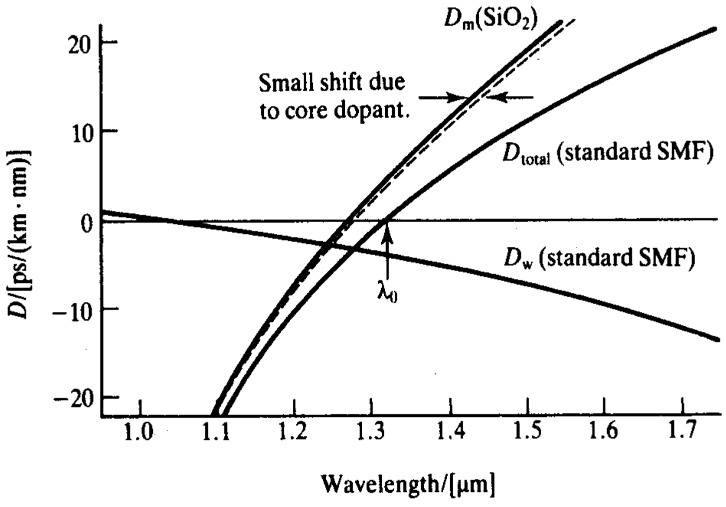
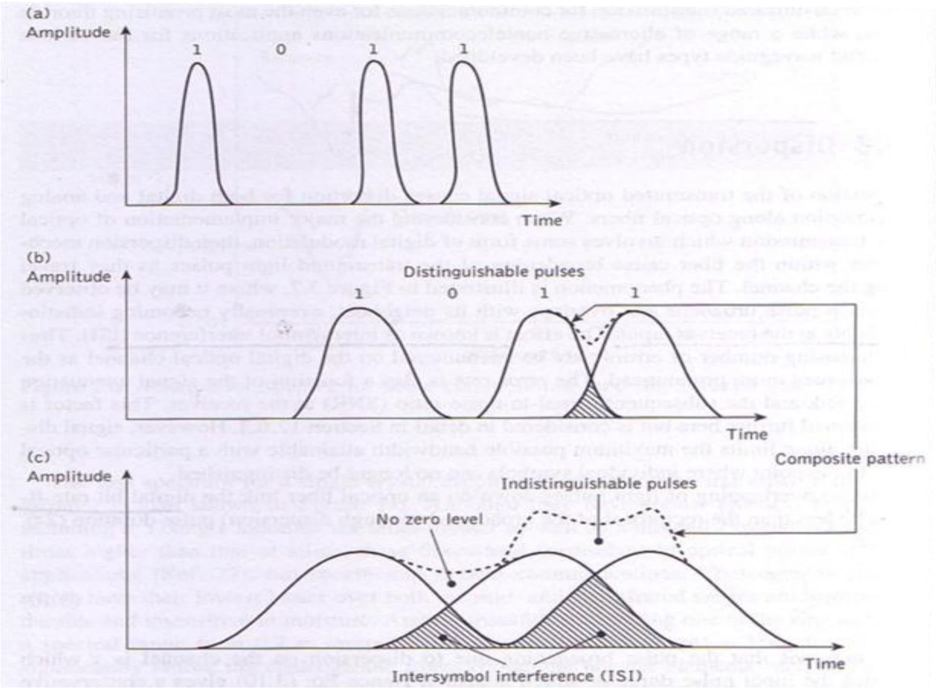
Topic 22

22 Different kinds of LDs

22.1 Introduction
22.2 Short Cavity FP
22.3 DBR
22.4 DFB
22.5 VCSEL
22.6 Wavelength Tuning

Introduction (i)





- Previous slides:

1. Dispersion limits bit rate and long distance

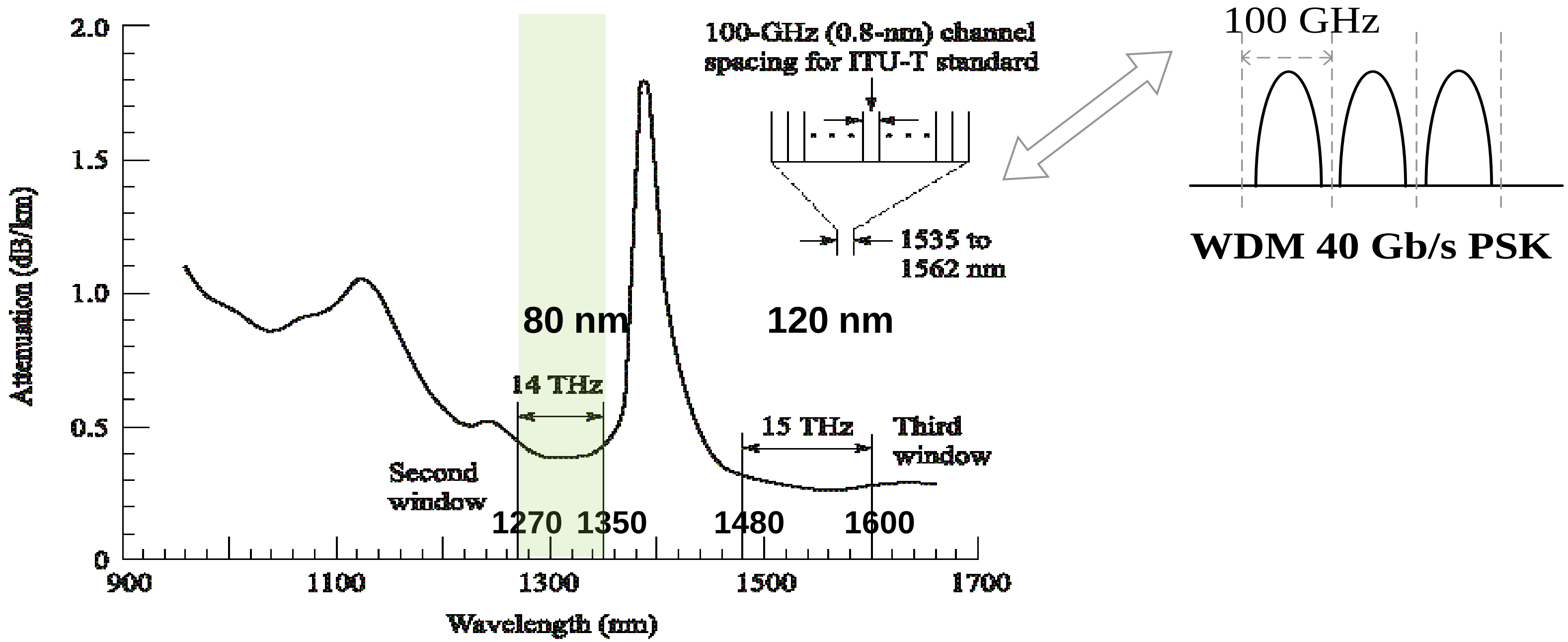
$\Delta\delta t = L\Delta\lambda D$

$B \propto 1/ (L\Delta\lambda D)$

A maximum pulse broadening of 50% of the bit slot: $BL = 1/(2\Delta\lambda D)$

2. Transmission – need a narrow linewidth to minimise pulse broadening

Introduction (ii)



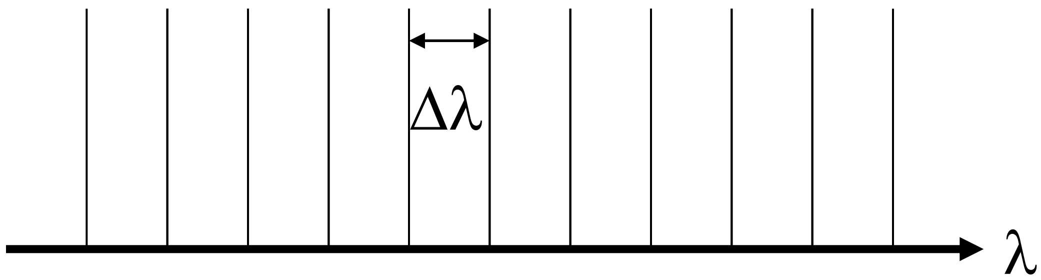
- We also need a narrow linewidth emitter in order to maximise WDM capacity
- **Optical Band width**

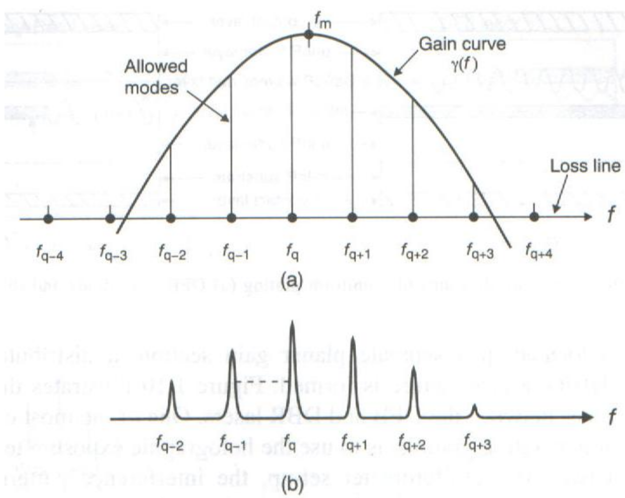
$$\boxed{|\Delta \nu| = \left(\frac{c}{\lambda^2}\right)|\Delta\lambda|}$$

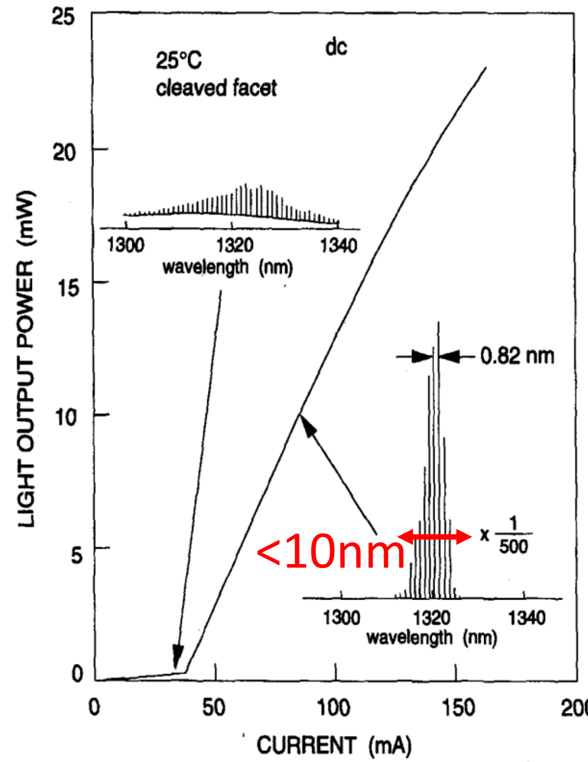
Laser line width is 0.8 nm **(~100 GHz)**, a single optical fibre can carry 50 pulses

- **Temperature stability**
- **Single mode**

Single Mode Laser – widely spaced FP modes







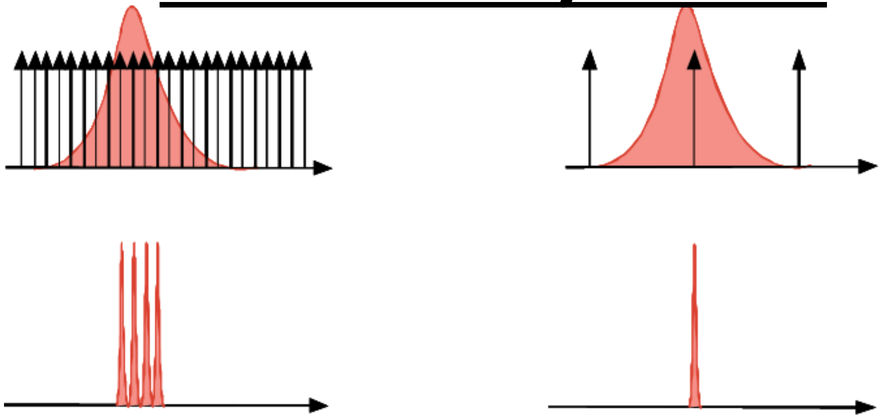
- Previous slides show:

  $m\lambda/2 = nL$

  $\Delta\lambda = \lambda^2/2\,nL$

- Make the spacing large enough so that only one lasing mode is allowed
- Requirements: **mode spacing ≥ gain spectrum width**

Short Cavity Lasers



- For example: refractive index ~3, λ_0 = 1.55 um, if $\Delta\lambda$ required: 20nm
- The cavity length: $\Delta\lambda = \lambda^2/2nL$
- So L=20 μm

Problems to overcome –

$$g_{th} = \frac{1}{\Gamma}\left[\alpha_i + \frac{1}{2L}\ln\left(\frac{1}{R_1 \cdot R_2}\right)\right]$$

- L is so small that mirror reflectivity needs to increase, ensuring low losses

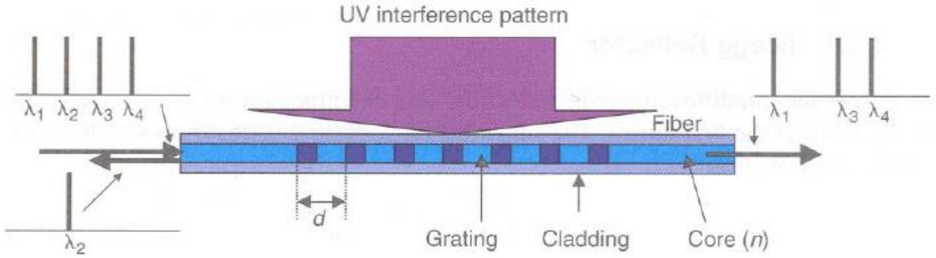
- High power: need large current through small volume – cooling problems?

- Cleavage: **extremely difficult (Recently, laser cleaving)**

– try cleaving 20 μm from a 100 μm thick semiconductor….
analogous to braking 5mm thick chocolate into 1mm slices

Bragg Gratings

• Previously we have known: **Fibre Bragg gratings** can be used as a wavelength selective filter



•The selective wavelength must meet the requirements in order to form constructive interference between the reflected beams

$$\boxed{\lambda = 2 \cdot n_{eff} \cdot d}$$

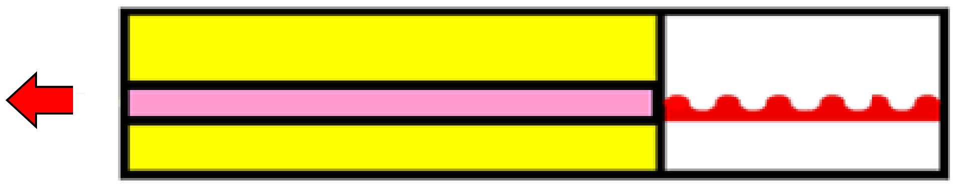
where n_{eff}: the average refractive index of the material; d: grating period.

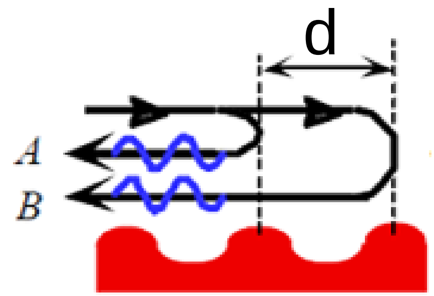
• If d is fixed, **only λ meeting the above equation can be selected**

The idea can be used for the fabrication of a single wavelength laser

- Grating **in the gain region** (active region): **DFB laser**
- Grating **outside the gain region** (active region): **DBR laser**

Distributed Bragg Reflector (DBR) Laser





• **Bragg condition**: $\lambda_B = 2\, n_{avg} d\, /\, m$, where m=1,2......, and **d: period**

• Only allowed wavelengths: **when the wavelength satisfies the Bragg condition to form constructive interference**

For example to design DBR/DFB structure (i.e., **d: period**)

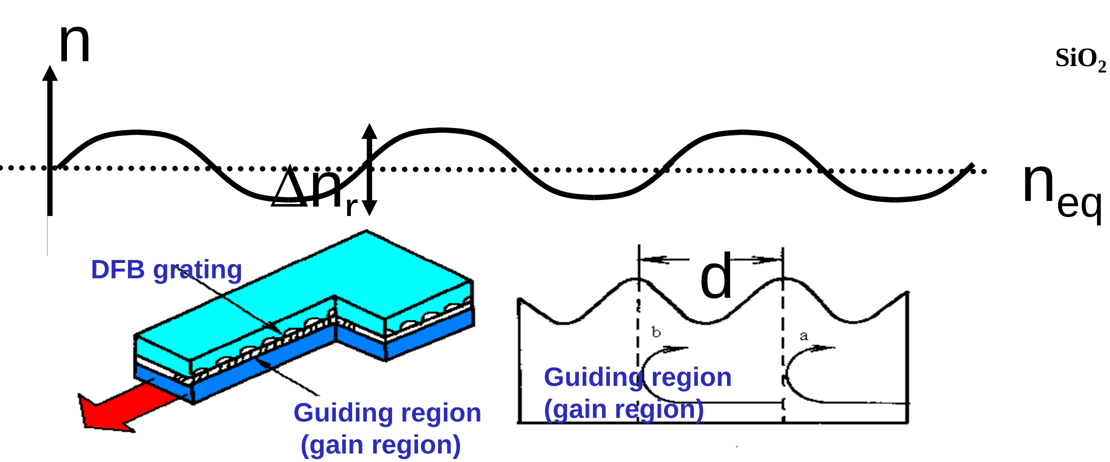
$\lambda_{Bragg} = 2n_{avg}d/m \qquad \Rightarrow \qquad d = m\lambda_{Bragg}/2n_{avg}$

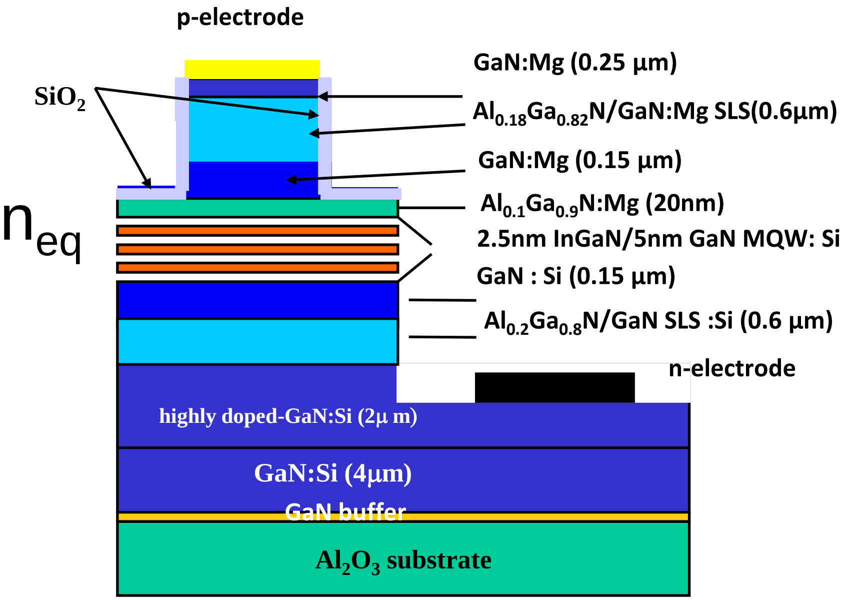
Choose the 1st order: m = 1, λ_{Bragg} = 1.55um, n_{eq}= 3

Therefore, we can obtain: d ~ 250nm

• **The period required is on the nanometre scale** (think how to fabricate)

Distributed Feedback Laser





- **Bragg condition**: $\lambda_B = 2\, n_{eq} d / m$, where m = 1,2……, and **d: period**

Usually use m=1. m ≠ 1 not on gain peak.

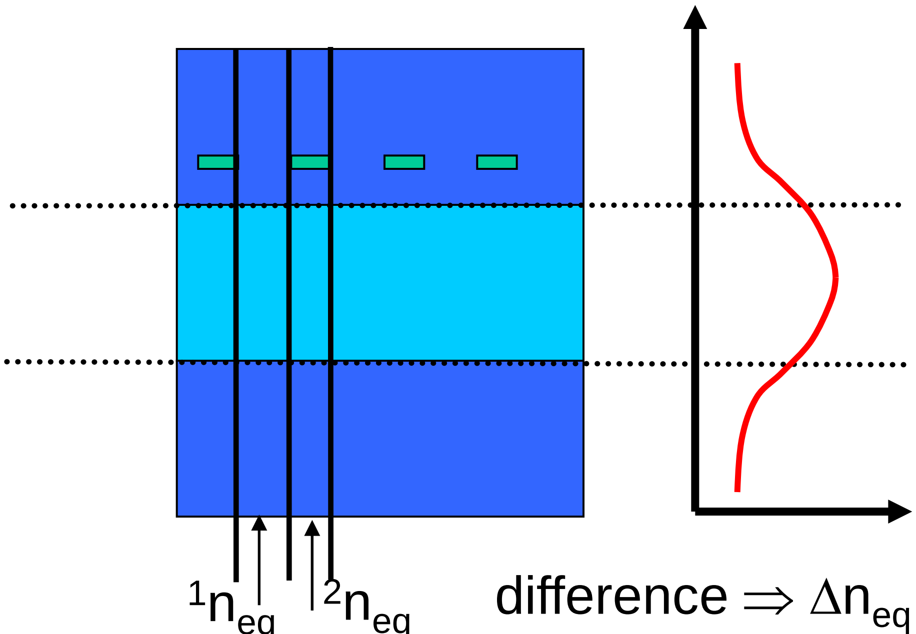
Basically, when the lasing λ is close to λ_B, such lasing wavelength is allowed

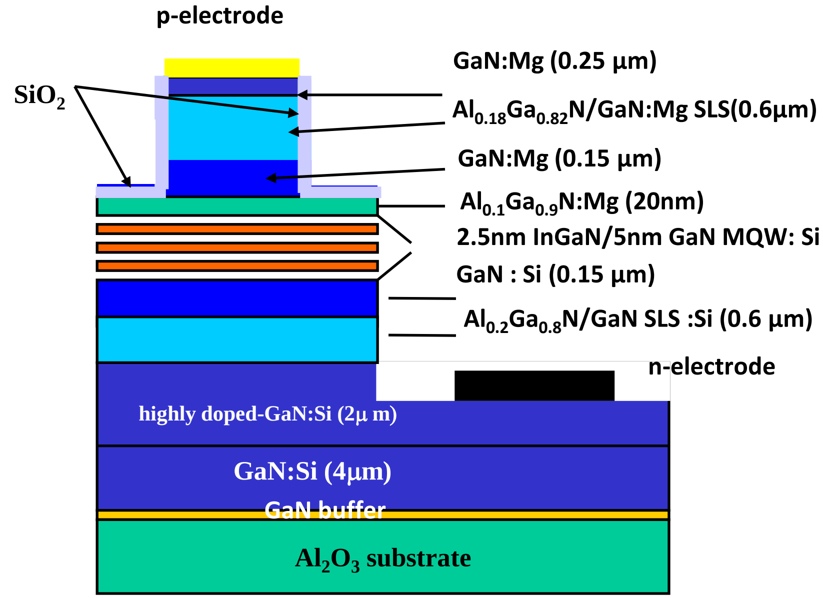
In reality, it is not so simple. The special grating:

(1) It modifies the **refractive index** periodically

(2) It also modifies the **gain in the active region** periodically

Distributed Feedback Laser – Coupling Strength





- A detailed calculation is complicated, depending on **Coupling Strength**, i.e., the fraction of optical power reflected:

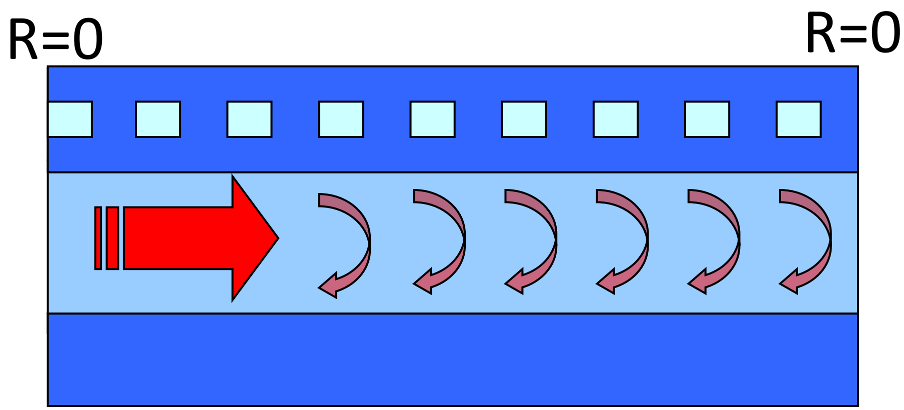
(1) Thickness of the waveguiding layer; (2) Depth of the grating pitch; (3) Length of the grating region

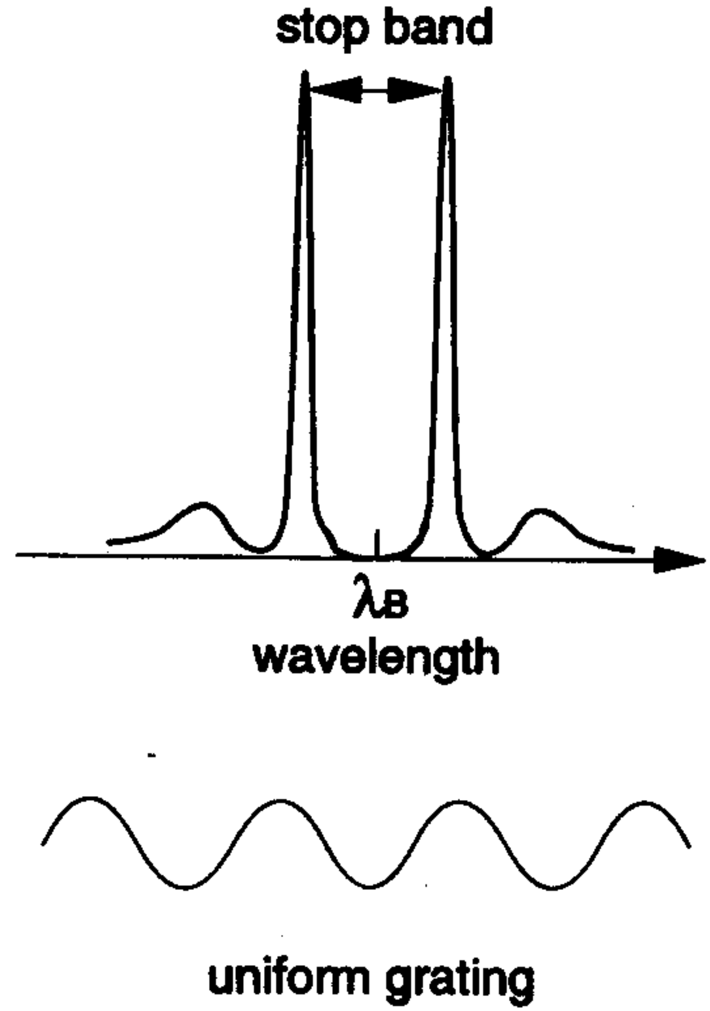
- **Introduction of a coupling constant** (based on perturbation assumption)

$\kappa = \pi \Delta n_{eq} / \lambda_B$

Increase κ by increasing index contrast – thicker grating layer, closer to optical mode, etc.

DFB Modes – Emission Spectra





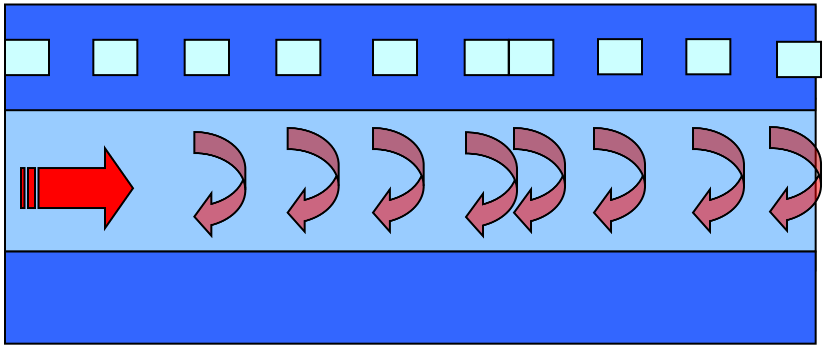
- In reality, the allowed wavelengths are close to λ_{Bragg} , but **not exactly λ_{Bragg}**
- Lasing at two modes on either side of λ_{Bragg}

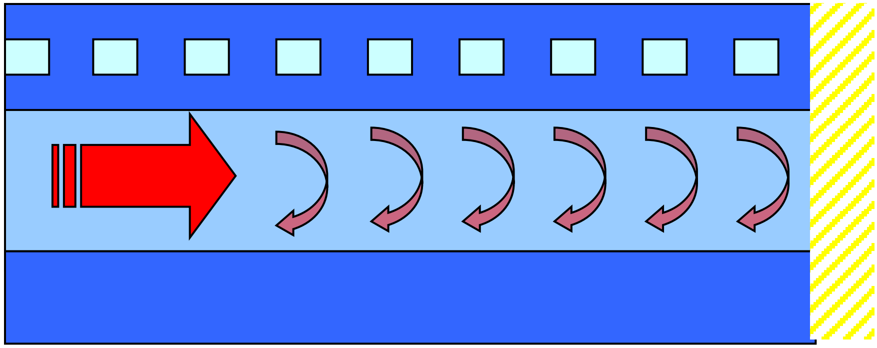
$$\boxed{\lambda = \lambda_{Bragg} \pm \frac{\left(m + \frac{1}{2}\right)}{2nL} \lambda^2{}_{Bragg}}$$

- **Stop band width is function of κ**

It is still not good enough as two modes are allowed

Single mode DFB laser

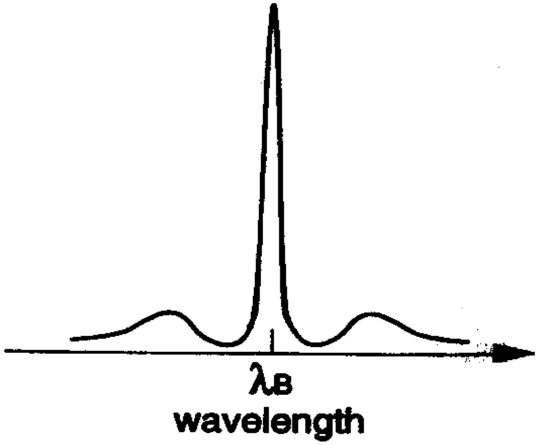


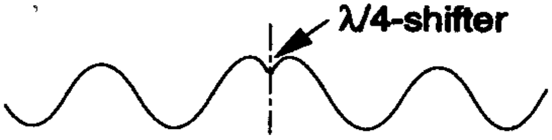


- Introducing additional **π/2 phase shift** to get single mode operation (introduce "defect" or destroy "symmetry" in order to lift degeneracy)

1- Put phase shift in grating

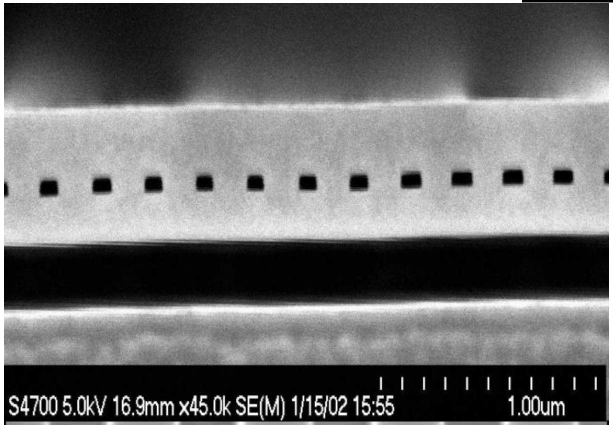
2- Make one facet a high reflecting mirror

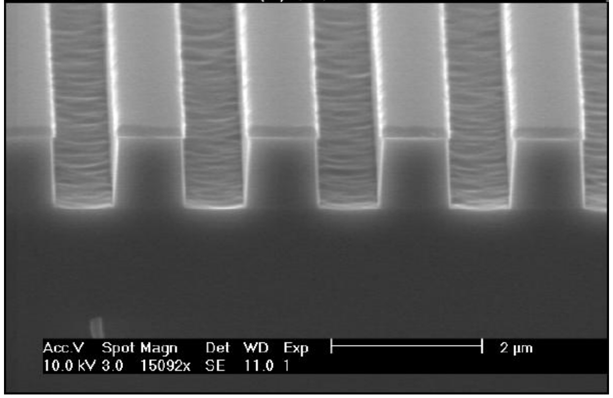


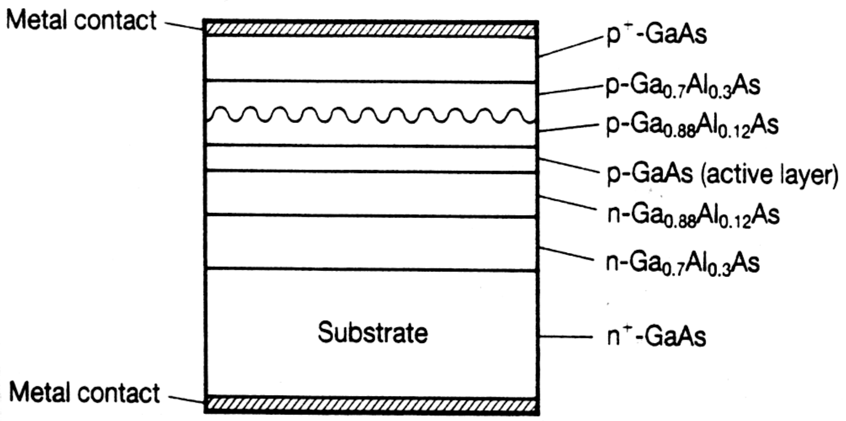


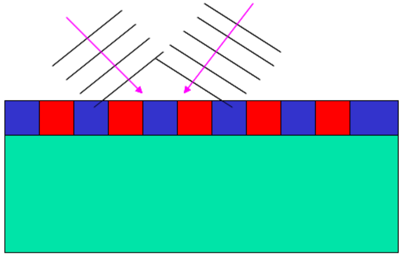
grating with λ/4 phase shifter

DFB laser Fabrication (i)





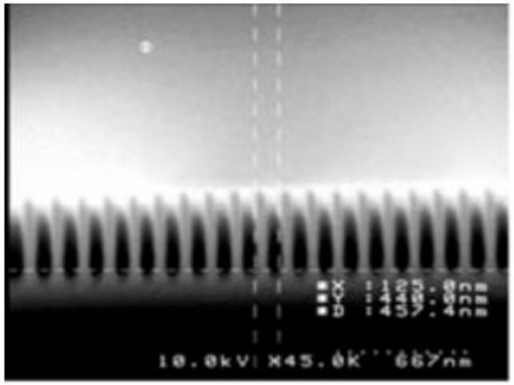


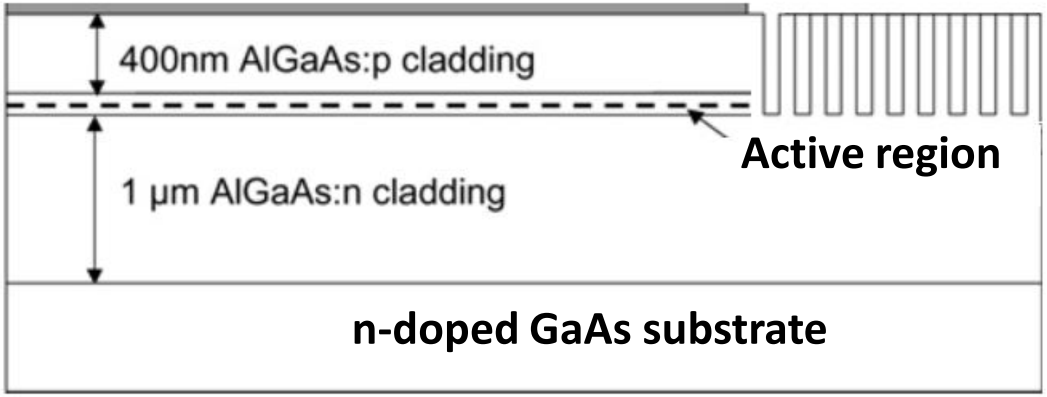


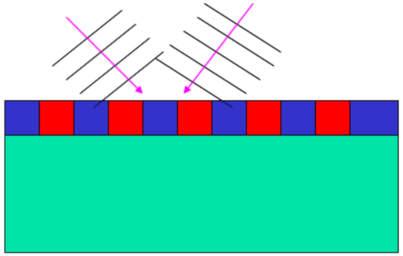
- **Combination of epitaxial overgrowth and nanofabrication techniques**

(1) Partial epitaxial growth of laser structure (interrupted at guiding layer just above active region): **MBE or MOCVD**
(2) Designing/patterning grating structure: **holography or e-beam lithography**
(3) Fabricating grating structure: **dry-etching or wetting etching**
(4) Completing epitaxial growth: **MBE or MOCVD**

DBR laser Fabrication (ii)



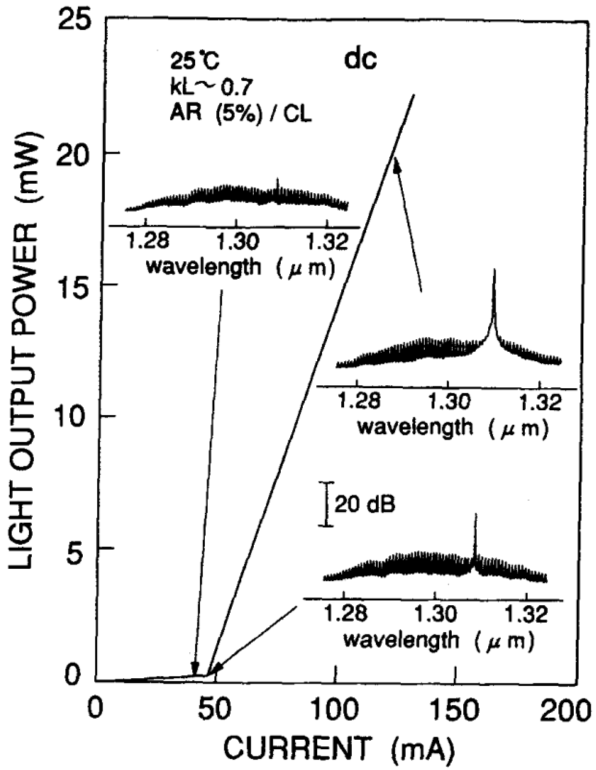


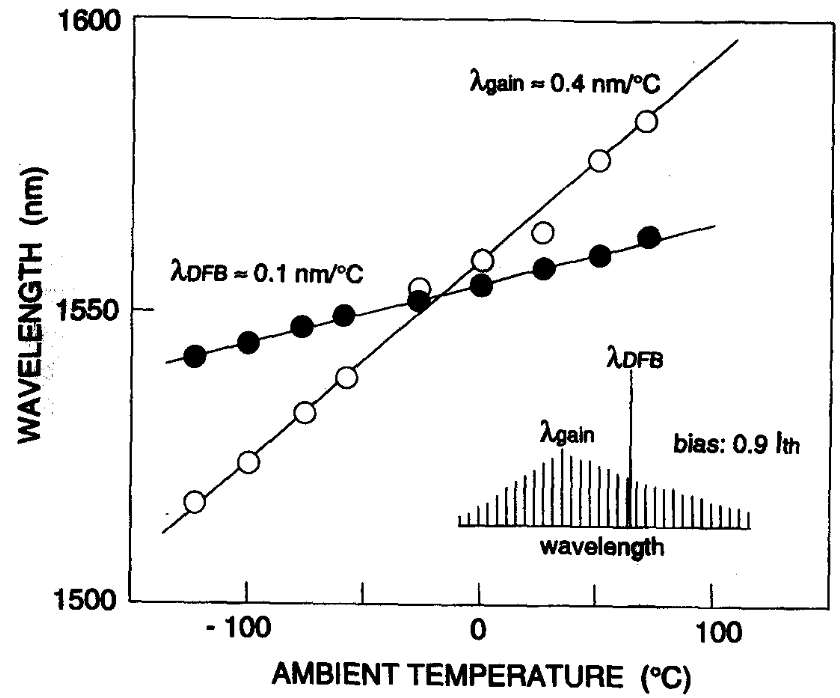


- **Easier than fabrication of DFB, and epitaxial overgrowth is unnecessary**

(1) Design/patterning grating structure: **holography or e-beam lithography**
(2) Fabricating grating structure: **dry-etching or wetting etching**

DFB Performance





Compared with other laser diodes

- **Extremely narrow** linewidth
- Wavelength set by grating – **less sensitive** to temperature

Both meet requirements for the DWDM application very well

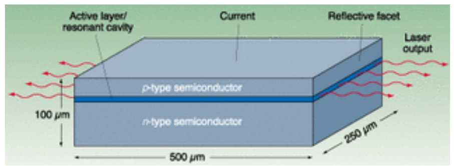
Vertical Cavity Surface Emitting Laser (VCSELs) (i)

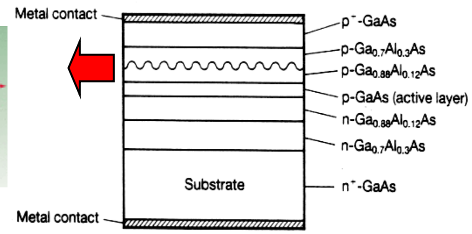
So far, we have known a number of laser diodes:

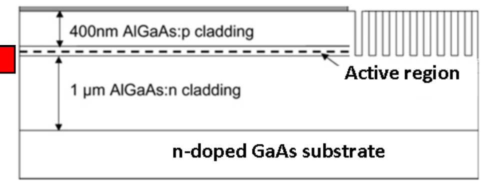
(1) F-P laser

(2) DBR laser

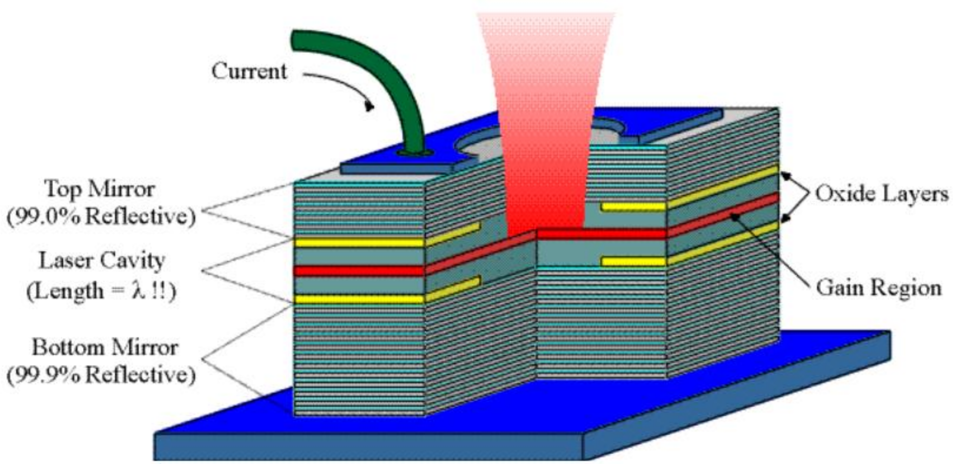
(3) DFB laser





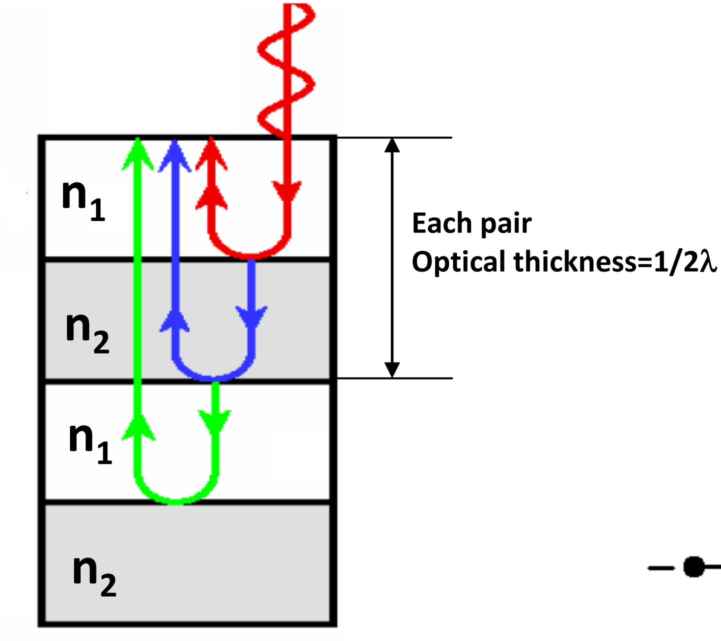


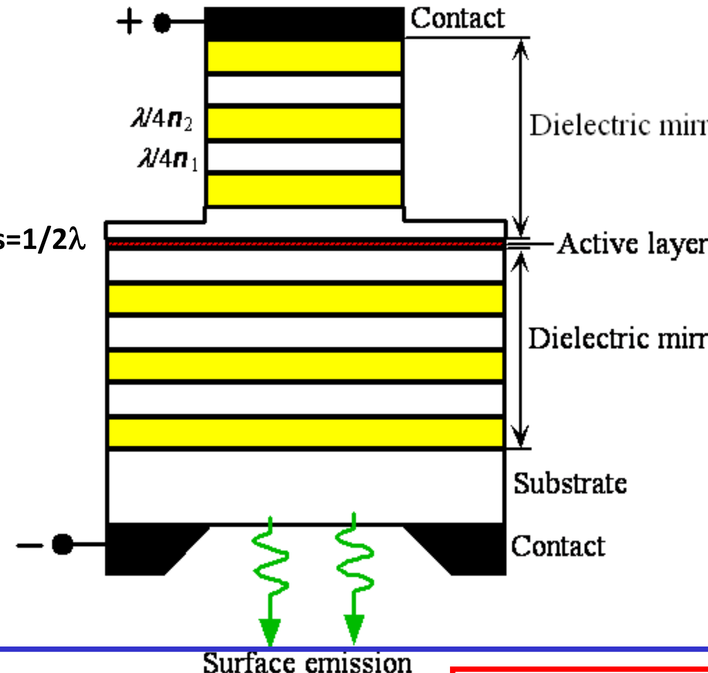
Basically, they are (1) under an edging–emitting configuration; and (2) based on an optical cavity on the **ten or hundred micrometre scale**

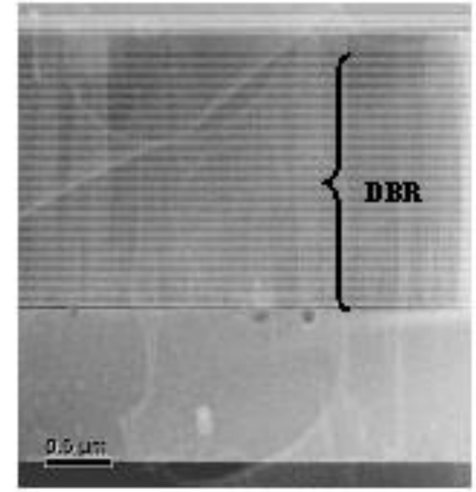


- **Surface emitting laser**
- Cavity length: **wavelength scale (~ λ)**
- **DBR** on top and bottom (reflectivity~100%)

Vertical Cavity Surface Emitting Laser (VCSELs) (ii)







Sheffield nitride DBR

- Both bottom and top DBRs require:

(1) ~100% reflectivity;

$$R = \left[\frac{(n_{h1}/n_{L2})^{2N} - 1}{(n_{h1}/n_{L2})^{2N} + 1} \right]^2$$

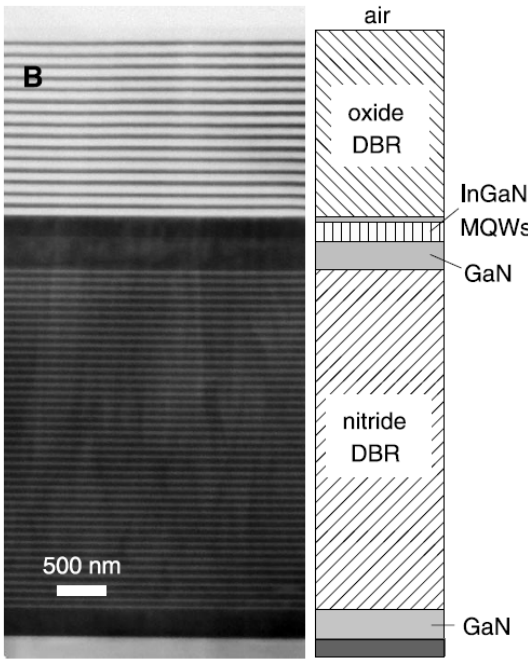
(2) Many pairs required: each pair consisting of **two layers** with an optical thickness 1/2λ, i.e., **$1/2\,\lambda = n_1 d_1 + n_2 d_2$**

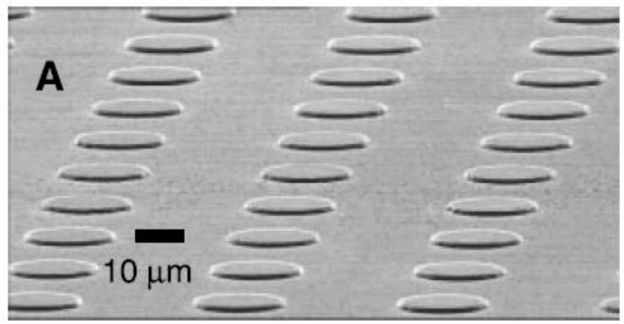
where n_1 and n_2: refractive indices; and d_1 and d_2: thickness for each layer

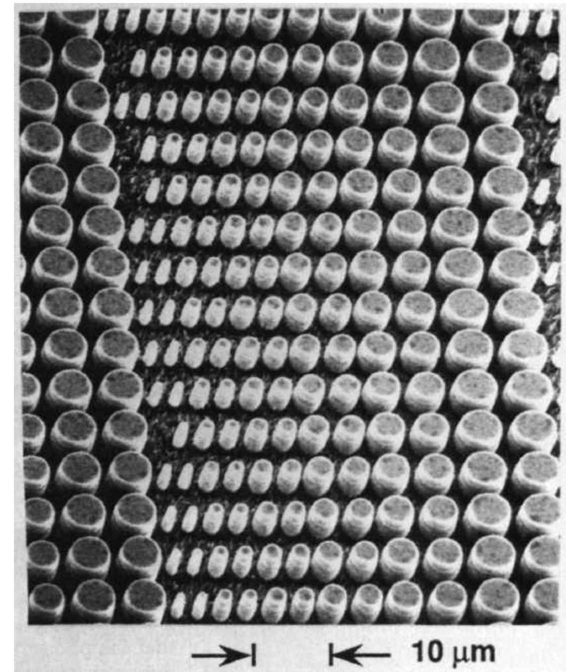
(3) Optical cavity (L): **m (nλ),** where m: integer, n: refractive index

- For example: d_1 and d_2: ~120 -130 nm (if λ=1.55µm, n_1 and n_2:~3.2/3.0)

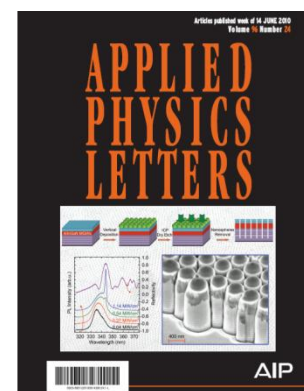
Fabrication of VCSELs

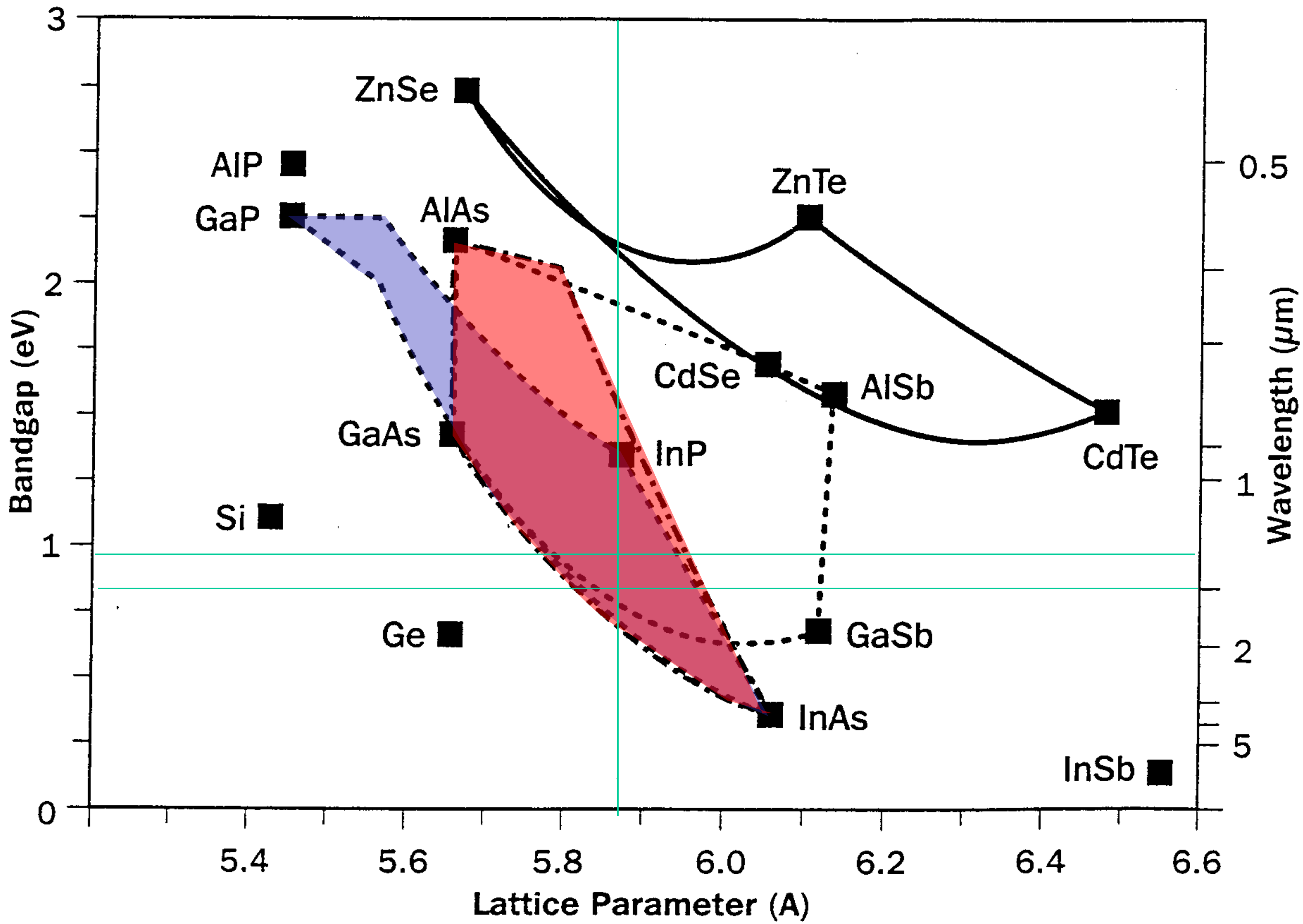




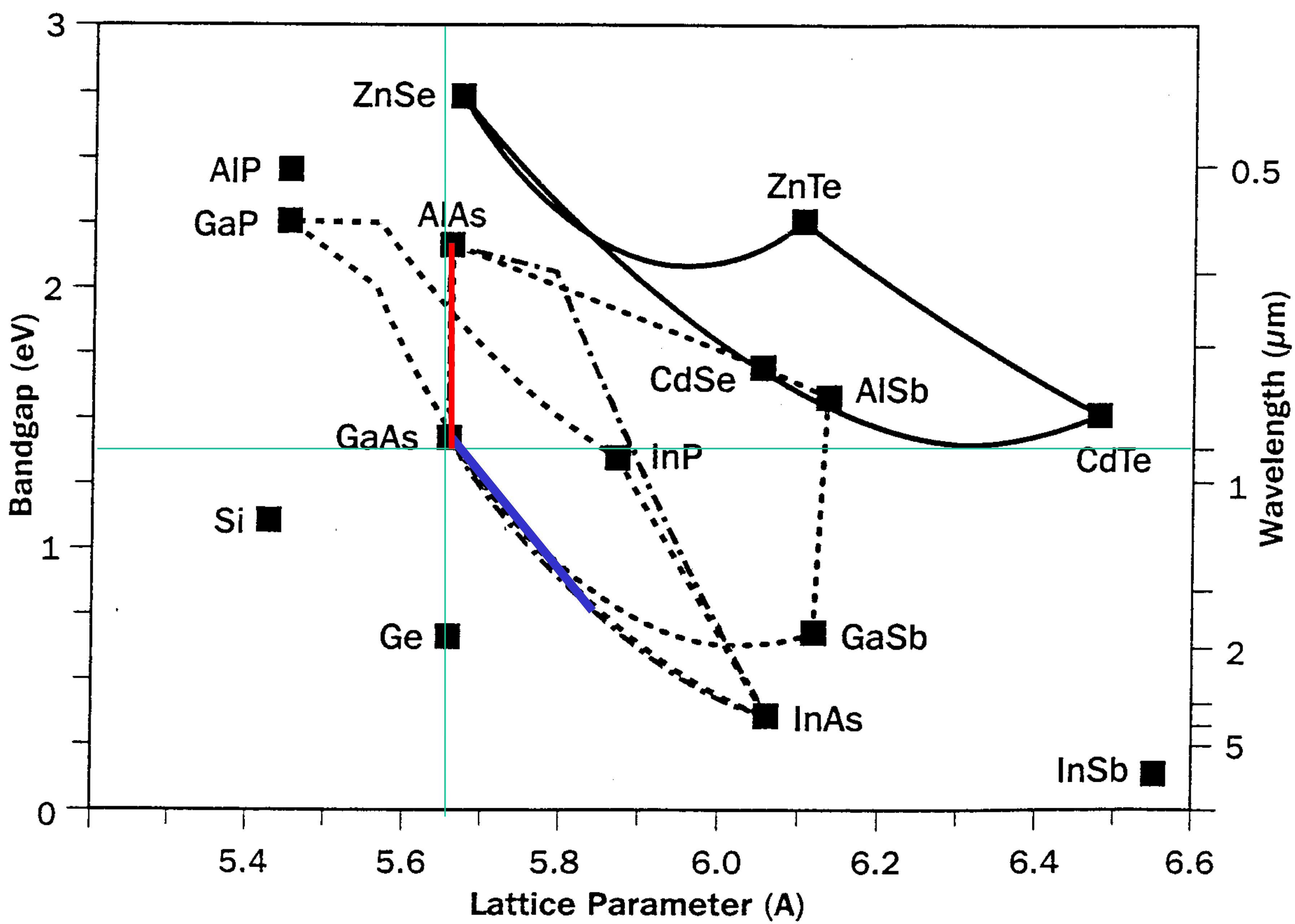


- Ease fabrication in a **two dimensional array**
- Laser beam shape: best due to a circularly symmetric confinement, thus offering excellent coupling with optical fibre
- Challenge: material growth due to the requirement of many pairs of DBR
- Sheffield team has achieved the shortest wavelength VCSELs





3
2
1
0
Bandgap (eV)
5.4
5.6
5.8
6.0
6.2
6.4
6.6
Lattice Parameter (A)
0.5
1
2
5
Wavelength (μm)
ZnSe
AlP
GaP
AlAs
ZnTe
CdSe
AlSb
GaAs
InP
CdTe
Si
Ge
GaSb
InAs
InSb



3
2
1
0
0.5
1
2
5
ZnSe
AlP
GaP
AlAs
ZnTe
CdSe
AlSb
GaAs
InP
CdTe
Si
Ge
GaSb
InAs
InSb
Bandgap (eV)
Wavelength (μm)
5.4
5.6
5.8
6.0
6.2
6.4
6.6
Lattice Parameter (A)

Materials and Applications

•1.3um – 1.65 um
-InP based materials, AlInGaAs, GaInAsP alloys
~MANs ~ 1300nm systems
(~10GBit/s ~10km 1300nm DFB)
(~1 Gbit/s ~few km 1310nm FP)
~WANs ~1550nm systems
(~10GBit/s ~40km 1550nm DFB)

•850nm
-GaAs based materials (AlGaAs, InGaAs alloys)
~LANs – e.g. 10GBit/s over ~300m

•980nm-EDFA Pump laser
- GaAs based materials (AlGaAs/InGaAs)

Wavelength Tuneable Lasers

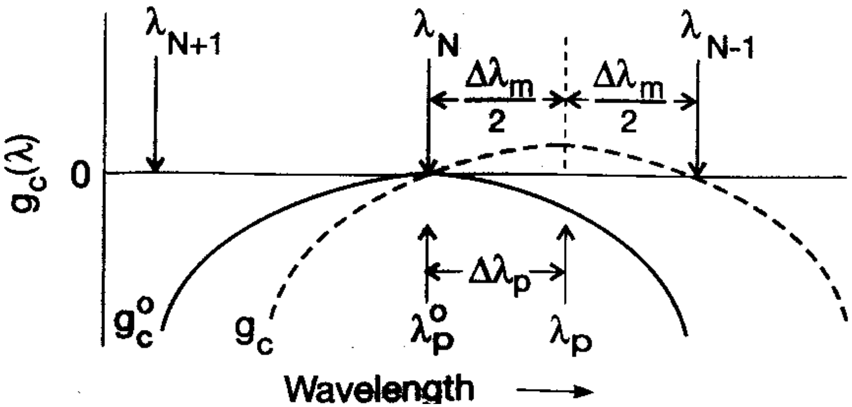
For DWDM it is desirable to have wavelength tuneable lasers

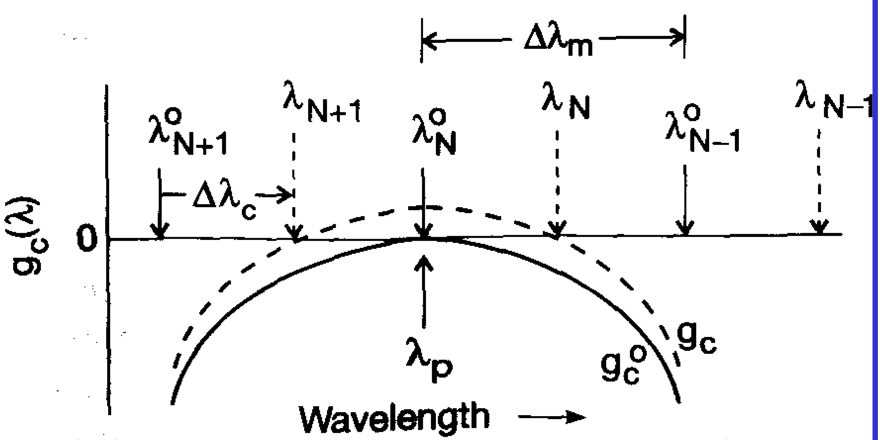
- Need to compensate for the ageing of laser
  wavelength shift with age

- Need to reduce component inventory
  both manufacturer and in field

- Also many applications in gas sensing, spectroscopy, etc.

Tuning Methods





1) Alter cavity gain spectrum

– short cavity laser
with thermal or free carrier tuning of gain spectrum peak wavelength

- Increased current changes λ_{Bragg} for mirrors – thermal and free carrier effects

- Thermal tuning allows gain spectrum change

2) Alter allowed modes

Extra cavity

3. Alter allowed modes and gain

Summary Topic 22

- Narrow linewidth of laser emission is desirable (DWDM, dispersion)
- A number of possibilities exist – short cavity F-P, DFB, DBR, VCSEL, all with their relative advantages and disadvantages
- Tuneable wavelength is also desirable …DWDM
- Various possibilities exist – tune gain spectrum, lasing modes, or both

Tutorial Questions

T22.1 Describe the possible optical modes of a laser diode and how they may be controlled to obtain a single mode laser.

T22.2 Review the different methods to obtain a single longitudinal mode laser.

T22.3 Why is a tuneable single-mode laser desirable? How may this be achieved?

T22.4

(a) A laser diode has length 100 µm, operates at 1300nm, has effective refractive index of 3.5. What is the F-P mode spacing?

(b) For this laser both facets have a reflectivity of 0.5. Assuming no internal loss, calculate the threshold gain of the laser.