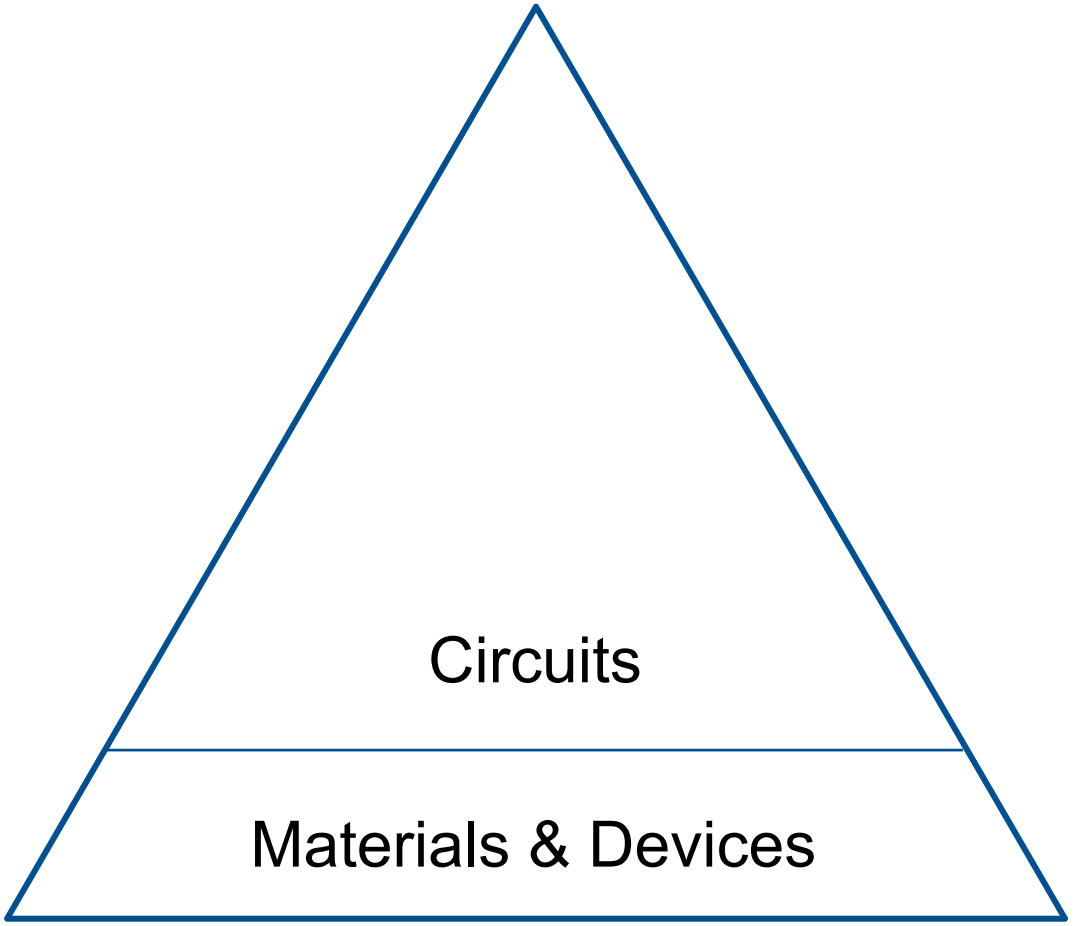
Si (silicon) crystal

Hierarchy of ECE Area



Silicon & Transistor

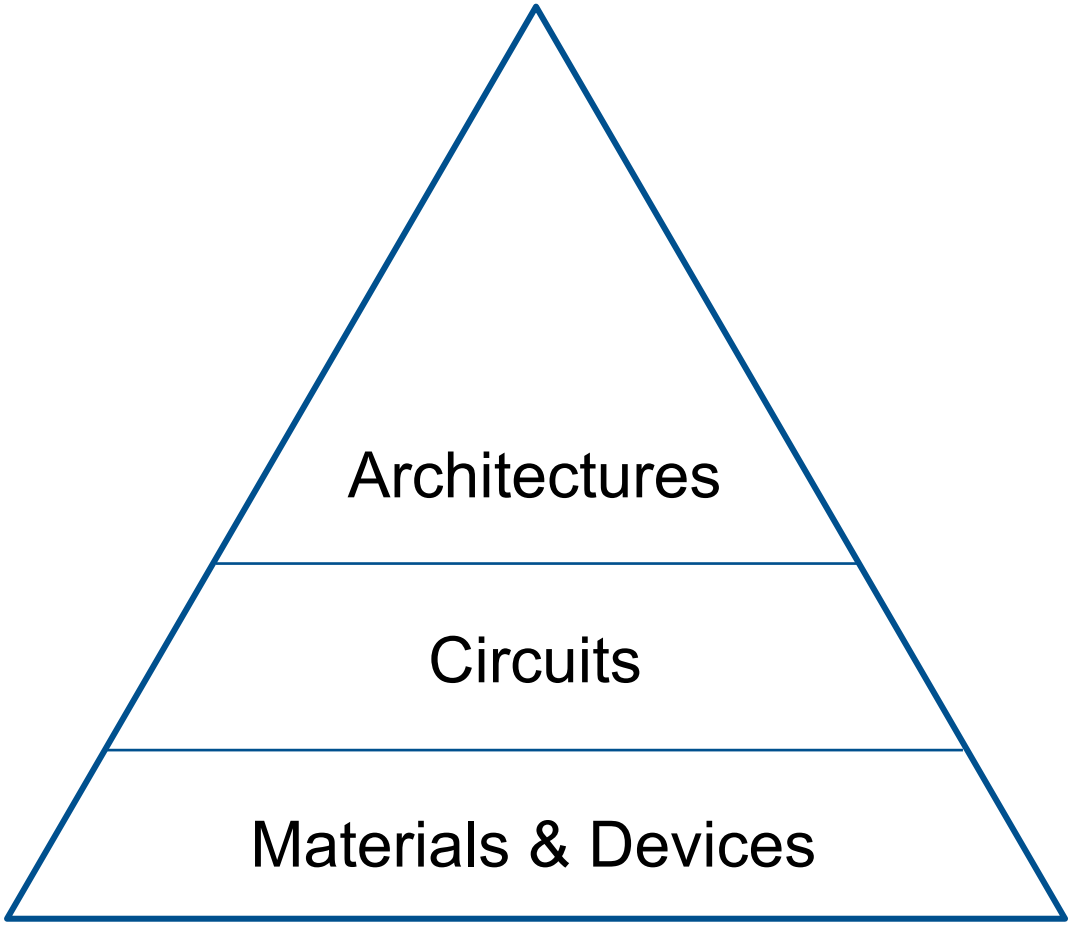
Hierarchy of ECE Area



CPU, Memory

Silicon & Transistor

Hierarchy of ECE Area

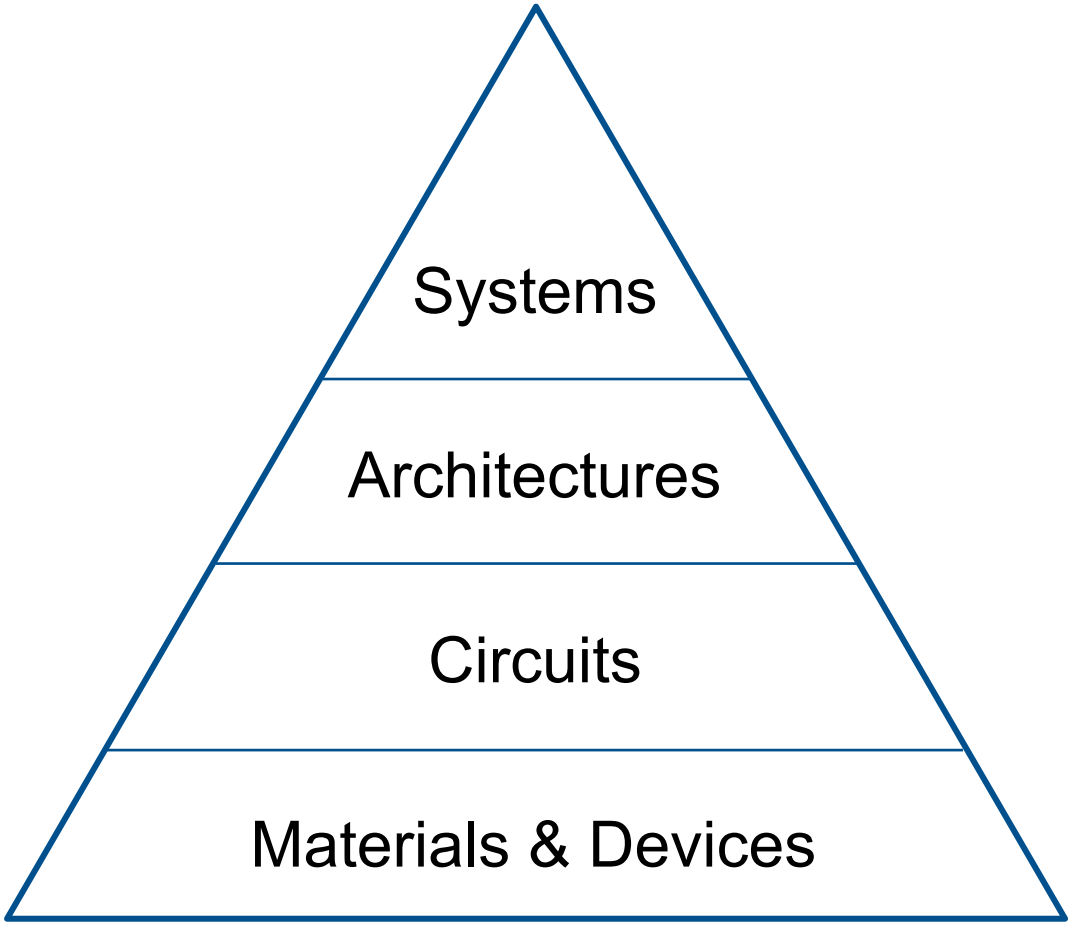


I/O, Motherboard

CPU, Memory

Silicon & Transistor

Hierarchy of ECE Area



Computer

I/O, Motherboard

CPU, Memory

Silicon & Transistor

Electronic Materials and Devices

Electronic Materials and Devices is an area of study (research) which is

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- the most fundamental

(everything we create or build up in ECE is based on materials and devices)

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- at the boundary between engineering (ECE) applications and fundamental sciences

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Electronic Materials and Devices is an area of study (research) which is

- the most fundamental

(everything we create or build up in ECE is based on materials and devices)

- at the boundary between engineering (ECE) applications and fundamental sciences

- the most closest to other disciplines (inter-disciplinary)

    - Other ECE areas
    - Materials Science and Engineering
    - Mechanical/Biomedical/Chemical Engineering
    - Physics, Chemistry

Materials

Materials Research Society (MRS) is an organization of materials researchers worldwide

- https://www.mrs.org/home

- See the recent CFP (call for proposal) in the MRS Meeting (conference) to know what materials are being considered hot

Topics of interest include, but are not limited to:

- Characterization, Techniques and Tools
- Electronics and Optics
- Energy Conversion and Storage, and Sustainability
- Modeling, Simulations and Data-Driven Approaches
- Multifunctional Materials
- Soft Materials and Biomaterials
- Synthesis, Prototyping, Manufacturing
- Nano and Quantum Materials
- Structural Materials

Proposals in emerging and rapidly developing topics are especially encouraged, including:

- 2D Materials
- Adaptive and Responsive Materials
- Additive Manufacturing
- Artificial Intelligence, Machine Learning and Automation
- Flexible, large area electronics
- Materials for Health
- Materials under Extreme Conditions
- Nanosynthesis
- Organic and Molecular Electronics
- Plasmonics
- Quantum Materials
- Materials for Robotics
- Self-assembly

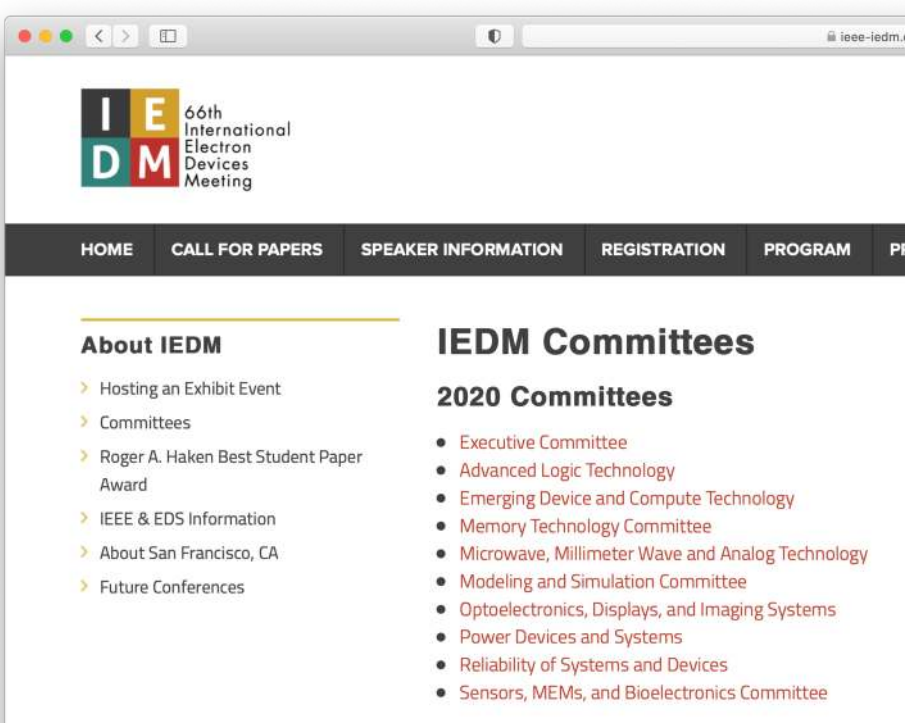
Topics of Primary Interests in 2022 MRS Meeting

Devices

IEDM (International Electron Devices Meeting) is an IEEE-sponsored organization of devices researchers worldwide

- https://ieee-iedm.org

- See the recent CFP (call for paper) in the IEDM conference to know what devices are being considered hot



Committees in 2022 IEDM

Module 10 Outline

1. Introduction
2. **Opportunities in Education**
   - What courses are available at UTSA?
3. Opportunities in Research

Courses Offered in Electronic Materials and Devices

Instructor: Dr. Ethan Ahn (microelectronics/nanotechnology)

EE4523 (cross-listed with EE5503), Spring 2021

Introduction to Nanoelectronics; *how do materials & devices work?*

EE4533 (cross-listed with EE5413), Fall 2021

Principles of Microfabrication; *how do we make materials & devices?*

EE6493 (cross-listed with MATE5253), Spring 2021

Magnetic Materials and Devices; *magnetism, spintronics, quantum computing*

Courses Offered in Electronic Materials and Devices

Instructor: Dr. Ethan Ahn (microelectronics/nanotechnology)

EE4523 (cross-listed with EE5503), Spring 2021

Introduction to Nanoelectronics; *how do materials & devices work?*

"Amazing class, literally re-laid a foundation I needed for other courses. This man would do wonders teaching quantum mechanics, devices, materials. ***This is the true college experience where the real learning is.*** Amazing job." (Spring 2019)

"This is a great course, professor Ahn really knows what he is talking about and truly cares about the student's understanding of the concepts he is teaching. UTSA should get more professors like Ahn." (Spring 2019)

Courses Offered in Electronic Materials and Devices

Instructor: Dr. Ethan Ahn (microelectronics/nanotechnology)

EE4533 (cross-listed with EE5413), Fall 2021

Principles of Microfabrication; *how do we make materials & devices?*

"I enjoyed how we had ***field trips outside of the classroom*** and got to see a little more of the industry side. Dr. Ahn was very good about returning graded work on time this was appreciated." (Fall 2019)

Courses Offered in Electronic Materials and Devices

Instructor: Dr. Ethan Ahn (microelectronics/nanotechnology)

"Excellent professor and excellent course. More professors like Ahn would make UTSA even better." (Spring 2019)

I liked how we were exposed to new and current research. Also, I believe this course ***helped me to read research papers better***. At the same time, I also wish there were more ***critical thinking/analysis*** questions." (Spring 2019)

EE6493 (cross-listed with MATE5253), Spring 2021

Magnetic Materials and Devices; *magnetism, spintronics, quantum computing*

(available for undergraduate students as a tech elective)

Courses Offered in Electronic Materials and Devices

Other Courses

EE3213, Spring/Fall (Dr. Sutherland)
Electromagnetic Engineering

EE3323, Spring/Fall (Dr. Joo)
Electronic Devices

EE4323/5403, Spring (Dr. Guo)
Advanced Dielectric
& Optoelectronic Engineering Lab

EE5693, Fall (Dr. Guo)
Dielectric & Optoelectronic Devices

EE5593, Spring (Dr. Bhalla)
Advanced Sensor Devices

Module 10 Outline

1. Introduction
2. Opportunities in Education
3. **Opportunities in Research**
   - What innovations can materials/devices lead to?

Dr. Ahn's Research Highlights

"Microfluidic Sensor for Haptic Feedback"

Funding Agency

AAMTI (January 2018 – December 2018)

Collaborators

UTHSCSA, USAISR, UTSA ME and BME Depts.

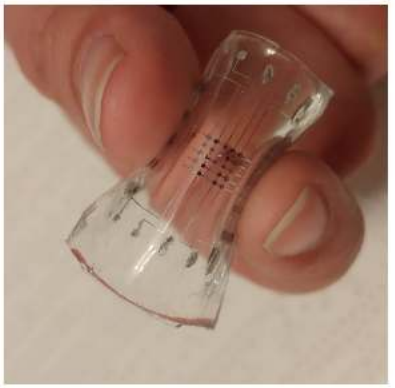
Significance

Dramatically improving the sensor's reach, sensitivity, size, weight, power and duration for pre-hospital patient treatment (airway management, etc.)

Key Results

- Fabricating a novel tactile force sensor
- Addressing the challenges in digital intubation

Pre-hospital environment on battlefield and digital intubation



Microfluidic force sensor fabricated

Dr. Ahn's Research Highlights

"Smart Wireless Charging for Future Vehicles"

Funding Agency

DoT (March 2018 – September 2019)

Collaborators

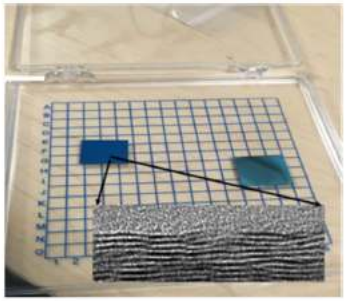
Dr. Taha (Univ. of New Mexico)

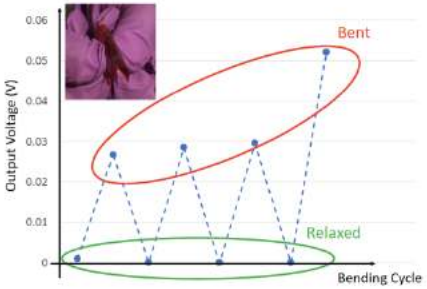
Significance

Enhancing the operational range of battery-powered vehicles in the environment where the renewable energy sources are available

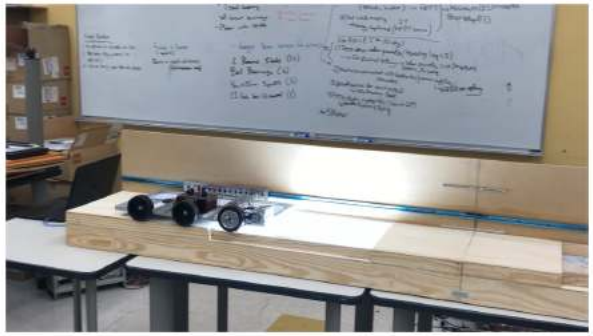
Key Results

- Developing a large-area nanomaterial for piezoelectric energy harvesting
- Fabricating a lab-scale prototype of charging system





Centimeter-scale 2D nanomaterial and piezoelectric voltage



LED-to-PV wireless energy transfer

Dr. Ahn's Research Highlights

"Next-generation Logic Device"

Funding Agency

NSF EAGER (June 2019 – May 2020)

Collaborators

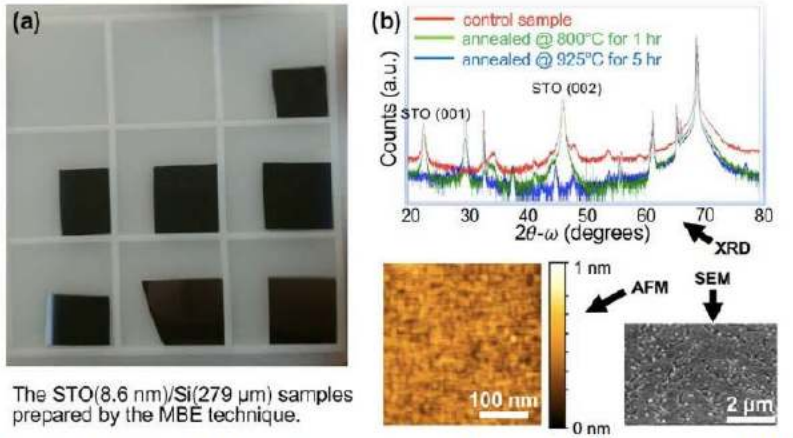
Dr. Theodoropoulou (TX State Univ. Physics)

Significance

High speed, high energy-efficiency, and high reliability simultaneously achieved to enhance warfighters' computing performances

Key Results

- Studying the feasibility of a novel logic device of epitaxial oxide resistive FET (EOR-FET)
- Proposing a practical device stack that can implement the electrostrictive FET concept
- Enabling researchers to rethink the role of oxides in microelectronics



The STO(8.6 nm)/Si(279 μm) samples prepared by the MBE technique.

Perovskite oxide thin films prepared (a) and characterized (b)

Dr. Ahn's Research Highlights

"Non-volatile Memory for Machine Learning"

Funding Agency

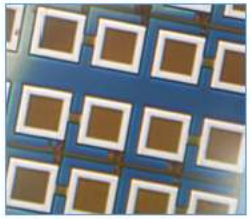
UTSA VPR Office (seed grant)

Collaborators

Dr. Duan (UTSA ECE), Dr. Kang (Qualcomm)

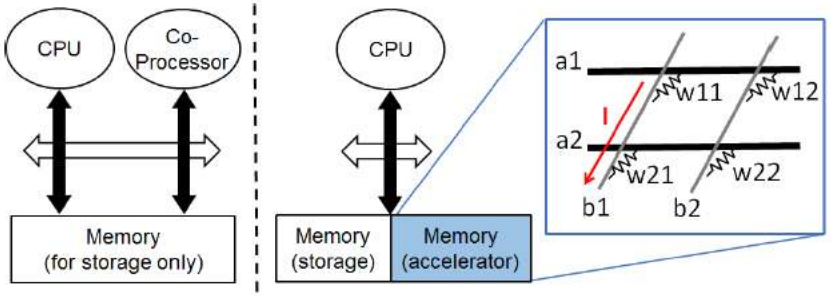
Significance

Taking advantage of IC's ability to advance future computing paradigm (machine learning) by implementing high-density neural networks in hardware

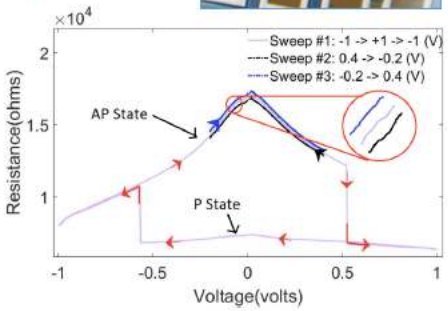


Key Results

- Proposed non-uniform data quantization scheme
- Achieved reconfigurable multiple resistance levels in STT-MRAM



Compute-in-memory as future computing paradigm



Analog-programming of magnetic synapse

Dr. Ahn's Research Highlights

"All-spin Logic, enabled by 2D Materials"

Funding Agency

AFOSR (quantum electronics)

Collaborators

Dr. Birge (MSU), Dr. Akinwande (UT Austin)

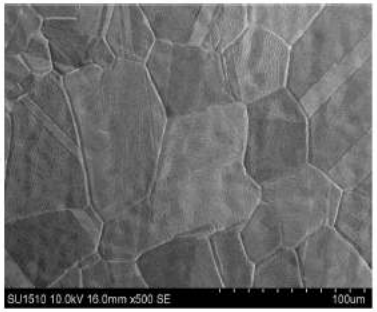
Significance

- Serving as the first experimental demonstration of the emerging concept of all-spin logic

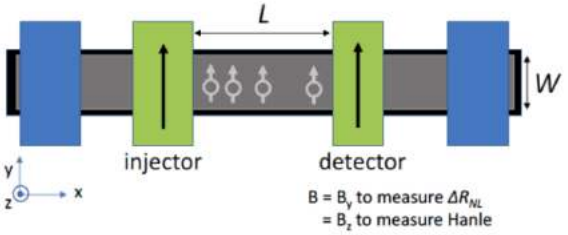
- Due to very low power consumption, it may help to advance quantum computing

Key Results

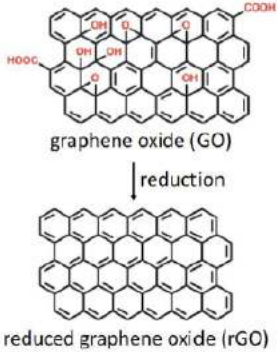
- Prepared and characterized 2D materials
- STS experiments planned in 2019 summer (at MSU)



CVD-grown graphene



Non-local spin valve device



rGO spin tunnel barrier (patent filed)

Conclusion – Electronic Materials and Devices

- Properties and characteristics of materials are investigated to develop novel devices that can form a useful part of the system
- Most fundamental area of study in ECE
- Good for those who have backgrounds and/or are interested in physical sciences
- Can enable BIG in various engineering disciplines
- Career paths in industry, military, and academia