9.1. Density of States, DOS

Let us consider particle-in-a-box as a model of quantum confinement. For simplicity, assume infinite potential walls.

9.2. Quantum Confinement of Electrons and Holes

Infinite-depth QW is usually a good model of the real ones.

However, the heterostructure quantum wells are not of infinite depth, but often shallow. The depth depends on the band off-set. This modifies the level spacing, accordingly.

Difference between the superlattice and multiple–QW (MQW) is in the well separation. There is no tunneling from one well to the next in MQW structure.

A factor

$$Q = \Delta E_c / \Delta E_g = \Delta E_c / (E_{gB} - E_{gA})$$

characterizes the band off-set.

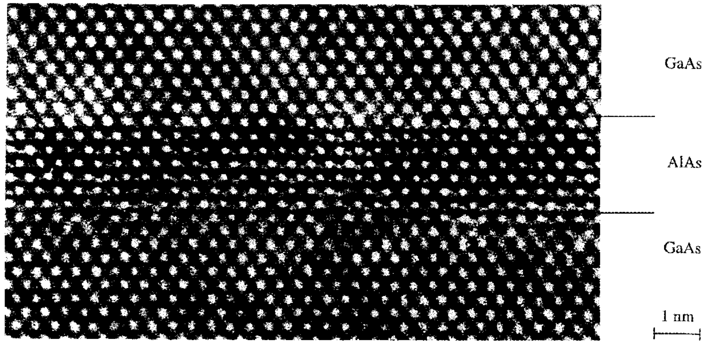


Fig. 9.1. High resolution TEM micrograph of GaAs/AlAs superlattice for a [110] incident beam.

9.2.1 Semiconductor Materials for Quantum Wells and Superlattices

Mostly III-V compound semiconductors are used, grown on GaAs or InP with MBE or MOCVD: GaInAs / GaAs, GaInAsP / InP, AlGaInAs / GaAs, InGaP / GaAs, GaInAsN / GaAs,GaN / sapphire, InGaN / sapphire. Atomic layer accuracy introduces the main challenges for technology.

Sharp defect-free interfaces are important for high quality devices. For *homojunction* interfaces this is not a problem, but it becomes a real challenge in case of *heterojunction* interfaces between dissimilar materials, see Fig. 9.1, above. The crystal structure and lattice constants of the two materials should same to allow *pseudomorphic growth* of the *epitaxial layer* (or epilayer) onto the substrate. This is called *lattice matching.*

Selecting *binary, ternary* or *quaternary* compounds with the same lattice constant but chosen band gaps is called *band gap engineering.* In Fig. 9.2. the compound families of nearly same lattice constants are indicated by shading.

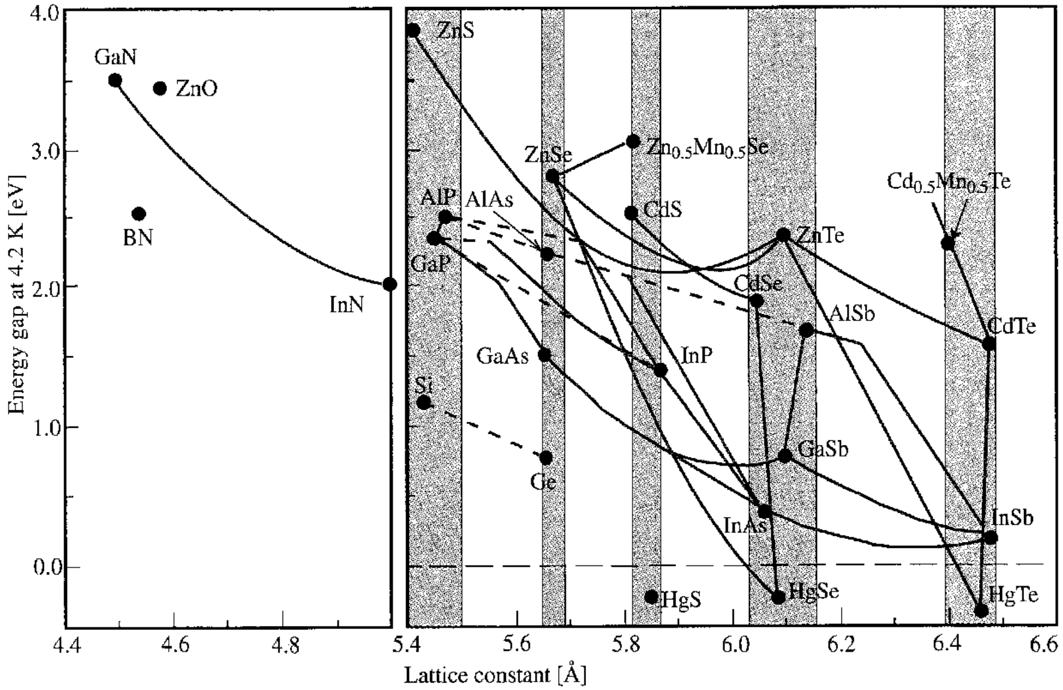


Fig. 9.2. The wurtzite compounds on the left and zinc-blende (and diamond) compounds on the right.

The case of epilayers with lattice constant different from the substrate is called *lattice misfit.* It will result in strain in the pseudomorphic epilayers. The strain energy will increase as the grown layer thickness increases. At the *critical layer thickness* this consequently leads to misfit dislocations to relax the strain. The critical layer thickness depends on the difference of the lattice constants of the two materials.

For thin layers the dislocations may be avoided and strain in the epilayer can be used to modify its properties, the electronic structure in particular. Strained-layer superlattice (SLS) is one of the used constructions of this type. The Si/Ge SLS, e.g., involves lattice mismatch of 4%.

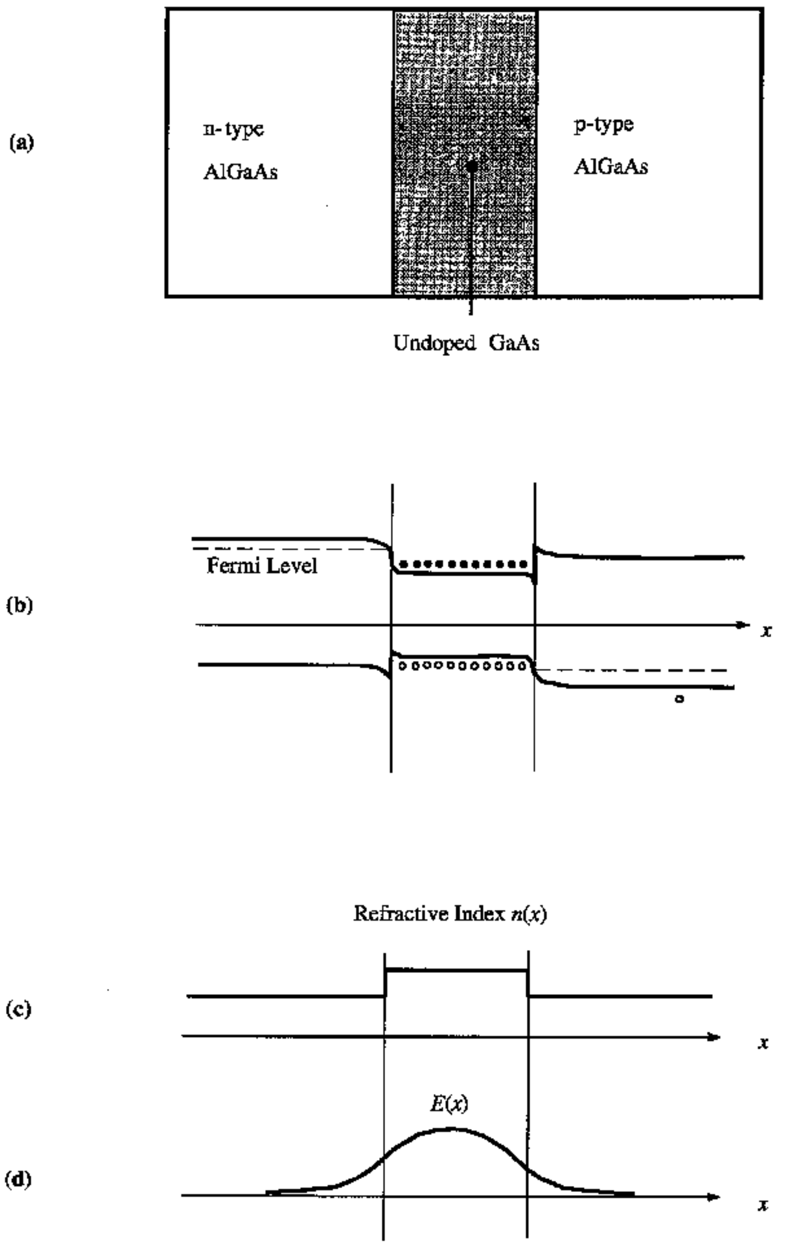
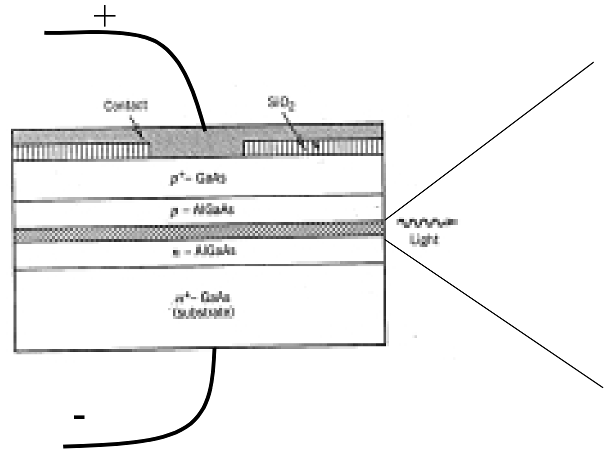


Fig. 9.3. Simple model of a quantum well laser (or a LED). (a) double heterojunction, (b) band diagram, (c) refractive index and (d) the electric field (in the edge-emitting laser, EEL).

LED (or LASER)



<u>LED</u>

+ easy to fabricate
+ low cost
– broad (30 – 40nm) and incoherent spectrum
– low bandwidth
– low output power
– relatively large angular spread => low coupling efficiency into fiber.

Suitable for low cost and low bit rate (speed) applications, few hundred Mb/s up to a few km.

<u>Resonance cavity LED (RCLED)</u>

between an LED and laser. Similar structure to LASER but emits light through spontaneous emission.

• Increased performance

• Improved directionality,

• Spectral purity,

• Enhanced external efficiency and

• Better temperature stability

• Suitable for low cost and medium bit rate applications, especially red RCLED (650 nm) for novel plastic optical fiber based networks up to 622 Mb/s over 100 m

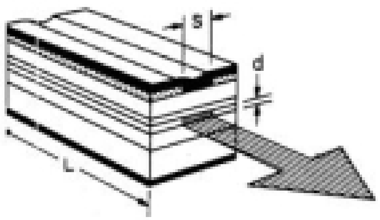
Semiconductor LASER (DIODE)

Similar type structure as LED but has an optical cavity to ensure optical feedback. Semiconductor lasers are used to convert electrical signals into optical signals, and write and read data in data storage (CD, DVD, for example).

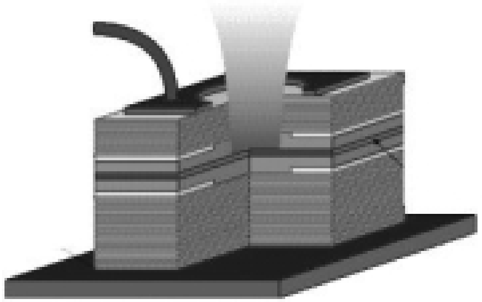
Properties of laser light:

- coherent
- monocromatic
- collimated
- high intensity

from Light Amplification by Stimulated Emission of Radiation (LASER):



Traditional edge-emitter



Novel surface-emitter

OPTICAL COMMUNICATIONS

Short distance data communications

- utilizes LEDs (650, 1300 nm, free-space or silica fiber)
- RCLEDs (650 nm, free-space or plastic optical fiber)
- FP lasers (1300 nm, silica fiber)
- VCSELs (850 nm, free- space or silica fiber)

Long distance optical communications

- extremely important and complex technology
- utilizes DFB, DBR and FP lasers with silica fibers
- develops at astonishing speed
- low cost VCSELs are highly needed