BOSTON UNIVERSITY

EK 307: Electric Circuits

Fall 2017

Lecture 1

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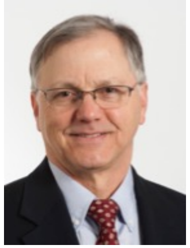
Department of Electrical and Computer Engineering
Boston University

Administrivia

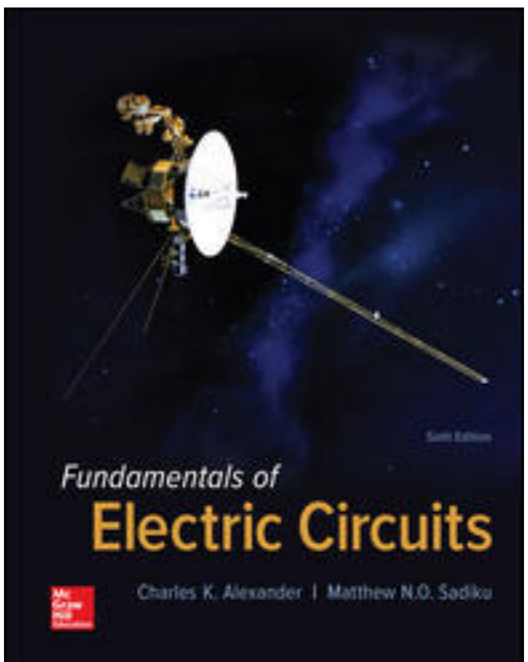
- Instructor:
  - Prof. Miloš Popović — Section A1
    - Office: PHO 717
    - Office hours: Fridays 2-3pm
    - Email: mpopovic@bu.edu
  - Prof. Mark Horenstein — Section A2
  - Prof. Min-Chang Lee — Section A3

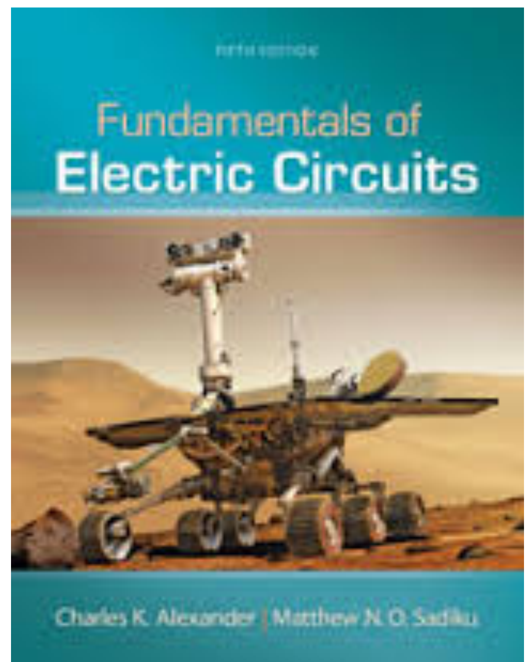


- Sections: A1-A3 lecture, B1-B6 discussion, C1-C8 lab
- ~~Course Material: http://learn.bu.edu~~
  - Labs website: http://sites.bu.edu/engcourses/ek307/
    - also for course materials and homework sets/solutions
  - ~~Homework: BU edX (edge.edx.org)~~

Administrivia

- Textbook
  - Fundamentals of Electric Circuits, by C. Alexander and M. Sadiku, 6th Edition.
  - 5th edition also works, very similar





Administrivia

- Grading:
  - Midterm Exam 1 20%
  - Midterm Exam 2 20%
  - Final Exam 30%
  - Homework 10%
  - Labs 20%

- Homework:
  - Distributed and graded on edX
  - Out each Friday, due by Monday 10 days from then (usually)

EK 307 - Electric Circuits - Fall 2017

Week\Day	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
September 2017							
1	3	4	5 L1	6 L1, L1	7 L2	8 h1 out	9
2	10	11 L2, L2	12 L3	13 L3, L3	14 L4	15 h2 out	16
3	17 h1 due	18 L4, L4	19 L5	20 L5, L5	21 L6	22 h3 out	23
4	24 h2 due	25 L6, L6	26 L7	27 L7, L7	28 L8	29 h4 out	30
October 2017							
5	1 h3 due	2 L8, L8	3 L9	4 L9, L9	5 L10	6 h5 out	7
6	8 h4 due	9 Holiday	10 L10, L10	11 L11, L11	12 L11	13 h6 out	14
7	15 h5 due	16 L12, L12	17 L12	18 L13, L13	19 L13	20 h7 out	21
8	22 h6 due	23 L14, L14	24 L14	25 L15, L15	26 L15	27 h8 out	28
November 2017							
9	29 h7 due	30 L16, L16	31 L16	1 L17, L17	2 L17	3 h9 out	4
10	5 h8 due	6 L18, L18	7 L18	8 L19, L19	9 L19	10 h10 out	11
11	12 h9 due	13 L20, L20	14 L20	15 L21, L21	16 L21	17 h11 out	18
12	19 h10 due	20 L22, L22	21 L22	22	23 Thanksgiving	24 **h12 out**	25
December 2017							
13	26 h11 due	27 L23, L23	28 L23	29 L24, L24	30 L24	1 h13 out	2
14	3 h12 due	4 L25, L25	5 L25	6 L26, L26	7 L26	8 h14 out*	9
15	10 h13 due	11 L27, L27	12 L27	13	14	15	16
	17	18 EXAM WEEK	19	20	21	22	23

Instructors (teach lectures according to color code, by default)

- Popović
- Horenstein
- Lee

Special notes:

Mark will teach L2

Miloš will teach L3

Homework:

Homeworks will be on material up to the end of that week's...

...Wednesday lecture, for weeks 1-5

...Thursday lecture, for weeks

h11 is only on lecture L20 (short homework bc of Thanksgiving break)

h12 is on L21 and L22 (also not huge bc of Thanksgiving weekend lost)

h14 is on L25-L27, but is not due or graded, solutions provided Friday Dec 15.

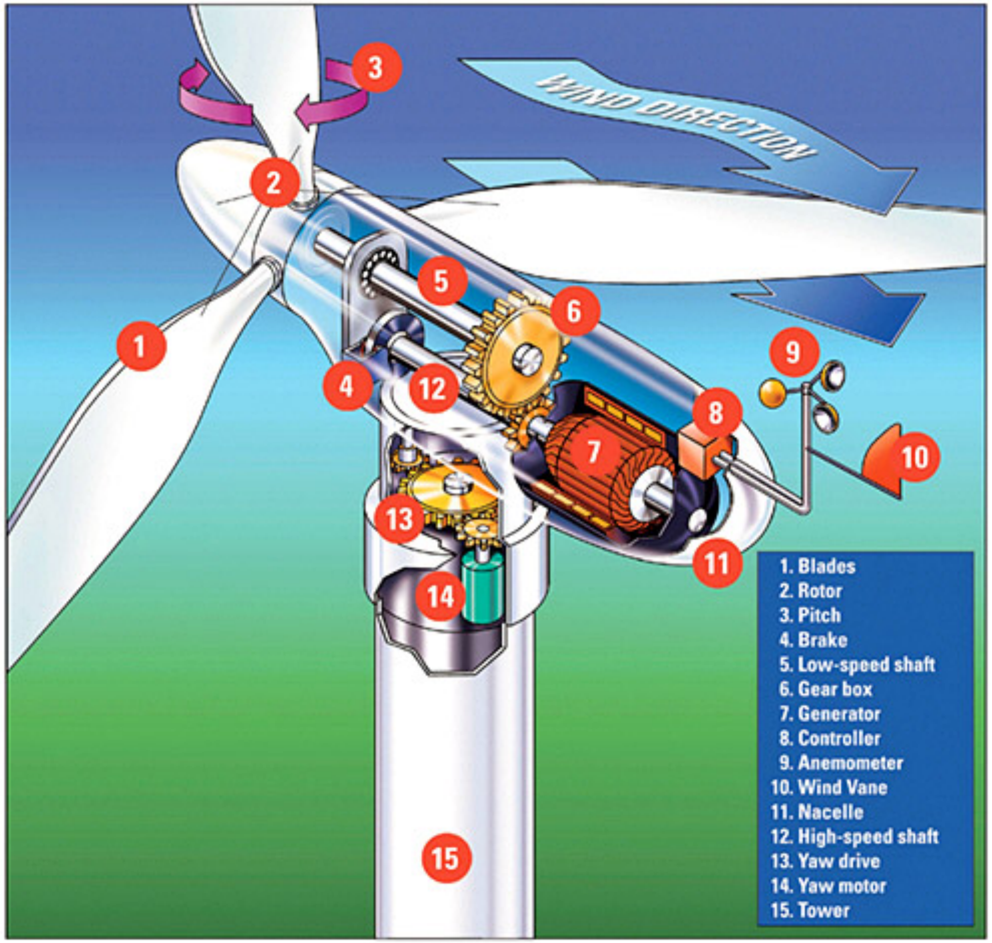
Syllabus

- Updated syllabus provided as separate file.

Why learn circuits?

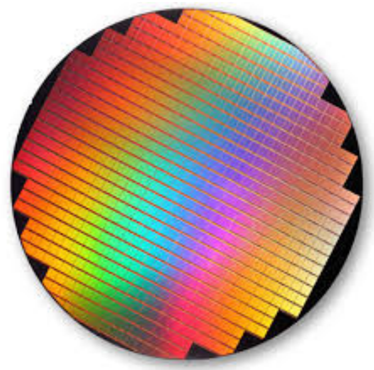
- Energy generation, conversion, storage
- Computing
- Communication
- Control systems
- Transportation – electric cars, planes, etc
- Sensors (medical, environmental, home, etc..)

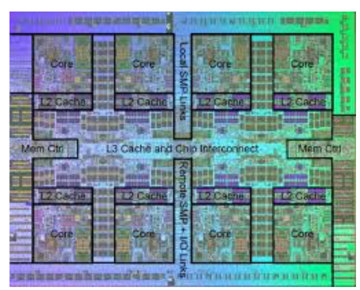
Energy


WIND DIRECTION
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
1. Blades
2. Rotor
3. Pitch
4. Brake
5. Low-speed shaft
6. Gear box
7. Generator
8. Controller
9. Anemometer
10. Wind Vane
11. Nacelle
12. High-speed shaft
13. Yaw drive
14. Yaw motor
15. Tower

Silicon CMOS microelectronics



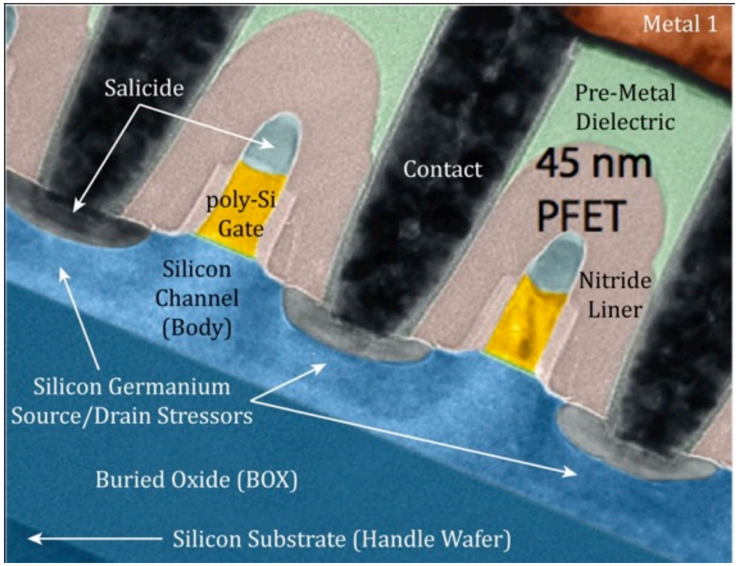



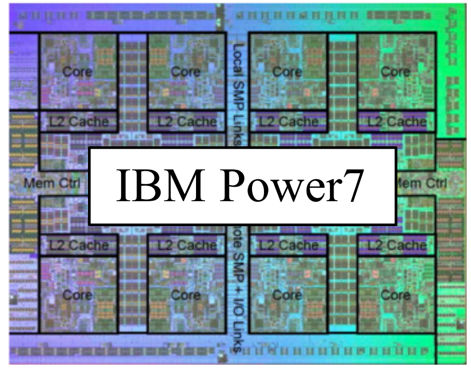



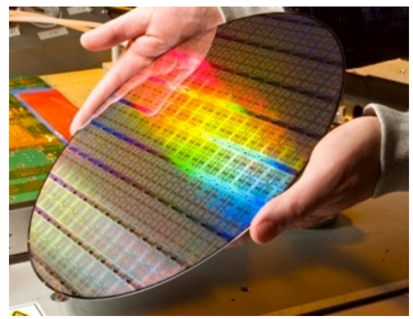

$300B industry

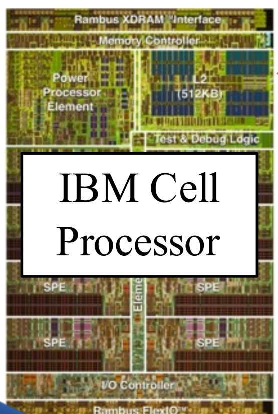
22nm -> 14nm -> 7nm FinFET node

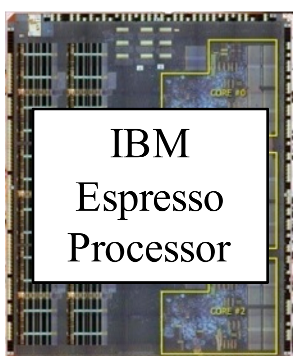
IBM 45nm CMOS microelectronics process



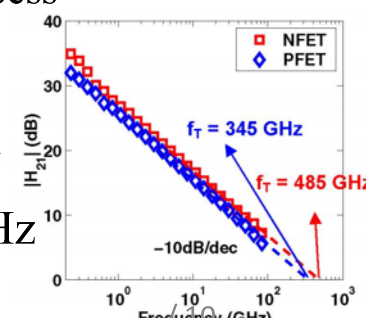








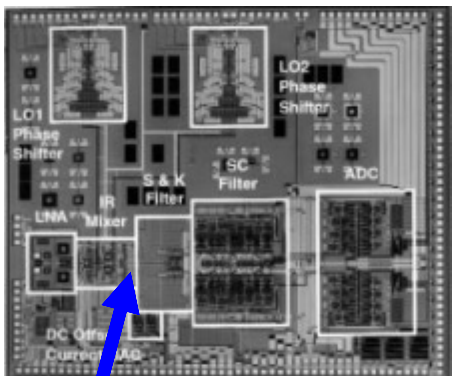
- IBM 12SOI (45nm SOI) CMOS process
  - 300mm wafer, commercial process
  - Trusted Foundry (TAPO) MPW access
- Advanced; used in microprocessors
  - N-FET transistor f_T = 485 GHz
  - Standard process is 250-350GHz

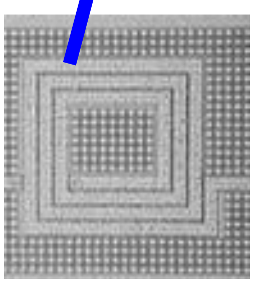


Integrated Circuits

1997

One of the first CMOS radios
Rudell & Gray

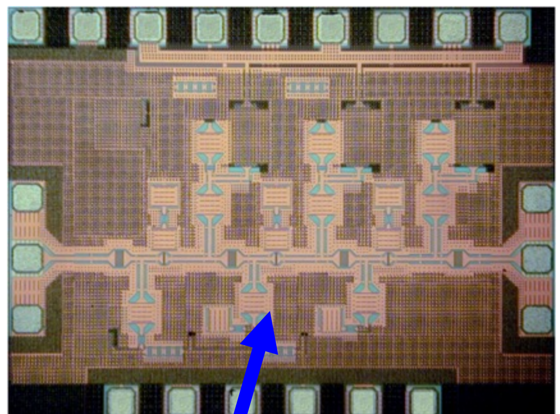


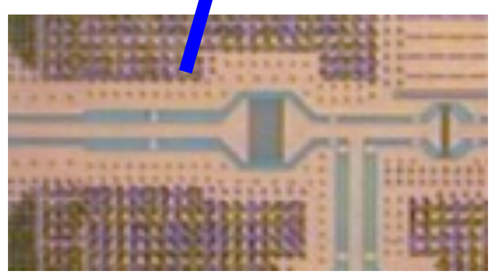


Inductors in IC process
Nguyen & Meyer
1990

2004

First 60GHz CMOS amplifier
Niknejad & Brodersen

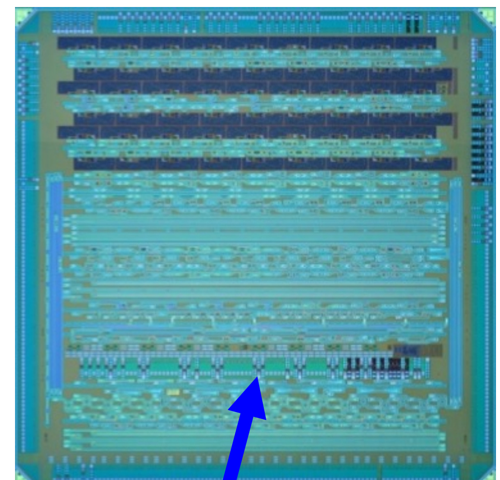


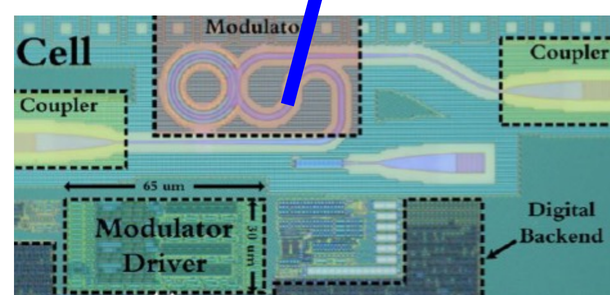


Transmission lines

2012

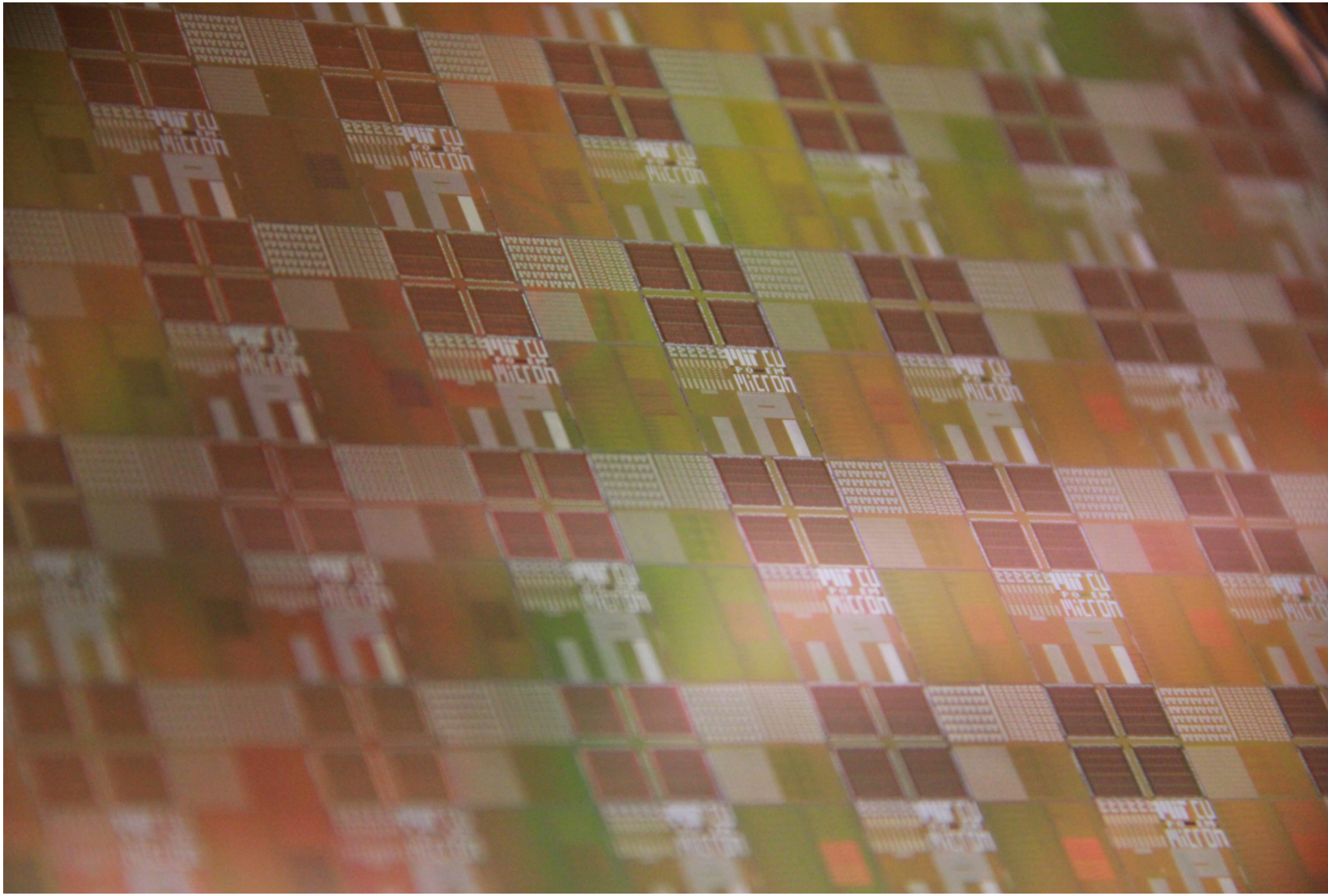
First Si photonic transmitter in 45nm SOI CMOS
Stojanovic, Popovic, Ram





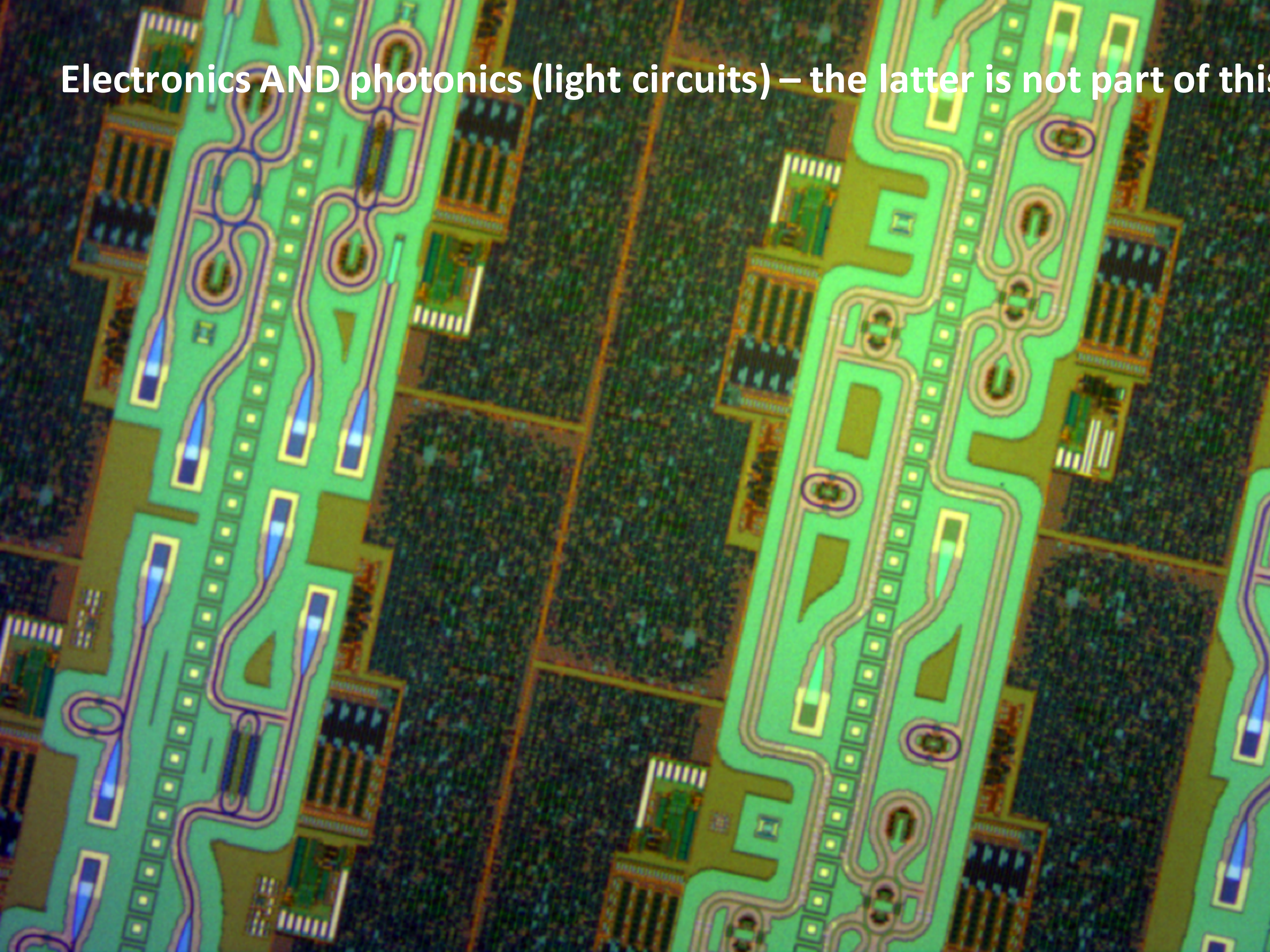
Silicon photonics

Silicon wafer with many chips in a NOR Flash process

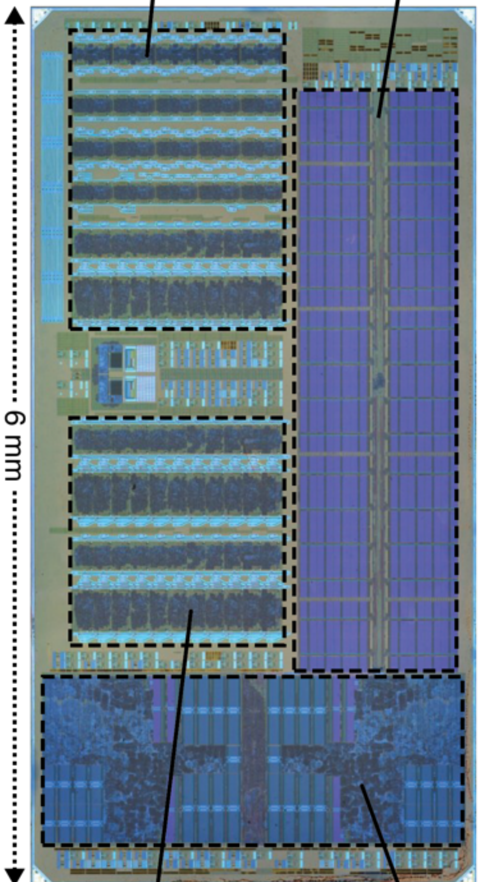


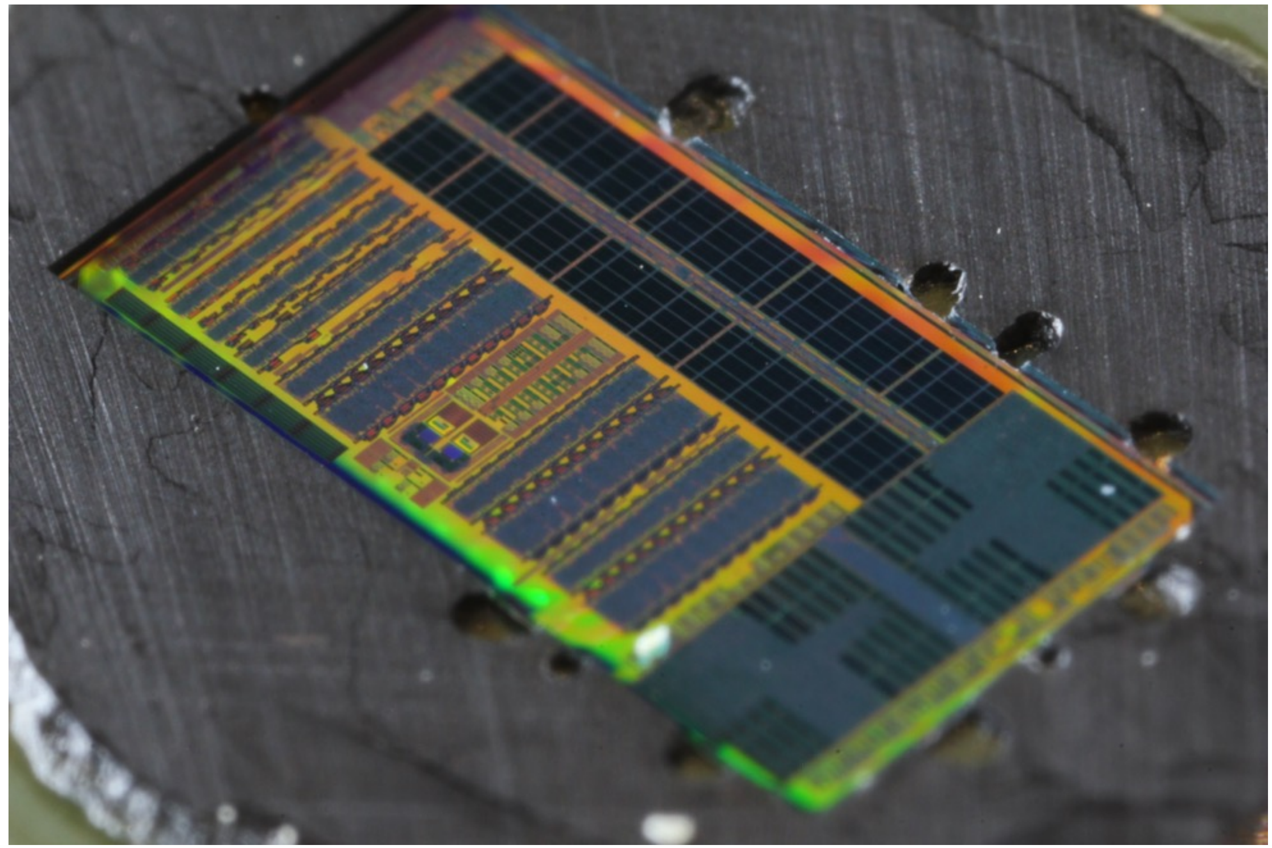
Shainline et al CLEO 2013
(Fabricated by Micron Technology)

Electronics AND photonics (light circuits) – the latter is not part of thi



An Electronic-Photonic System-on-Chip: Microprocessor with photonic I/O

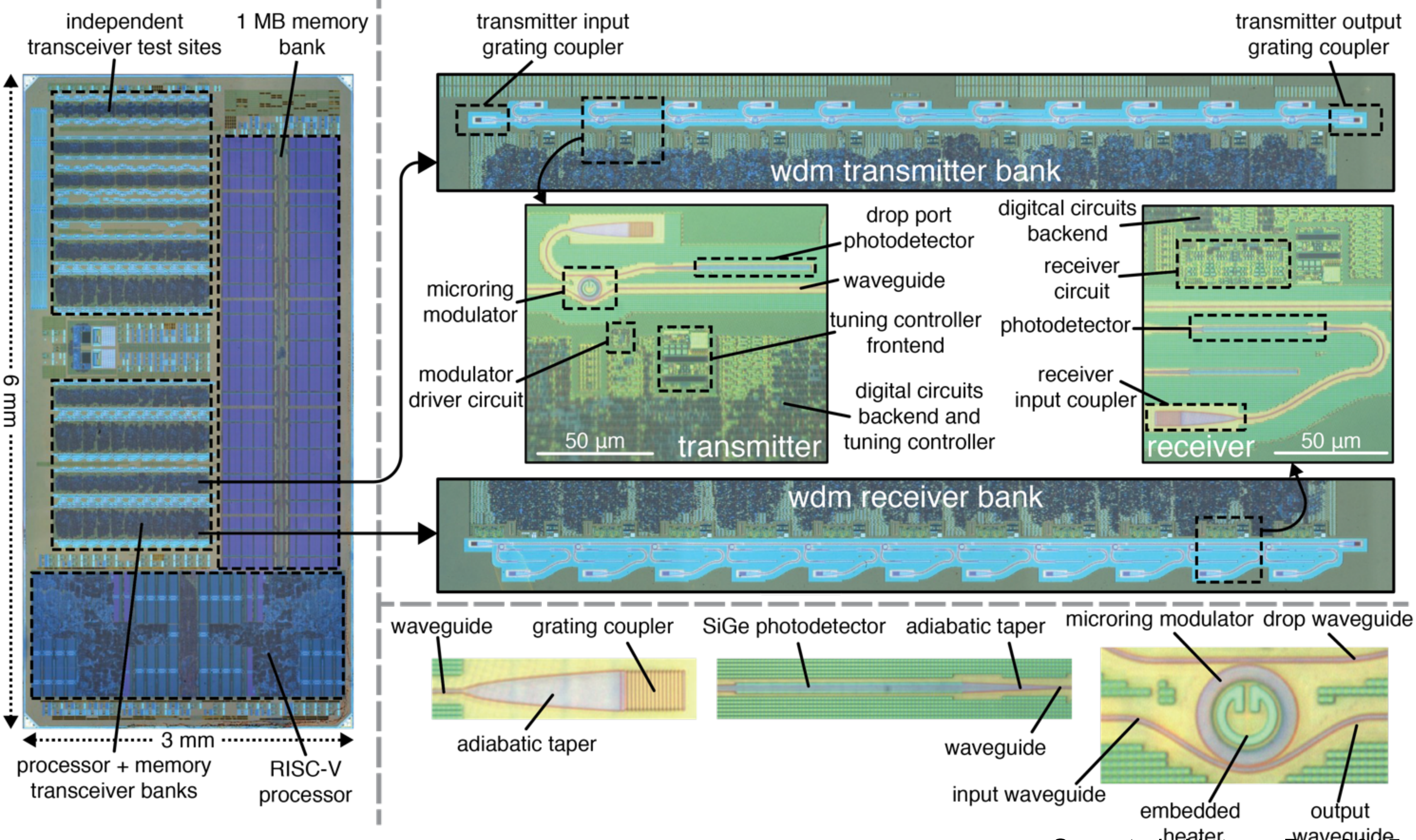




- RISC-V processor w/ 2 vector cores + integrated photonic I/O to memory
- 70M transistors, 1000 photonic devices
- 11-wavelength WDM photonic links at sub-pJ/bit energy

Sun *et al.*, Nature, Dec 2015.

Microprocessor with photonic I/O



Sun *et al.*, Nature, Dec 2015.

What you should know at end of this lecture

1. What is charge, current, voltage?
2. What is electrical energy and power?
3. Basic circuit elements and sources
    - Independent and dependent
    - VCVS, CCVS, VCCS, CCCS
4. Ohm’s law

Introduction

- The purpose of the course is to introduce analysis, design and evaluation of linear circuits.
- **Circuits** are important in electrical engineering because they process electrical **signals** that carry energy and information.
- **Circuit** - an interconnection of electrical devices.
- **Signal** - a time varying electrical entity

Linear circuits

- In this course we are primarily interested in **linear circuits.**
- An important feature of a linear circuit is that the amplitude of the output signal is proportional to the input signal amplitude:

$$S_{out}=a*S_{in},$$ where *a* is constant.

- The proportionality property of linear circuits simplifies the process of circuit analysis and design.
- Most circuits are linear only within a restricted range of signal levels.

Interface

- Definition: a pair of accessible terminals at which signals may be observed or specified.
- The interface idea is particularly important with integrated circuits (IC) technology.

Course objectives

- **Analysis** - finding the output signals of a given circuit with known input signals
- **Design** - devising one or more circuits that perform a given signal-processing function. There usually are several possible solutions to a design problem.
- **Evaluation** - involves picking the best solution from among several candidates using factors such as cost, power consumption, and part counts.

Circuit Variables: Charge

- Electrical charge – *q*, coulombs (C)
  - explains the very strong electrical forces that occur in nature.
  - Time varying, *q(t)*
  - Can be positive or negative – same times repels, different time attracts.
  - The smallest quantity of charge in nature is an electron's charge q_E=-$1.6^{-19}C$.
    - There are $1/|q_E|=6.25x10^{18}$ electrons in 1 coulombs of charge.

Circuit Variables: Current

- Current – *i*, ampere (A)
  - Current is a measure of the flow of electrical charge.
  - $i = dq/dt$
  - 1 coulomb/second=1 ampere=1A
  - The direction of current as the direction of the net flow of **positive** charge. Since electrons have negative charge, they move in the opposite direction of the current.

Circuit Variables: Voltage

- Voltage – *v*, volts (V)
  - related to the change in energy that would be experienced by a charge as it passes through a circuit.
  - $v = dw/dq$
  - 1 joule/coulomb=1volt =1V
  - The symbol *w* is commonly used to represent energy. Energy carries the units of joules (abbreviated J).

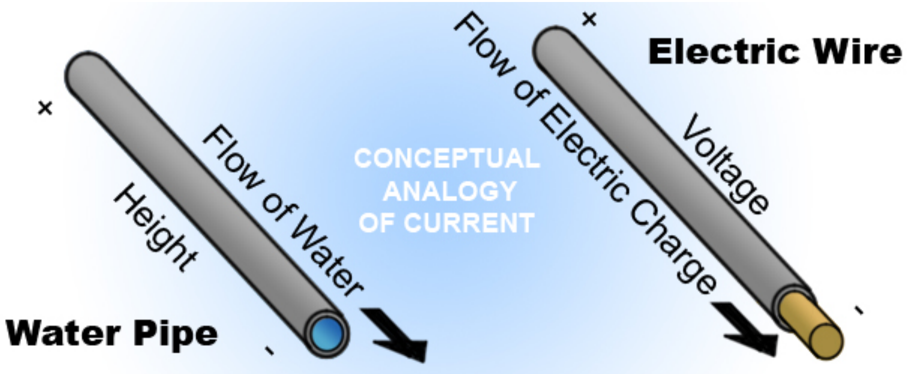
- Voltage does not depend on the path followed by the charge *dq* in moving from point A to point B.
- There can be a voltage between two points even if there is no charge motion

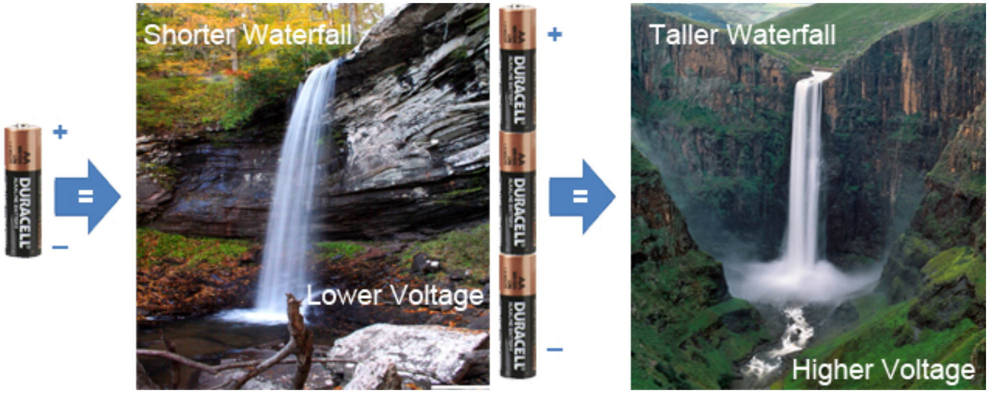
Circuit Variables: Power

- Power: *p*, watts (W)
- Power is the time rate of change of energy
- $P = dw/dt$
- 1 joules per second = 1 watt

- $P = (dw/dq)(dq/dt) \rightarrow P = v \cdot i$
- The total energy transferred during the period from t_1 to t_2 is found by solving for *dw* and then integrating:
- $w_T = \int_{w_1}^{w_2} dw = \int_{t_1}^{t_2} p dt$

Voltage and current: Waterfall analogy





Taken from: http://sargosis.com/articles/science/intro-guide/basic-electric-concepts/

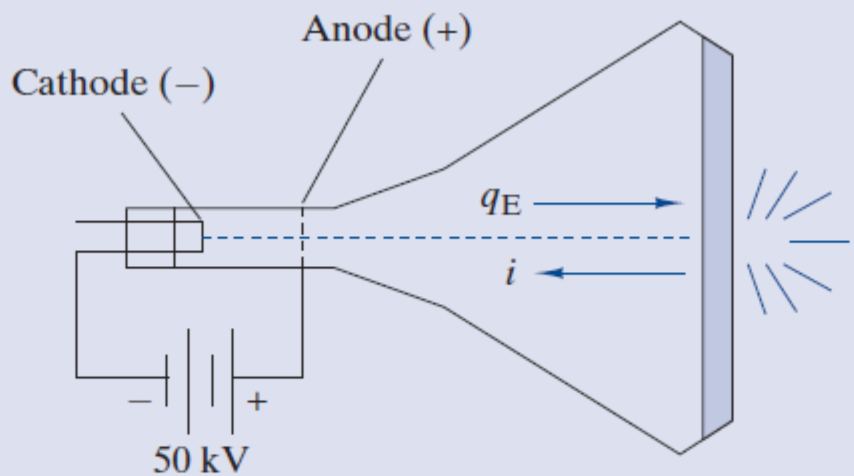
Measuring the circuits variables

- Current is measured at individual points
- Voltage always between two points
- Power at an element or a device

Example 1-1

EXAMPLE 1 – 1

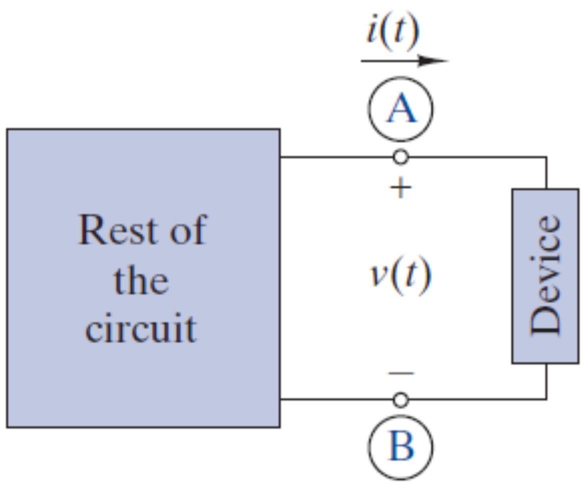
The electron beam in the cathode-ray tube shown in Figure 1–1 carries 10^{14} electrons per second and is accelerated by a voltage of 50 kV. Find the power in the electron beam.



$$i=|q_E|\frac{dn_e}{dt}=(1.6\times10^{-19})(10^{14}) = 1.6\times10^{-5} = 16\mu A$$

$$p = vi = (50\times10^{3})(1.6\times10^{-5}) = 0.8W = 800mW$$

The Passive Sign Convention



Ground

- Voltage is defined between two points
- Common voltage reference point – **Ground**