MTLE-6120: Advanced Electronic Properties of Materials

- **Instructor:** Ravishankar Sundararaman (sundar@rpi.edu)
- **Lectures:** Tuesdays and Fridays, 10 - 11:50 am
- **Location:** WebEx
- **Website:** http://abinitiomp.org/teaching/mtle6120
- **Office hours:** Thursdays 5-6 pm at http://rensselaer.webex.com/meet/sundar
- **Primary text:**
  - *Principles of Electronic Materials and Devices* by S.O. Kasap
- **Background reading (as needed):**
  - *Introduction to Solid State Physics* by C. Kittel
  - *Introduction to Quantum Mechanics* by D.J. Griffiths
  - *Introduction to Electrodynamics* by D.J. Griffiths
- Please fill out brief survey/quiz on background and interests

Topics (1/3): Theoretical background

- Maxwell's equations in materials
- Classical Drude theory of conduction
- Basic quantum mechanics
- Atoms, many-electron theories and the periodic table
- Quantum kinetics: Fermi's Golden rule
- Band theory of solids

Topics (2/3): Material properties

- Fermi theory of metals
- Electron transport: phonons and electron-phonon scattering
- Intrinsic and extrinsic semiconductors
- Insulating materials: dielectrics, ferroelectrics, piezoelectrics etc.
- Magnetism: dia-, para- and ferro-magnetism, hysteresis
- Superconductivity
- Optical properties: absorption, emission, luminescence, fluorescence, lasing
- Low-dimensional materials

Topics (3/3): Interface properties

- Metal-vacuum interfaces: thermionic and field emission
- Metal-metal junctions: Seebeck effect, thermocouples, Peltier effect
- Metal-semiconductor Schottky junctions
- Semiconductor p-n junction diodes; LEDs, lasers and photovoltaics
- Semiconductor transistors for logic and memory

Learning outcomes

- Understand how the physics of electrons in materials results in a variety of electronic, magnetic and optical properties of materials
- Understand how these properties are exploited and optimized for in technological applications
- Navigate literature in active areas of research in electronic, magnetic or optical materials

Assessment

- **20%**: Weekly quizzes in Friday classes based on most-recent lectures and homework; one lowest score not counted
- **20%**: In-class midterm examination on Mar 3, which along with all previous homeworks will be used to provide you with performance feedback by 3 pm on Mar 3
- **40%**: Final examination on the penultimate day of classes (Apr 21)
- **10%**: Short oral presentation on an area of active research in electronic, optical or magnetic materials in the last class (April 25)
- **10%**: Participation in class by asking questions and contributing to discussions

Academic integrity

Student-teacher relationships are built on trust. For example, students must trust that teachers have made appropriate decisions about the structure and content of the courses they teach, and teachers must trust that the assignments that students turn in are their own. Acts that violate this trust undermine the educational process. The Rensselaer Handbook of Student Rights and Responsibilities and The Graduate Student Supplement define various forms of Academic Dishonesty and you should make yourself familiar with these.

- Homework: discussions and team work encouraged (not for grade)
- Quizzes / exams: books and printed notes allowed; no discussions
- First violation: zero score on that assignment
- Second violation: F grade on course

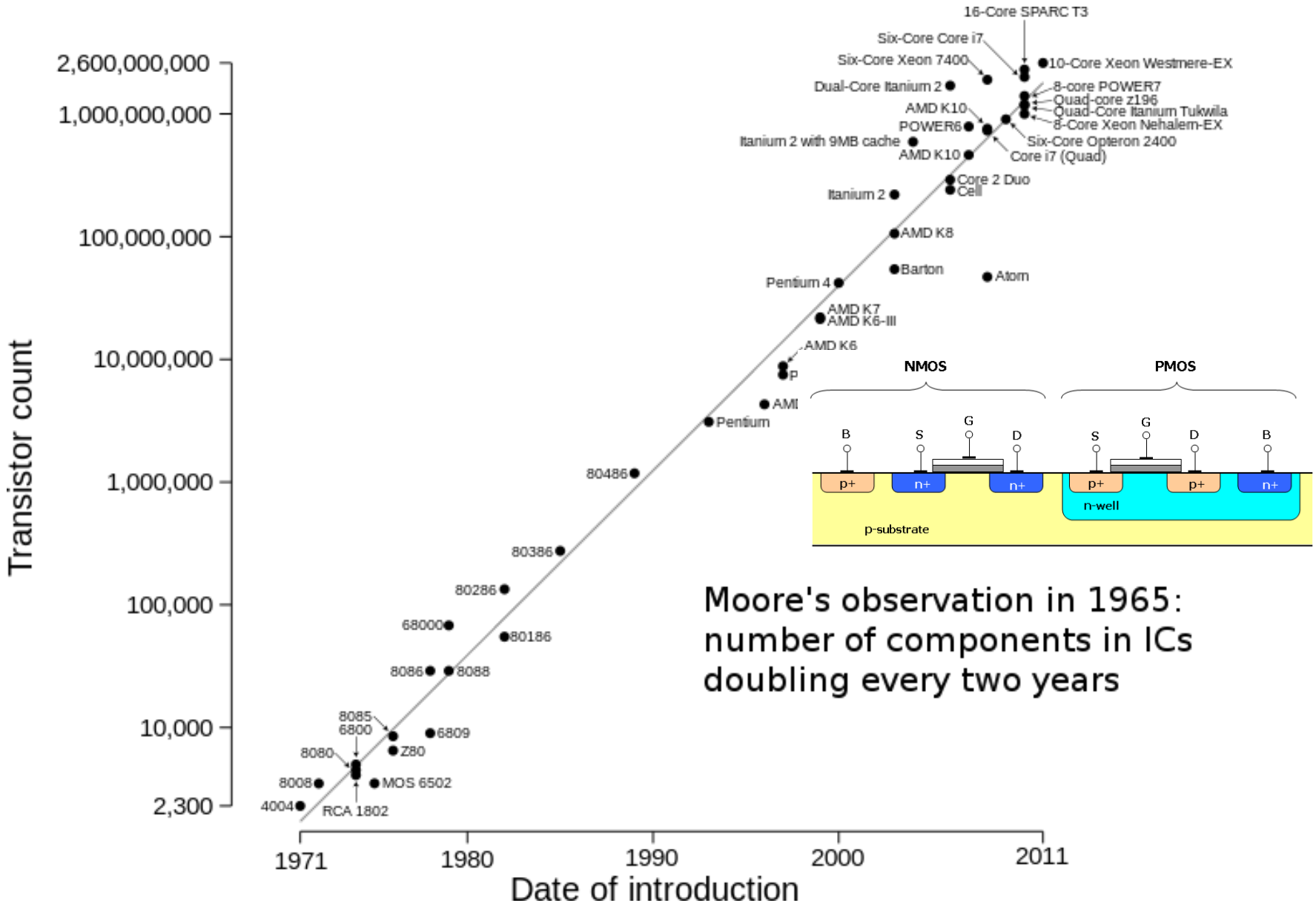
If you have any question concerning this policy, please ask for clarification.

Fastest advancing technologies

- Computer processors
- Magnetic storage (hard drives)
- Solid-state storage (flash memory)
- Optical communications
- Photovoltaics (solar cells)

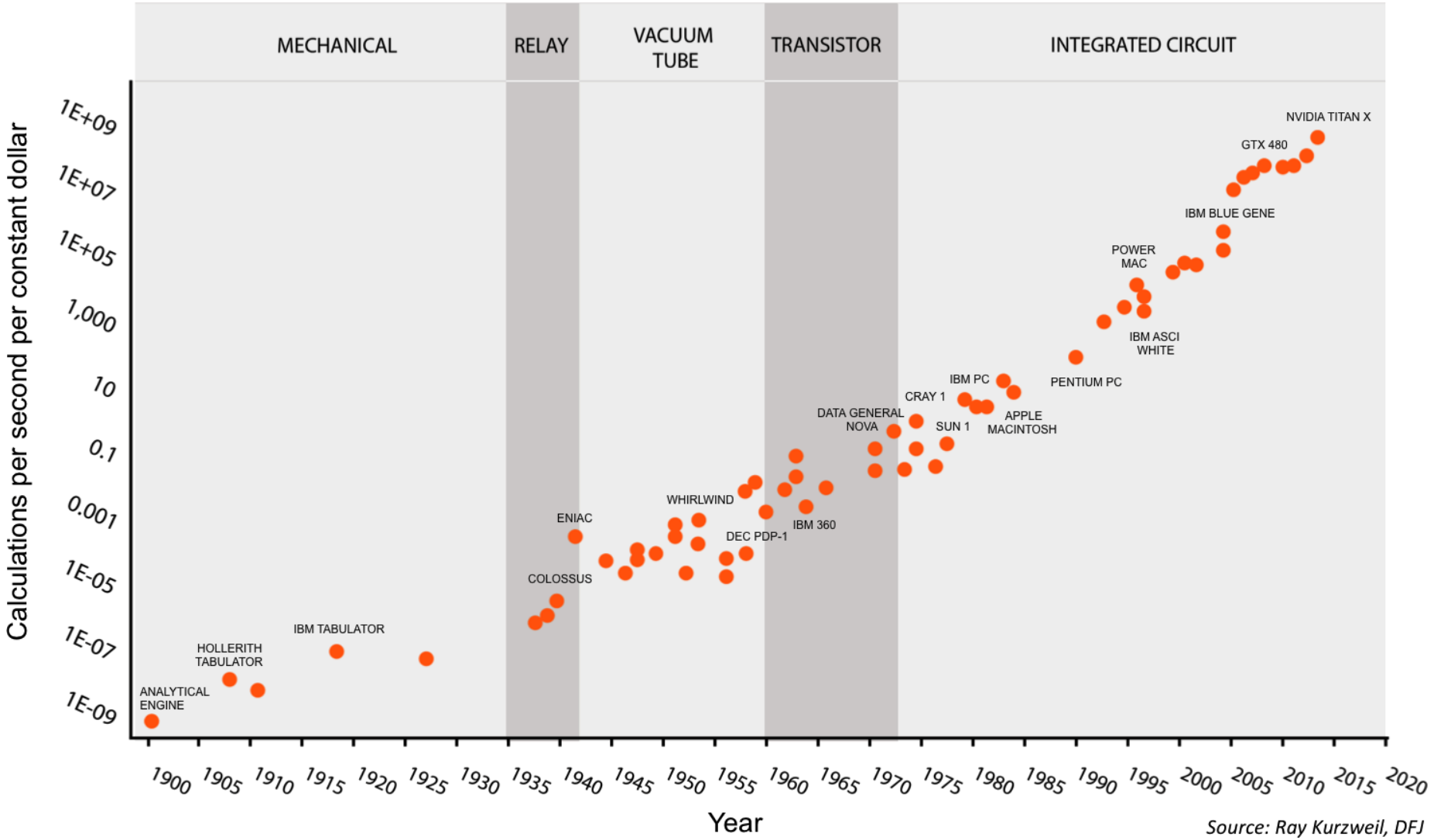
Spolier: they all involve electronic, magnetic and optical materials

Moore's law: CMOS transistor count



Source: Wgsimon/Wikimedia commons

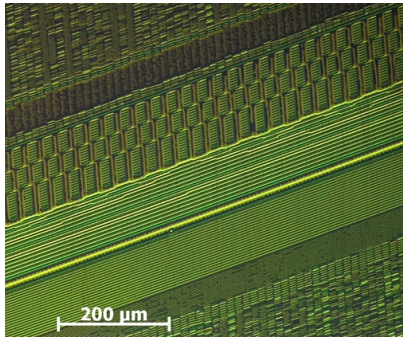
Moore's law: computation rate per cost

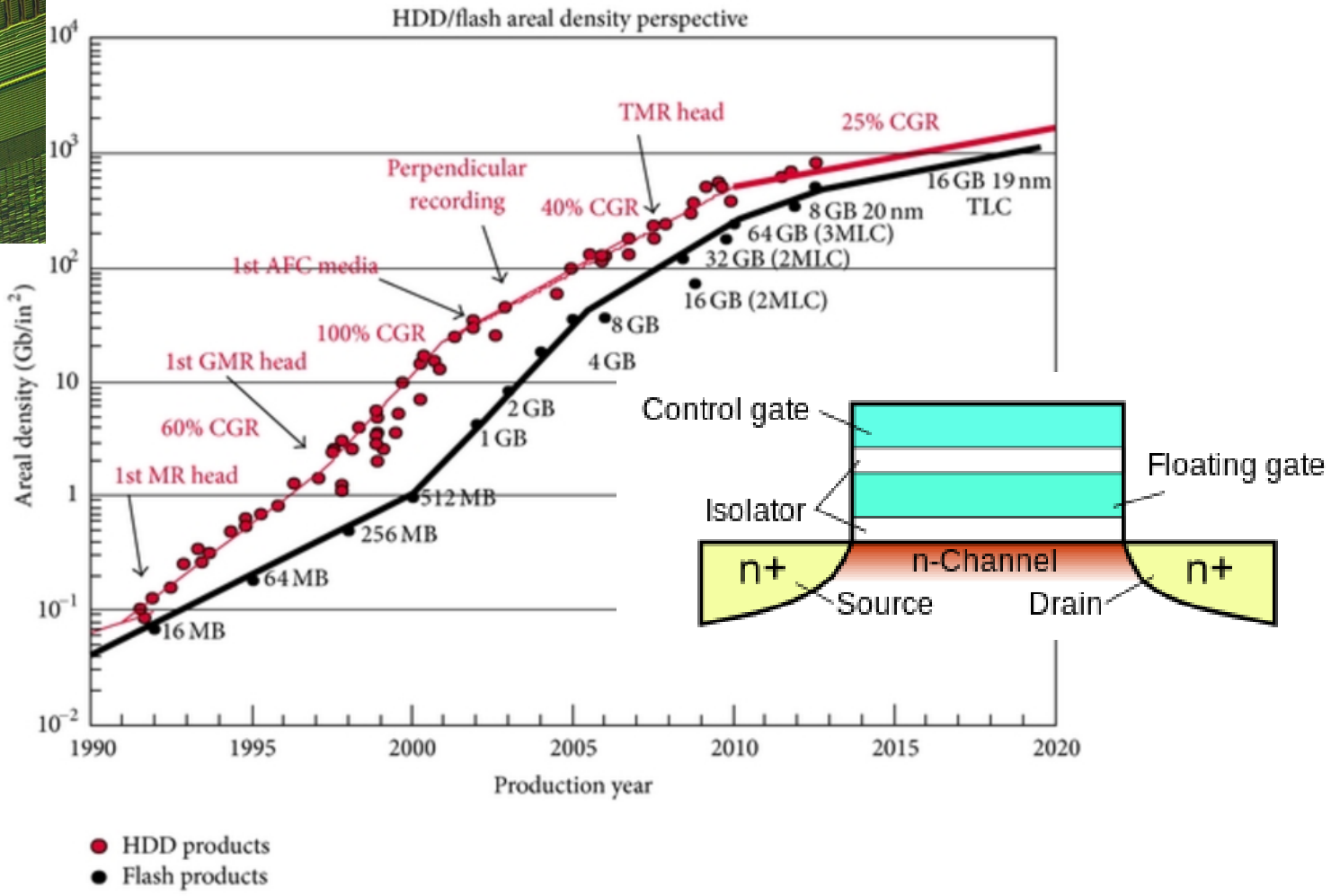


Where would you mark yourself on this plot?

Source: S. Jurveston/Wikimedia commons

Moore's law: storage aereal density





Source: *Adv. Tribol.* **2013**, 521086 (2013)

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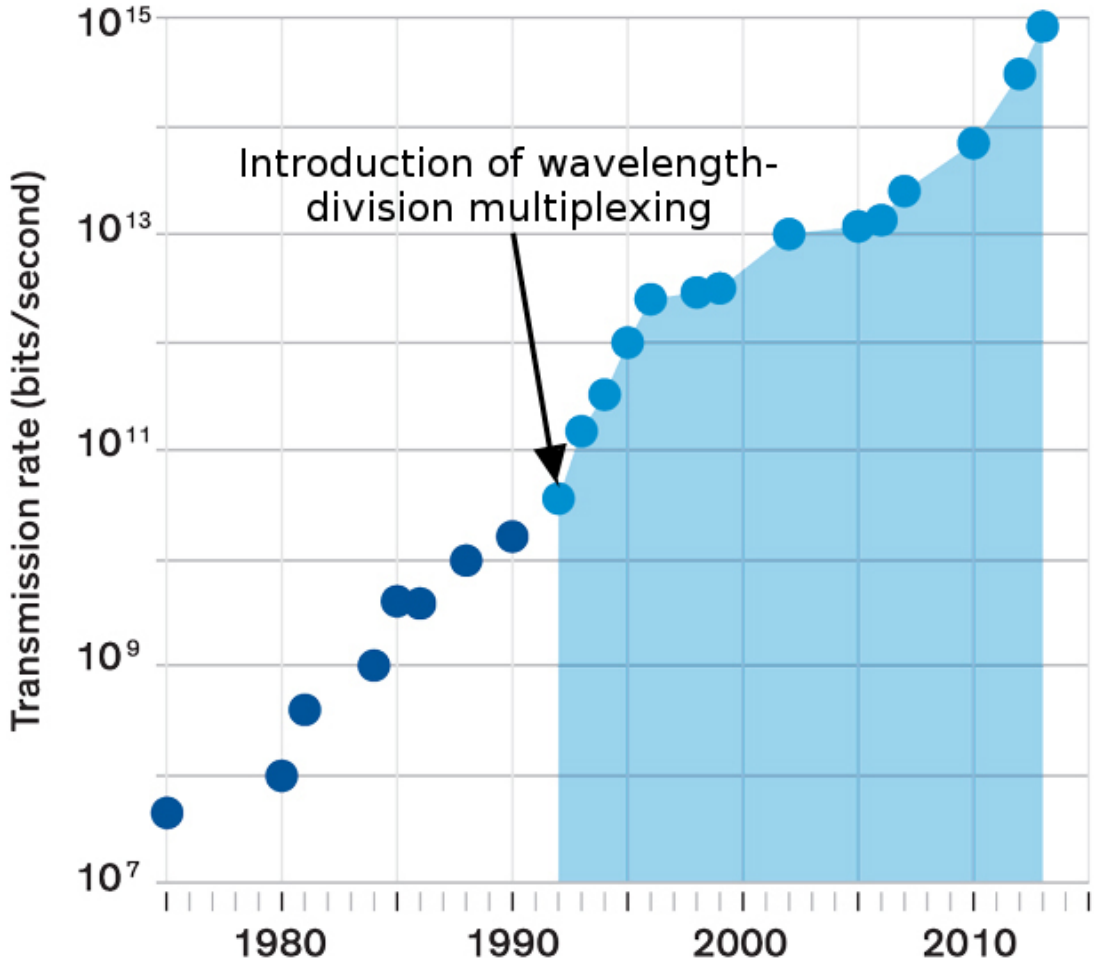
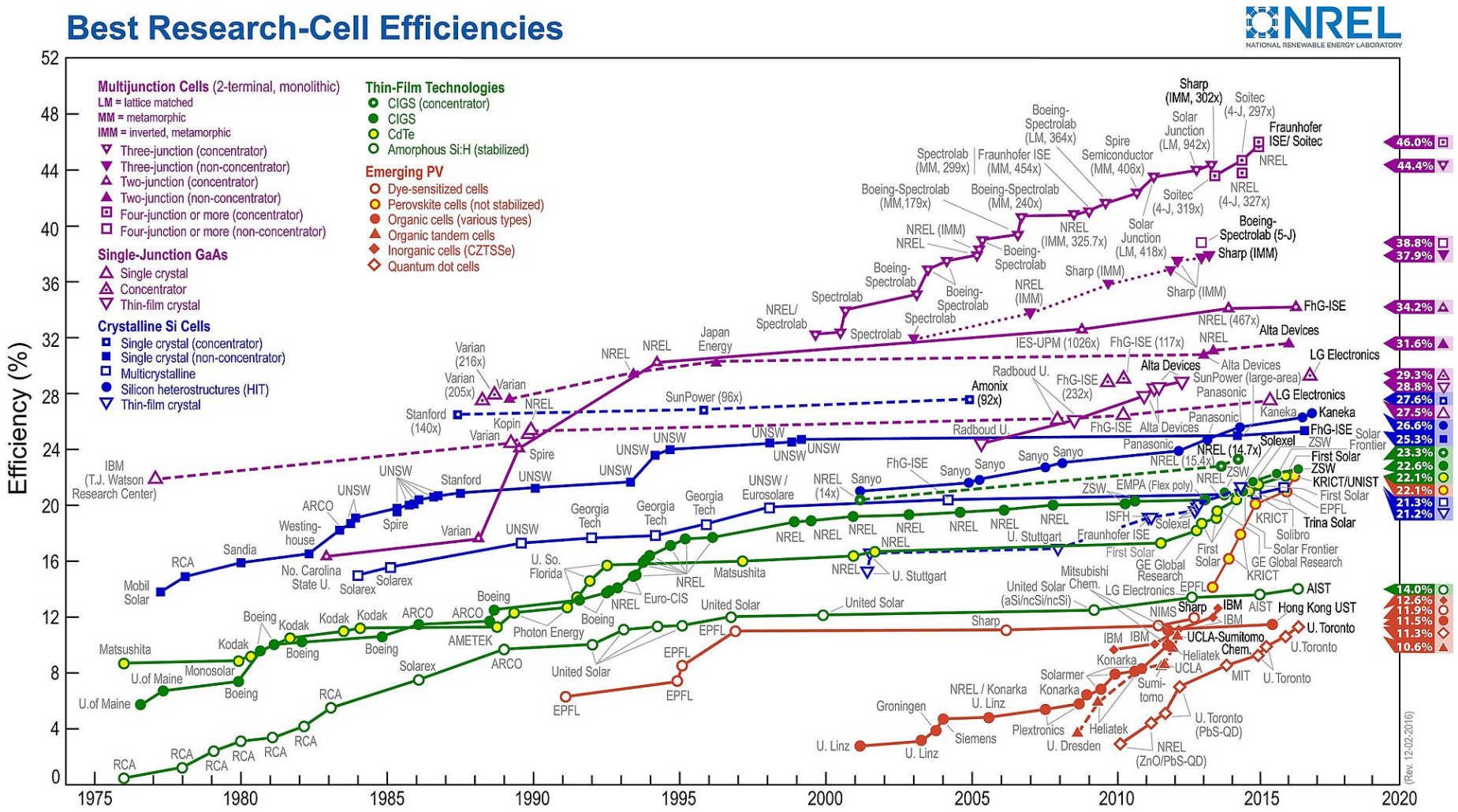
Keck's law: fiber optic communication rate



Source: J Hecht on IEEE spectrum, 26 Jan 2016

Photovoltaic efficiencies



Equally impressive: efficiency is much harder than device scaling

Source: S. Kurtz and D. Levi, NREL

Goals of this course

- Physical laws $\rightarrow$ material properties
- Material properties $\rightarrow$ device functionality
- Device functionality $\rightarrow$ technologies (briefly)