Band Gap Engineering

A process of varying the elemental components of the semiconductor alloy in a controlled way to achieve a desired band gap that can emit a desired wavelength of radiation.

2 critical considerations

1. **The wavelength of the radiation emitted**
2. **The lattice parameters of the compounds**

The wavelength → visible, UV or IR

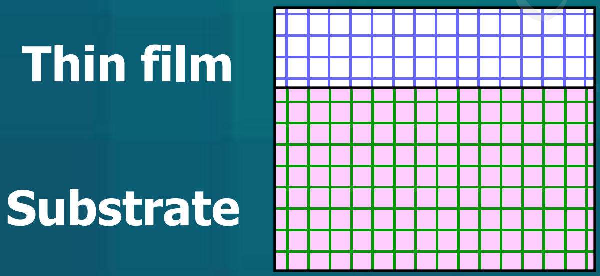
The lattice parameter → for epitaxial growth

Why?

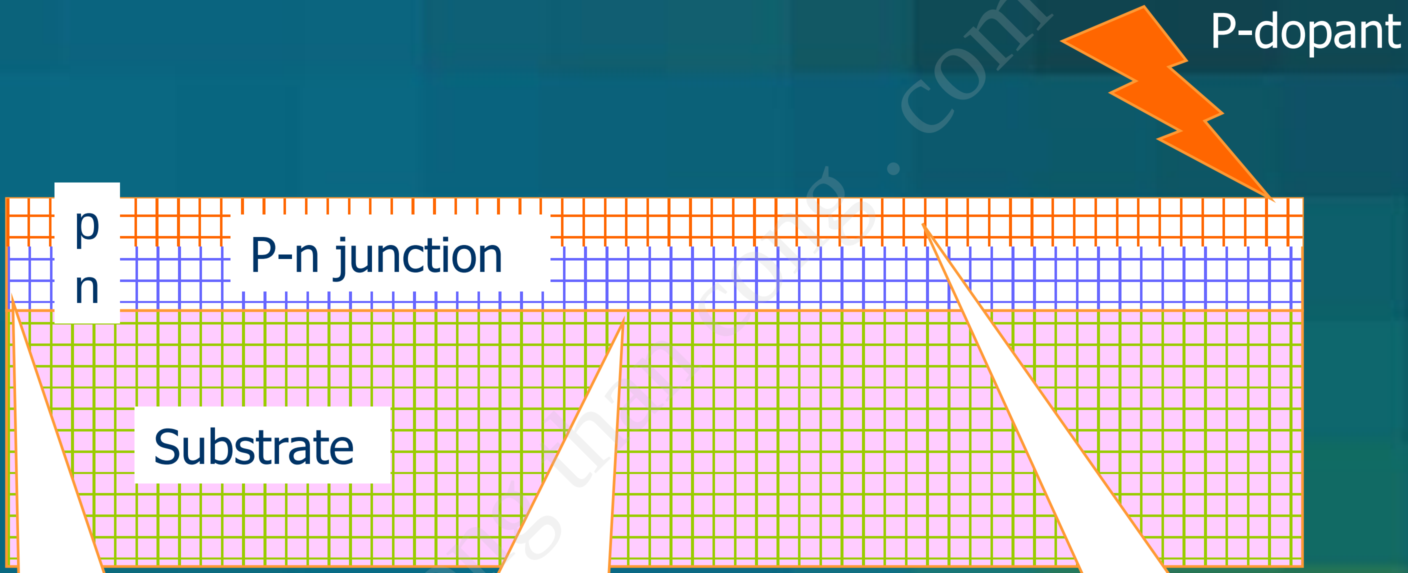
A good device requires a defect free semiconductor films. Defect free → good crystallographic orientation of the grains of the semiconductor materials, low defect

How?

To achieve defect free semiconductor thin film, adopt a so-call **epitaxial growth** of the film on a substrate → growth process where the deposited films will 'follow' the surface structure of a substrate.



Epitaxial growth



Semiconductor materials need to be deposited onto a textured substrate (thin film technology)

Substrate must have similar lattice parameter to that of the semiconductor thin film to avoid lattice mismatch (strain at the interface will induce crack) and to allow epitaxial growth

The semiconductor then need to be doped to achieve both p and n type → require p-n junction

IR & Red LED

- GaAs → direct band gap, p-n junctions are readily formed with high radiative efficiency. High radiative efficiency can be induced by doping GaAs with Zn or Si. Si doped GaAs is now the industry standard near IR LEDs.
- GaAsP → direct – in direct transition
- GaInAsP → Grown on InP substrate and band gap can be varied to get wavelength from 919nm to 1600nm. A true story of band gap engineering.

Band Gap and Lattice Constant

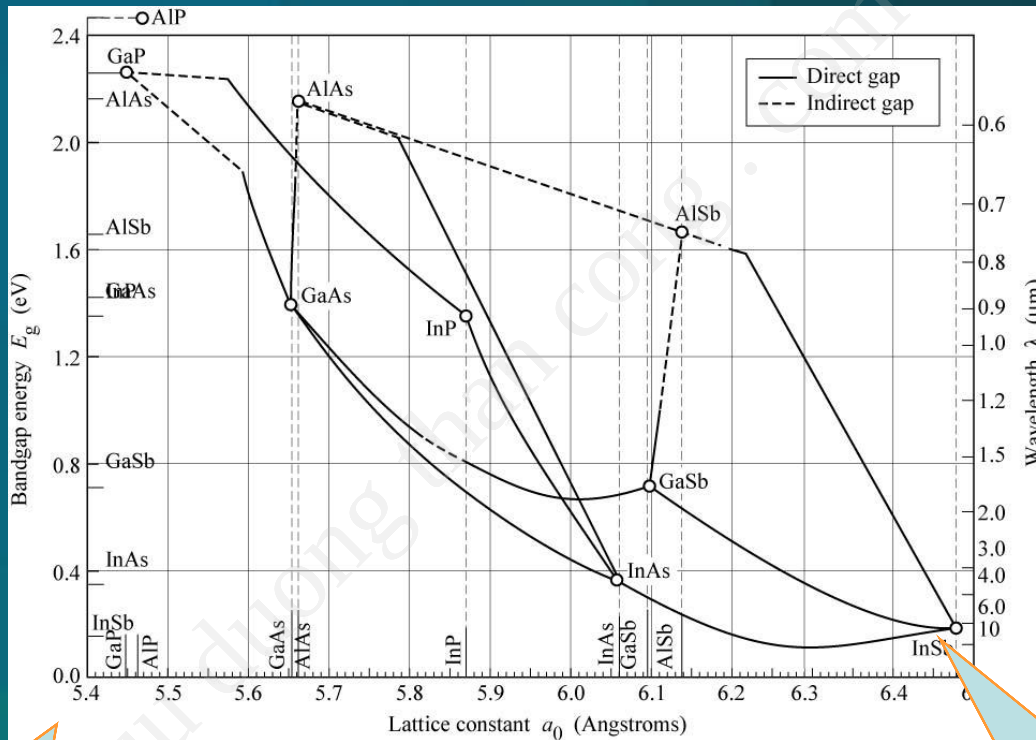


Fig. 12.6. Bandgap energy and lattice constant of various III–V semiconductors at room temperature (adopted from Tien, 1988).

E. F. Schubert
Light-Emitting Diodes (Cambridge
www.LightEmittingDiode

Substrates must have similar lattice parameter to the semiconductor films, GaAs, GaN and InP are often used as substrates.

The band gap energy can be tailored to get desired visible light radiation

LED + band gap engineering

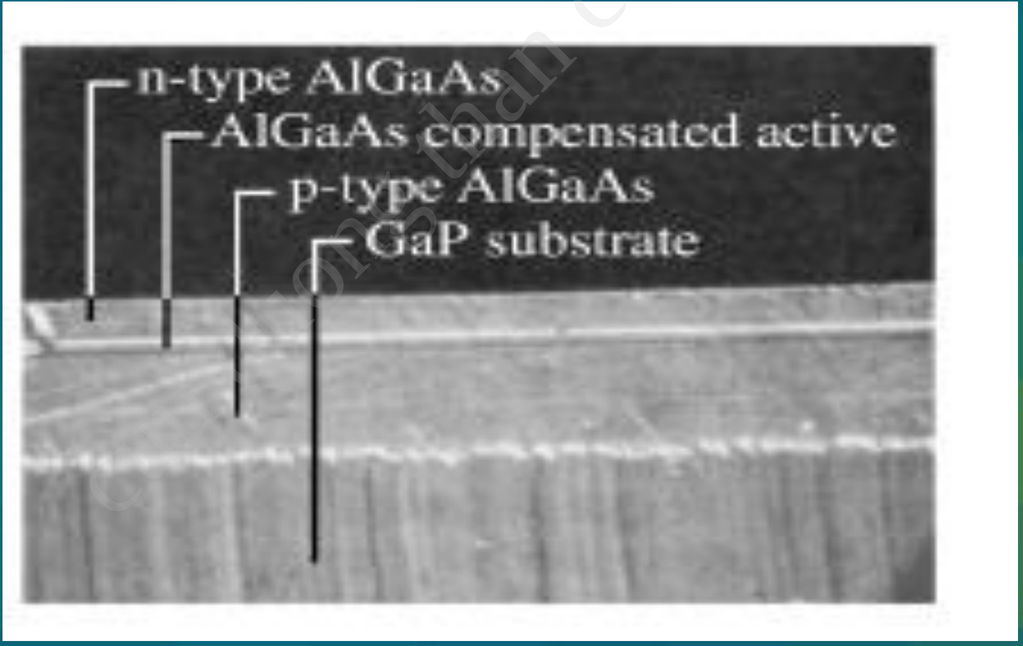
"LEDs are specialized semiconductor devices that can potentially convert electricity to light, without the wasteful creation of heat. The color emitted is controlled in large part by the energy gap of the semiconductor and in advanced structures by the "photonic band gap," a range of wavelengths that cannot travel through that particular tance. By suppressing certain w ngths and enhancing others th and gap

One of the pioneers in the field of LED; Fred Schubert

Examples of Substrate/semiconductor p-n diode/visible light produces

GaAsP / GaAs 655nm / Red
GaP 568nm / Yellow Green
GaP 700nm / Bright Red
GaAsP / Gap 610nm / Amber
GaP 555nm / Pure Green
GaAsP / GaP 655nm / Hi-Eff.Red
GaP 568nm / Yellow Green
GaA1As / GaAs 660nm / Red
InGaA1P 574nm / Ultra Green
InGaA1P 574nm/Ultra Green
InGaA1P 620nm / Ultra Orange
InGaA1P 595nm / Ultra Yellow

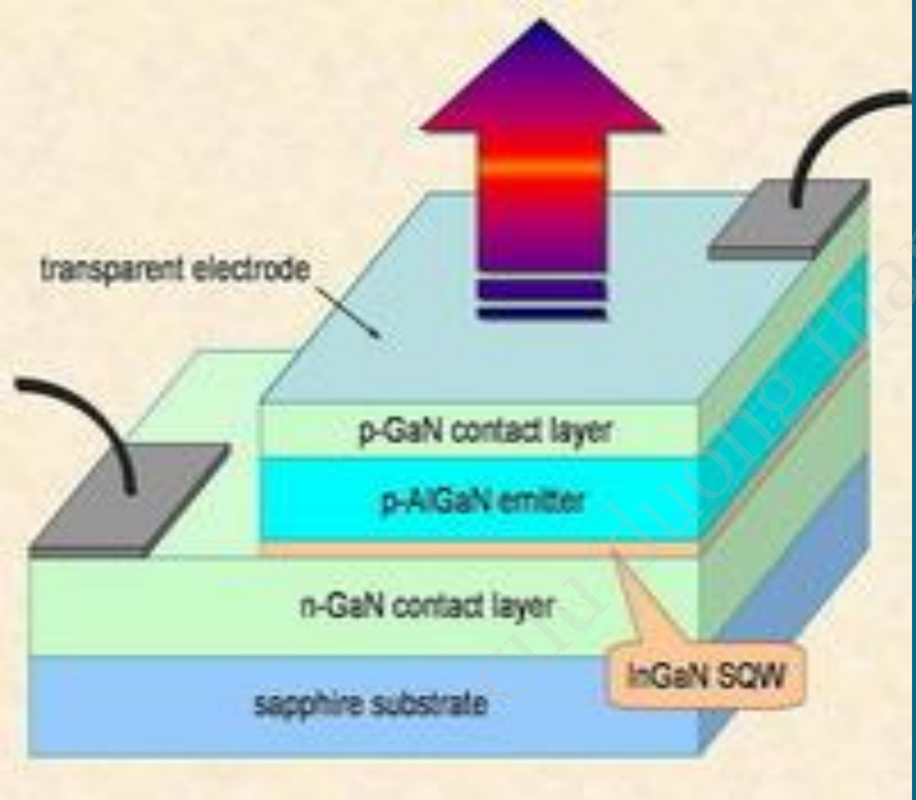
Cross section of a typical epitaxial layers



The nitrides and blue LED

- **Difficulties:**
  - to find suitable substrates for the nitrides.
  - to get p-type nitrides
- **But with constant R&D works, better materials are produced**
- **GaN, InGaN, AlGaN → high efficiency LEDs emitting blue/green part of the spectrum.**
- **First blue LED 1994 Shuji & Nakamura (10 000 hours lifetime)**
- **SiC can also be used as blue LED- SiC on GaN substrate**

The device



Applications:

- Flat panel displays (display requires, R,G,B now B is found, all LED displays can be made.
- High resolution printers
- Light source for communications
- Microwave transistors (electrons have high mobility)

UV-LED

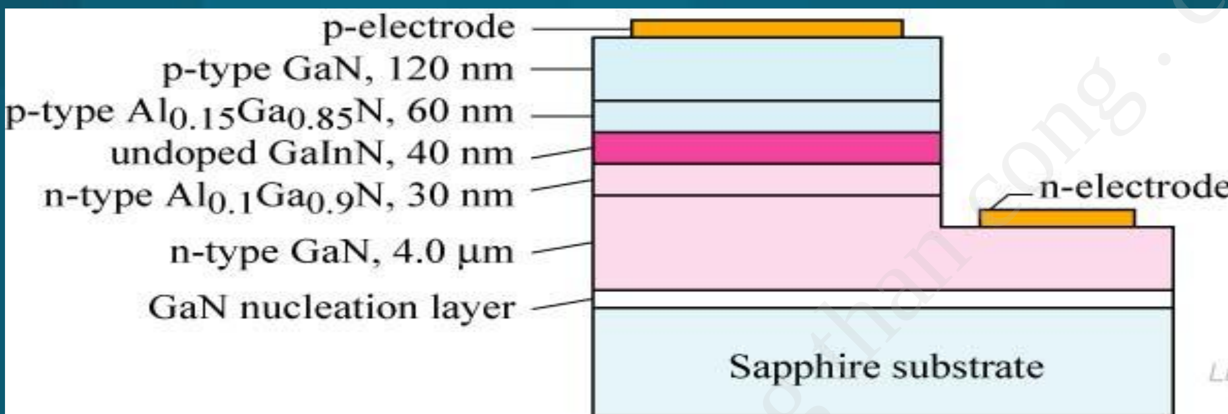


Fig. 13.2. Layer structure of GaInN UV LED grown on saphire substrate emitting at 370 nm (after Mukai *et al.*, 1998).

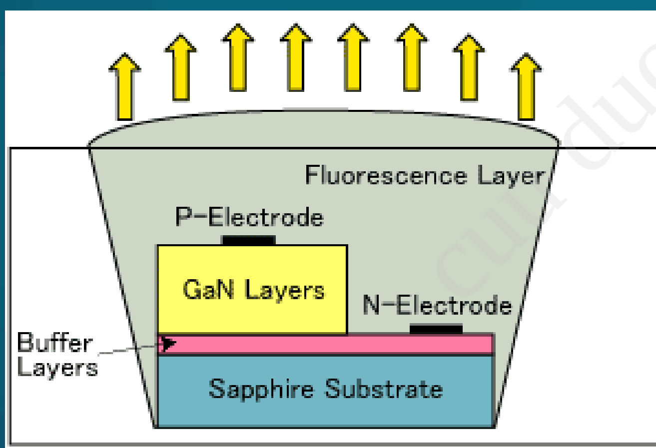
E. F. Schubert
Light-Emitting Diodes (Cambridge Univ. Press)
www.LightEmittingDiodes.org

Apart blue LED, UV LED can also be made using nitrides.

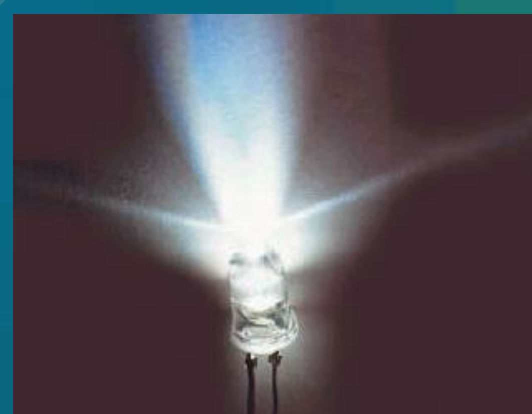
UV-LED can be used as UV calibration devices, UV detector etc.

The Blue-Violet LED + Phosphor and White LED

White LEDs are slightly more efficient than a 100W incandescent bulb and three times more efficient than a 7W night light type bulb. The lifetime of white LED could reach >10 000 hours while incandescent filament (100watt) normally reaches about 750-1500 hours.



Basic Structure of White LED Lamp



Phosphor

Another typical exam question

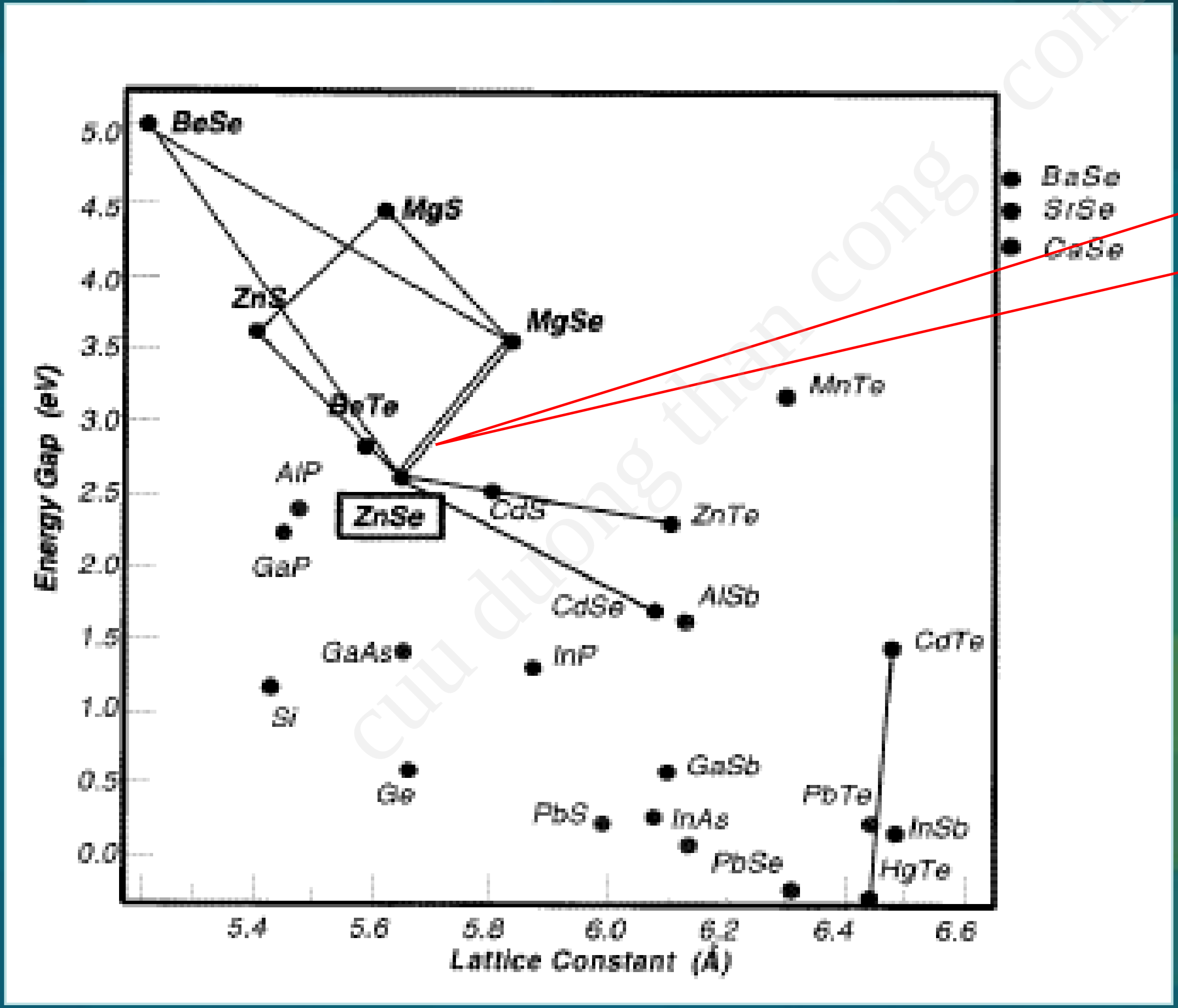
Draw a table to list down some examples of possible materials for visible LEDs. In your table state also the visible wavelength your LED will emit as well as some applications of a given visible LED. Explain why group III-V materials have been selected as an LED emitter for use in an optical fiber network.

(100 marks)

The Selenide

- Group II-V is also important (ZnSe especially even though ZnO has being a contender as well)
- ZnSe can be made into LED, emitting blue and green lights.
- Problem with finding suitable template (substrate) for growth.
- GaAs and GaN can be used as the substrate for selenide. The lattice parameter for GaAs = 5.6Å and ZnSe = 5.5Å
- ZnSe has been used as blue/green laser (study later).
- The selenide degrade more rapidly hence shorter working life-time

The selenides - E gap vs lattice parameter



ZnSe can be made ternary allow with ZnTe to produce ZnSeTe → blue-green