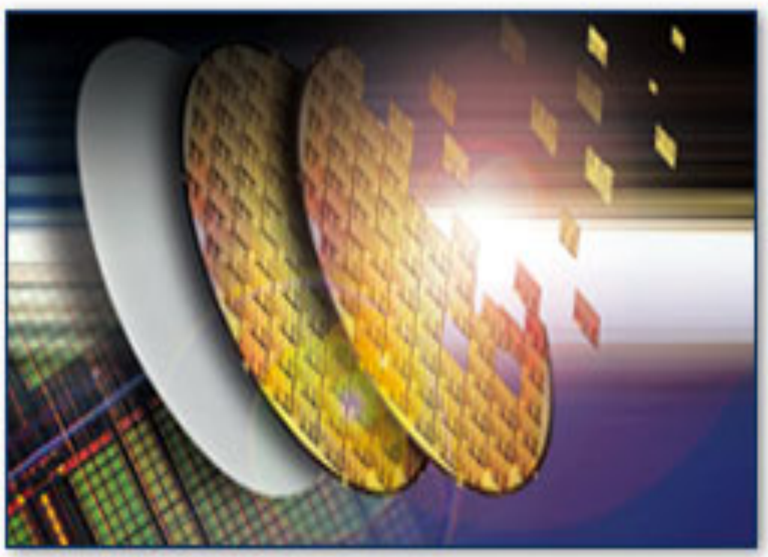
Silicon Wafer Circuit Fabrication

- Semiconductor Basics
- Silicon Wafer Fabrication
- Integrated Circuit (IC) Fabrication



Goals

• List the basic steps for making electronics-grade Si.

• Distinguish between three types of semiconductors.

• Recognize similarities and differences between IC and PCB fabrication processes.

•Describe how an NPN transistor is turned <u>on</u> or <u>off</u>.

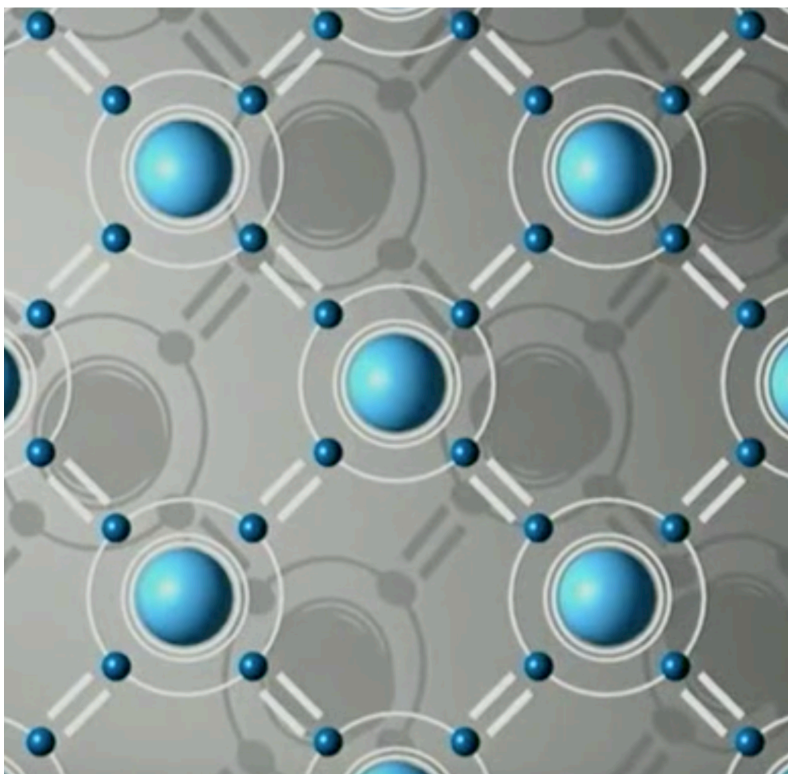
Refinement of Silicon for Electronics

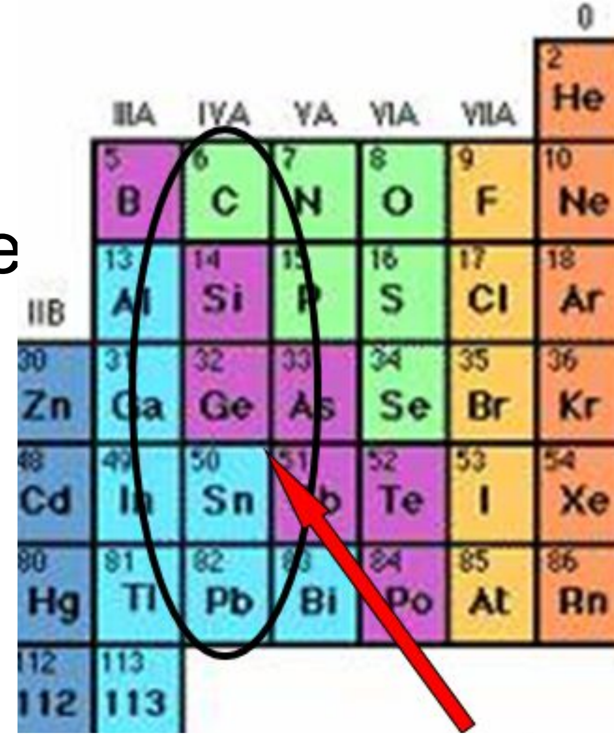
Metallurgical grade, polycrystalline Si

Highly pure, single crystal Si (Boule)

Pure Silicon (Si) – A Semiconductor Element

- Group IV: 4 valence electrons
- Si must share e^- (Octet rule)
- No free e^-'s ⟹ non-conductive

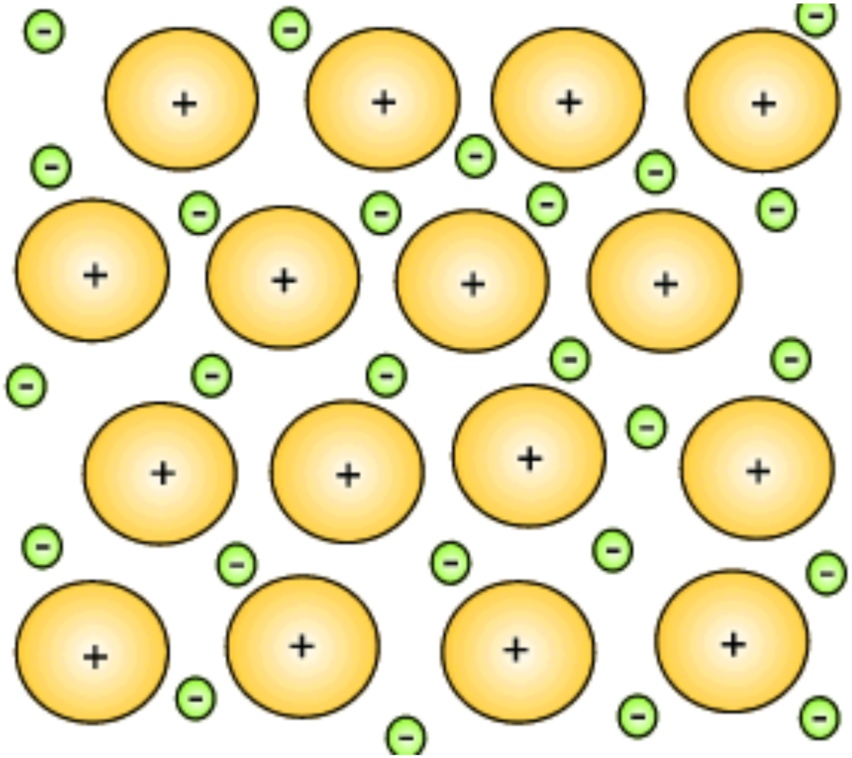




Semiconductor-Forming Elements

Atomic Structure of Metals

- All atoms share All valence electrons
- Electrons very mobile ⟹ highly-conductive



Three Semiconductor Categories

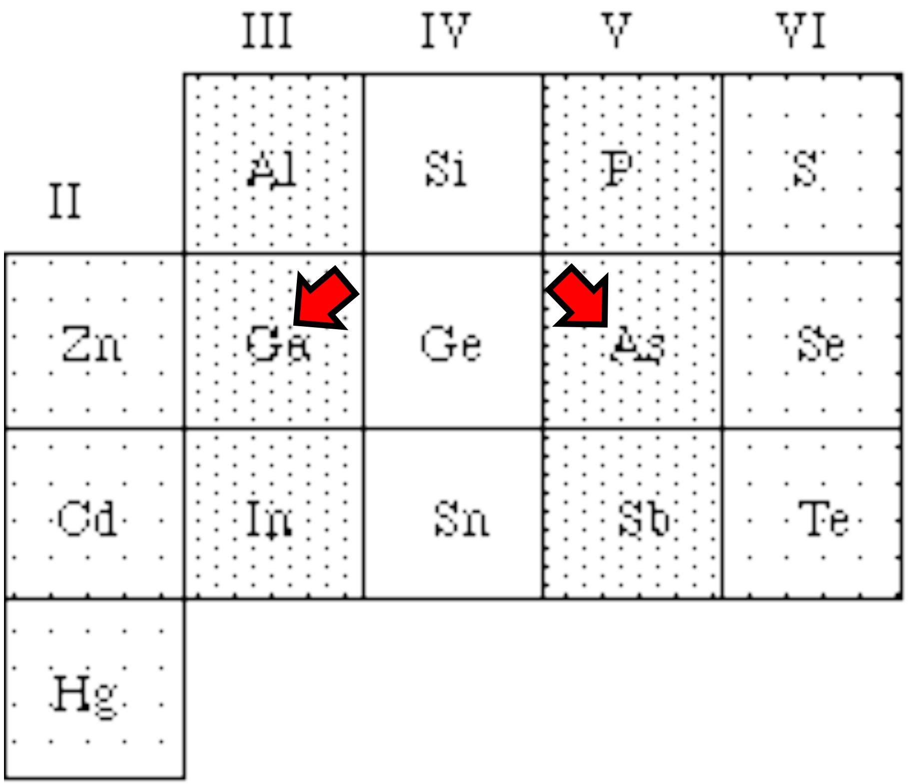
- Pure (**Intrinsic**): Pure, behaves with its **intrinsic** properties – very low conductivity at room temperature.
  Ex: Pure Si before doping

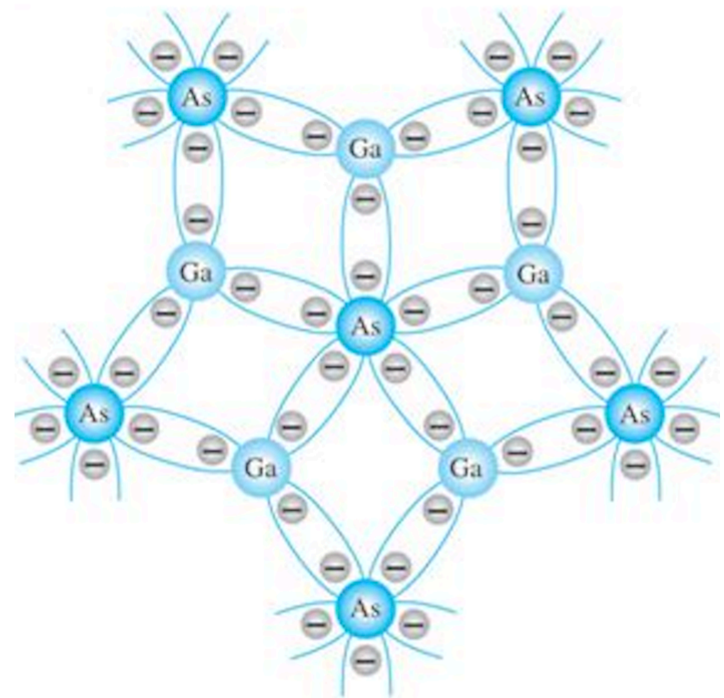
- Doped (**Extrinsic**): Dopant added to increase free charge carriers - behaves with **extrinsic** properties.
  Ex: N-type Si

- **Compound** Semiconductors: Mixtures of different Groups from periodic table.
  Ex: GaAs

Compound Semiconductors

Formed by combining groups III & V or groups II & VI atoms



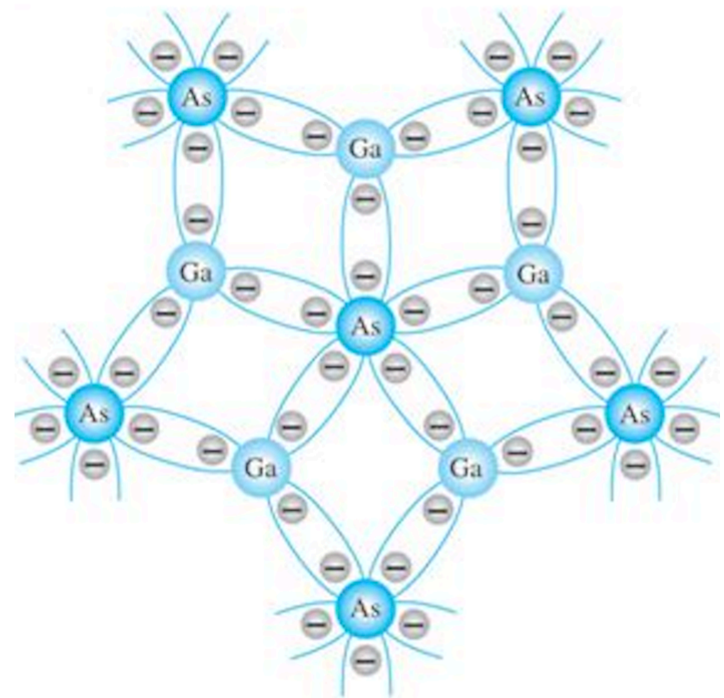


Ga (III) + As (V)
Gallium Arsenide

Compound Semiconductors

Formed by combining groups III & V or groups II & VI atoms

II	III	IV	V	VI
	Al	Si	P	S
Zn	Ga	Ge	As	Se
Cd	In	Sn	Sb	Te
Hg				



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? **Is pure GaAs conductive?**

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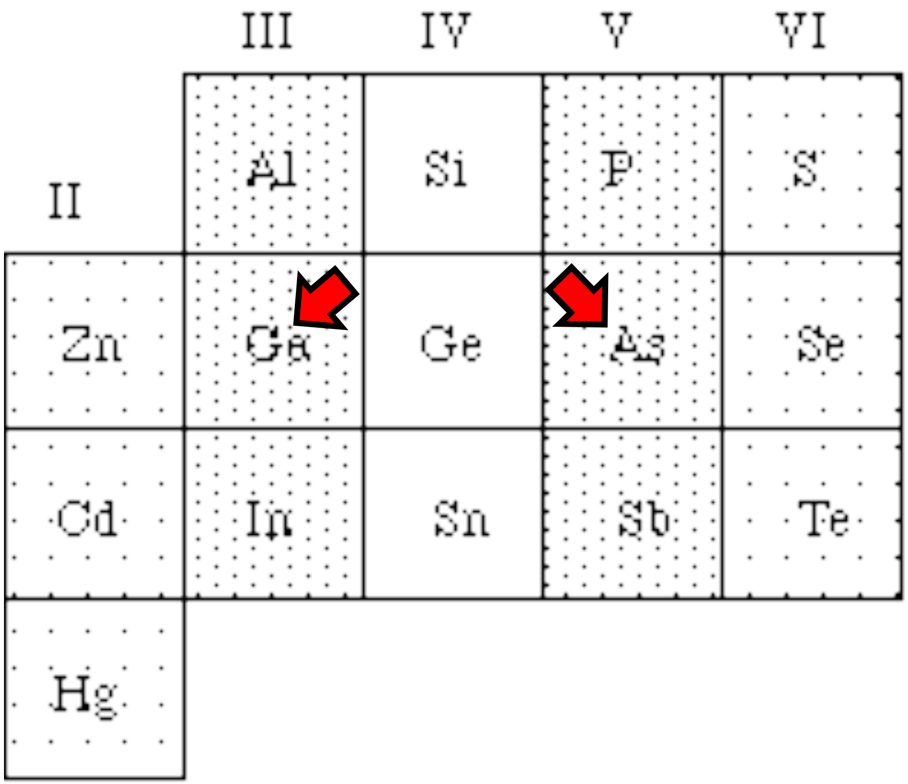

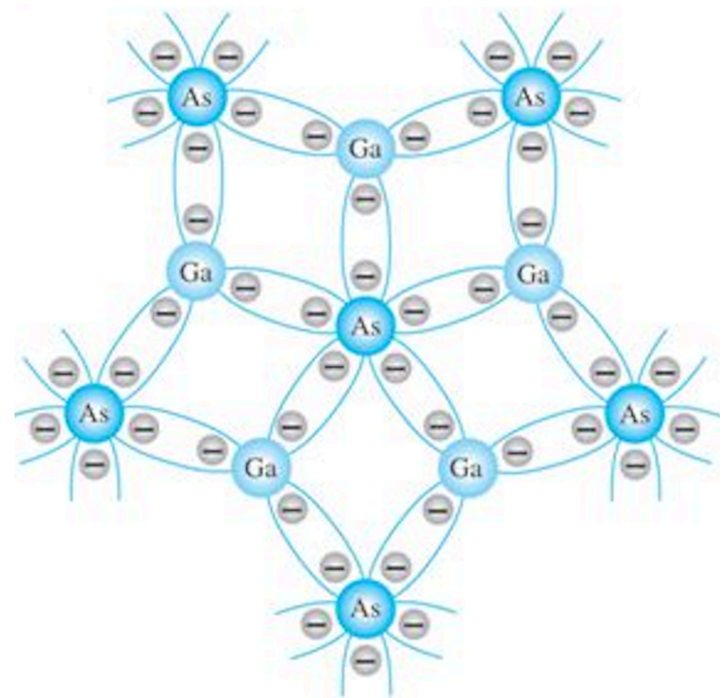

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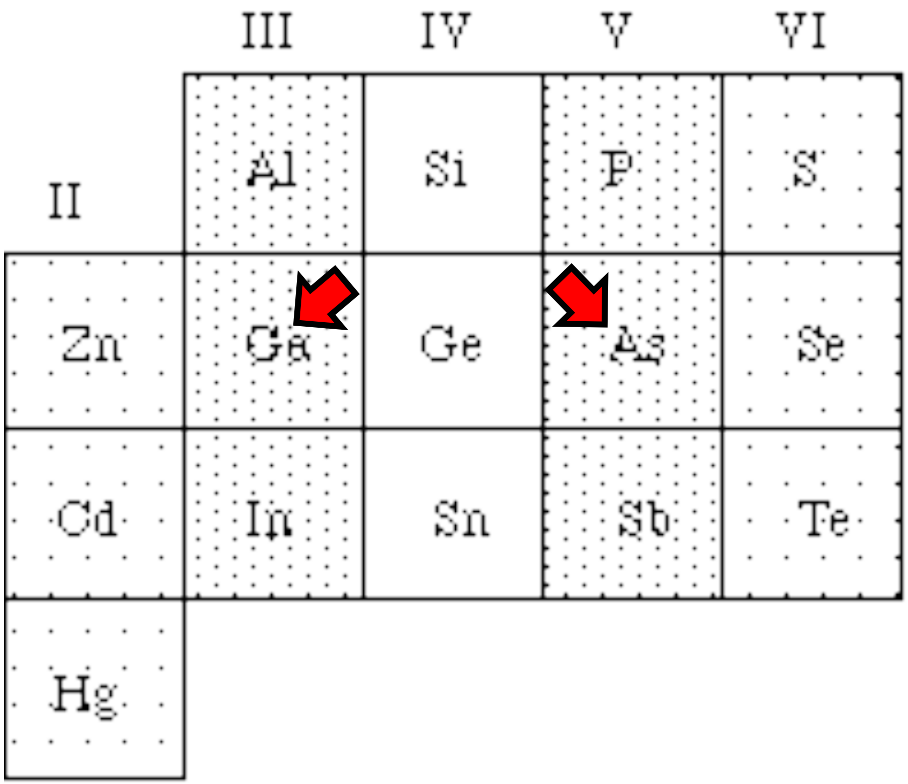
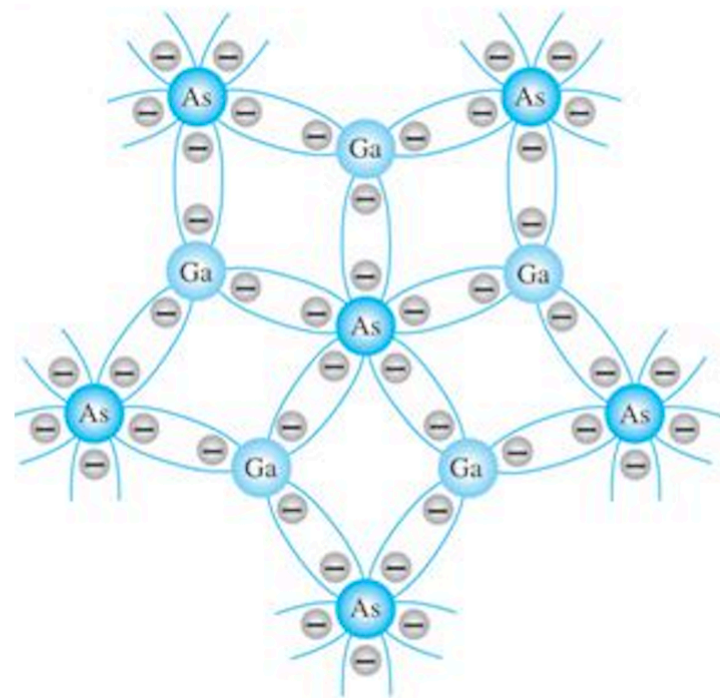


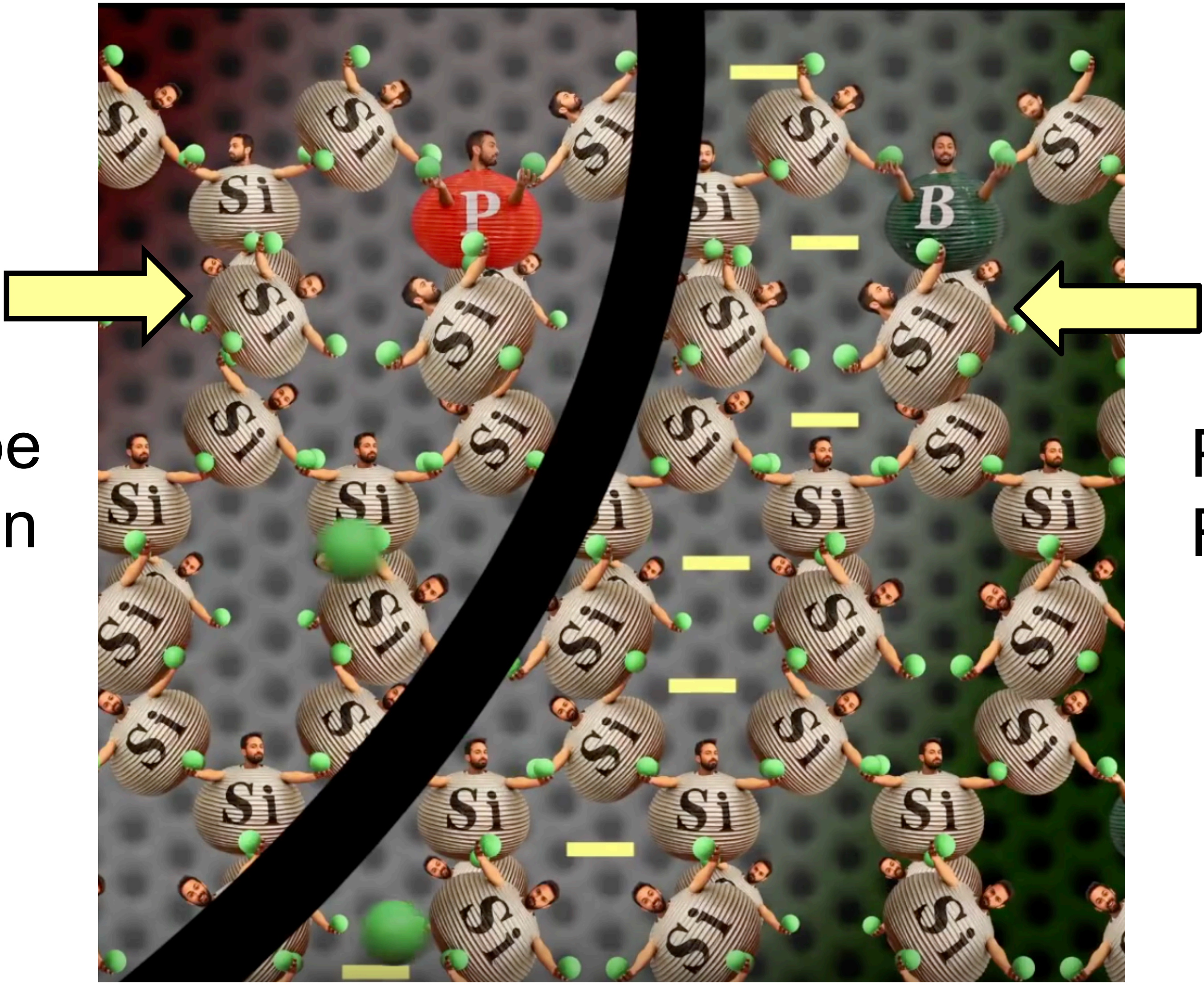


Ga (III) + As (V)
Gallium Arsenide

? **Is pure GaAs conductive?** **No, must be doped… With what?**
Depends on <u>size</u> of dopant and its <u>valence</u>. E.g., Si (N) or Be (P)

How a Transistor Works – Video

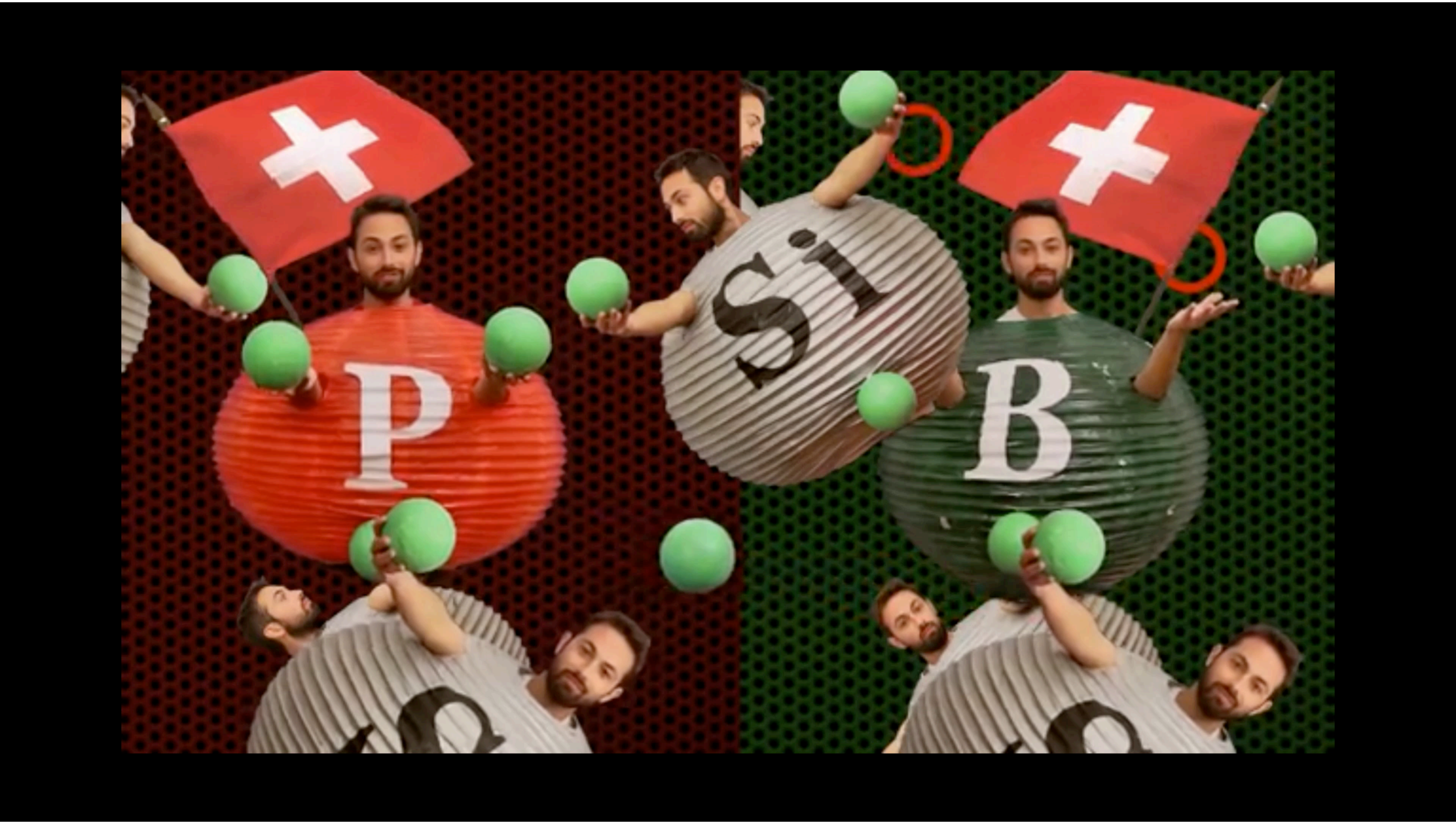
N-Type Region



P-Type Region

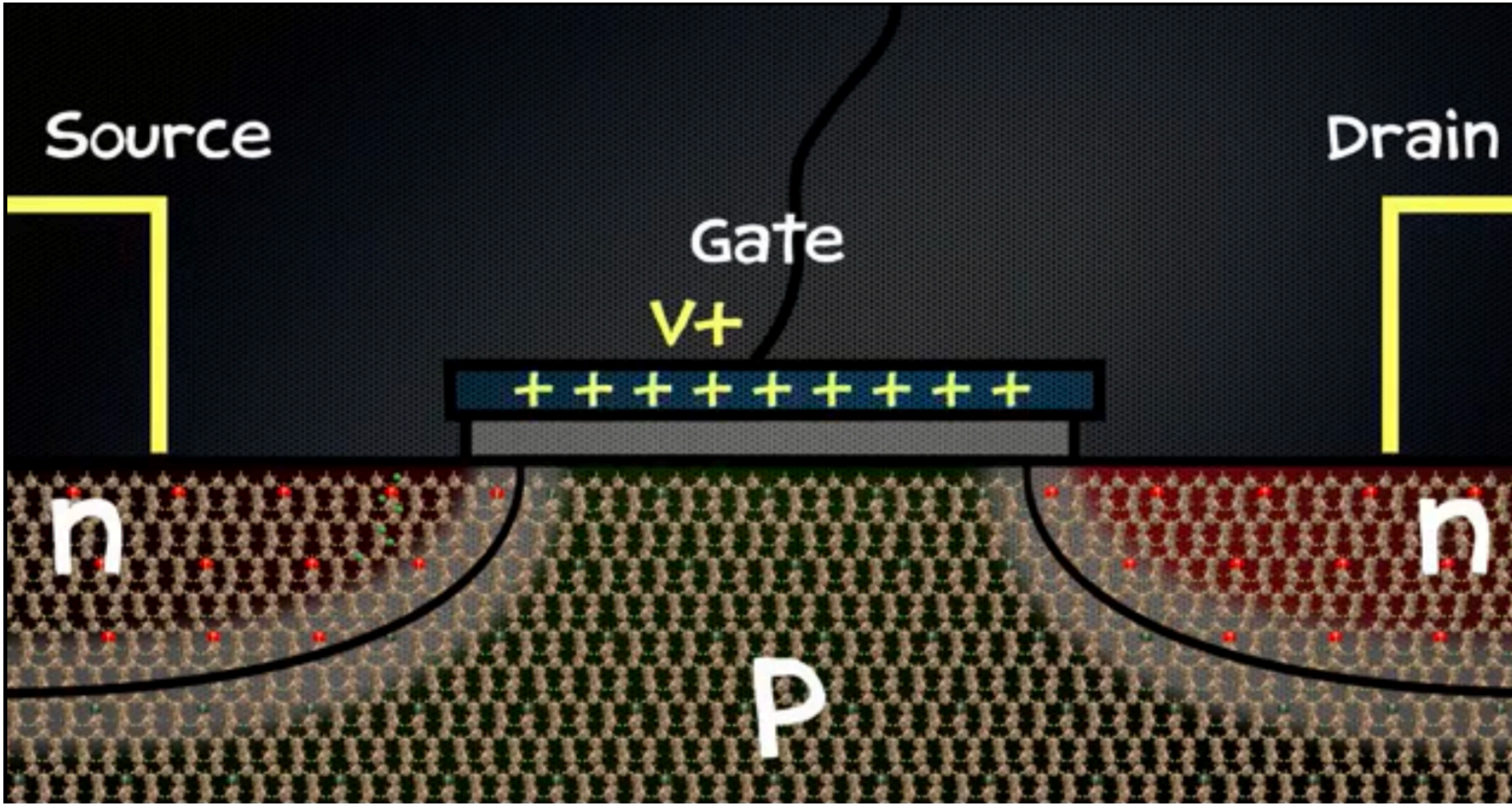
With <u>no</u> voltage applied at gate, what's happening?

How a Transistor Works – Video



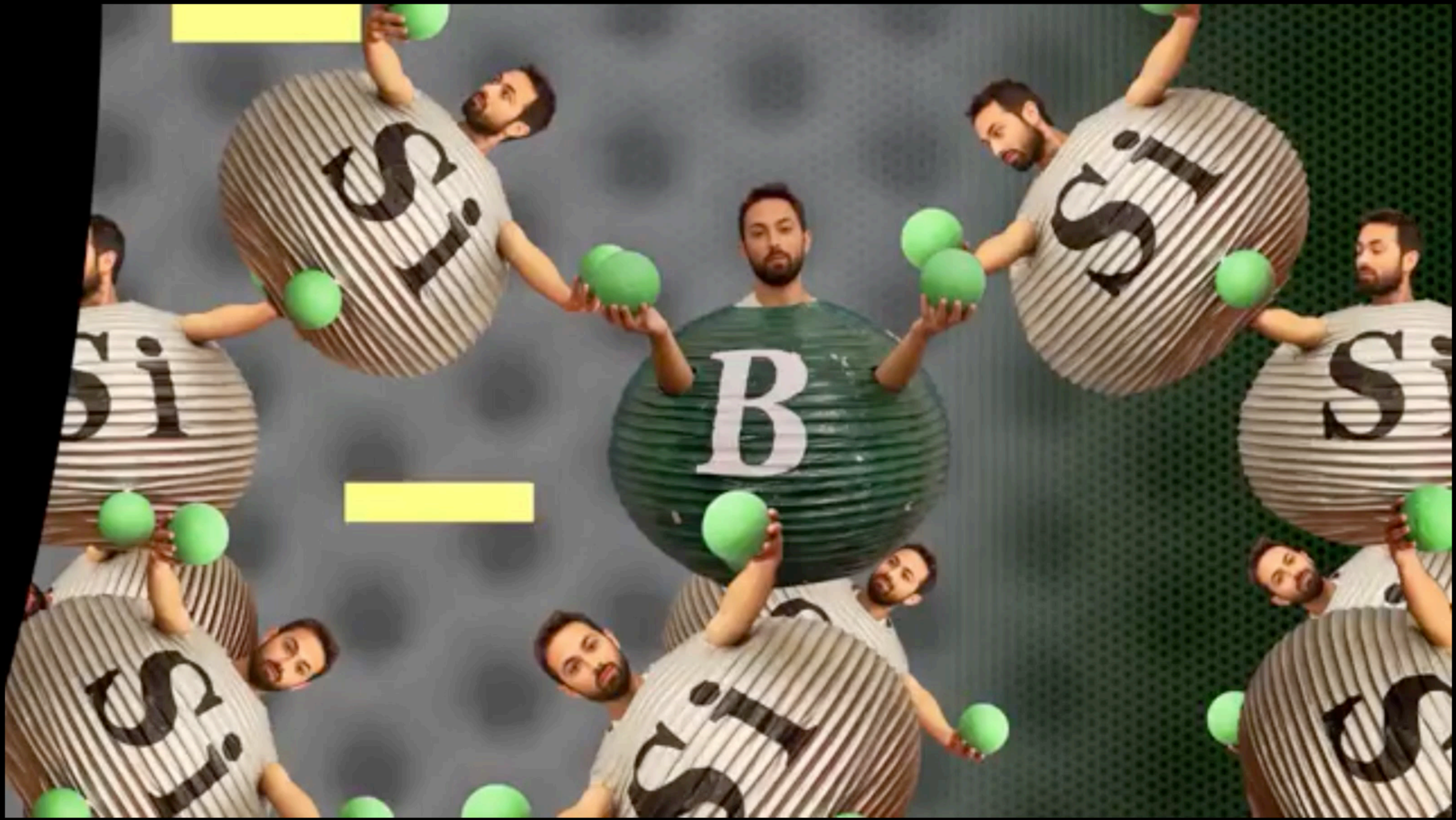
With <u>no</u> voltage applied at gate…

How a Transistor Works – Video



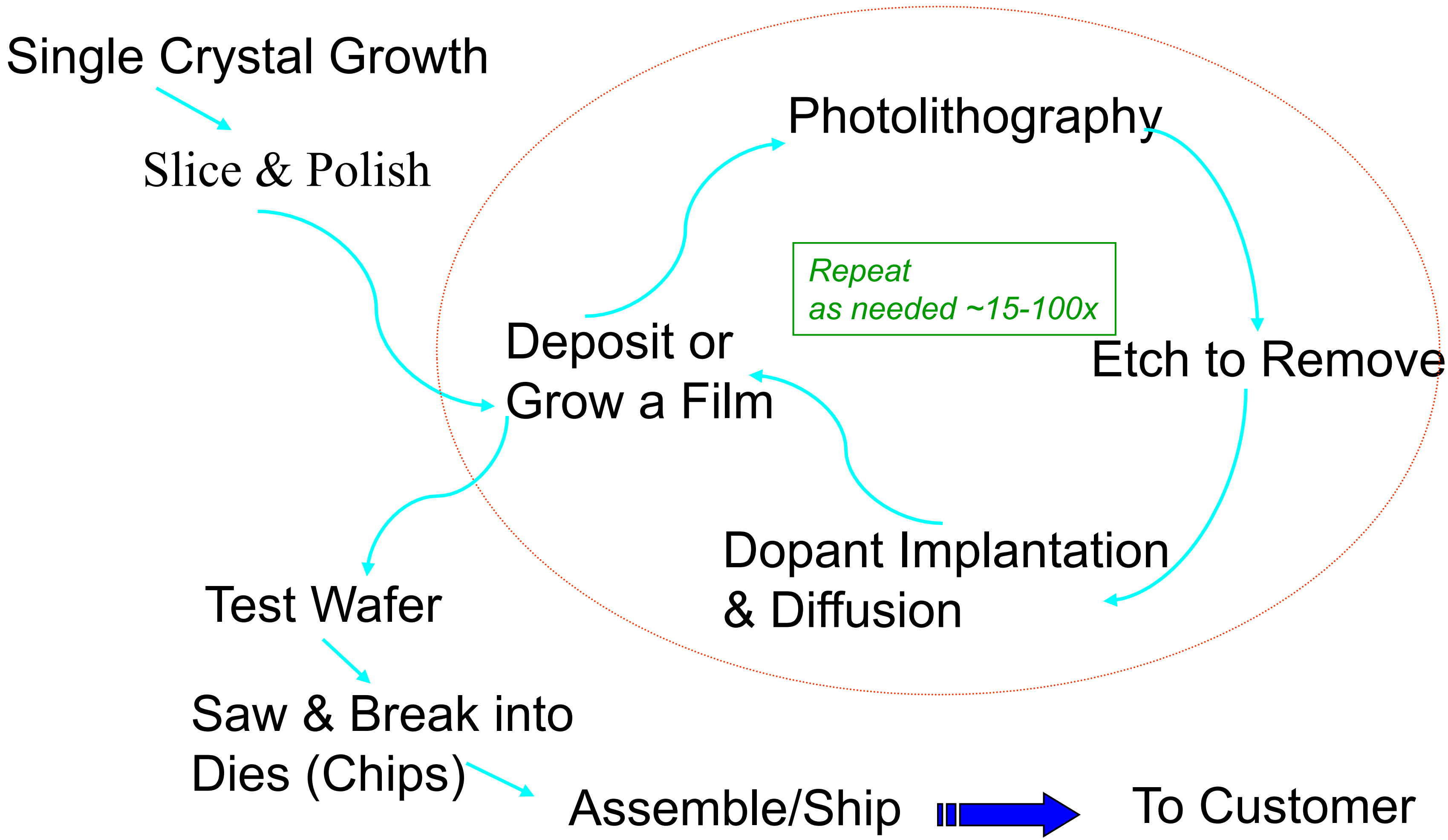
What happens with positive gate voltage applied?

How a Transistor Works – Video



With positive gate voltage applied…

Silicon Wafer Circuit Fabrication



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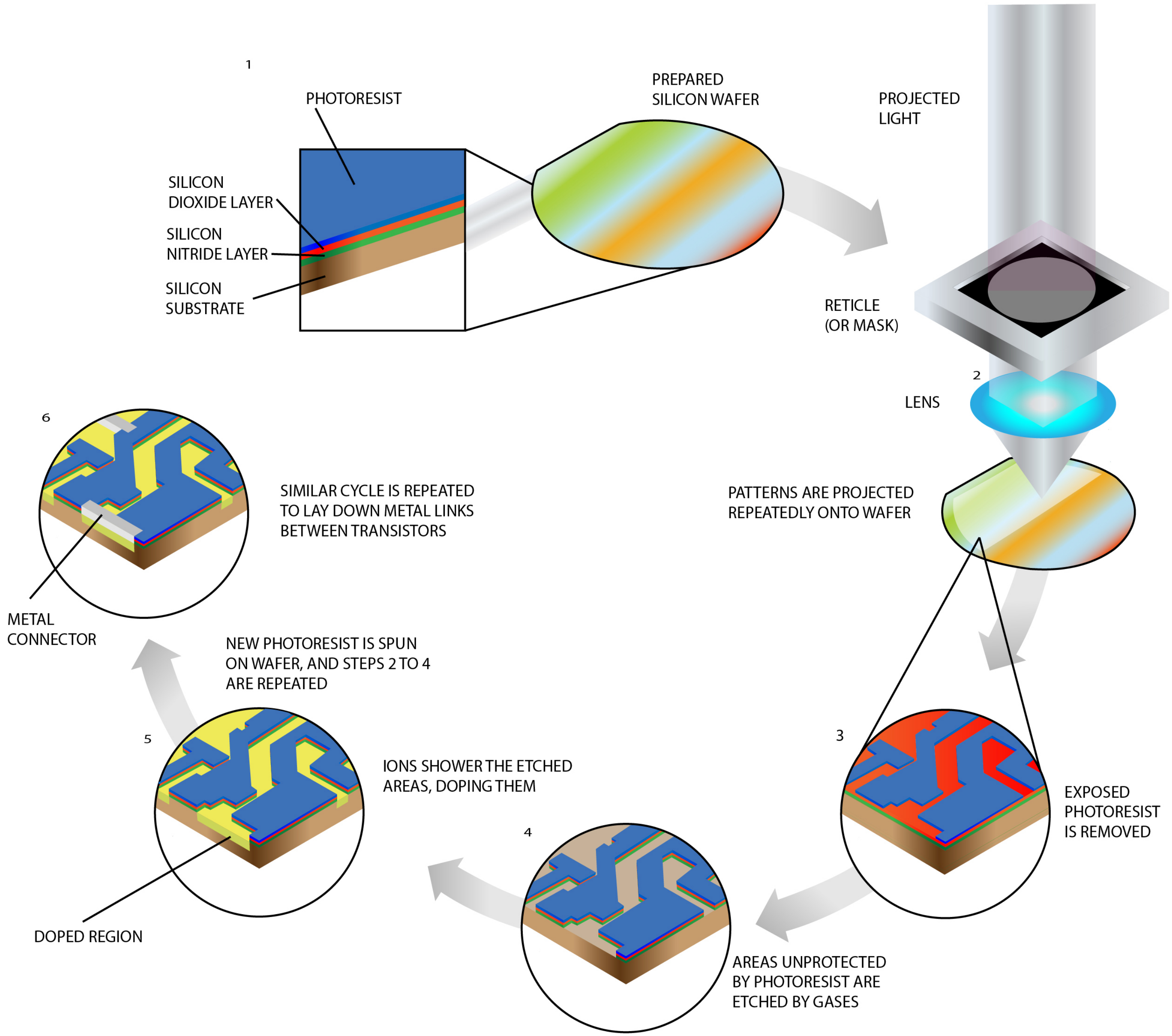
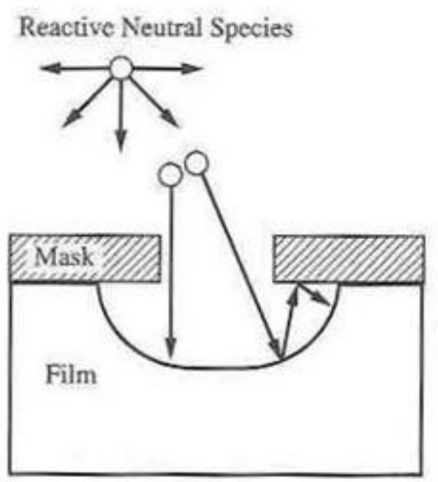
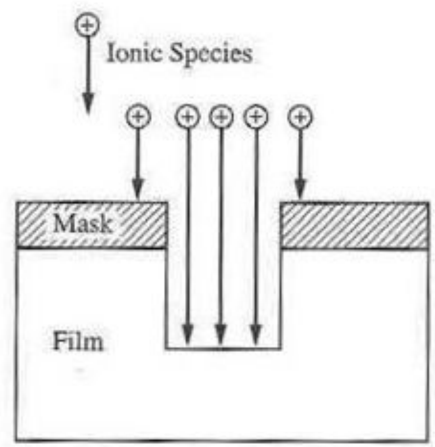


Etching

- Purpose: Remove materials (such as SiO_2) from areas unprotected by photoresist
- Plasma etching used to avoid "undercutting"
  - Wet chemicals etch isotropically (in all directions)
  - Plasma etching is anisotropic (only in one direction)



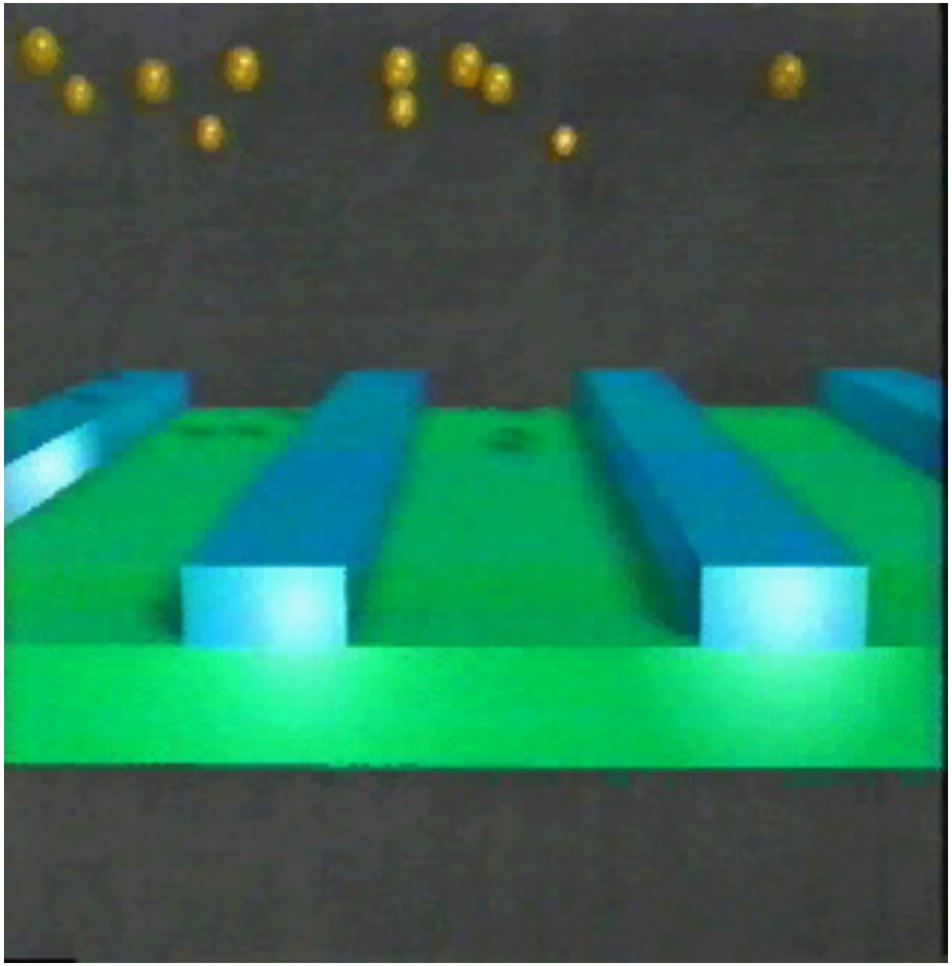
Wet chemical etching



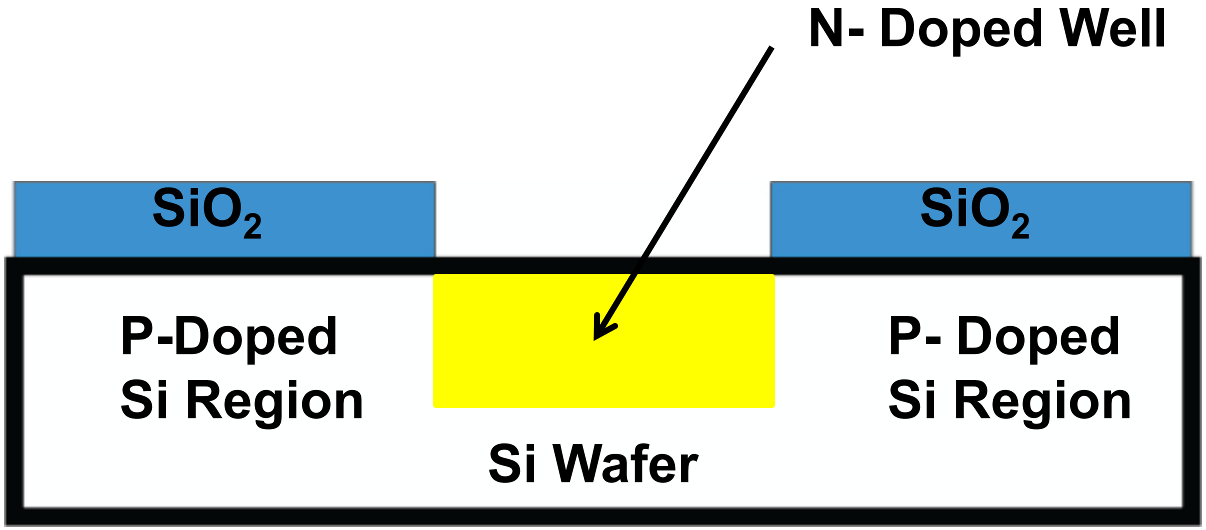
Plasma etching

Ion Implant & Diffusion

- Ion Implant
  - Dopant atoms injected into Si wafer not covered by SiO_2
  - SiO_2 acts as a stencil
  - Depth of penetration of dopant atoms depends on energy level
- Diffusion
  - Heat causes dopant atoms to diffuse deeper into Si creating “wells”
  - Wells are IC transistor substrates



Well Formation after Diffusion



Well separates two highly doped regions

Smallest Feature Size in Semiconductors

10 µm — 1971
3 µm — 1975
1.5 µm — 1982
1 µm — 1985
800 nm (0.80 µm) — 1989
600 nm (0.60 µm) — 1994
350 nm (0.35 µm) — 1995
250 nm (0.25 µm) — 1998
180 nm (0.18 µm) — 1999
130 nm (0.13 µm) — 2000
90 nm — 2002
65 nm — 2006
45 nm — 2008
32 nm — 2010
22 nm — approx. 2011
16 nm — approx. 2013
11 nm — approx. 2015

***2017 ~ 10 nm**
2019 - ?

? If a silicon atom is ~0.2 nm in diameter, approximately how many atoms wide are the smallest transistor features today?