Double Hetero structure laser

| AlGaAs | GaAs | AlGaAs |

1. Large refractive index active region
2. Low $E_g$ active region

$\eta_b$ is increased
- faster inversion for same injection current
- light concentrated for stimulated emission

Confinement

$\Gamma$

$\Gamma = \frac{1}{d}$

$\Gamma \propto \Delta n d^2$

$\Gamma \propto \Delta n d$

DH: Double Heterostructure
SQW: Single Quantum Well
SCH: Separate Confinement Heterostructure

Notes:
(band structure engineering)

light (guided) confinement
carrier (electron and hole) confinement

$100 \times \downarrow$ of $J_{th}$
Density of States of QW

\[ \rho(E) = 10^{12} \text{ states/cm}^2 \text{ for } \Delta E = kT \]

\[ \frac{\rho(E)}{\hbar d} = \frac{2m_r}{\hbar d} \]

Threshold current density

\[ J_{th} = eR_{th} \]

\[ J_{th} \approx 6.4 \text{ kA/cm}^2 \cdot \mu \text{m} \]

Threshhold current density

\[ R_{th} = \text{threshold recombination rate} \]

Notes

- \( n_{th} \downarrow \text{ as } d \downarrow \)
- \( g(\nu) \propto f_g(\nu) \cdot \rho_{\text{bulk}}(\nu) \)
- \( g_p : \text{peak gain} \)
- \( \text{higher } T \text{ stability} \)
- \( g(\nu) \propto f_g(\nu) \cdot \rho_{\text{QW}}(\nu) \)
- \( \rho(\nu) = 10^{12} \text{ states/cm}^2 \text{ for } \Delta E = kT \)
DH:
\[ J_{th} = 1.2 \text{ kA/cm}^2 \]
\[ I_{th} \approx 10 - 20 \text{ mA} \]

SQW:
\[ d < 300 \text{ Å} \]
\[ J_{th} < 180 \text{ A/cm}^2 \]

SQW
1. E levels quantized → lasing @ QW transitions
2. \( \rho(\nu)(2D) \) more efficient, \( g_p = \text{const}(\nu) \)
3. \( g \) saturates
4. QW \( \approx 10^{12} \) states/cm\(^2\)
   DH \( \approx 10^{13} \) states/cm\(^2\) in \( d = 1000\text{Å} \)
5. Confinement optimized by separation SCH

Strained Layers

Strain (compressive)
- raises the LH sub band
- reduces carriers to invert \( \Rightarrow J_{th} \downarrow \)
  \( \Rightarrow \eta_{id} \uparrow \)

Unstrained

Strained

Notes
C

V

d<300Å
with band filling, transition not @ \( g_p \) are useless
III-V Compound Semiconductor Processing

1. Substrate Preparation
   GaAs, InP
2. Epitaxial layer growth
   LPE, MBE, MOCVD, CVD
3. Etch
   Dry (RIE), wet
4. Contacts
   Au, silicides, metals

1. Process Constraints
   A. CSBH laser provides (CSBH: Channeled-Substrate Buried Heterostructure) lateral optical and electrical confinement.
      i. grow InP:Fe SI layer
      ii. etch channel
      iii. grow InP/InGaAsP/InP DH in channel
   B. APD detector (SAM)
      i. grow InGaAs/InP het.
      ii. SiNx dielectric deposition
      iii. etch contact window
      iv. diffuse p+ contact/junction
      v. implant p- guard ring

Both devices employ deposited dielectrics for AR coatings (APD) and facet reflectors (laser).

2. Issues
   A. Groups V volatility
      i. incongruent vaporization of P from InP @ T > 360°C
      ii. as from GaAs @ T > 600°C
      Solution: group V overpressure or stable dielectric cap layer.
      iii. RIE creates group III rich suffice
      Solution: lower T, lower E, high Z (Z: atomic number)
B. Preferential etch of V groove  
**Solution:** surface prep.

C. Metallization reactions  
**Solution:** barriers or stable phases

D. Degradation of $\eta_i$  
**Solution:** defect control, life testing

3. Epitaxial Growth

A. Dislocation density  
B. Stoichiometry

**Concept:** Single crystal film bonded to a single crystal substrate with a common interface and the lattice of the film having a definite orientation w.r.t. the substrate lattice.

**Substrate:** semi infinite thickness

**Surface:** atomically flat (ledges) (bond reconstruction)

**Film:** homogeneous, 2D ($x, y >> t$) (phase separation?)

**Interface:** sharp (interdiffusion)

**Tangential forces:** sinusoidal in $a_0$

**Growth Modes**

$E_{fs} =$ film/substrate bond strength  
$E_{ff} =$ film/film bond strength  
$W = \frac{E_{fs}}{E_{ff}} =$ relative strength of bonds to substrate  

$\eta =$ lattice misfit $= \frac{a_s - a_f}{a_f}$

Notes

$\text{Si}(100) \ 2 \times 1$  
or  
$\text{GaAs}(100) \rightarrow \text{rows of AS}$  
$\text{V-termination} \rightarrow \text{flat surface}$
**Lecture**

**Epitaxy**

equilibrium:
- low deposition rate
- high T (surface diffusion)
- minimize $\frac{\Delta G}{N_f}$ (system energy)

**Coherency** (dislocations)

1. variables: a, $E_{ff}$, h
2. minimize energy

$$E_e = \varepsilon^2 Bh$$

separation of parallel misfit dislocations:

$$S = \frac{|b|}{\delta}$$

$$\eta \text{ (relaxed)} = \varepsilon + \frac{1}{S} |b| \cos \lambda$$

projection of $\bar{b}$ on plane of interface

**Critical $h_c$**

minimize $E_e$ vs. $E_{\text{dislocation}}$

Matthews–Blakelee

$$h_c = \frac{b}{8\pi\eta(1+\nu)} \left[ \ln \left( \frac{h_c}{b} \right) + 1 \right]$$

$$h_c \approx \frac{b}{4\eta}$$

$$|b| \approx 1 \text{ Å} \Rightarrow h_c = 100 \text{ Å} \text{ of } \eta = 10^{-2}$$

**Notes**

Frank-Vander Merwe 1D harmonic chain

$\delta$ = strain relief by dislocations

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Morphology (wetting)

\[ \mu_r = \frac{\partial G}{\partial N} \]

ML: monolayers

Nucleation barrier to clustering

\[ \Delta G^* = \frac{8\pi\gamma_{c/v}^3}{3\rho_0^2 [\Delta F(\eta)]^2} \]

\[ N^* = \frac{16\pi\gamma_{c/v}^3}{3[\Delta F(\eta)]^3 \rho_0^2} \]

\[ I = N_s \Gamma \exp(-\Delta G^*/RT) \]

Morphology + Coherency are determined by nucleation barriers \( \Delta G^* \) for dislocation formation clustering

Metastability is common
4. **Contacts**

- stable
- selective
- low $R_c$
- low $T$ deposition
- adhesion

**Eutectics**

- Au(Be) P
- Au(Ge) n

- small process window
  - RTA
- unreliable

**Silicides**

- Stable
  - undefined interface
    $\rightarrow R_c \uparrow$

**Metals**

- reactive with compounds
  $\rightarrow$ defects, dissociation
  $\rightarrow$ phase stability

\[ R_c < 10^{-6} \Omega \cdot \text{cm}^2 \]

for lasers

surface defects pin $E_F$

$\rightarrow$ contact resistance
(Schottky Barrier)

for n-GaAs
  - p-InP

$\Rightarrow$ heavily doped epilayer under contact
AB dominant

500 °C

Ga

GaAs

As

MA_x

MB_y

A

AB

B

No phase dominant

300 °C

Pt

GaPt

PtAs_2

Ga

GaAs

As

PtGa_3

PtAs_2 + PtGa

GaAs

PtGa_3

PtAs_2

GaAs

Ti

TiGa_4

TiGa_3

TiAs

Ga

GaAs

As

TiGa_4

TiGa_3

TiAs

Ga

GaAs

As

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Lecture 15: III-V Processing
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NiP (conductor)

Ni

In

InP

P

Ni

InNi

InP

P

NiP (conductor)
Adhesion:
- local structural relaxation
- ion beam mixing
- chemical bonding
  \((\text{Cu}/\text{Al}_2\text{O}_3 \text{ with excess } 2)\)

Interdiffusion
- Polycrystal: grain boundary diffusion
  \[D_{\text{bulk}} = \frac{E_a}{4}, \quad D_{\text{disloc}} \sim \frac{3E_a}{4}, \quad D_{\text{gb}} \sim \frac{E_a}{2}\]
  \[D = D_{\text{bulk}} + f \cdot D_{\text{gb}}\]

  \[D_{\text{bulk}}(T_{\text{MP}}) \sim D_{\text{gb}} \left(\frac{1}{2} T_{\text{MP}}\right)\]

- Diffusion Barrier (Ti/Pt)Au
  - high \(T_{\text{MP}}\)
  - chemically stable
- Intermetallic Compound
- Coherent Interface

Dielectric Deposition
SiO\(_2\), SiO\(_x\)N\(_y\), SiN\(_x\)
- sputter
- PECVD
- e-beam
  facets, isolation, diffusion masks

Etch
- Wet etch (Br:CH\(_3\)OH, HCl)
  - layer stop \(\text{H}_2\text{SO}_4 : \text{H}_2\text{O}_2 : \text{H}_2\text{O}\)
  - v-groove
- Dry etch (CF\(_2\)Cl\(_2\), (HBr, HI)
  - Anisotropy
  - Photoelectrochemical etch
    anisotropy

refractory TM: Cr, Ni, Ta, Ti, Hf