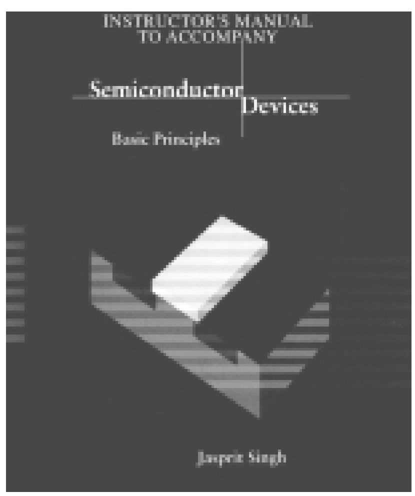
AN OVERVIEW

Semiconductors form the active regions of "intelligent" devices. The following figures provide an overview of why semiconductors are important, what the various demands in semiconductor technologies are, and which semiconductors are used for various applications.



SEMICONDUCTOR TECHNOLOGY
MATERIALS, PHYSICS, DEVICES, TECHNOLOGY

The new industrial age is driven by information technology.

–Computation, communication and the exploding internet use is driving our new economy.

Semiconductor-based devices are the most critical component of the new industrial age.

Why semiconductors?

The reasons semiconductor technology dominates are:

- Physical properties of semiconductor devices can be altered rapidly.
- Response of semiconductor devices to external inputs can be tailored in a manner that allows the devices to implement all needed information processing operations. Semiconductor devices can be used to implement Boolean logic, amplify signals, generate signals, store and retrieve information, etc.

ELECTRONIC MATERIALS

Electronic materials can be classified into three categories:

METALS	SEMICONDUCTORS	INSULATORS
• Have very low resistivities (~10^{-6} Ωcm). • Resistance is difficult to alter or tailor.	Have resistivities that can be altered by up to 10 orders of magnitude by doping or external biases.	Have extremely high resistivities. It is difficult to alter the resistivity through doping or external fields.
⇕ because	⇕ because	⇕ because
Highest occupied energy band is partially filled with electrons.	Highest occupied energy band (valence band) is completely filled with electrons at low temperature. Next band (conduction band) is empty.	High bandgap between valence band (filled) and conduction band (empty) is large ($\gtrsim$4 eV).

SEMICONDUCTORS:
• Conductivity of the material can be altered (in times as fast as 1 ps).
• Optical properties (absorption coefficient, refractive index) can be altered.

USEFUL IN:

	Electronic devices:	ON/OFF switches, high gain amplifiers...
	Optoelectronic devices:	Detectors, modulators, lasers, light emitting diodes.

IMPORTANT SEMICONDUCTORS: DEMANDS

Like other industries, semiconductor technology feels the pressures of cost and performance. The following show factors that influence cost and performance.

COST

Availability of substrate. Only silicon, gallium arsenide, indium phosphide and germanium substrate are widely available.

Ease of doping, contact formation, insulator incorporation.
Only silicon has a high quality insulator that can be incorporated cheaply—Si/SiO_2.
It is difficult to dope large bandgap semiconductors.

Availability of reliable technology to fabricate devices and circuits.

Inertia of existing technology. Billions of dollars have been invested in Si technology.

PERFORMANCE

Electronic devices:

- High speed switching.
- High frequency operation.
- High power operation to generate microwave power.
- High temperature operation.
- Integration for high density chips.

Optoelectronic devices:

- Light emission at 1.3 μm or 1.55 μm for communication application.
- Light emission in red, green, and blue regimes for display.
- Short wavelength light emission for optical storage.
- Long wavelength detection for night vision, thermal imaging.
- High speed laser diodes.
- High speed modulators, optical switches.

IMPORTANT SEMICONDUCTORS: ELECTRONICS

High speed ⟹ low effective mass, superior mobility.
High power applications ⟹ large bandgap.
High temperature applications ⟹ large bandgap.

	ADVANTAGES	DISADVANTAGES
Silicon (Si):	The most important semiconductor system. MOSFETs, bipolar devices based on Si form over 90% of the electronic market.	Not as "fast" as other semiconductors. Not good for high power, high temperature operation. Cannot emit light, since it is an indirect gap material.
Silicon-Germanium (Si-Ge):	Can be grown on Si substrates and processed using Si technology. Bipolar divices have performance rivaling GaAs technology.	Strained system. Needs great care in crystal growth conditions.
GaAs; GaAs/ AlGaAs:	High speed devices for digital/microwave applications. Performance is superior to silicon.	More expensive than Si technology.
InP; InGaAs/ InP:	High speed performance is superior to GaAs based technology. Can be combined with longhaul optoelectronic communication technology.	Expensive.
GaN/ AlGaN	High power/high temperature applications.	Not as reliable yet; high cost.
SiC:	High power/high temperature applications.	Reliability; cost.

IMPORTANT SEMICONDUCTORS: OPTOELECTRONICS

Cosiderations:

- Correct bandgap (E_g) for light emission/detection at appropriate wavelength.
- Substrate availability for high quality growth.

LIGHT SOURCES

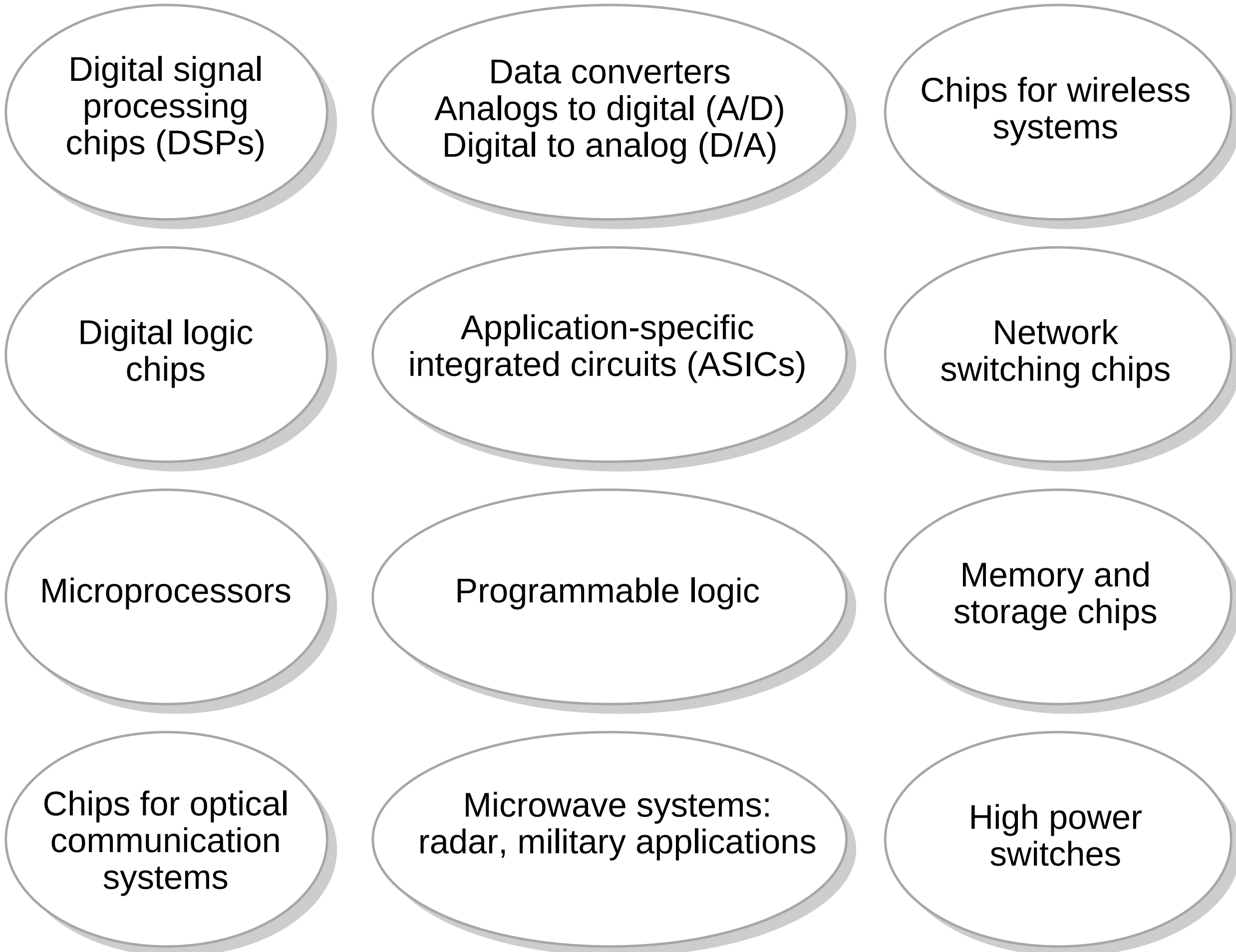
IMPORTANT MATERIAL SYSTEMS	COMMENTS
$In_{1-x}Ga_x As_yP_{1-y}$; $x = 0.47y$ for lattice match to InP $E_g = 1.35 - 0.72y + 0.12y^2$ eV	• Lattice matched to InP. • Wide range of emission energies can be accessed (~0.8 to 1.35 eV). • Material technology is quite advanced and can be exploited for communication applications.
AlGaAs $E_g = 1.43 + 1.25x$ eV; $x \leq 0.35$	• Lattice matched to GaAs. • Technology is quite advanced and can be used for LANs.
$GaAs_{1-x}P_x$	• Material becomes indirect at $x = 0.45$. • With N doping the LED can operate even if the material is indirect and green light emission ($\lambda = 0.55\ \mu m$) can be achieved. • The versatile material can provide red ($GaAs_{0.6}P_{0.4}$); orange ($GaAs_{0.35}P_{0.65}$:N), and yellow ($GaAs_{0.15}P_{0.85}$:N) as well.
SiC, GaN, ZnS, ZnSe, AlInGaP—large gap materials which can emit blue light and beyond.	• Important materials for blue light emission (for displays, memories). • Technology for optical sources is not mature, but rapid progress is being made.

IMPORTANT SEMICONDUCTORS: OPTOELECTRONICS

DETECTORS

Material	Properties
InGaAs (Tunable E_g)	• Excellent material for long haul communications (at 1.55 μm). • Can be lattice matched to InP.
AlGaSb (Tunable E_g)	• Excellent optical properties. • Can be used for long haul communications. • Suffers from poor substrate availability, since it has to be grown on GaSb, whose technology is not matured.
InGaAsP (Tunable E_g)	• Suitable for both 1.55 μm and 1.3 μm applications for long haul applications. • Can be lattice matched to InP substrates.
HgCdTe (Tunable E_g)	• Excellent material for long wavelength applications in night vision and thermal imaging. • Can be used for 1.55 μm and 1.3 μm, but the technology is not as advanced as the InP based technology.
Si (E_g = 1.1 eV)	• Indirect material with small α near the bandedge. • Has high β_{imp}/α_{imp} ratio and can be used in high performance avalanche photodiodes for local area network (LAN) applications. • Not suitable for long haul communication at λ = 1.55 μm or 1.3 μm.
Ge (E_g = 0.7 eV)	• Indirect material with small α near the bandedge. • Has high β_{imp}/α_{imp} ratio and can be used for avalanche photodiodes for both local area and long distance communications.
GaAs (E_g = 1.43 eV)	• Direct gap material. • Not suitable for high quality avalanche detectors, since $\alpha_{imp} \approx \beta_{imp}$. • Not suited for long distance or LAN applications.

TOOLS OF THE TRADE



Information technology depends upon these chips to generate, receive, process, store, and transmit information.