Lecture 19: Introduction to Diode Lasers - II

Semiconductor Optical Communication Components and Devices

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Index Guided Semiconductor lasers

Waveguides are employed to confine the emitted light for better interaction with the injected carriers. These layers have to be epitaxially grown first.

Multilayer Slab Waveguide

Electric field profile for a 6-layer slab waveguide
For lasing action to occur there also must be a resonant cavity. For edge emitting lasers this cavity is formed at the junction between air and the active material in the longitudinal direction; to achieve a sharp reflective boundary, the crystal is then cleaved along crystal planes.

When the substrate cleavage planes do not match the stripe geometry of the laser, dry etching with smooth surfaces may be used to form the reflective facet.
Electric Field Profiles for a rib w/g structure

A 2-D Rib waveguide may not be rectangular. Specially when wet chemical etching is used to cut out the rib (i.e., etch a depth of ‘h’).
Typical index guided Semiconductor Laser Structures

All these structures require one or more steps of REGROWTH. It is a process where the first epitaxial multilayer is processed and then few more layers are epitaxially grown in the growth chamber.
The structure of the edge-emitting heterostructure laser consists of a thin region of semiconductor with a small energy bandgap, called the active layer, sandwiched in between two oppositely doped semiconductor with wide bandgap energy. When the laser is forward biased, carriers flow into the active region and recombine creating light that gets emitted out of the side of the structure. A thin metal stripe is often used for the contact to confine the current to a small region of the device, which will be the laser output.

Note the collection of Electrons and Holes in the active region which increases the probability of recombination.
Often the step-like density of states in a quantum well is used in the lower band-gap layer sandwiched between higher to increase the photon gain in the active region of the laser. This gives to separate confinement (SC) of carriers in the quantum well whereas the photons are confined in the double heterostructure (DH).
Strained Quantum Well Lasers - I

Strained Layer Epitaxy for Lattice Mismatched Materials, such as InGaAs/GaAs for Optical Fiber Amplifier Pumping used earlier.

Defects in the Epitaxial Layer

Thin Epitaxial Layer

Through the Poission’s ratio it expands uniaxially due to biaxial compressive strain as the density remains constant.

Biaxially Coherent Compressively Strained Epitaxial Layer
Critical thickness of an $\text{In}_x\text{Ga}_{1-x}\text{As}/\text{GaAs}$ single quantum well on GaAs according to the theory of Matthews and Blakeslee. The strain can be coherently contained such that generation of defects due to mismatch is minimum.
Bi-axial strain can be resolved to a Hydrostatic Strain + Shear Strain. Shear Strain splits the HH-LH degeneracy \((m_J = 3/2, 1/2)\) levels. Moreover the dispersion relation of the valence band is modified such that the density of states of the VB comes closer to that of the CB. This helps the electron in the CB to easily find a hole in the VB with \(\Delta k = 0\). Results in higher efficiency of recombination.
1. How should the direction of the optical waveguide oriented with respect to the crystal axes for the formation of cleaved cavity mirrors for the diode lasers?

2. What is the effect of the introduction of Double Heterostructure in the active region on the performance of the Laser diode? Calculate the optimum thickness of a GaAs/Al\(_{0.3}\)Ga\(_{0.7}\)As DH structure from a consideration of the optical mode – carrier overlap.

3. What is the advantage of introducing QWs in the DH active region? How does the number of QWs determine the speed of operation of the device?

4. How does compressive strain in the active region improve the efficiency of a diode laser?