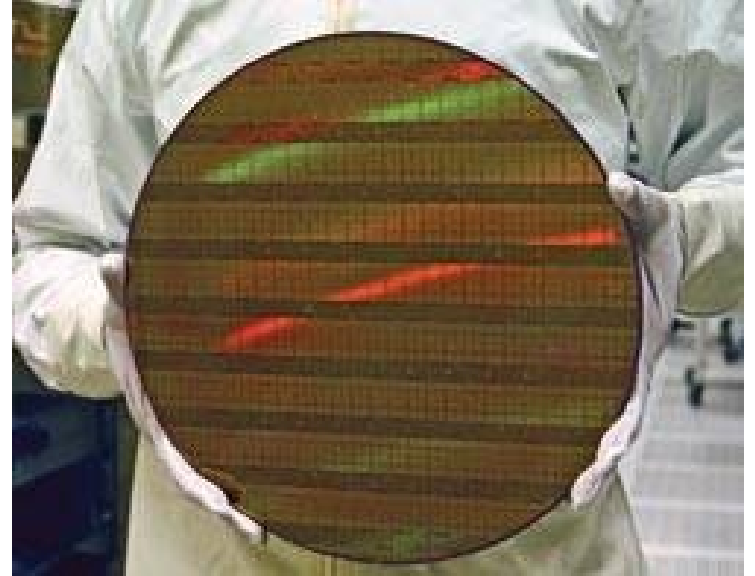


Area 1: Semiconductor Physics

Sorin P. Voinigescu

The world runs on a semiconductor platform!

The internet,
your laptop,
your cellphone,

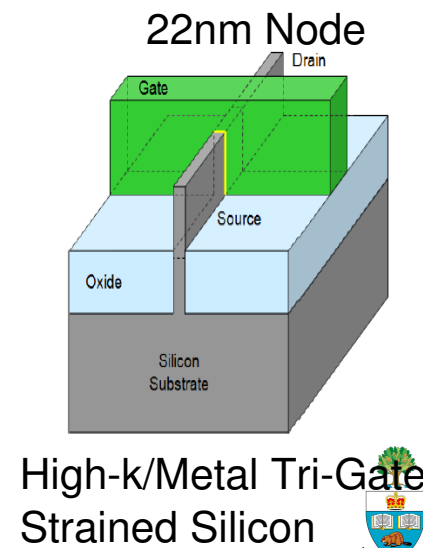
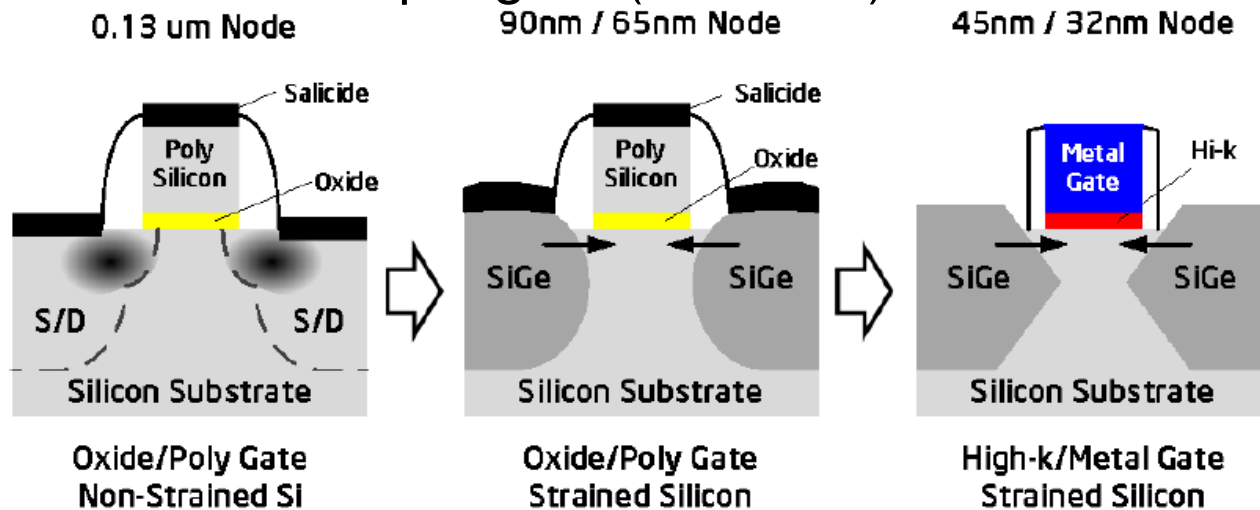


...and soon the Internet of Things,
and YOU will, too!



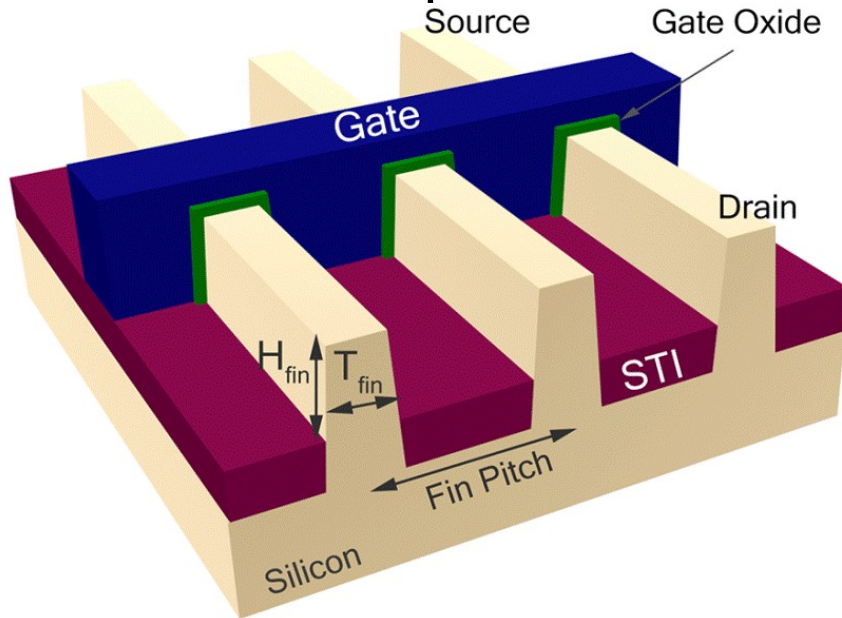
MOSFET Evolution

- 1926: Lilienfeld FET patent (filed in Canada first!)
- 1960: long channel ($V_{DD} > 20V$, $L > 10\mu m$) Si channel, Al gate, SiO_2
- 1970's: polysilicon gate and FOX (field oxide) isolation
- 1990's: dual polysilicon gates, self-aligned silicides
- 2003: strain engineering: SiGe source/drain regions
- 2007: HfO_2 gate stack and metal gates
- 2011: Multiple gate (MG-FET) or FinFET

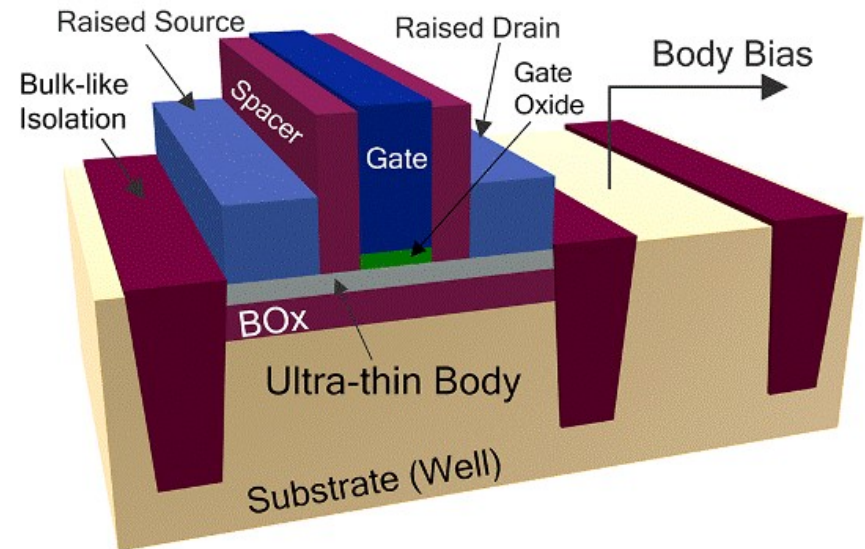


In your 2014 phone, laptop, tablet: MOSFETs

2nm oxide, 7nm channel, 20-24nm gate length,
> 300 GHz speed



3-D trigate FET (Intel)

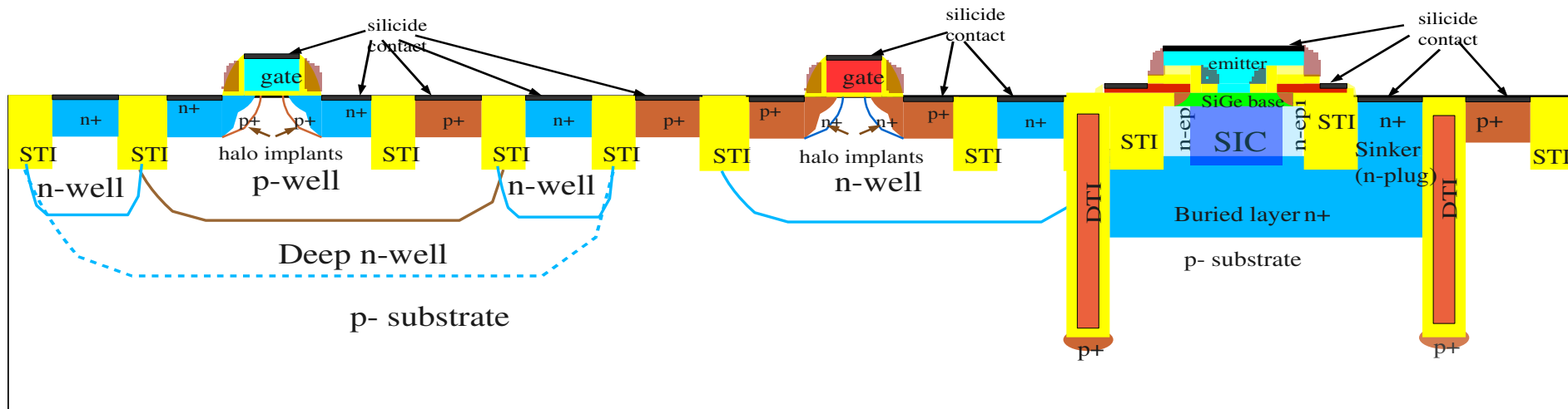


2-D quasi 2-gate FD-SOI (ST)

Semiconductor Physics

- Learn basics of semiconductor devices, underlying physics, IC fabrication techniques
- Also prepares you for courses in other areas:
 - digital/analog/RF IC design,
 - photonics,
 - energy conversion
- **Kernel** - ECE335F Introduction to Electronic Devices
 - Introduction to semiconductor materials and physics
 - Basic concepts on **pn diodes**, **MOSFETs** and **bipolar transistors**
 - Introduction to device and IC fabrication techniques.

SiGe BiCMOS Technology Cross-section

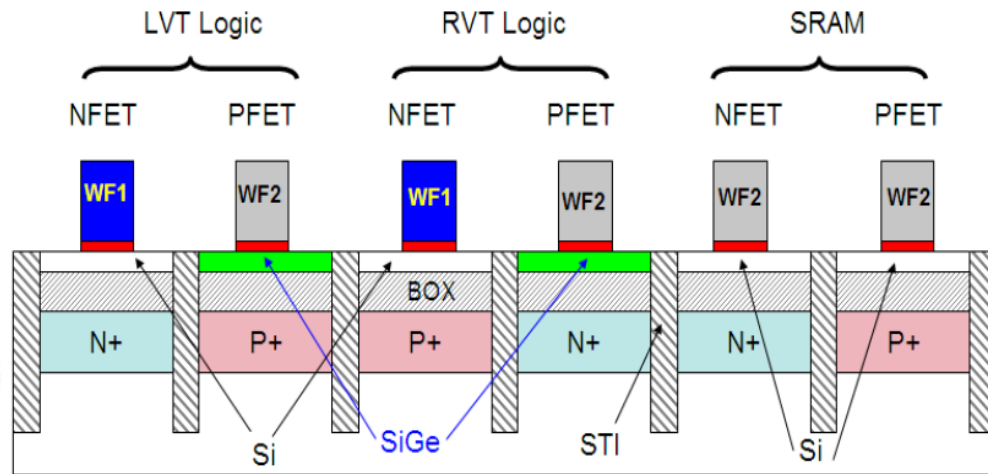
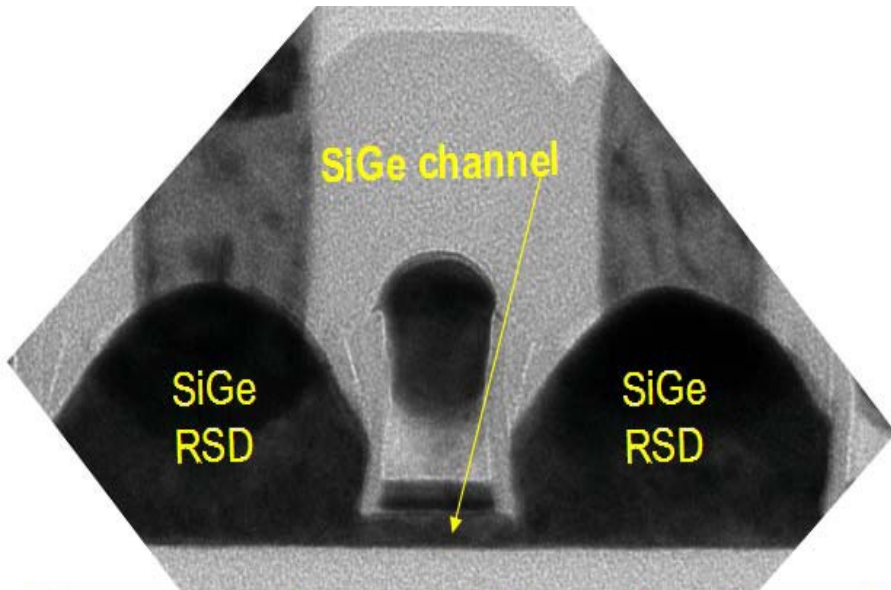


- In automotive cruise control and collision avoidance sensors
- In WiFi power amplifiers
- In Internet fiberoptic backbone

Depth Courses

- ECE422F: Micro/Nano Fabrication Technologies
 - In-depth study of semiconductor devices and IC process modules
 - Nanolithography and metrology techniques
- ECE535F: Advanced Electronic Devices
 - a continuation of ECE335F
 - exploring state-of-the-art CMOS, BiCMOS and III-V devices
- ECE330S: Semiconductor & Device Physics
 - Quantum & statistical mechanics and nanoengineering that underlie today's semiconductor and photonic devices
- PHY355S: Quantum Mechanics I
 - Build up fundamental knowledge at the atomic level. Understand the behavior of different materials

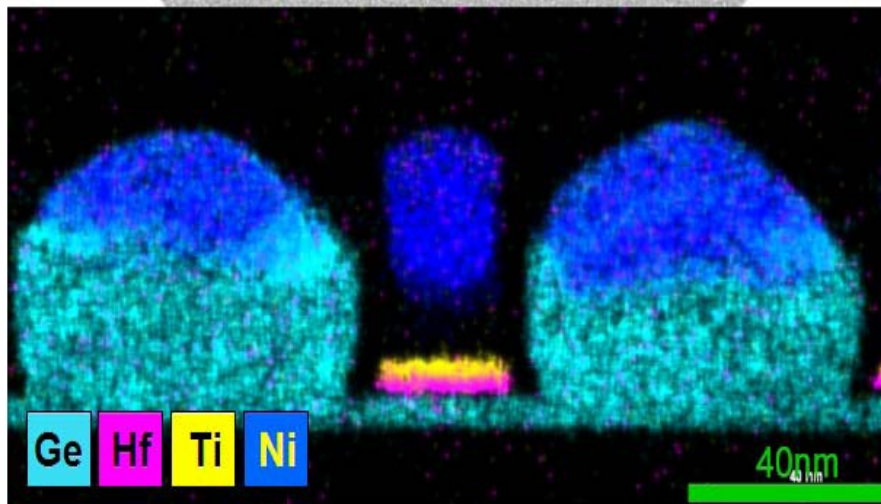
ECE535F: 22-nm Fully-Depleted SOI CMOS ICs



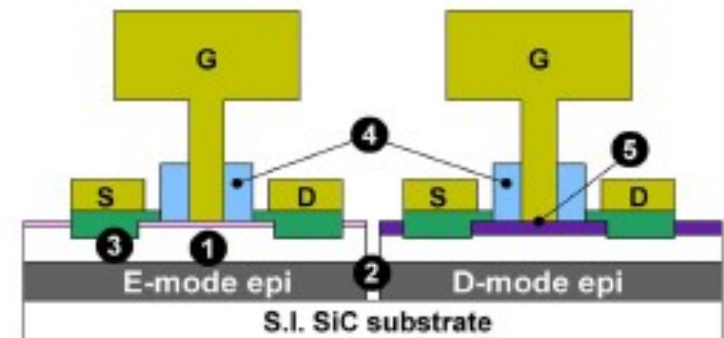
Rule of thumb: $t_{Si} = L_G/4$

6-nm thick SiGe channel
22 nm gate length

K. Cheng et al. IEDM 2012



ECE535F: 20-nm GaN HEMTs



- ① Vertically-scaled AlN/GaN/AlGaN DH-HEMT epi
- ② Monolithic E/D-mode epi integration
- ③ Low resistance n⁺-GaN ohmic contact regrowth
- ④ Manufacturable self-aligned-gate process
- ⑤ No gate recess process for high V_{th} uniformity

Figure 4. Technology cross-section of E/D-mode integrated self-aligned-sidewall-gate GaN DH-HEMTs.

E-mode epi		D-mode epi (Regrown)	
Al _{0.8} Ga _{0.2} N cap	2.5 nm	GaN cap	2.5 nm
AlN top barrier	2.0 nm	AlN top barrier	3.5 nm
GaN channel	20 nm	GaN channel	20 nm
Al _{0.08} Ga _{0.92} N back barrier		Al _{0.88} Ga _{0.12} N back barrier	
S.I. SiC sub.			

K. Shinohara et. al, IEEE CSICS 2012

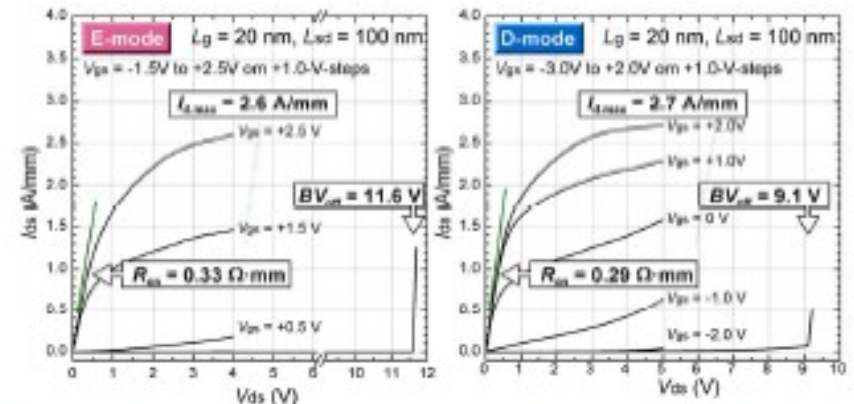


Figure 7. Output characteristics of 20-nm self-aligned-sidewall-gate GaN-HEMTs fabricated on E and D-mode epitaxial wafers (not integrated).

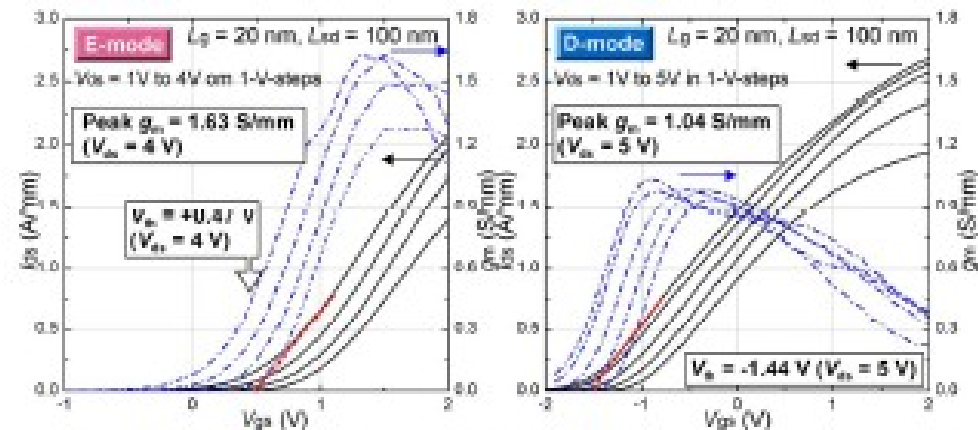


Figure 8. Transfer characteristics of 20-nm self-aligned-sidewall-gate GaN-HEMTs fabricated on E and D-mode epitaxial wafers (not integrated).

$$f_T/f_{MAX} = 320/400 \text{ GHz}$$

Careers in Semiconductor Companies

- **Device Engineer** — develop new devices (usually MASc or PhD)
- **Process Engineer** — develop new IC process modules (usually MASc or PhD)
- **Device Modelling Engineer** — develop and extract semiconductor device models (usually MASc or PhD)
- **Foundry Engineer** — monitors IC wafer fabrication
- **Test Engineer** — develop device/IC test methods
- **Sales/Applications Engineer** — sells/supports products to customers
- **Manager** — in charge of group

International Semiconductor Companies

■ Semiconductor IC Companies

- Intel, Samsung, AMD, Texas Instruments, Freescale, STMicroelectronics, Infineon, Qualcomm, Broadcom, NXP, Qorvo, Skyworks, Silicon Labs, Toshiba, Infineon, Renesas, Analog Devices
- Many small fabless semiconductor companies: e.g. GaN Systems (Ottawa startup)

■ Semiconductor Foundries (US, Europe, Israel, Asia)

- TSMC, Global Foundries, IBM, UMC, SMIC, STMicroelectronics, Jazz Semiconductor, Intel, Cree

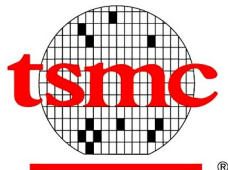
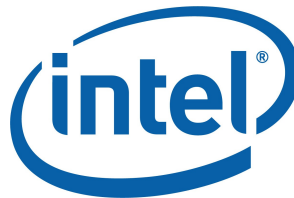
Semiconductor Industry

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Questions?