TSBB21

Guest Lecture

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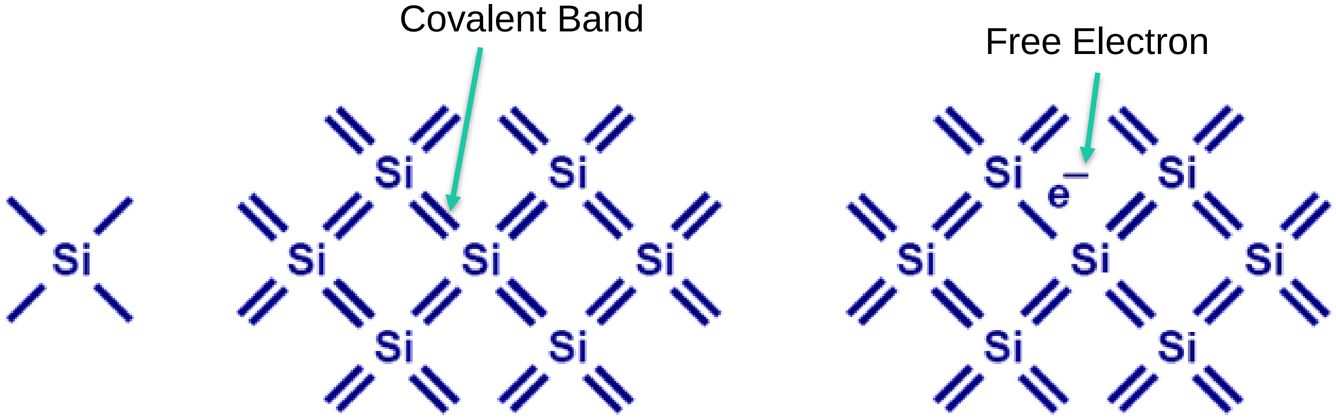
Outline

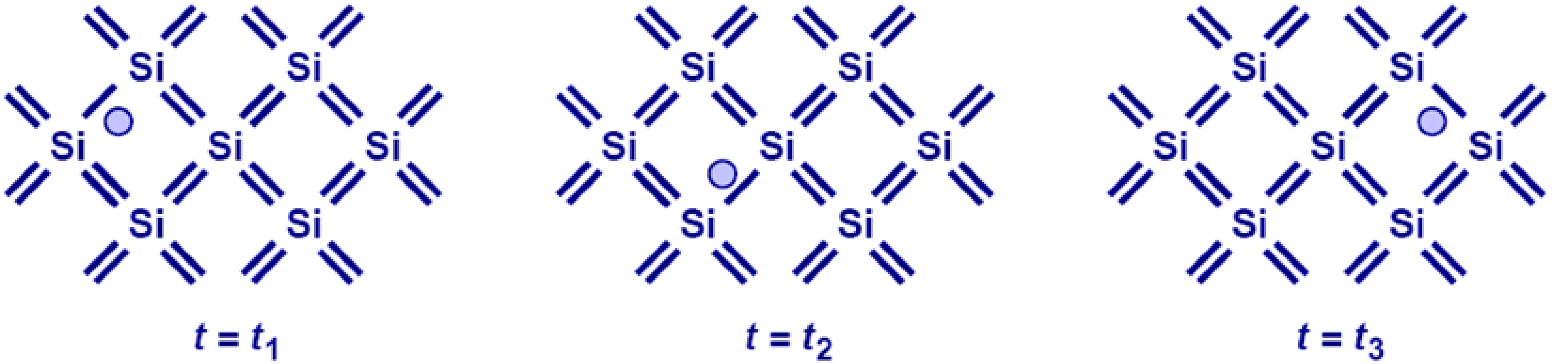
- Semiconductor: p-Type vs n-Type
- PN Junction Diode and Photodiode
- MOS Technology and Transistor
- MOS Capacitor
- Noise

Semiconductor: p-Type vs n-Type

- Semiconductor (Metalloid): Between metal and insulator (non-metals)
- They do not conduct electricity as well as conductors, but they do conduct a small amount of electricity. (example: Si, Ge)
- Si has four valence electrons can form covalent bonds with four of its neighbors.
- By increasing the temperature, electrons in the covalent bond can become free.



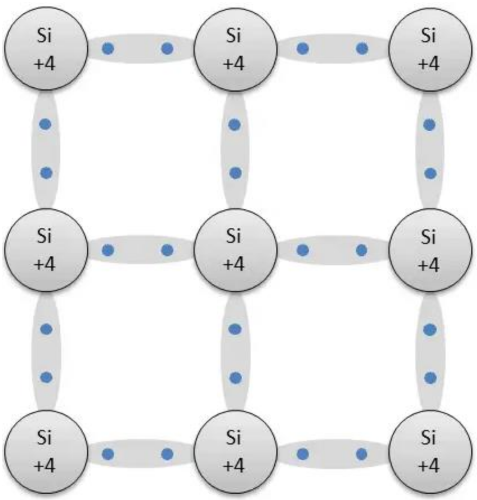
Semiconductor: p-Type vs n-Type



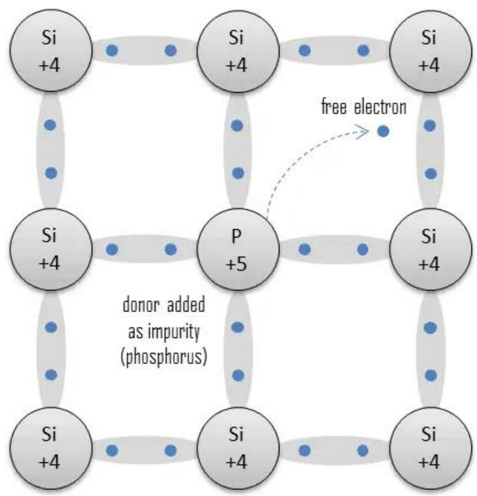
Razavi, Fundamental of Microelectronics

Semiconductor: p-Type vs n-Type

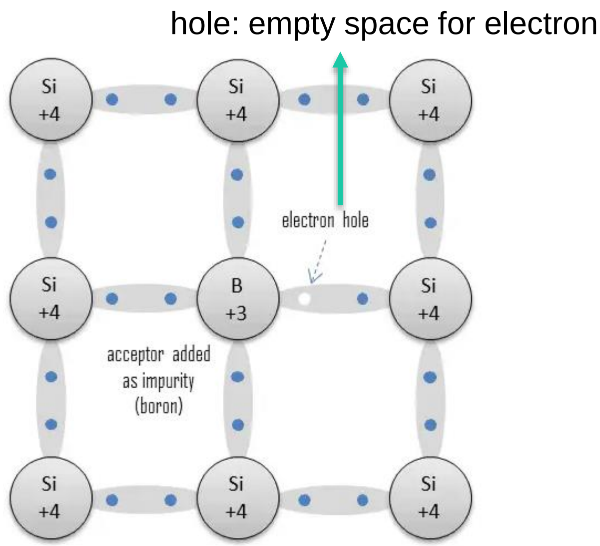
- Intrinsic: Do not conduct very well due to the limited number of free electrons/holes
- Extrinsic: By doping process, it is possible to add some impurities an intrinsic semiconductor to increase its conductivity



Perfect crystal

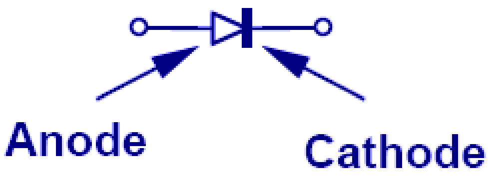


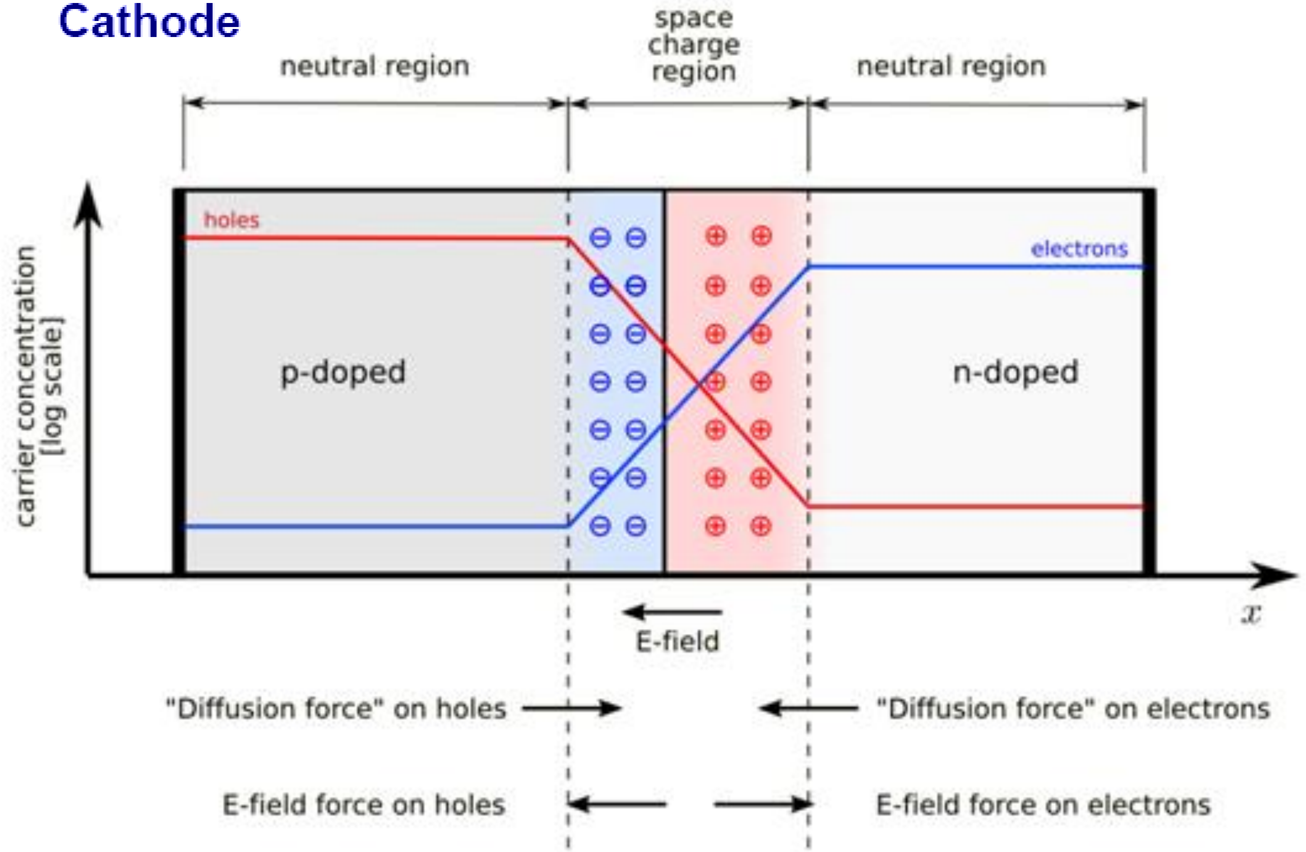
n-type



p-type

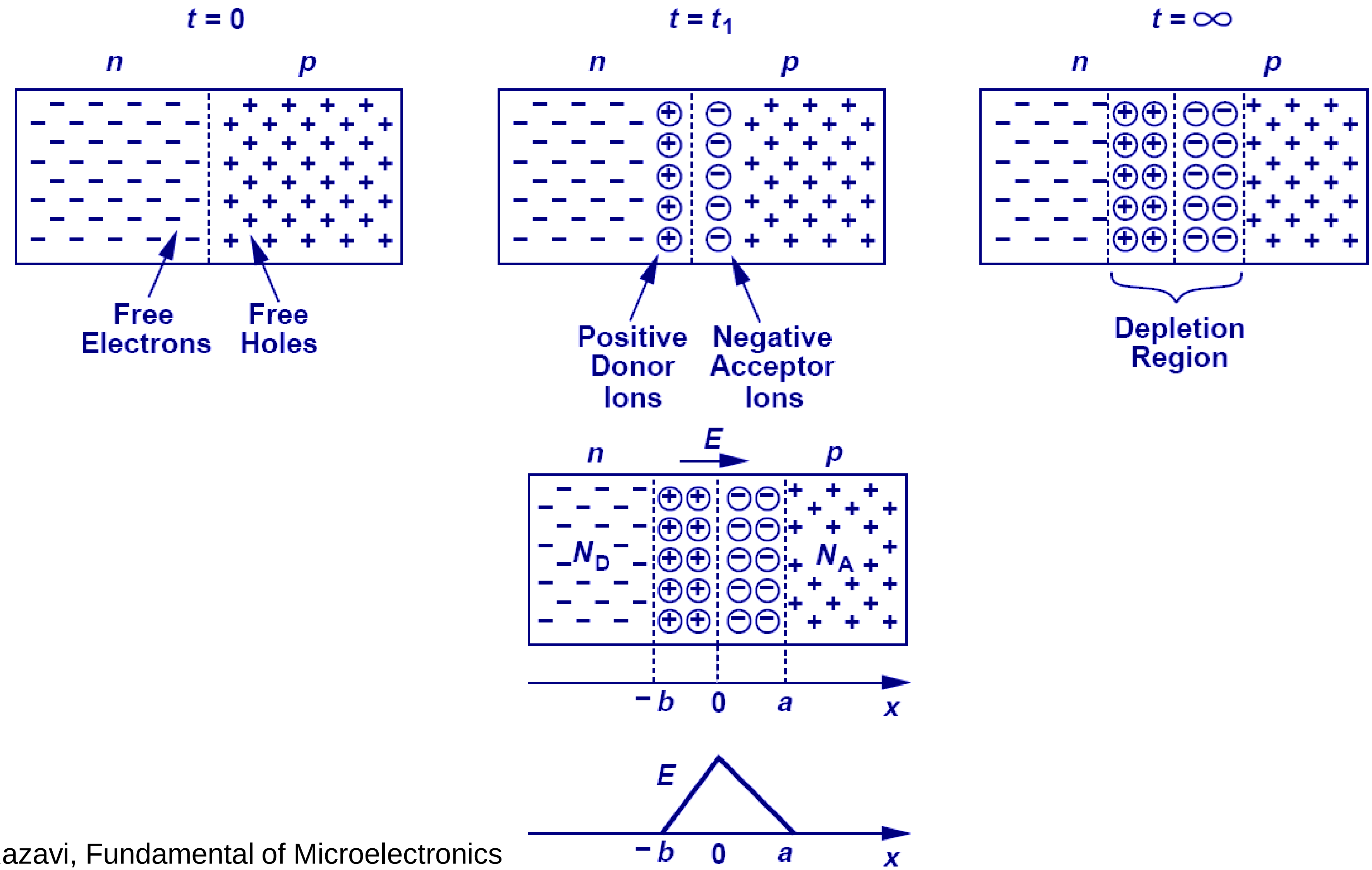
PN Junction Diode





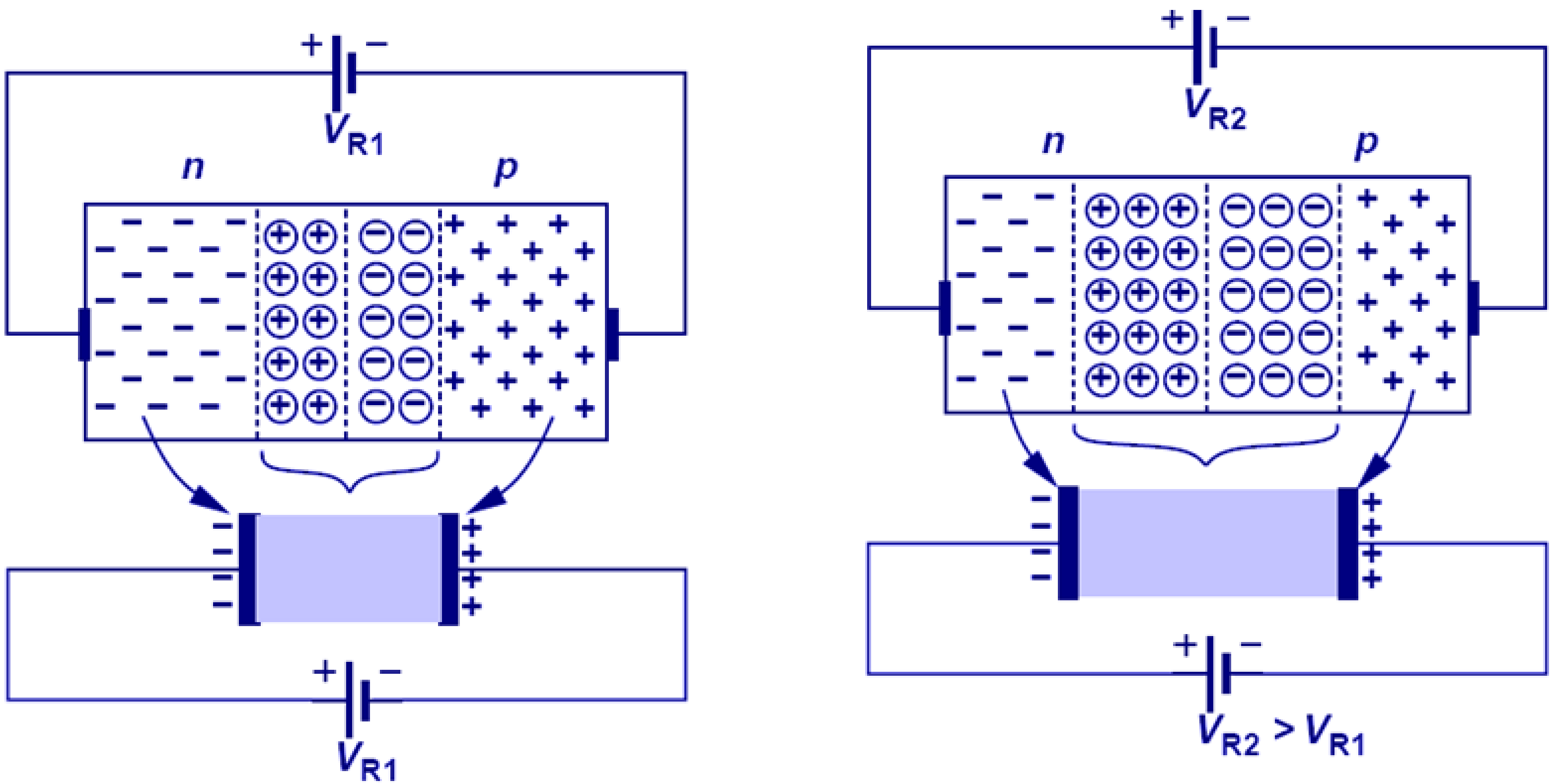
https://wiki.analog.com/university/courses/electronics/text/chapter-5

PN Junction Diode



Razavi, Fundamental of Microelectronics

PN Junction Diode as a Variable Capacitor

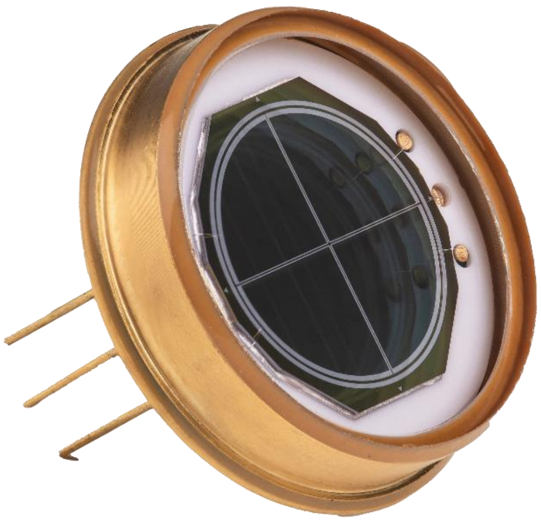


PN junction in its reverse bias condition can work as a capacitor. By varying V_R, the depletion width changes, changing its capacitance value. So, the PN junction is a voltage-dependent capacitor.

Razavi, Fundamental of Microelectronics

Photodiode

- A photodiode is a light sensitive diode.
- It produces current when it absorbs photons.
- Package of the device allows light to reach the sensitive part.
- Package may contain optical lense or optical filters.
- Photodiode operates in reverse bias.



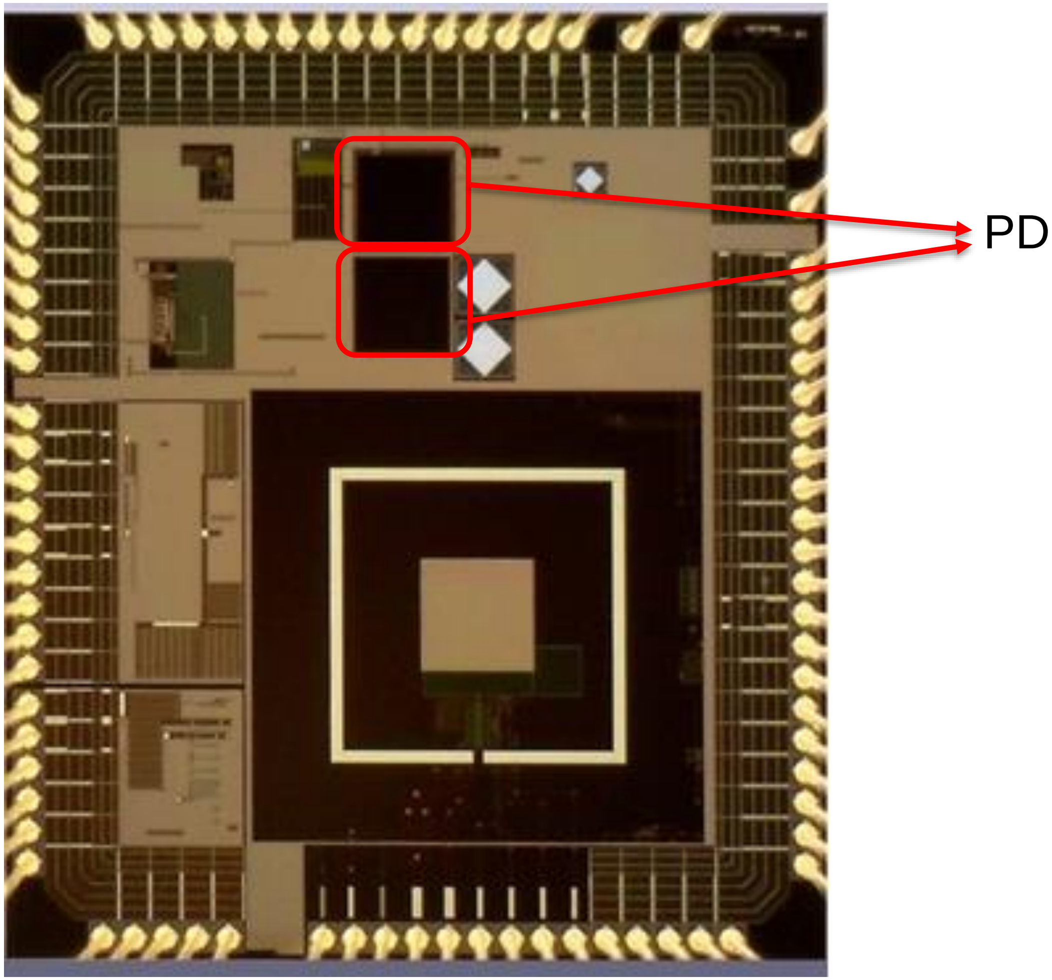
Silicon Photodiode

GaAs Photodiode

Used for the detection of light from UV to the near-IR regions.
Some applications within this spectrum: Position Sensing, Power Monitoring, X-Ray & Gamma Detection, etc.

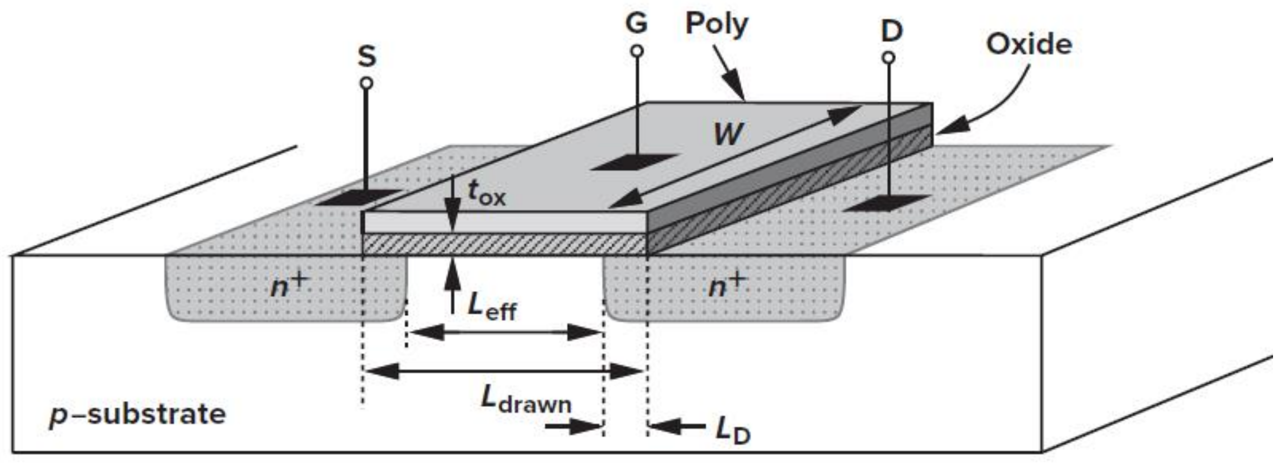
OSI Optoelectronics

Photodiode



EKS-ISY Designed Chip

MOS Technology and Transistor



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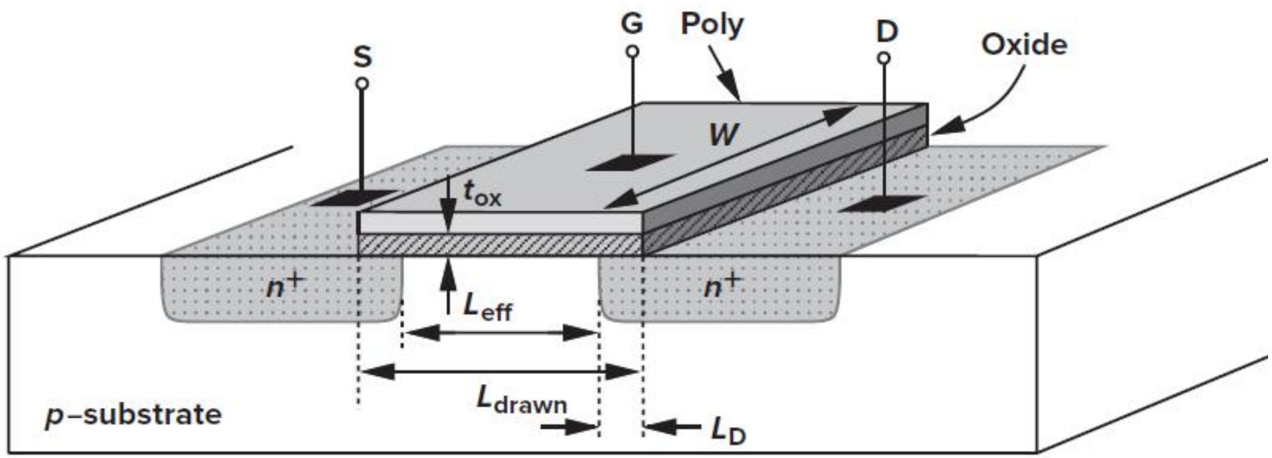
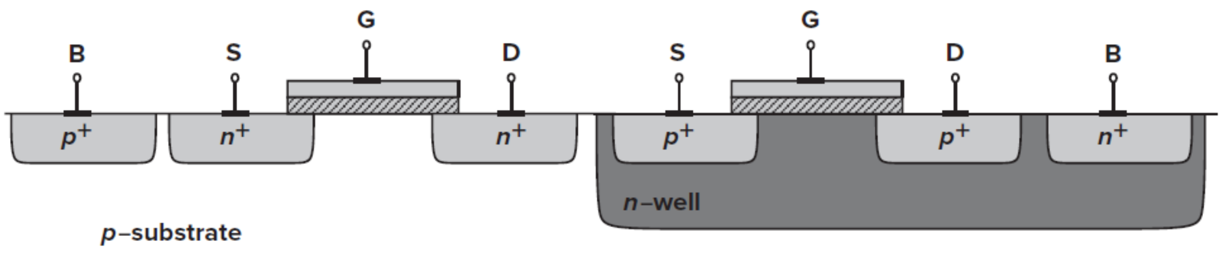
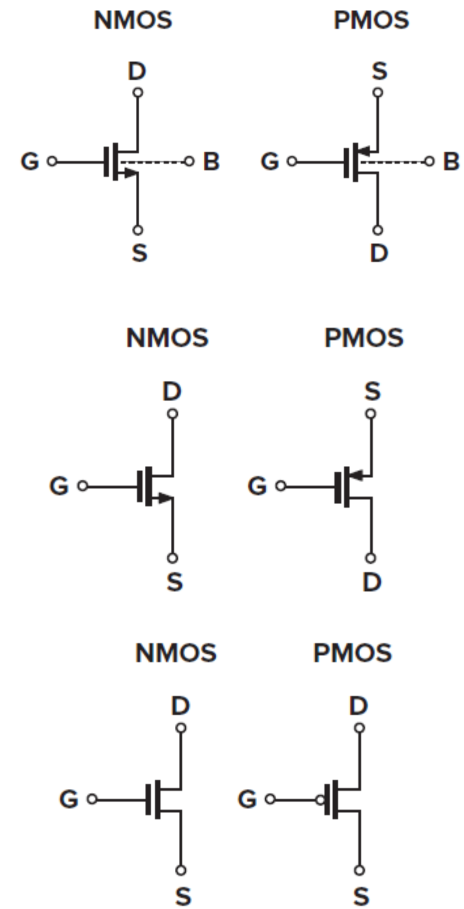
MOS Technology and Transistor



NMOS

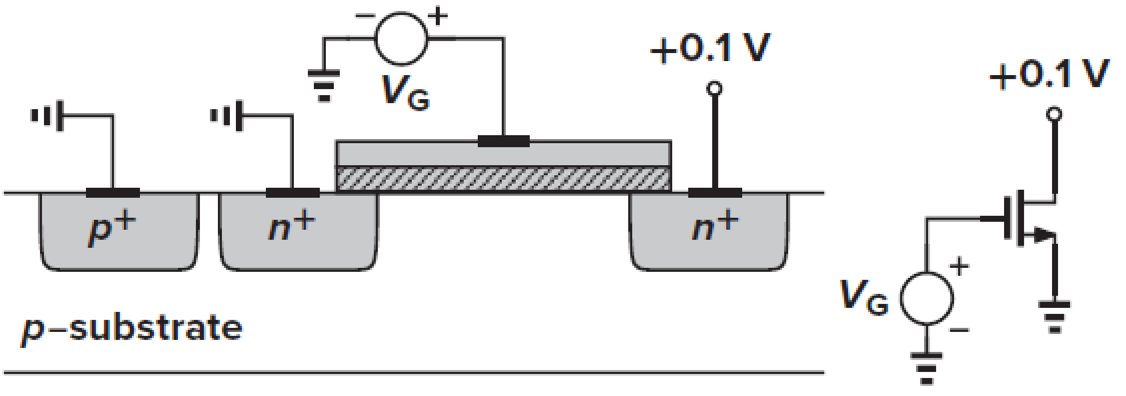
PMOS

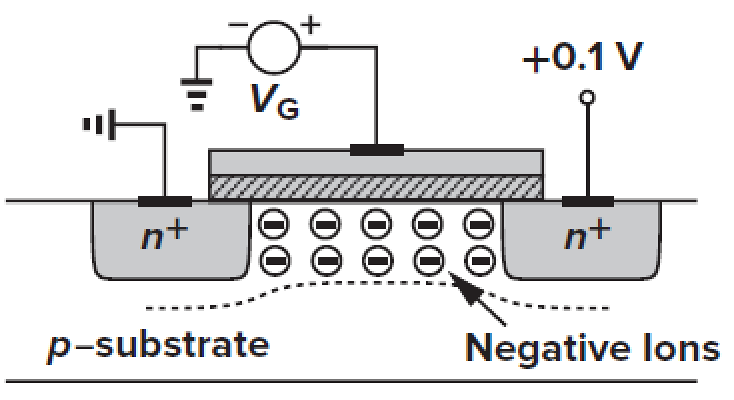


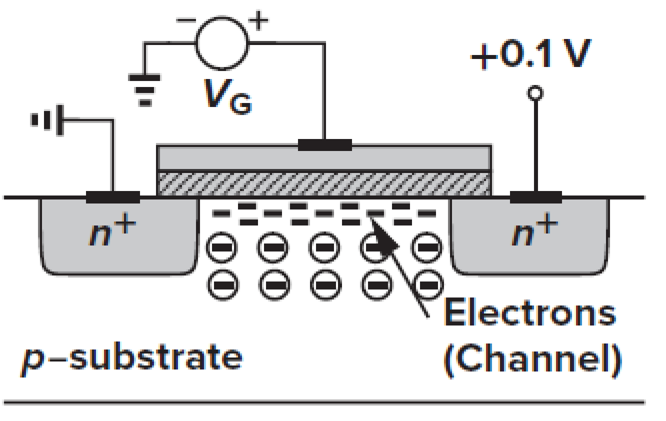


MOS symbols

MOS Channel Formation

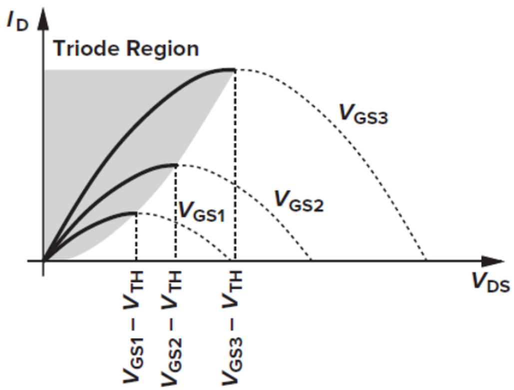






MOS Operation Region

- Triode/Resistive/Ohmic/Linear Region



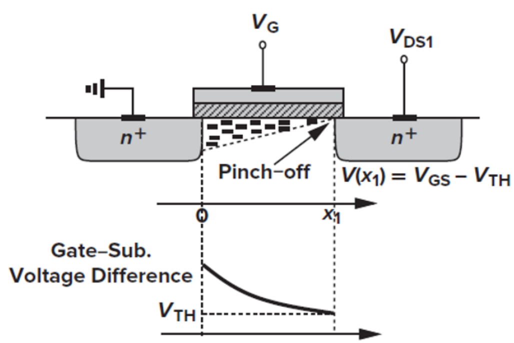
$$I_D = \mu_n C_{ox} \frac{W}{L}\left[(V_{GS} - V_{TH})V_{DS} - \frac{1}{2} V_{DS}^2\right]$$

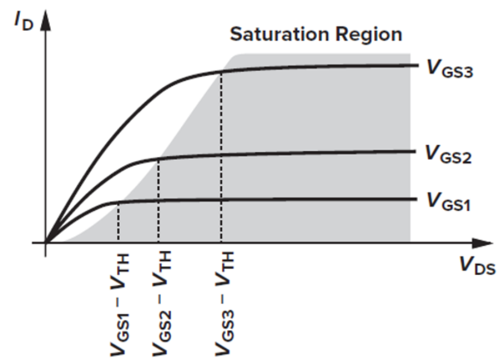
$$I_D = \mu_n C_{ox} \frac{W}{L}(V_{GS} - V_{TH})V_{DS}, \; V_{DS} << 2(V_{GS} - V_{TH})$$

$$R_{ON} = \frac{1}{\mu_n C_{ox} \frac{W}{L}(V_{GS} - V_{TH})}$$

Voltage controlled resistor

- Active/Saturation Region



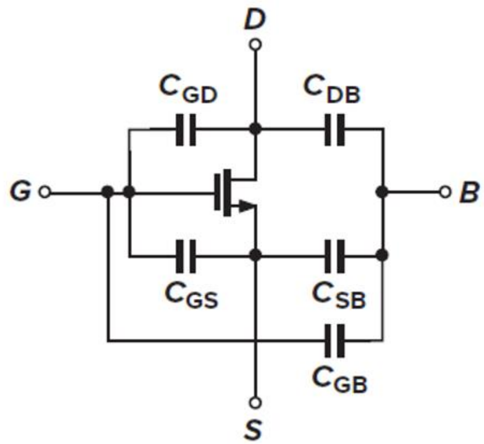


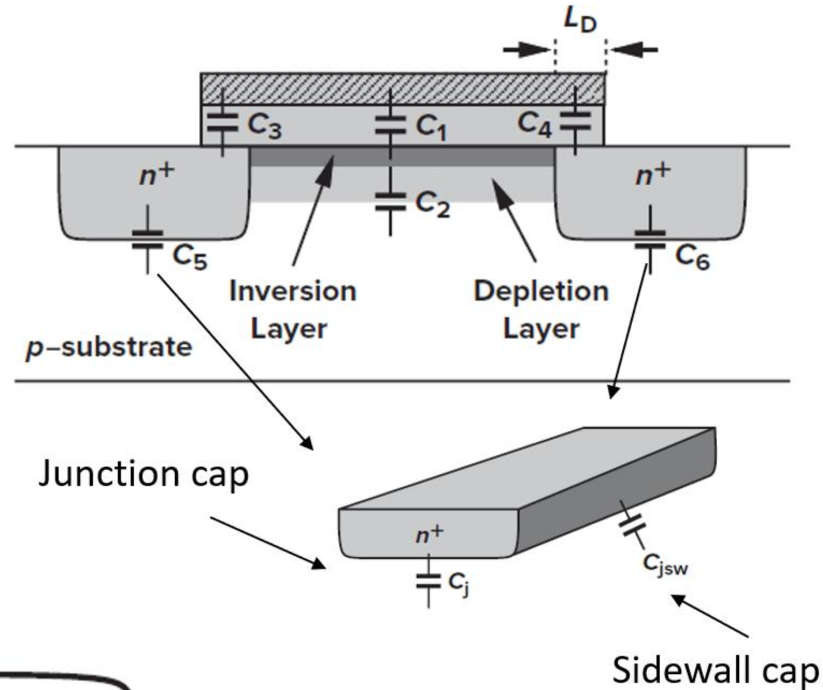
$$I_D = \mu_n C_{ox} \frac{W}{L}\left[(V_{GS} - V_{TH})V_{DS} - \frac{1}{2} V_{DS}^2\right] \Rightarrow I_D = \frac{\mu_n C_{ox}}{2} \frac{W}{L}(V_{GS} - V_{TH})^2$$

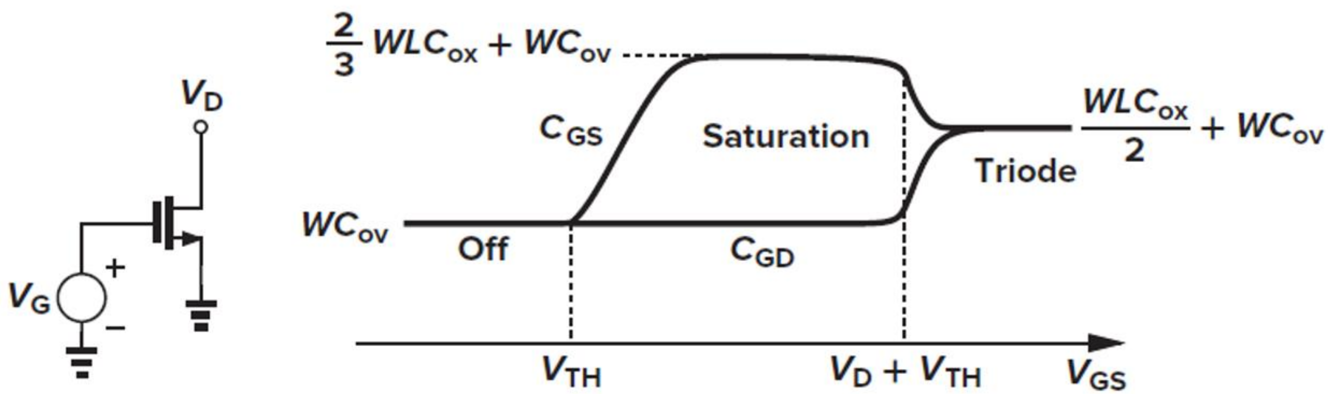
$$V_{DS} = V_{GS} - V_{TH} \qquad (Pinch - off)$$

Voltage controlled current source

MOS Intrinsic Capacitances



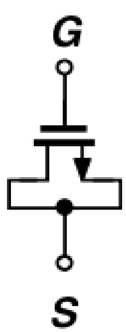


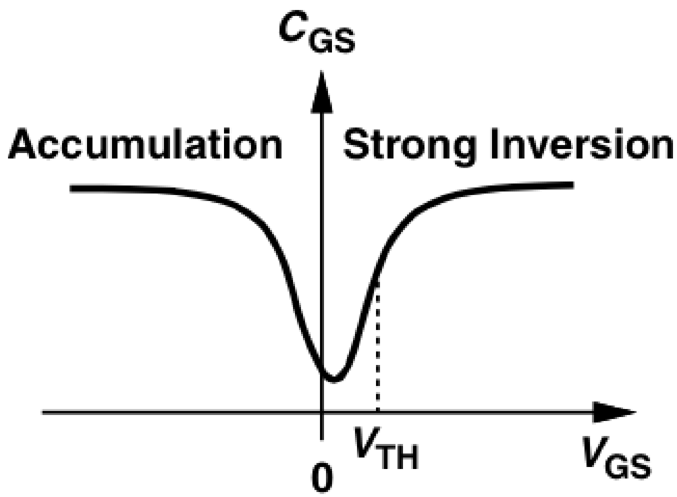


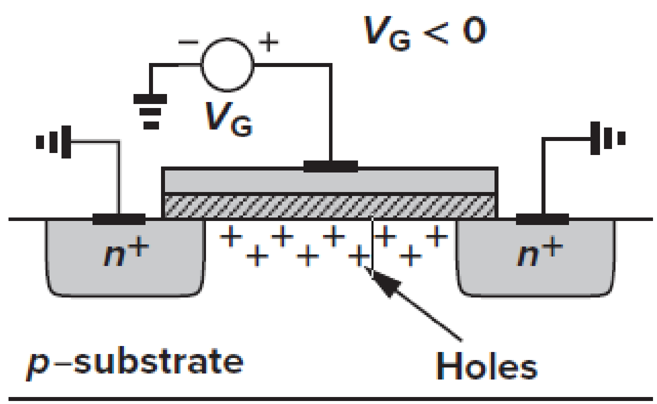
Example in 0.25µ CMOS : C_{ox} ~ 6fF/µm^2, C_j ~ 2fF/µm^2, C_{jsw} or C_{ov} ~ 0.3fF/µm

MOS Capacitor

- The gate-substrate capacitance of an ordinary MOSFET can also be used as a varactor.
- But characteristics of a normal transistor is not ideal for use as a C-V device.

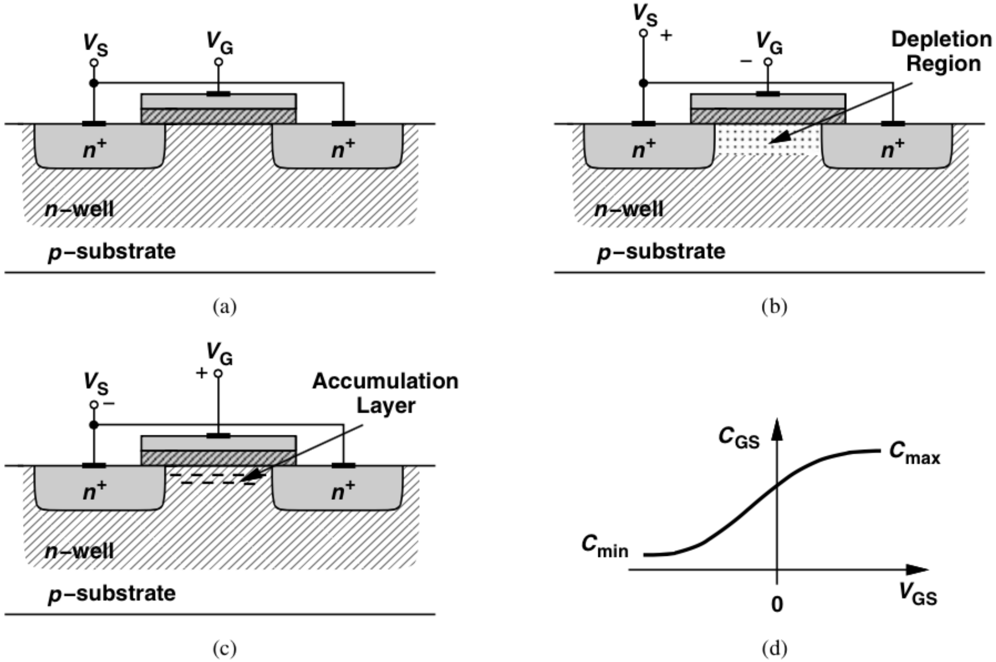






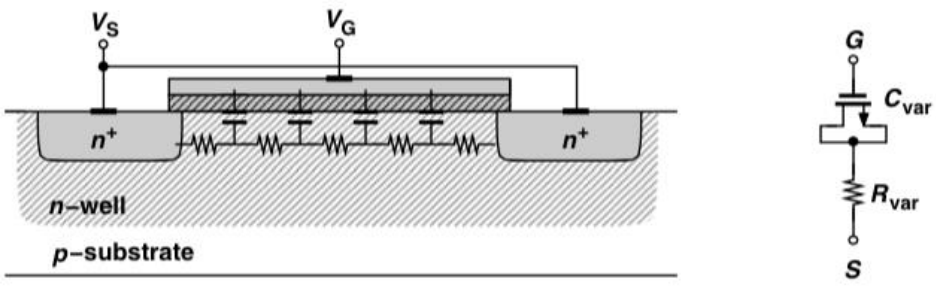
MOS Capacitor

- Instead, place the NMOS-transistor in a n-well. Now it does not work as a transistor anymore, just a capacitor with better characteristics. This is called an **accumulation-mode** MOS varactor.
- For 65 nm CMOS, C_{min} and C_{max} are reached at -/+ 0.5 V.

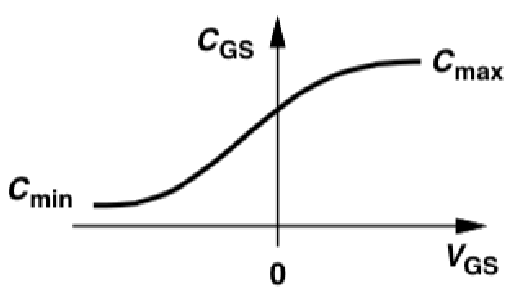


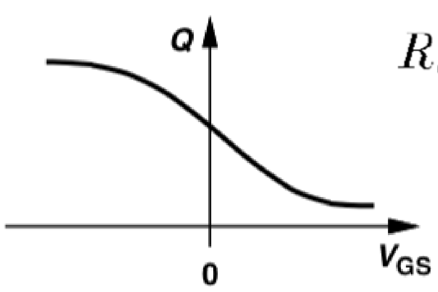
MOS Capacitor

- The Q of MOS varactors is determined by the resistance between the source and drain terminals.
- Q also varies with C: Q = 1/(ωRC)



(a) (b)

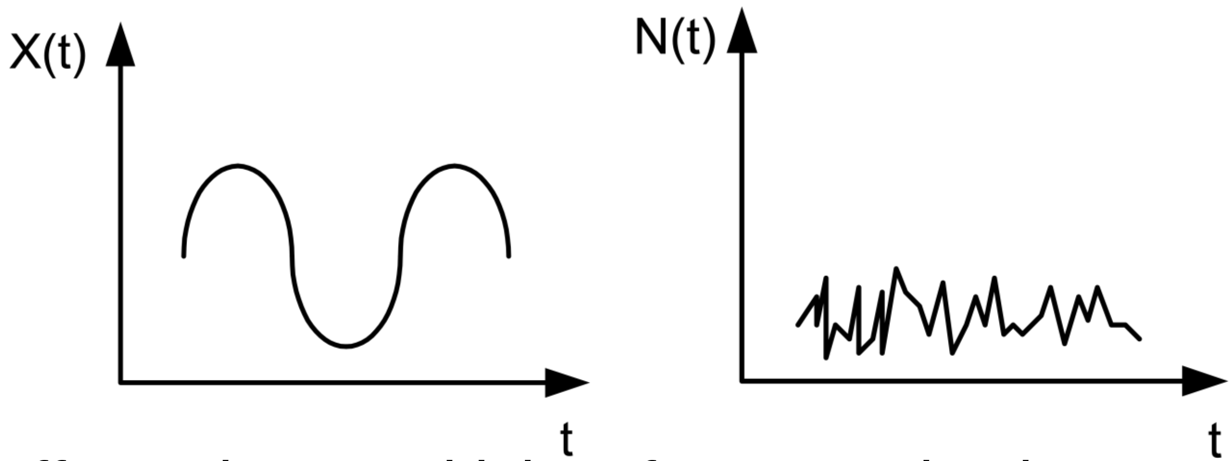




$$R_{on,a} = \frac{1}{\mu_n C_{ox} \frac{W}{L}(V_{GS} - V_{TH})}$$

Noise

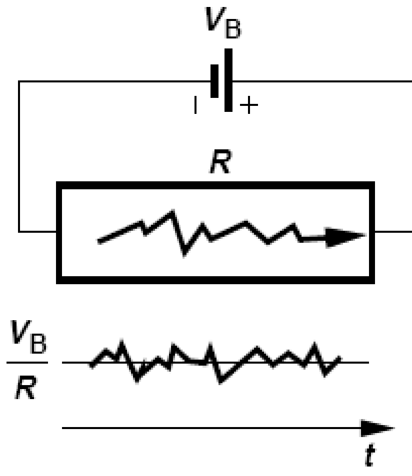
- What is noise? Typically, it is known as "everything except signal":



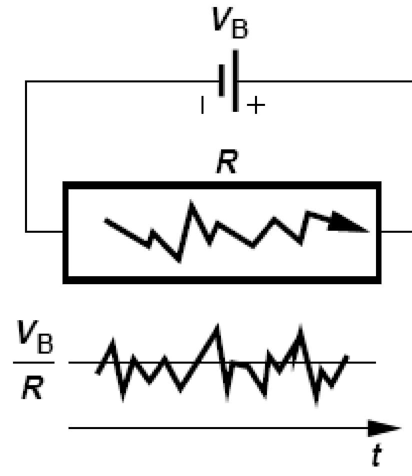
- It affects the sensitivity of communication systems
- There are different types of noise (e.g. thermal noise, shot noise, flicker noise, etc.)

Noise

- The average current remains equal to V_B/R but the instantaneous current displays random values.



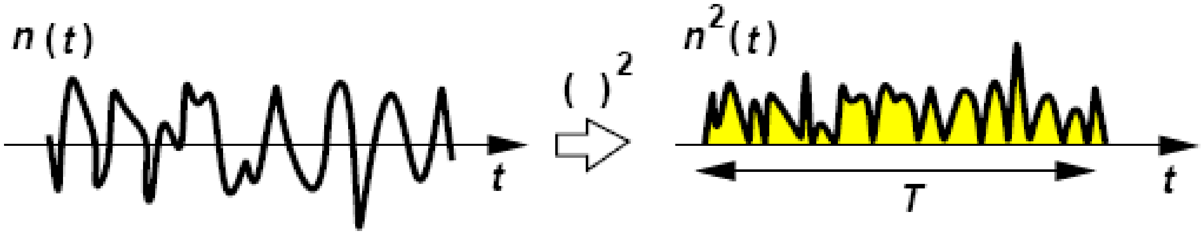
Lower temperature



Higher temperature

Noise Power

- Average noise power:

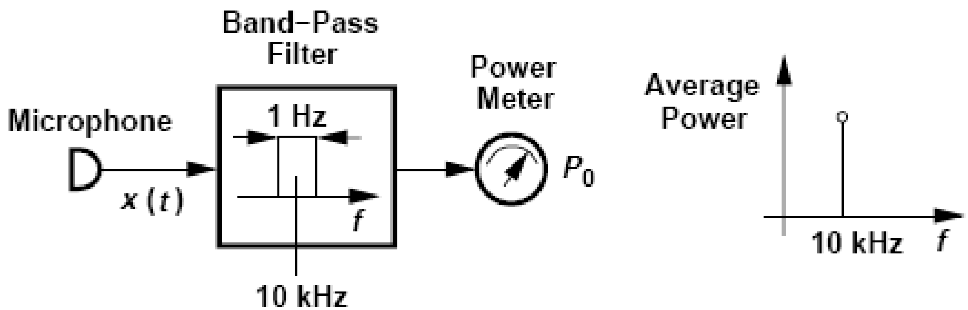


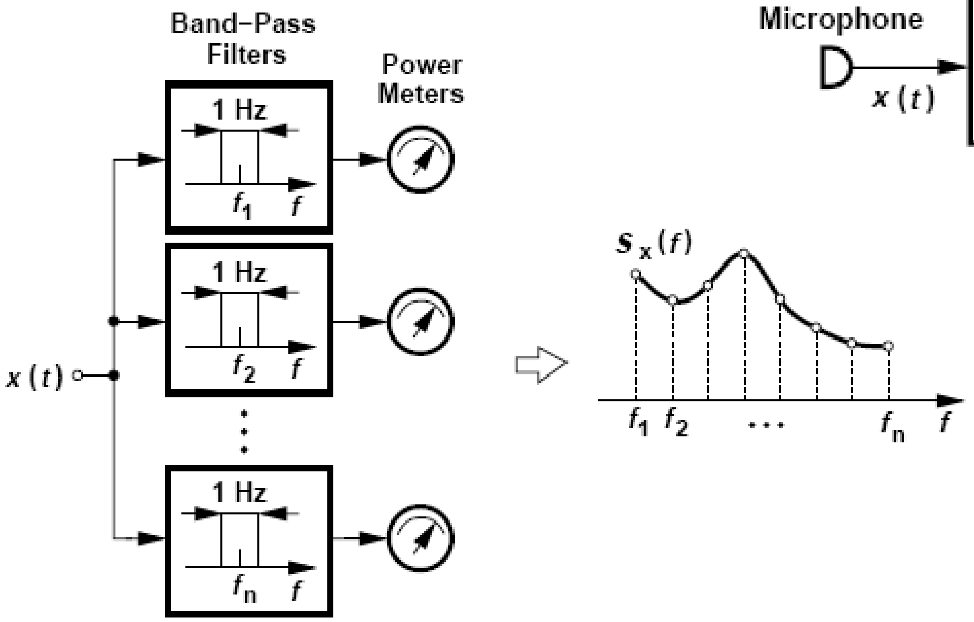
$$P_n = \lim_{T \to \infty} \frac{1}{T} \int_0^T n^2(t) dt$$

- T must be long enough to accommodate several cycles of the lowest frequency.

Noise Spectrum

- To measure the signal’s frequency content at 10 kHz, we need to filter out the remainder of the spectrum and measure the average power of the 10-kHz component.





Noise Spectrum

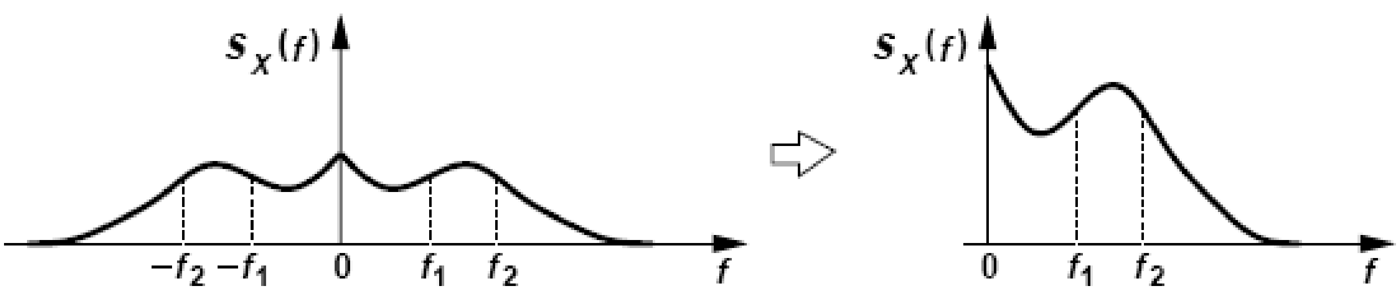
Power Spectral Density (PSD)

- Power Spectral Density (PSD) is the $S_x(f)$.
- Total area under $S_x(f)$ represents the average power carried by $x(t)$.

$$\int_0^{\infty} S_x(f)df = \lim_{T\to\infty}\frac{1}{T}\int_0^{T} x^2(t)dt$$

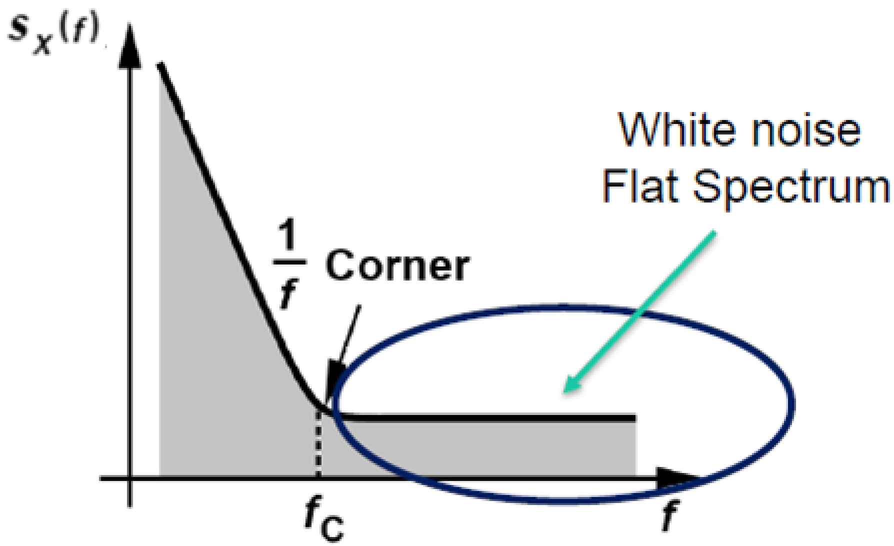
- Two-sided spectrum is scaled down vertically by factor of 2.

Two-Sided **One-Sided**



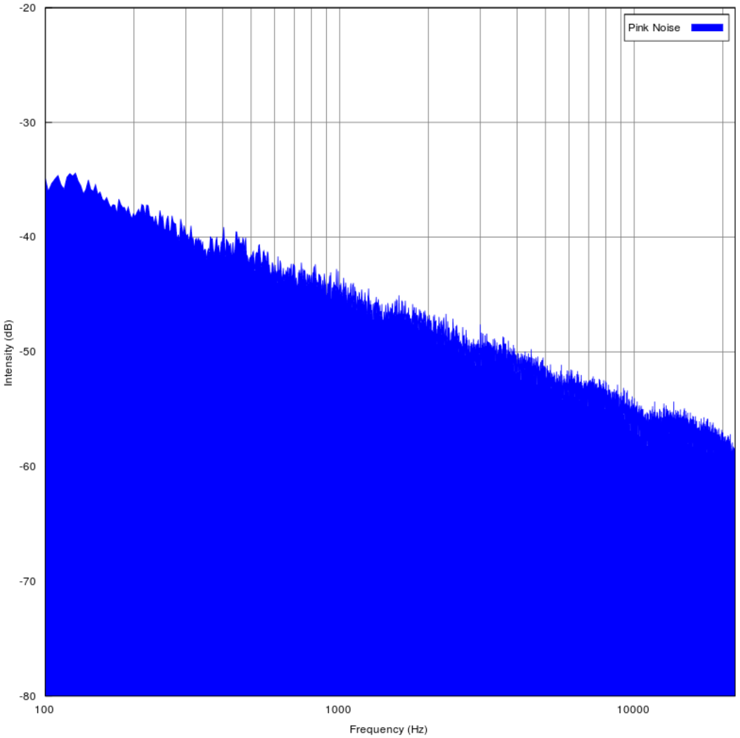
White noise

- Many noise sources are white noise.
- Flat spectrum up to extremely high frequencies.
- No correlation between the noise waveform samples.



Pink noise

- Pink noise (Wikipedia): Pink noise or 1⁄f noise is a signal or process with a frequency spectrum such that the power spectral density (energy or power per frequency interval) is inversely proportional to the frequency of the signal. Pink noise is the most common signal in biological systems. …
- The term **flicker noise** is sometimes used to refer to pink noise, although this is more properly applied only to its occurrence in electronic devices.



Types of Noise

- Noise may have different physical origins.
- Some types of noise:
  - Thermal Noise (also known as Johnson or Nyquist noise)
  - Flicker Noise (also known as 1/f or low frequency noise)
  - Shot noise or Poisson noise
  - ...
- Strictly, noise is random and can not be predicted (except average and variance values).

Thermal Noise

- Charge carriers, which are thermally affected generate a random varying current. It produces a random voltage which is called “thermal noise”.
- Thermal noise power is proportional to *T [K].* The one-sided PSD of a resistor is given by:

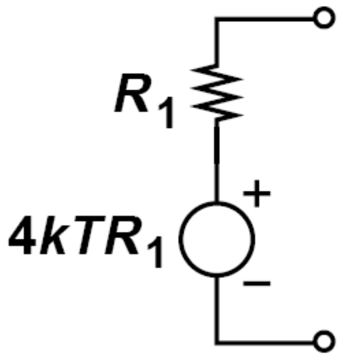
$$S_v(f) = 4kTR \quad (k\text{=1.38E-23 J/K}) \quad [\text{V}^2/\text{Hz}]$$

- It is independent of frequency, because it is considered as “white” noise (noise power is the same over any given absolute bandwidth).

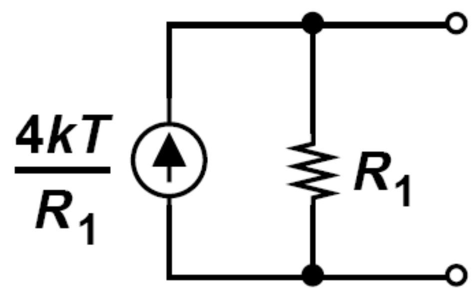
Thermal Noise

- Resistor thermal noise (PSD) models:

Thevenin



Norton



$$\overline{V_n^2} = 4kTR_1 \qquad \overline{I_n^2} = \frac{\overline{V_n^2}}{R_1^2} = 4kT/R_1$$

- Polarity of the sources is unimportant but must be kept same throughout the calculations

Noise in MOSFETs

- Thermal noise of MOS transistors operating in the saturation region is approximated by a current source tied between the source and drain terminals, or can be modeled by a voltage source in series with gate.

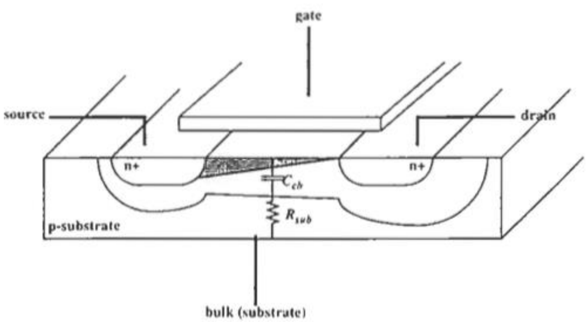
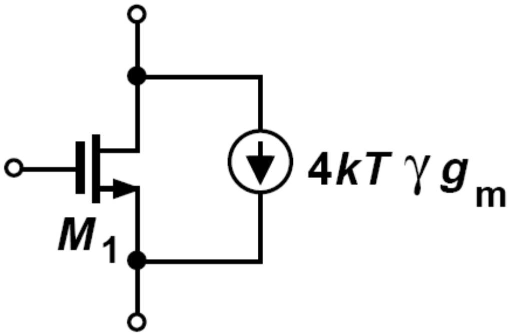
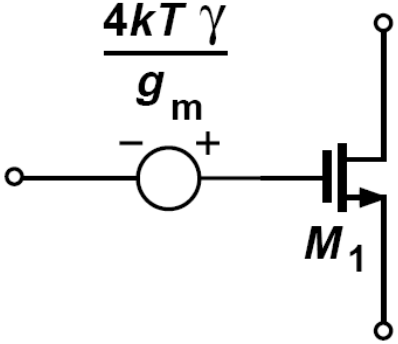


FIGURE 11.3. Simplified illustration of substrate thermal noise.





$$\overline{I_n^2} = 4kT\gamma g_m$$

$$\overline{V_n^2} = 4kT\gamma / g_m$$

”excess noise coefficient”, 2/3 for long channel and up to 2 for short channel devices

Flicker Noise

- Flicker noise or 1/f noise appears at low frequencies. It increases when frequency decreases.
- Flicker noise in MOSFET as a voltage source in series with the gate:

$$\overline{V_n^2} = \frac{K}{WLC_{ox}} \frac{1}{f}$$

Transistor width Gate length

- *K* is a process dependent constant, which is typically lower for PMOS devices than NMOS transistors.

Shot Noise

- Shot noise or Poisson noise

- In electronics, shot noise originates from the discrete nature of electric charge.
  - Number of carriers passing the junction is random.

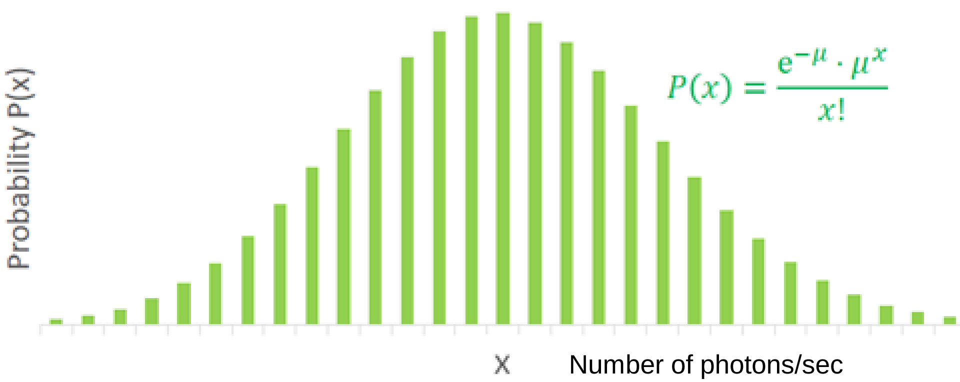
- For PN junction the mean square shot noise current is:

$$\overline{I_n^2} = 2(I_{DC} + 2I_o)qB$$

$$\overline{I_n^2} = 2I_{DC}qB$$

Shot Noise

- Shot noise in optical devices is associated with the particle nature of light.
- The arrival statistics of photons follow a Poisson distribution. Therefore, the number of photons estimated to arrive in a given time varies based on this probability.



- Photon Shot Noise = Sqrt (Numebr of photoelectrons accumulated in each pixel)
  - Photon Shot Noise = Sqrt(P*QE*t)

    t: exposure time QE: % of photons converted to electrons

https://scientificimaging.com/knowledge-base/signal-and-noise-graphical/

www.liu.se

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