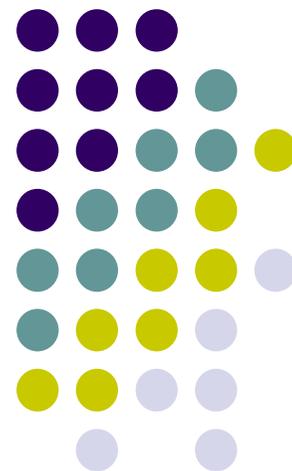
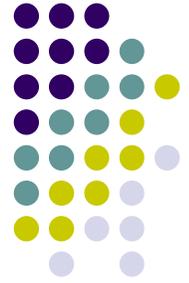


# 高速光傳輸模組Q值 與BER量測

中華技術學院 林晏瑞 博士

台灣科技大學 林淑娟





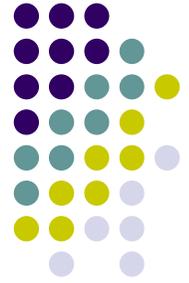
# Outline

- 動機與目的
- 光纖通信簡介
- Laser 特性與應用
- PIN-TIA特性與應用
- 光傳送接收模組之設計與分析
- 光傳送接收模組量測結果與討論



## ● 動機與目的

- 光纖通信簡介
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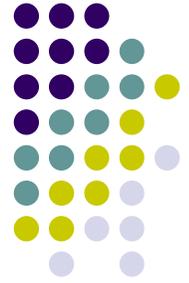


## 動機與目的

- 乙太網路(Ethernet)為現今區域網路中佔有比例最高(95%)的傳輸架構,隨著頻寬需求與使用者增加,原先技術已不敷使用。藉著引進光纖元件與系統技術,傳輸速度可大幅提升。
- 在光纖通訊網路上,光傳輸發射接收模組是不或缺的重要組件,無論是在價格上或是性能上,均對整個系統有決定性的重要因素。

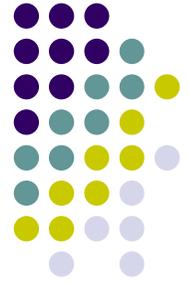


- 動機與目的
- **光纖通信簡介**
- Laser 特性與應用
- PIN-TIA特性與應用
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# 光纖通信簡介(1)

- 基本的通訊系統包含：  
發送器(transmitter)、接受器(receiver)  
以及資訊通道。
- 傳送的大概過程是將原始訊息經調變器(modulator)調變之後再由耦合器(coupler)將光訊號耦合至資訊通道中(光纖，fiber)，接收端利用偵測器(light detector)擷取訊號。

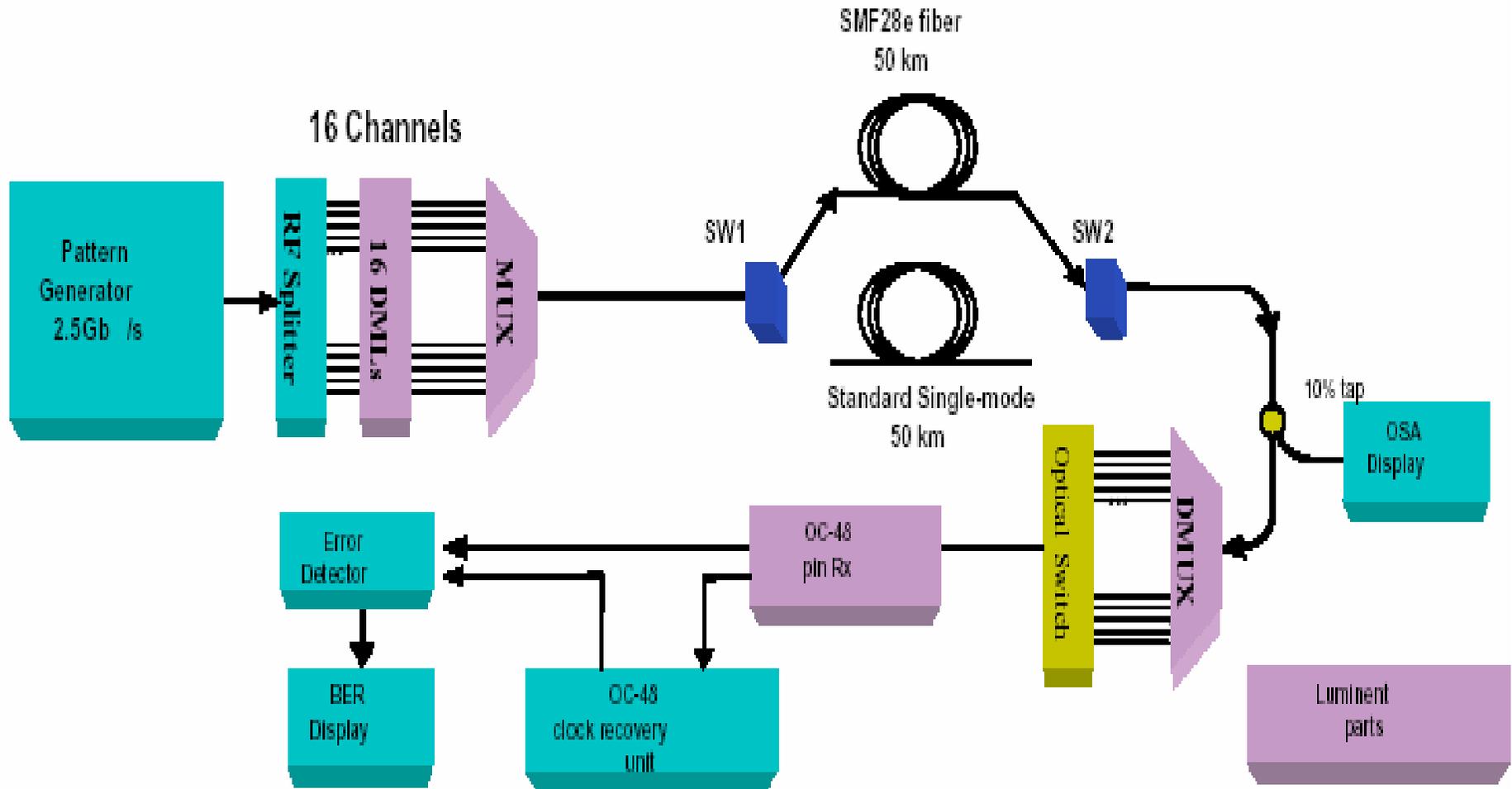


## 光纖通信簡介(2)

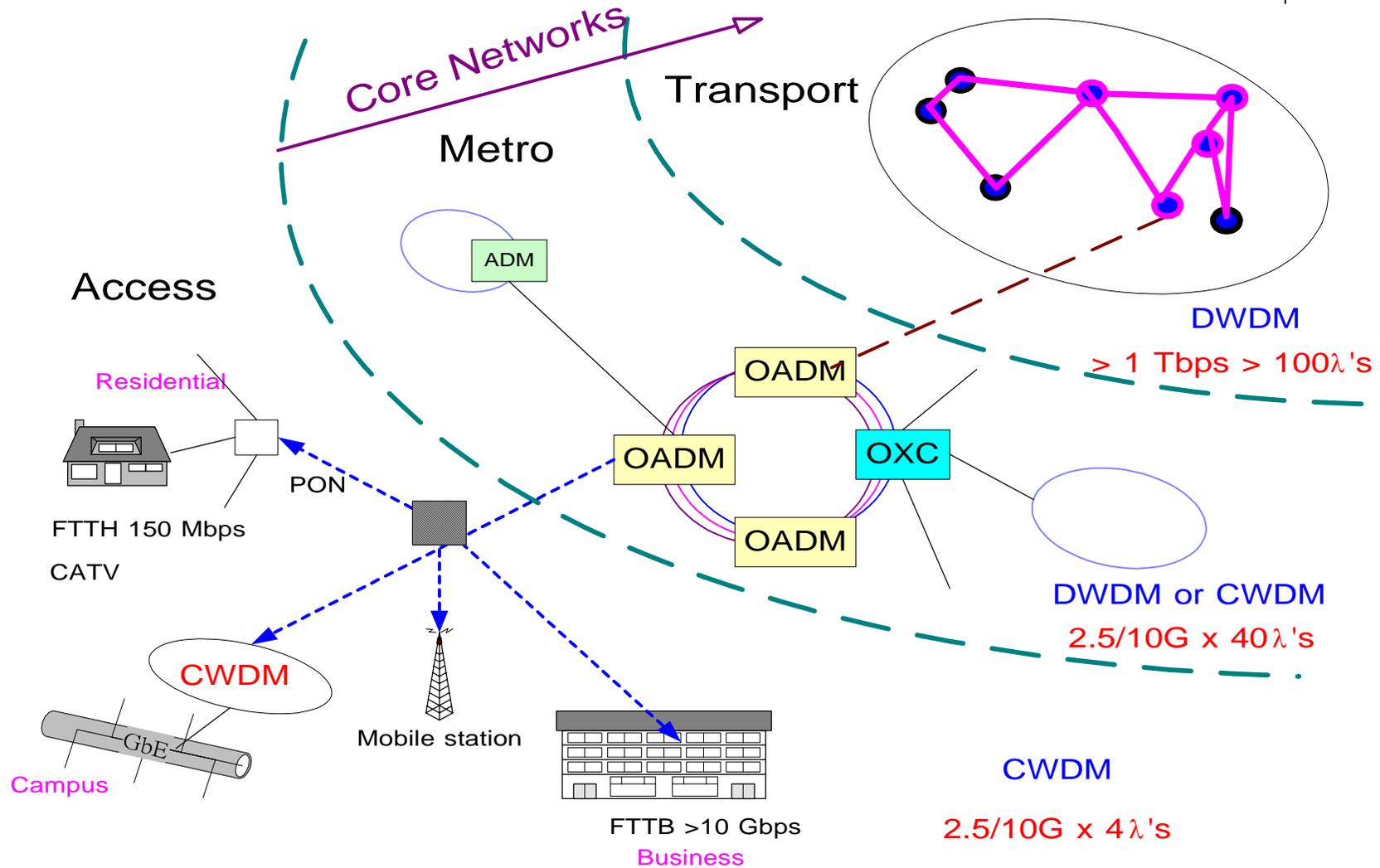
與電纜或微波等電通信方式相比，  
光纖通信優點如下：

- 頻帶寬、資訊容量大
- 低傳輸損失，傳輸距離遠
- 體積小，重量輕
- 抗電磁干擾，保密性佳
- 材料資源豐富

# 光纖通信架構範例



# 光纖網路架構



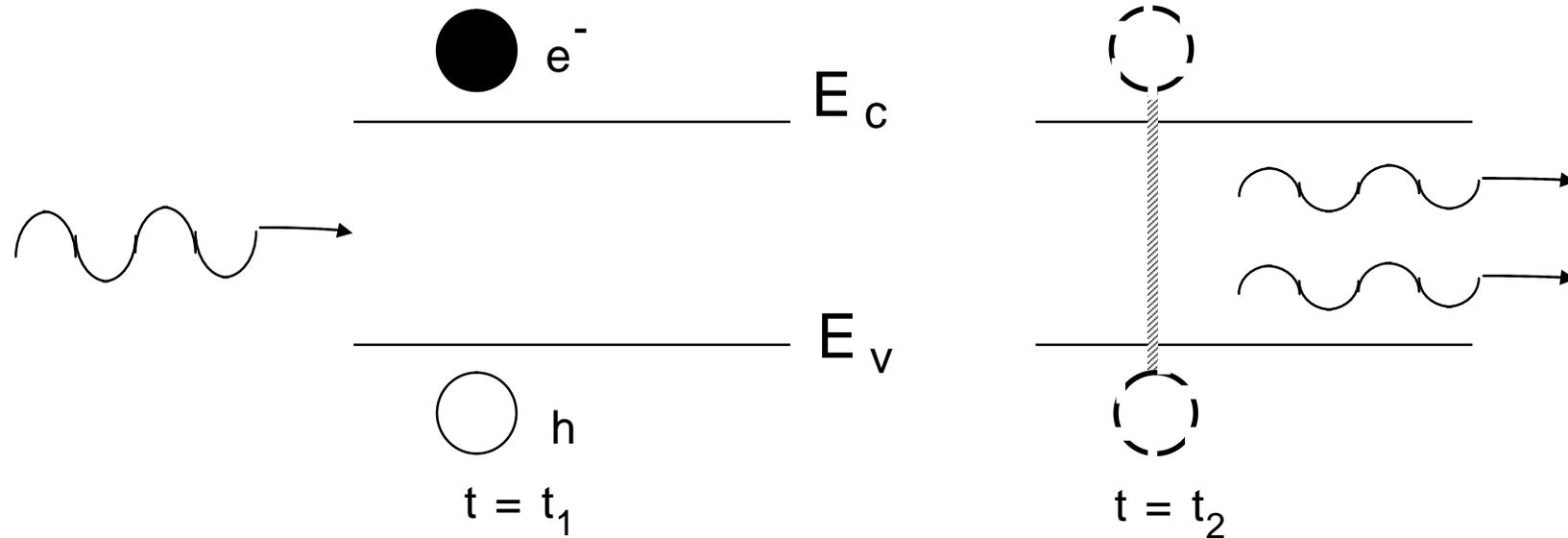


- 動機與目的
- 光纖通信簡介
- **Laser 特性與應用**
- PIN-TIA特性與應用
- 光傳送接收模組之設計與分析
- 光傳送接收模組量測結果與討論

# Laser原理



## Stimulated Emission



$$\tau_{stim} \ll \tau_{spont}$$

**Stimulated emission:  
-Photon cloning (in phase)**

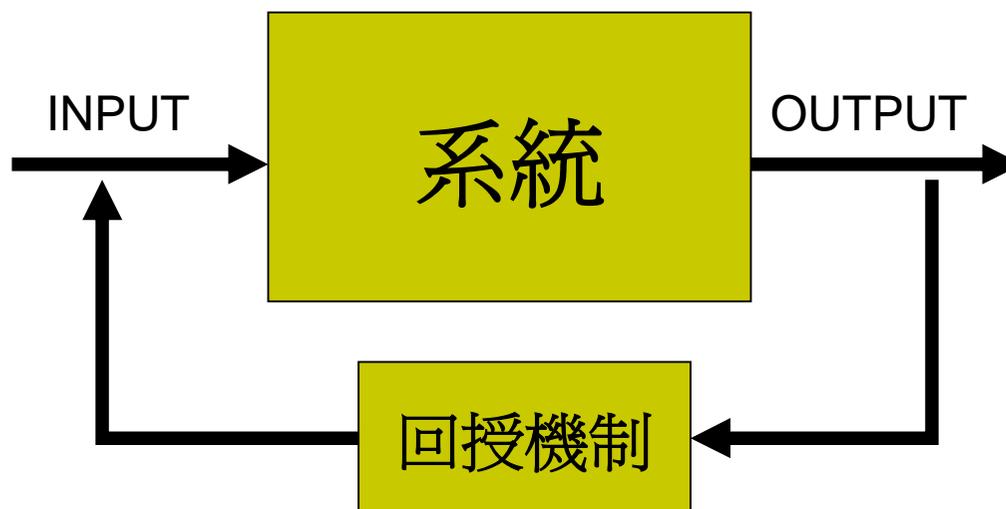


Laser是一種震盪器( oscillator )。

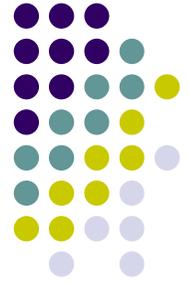
震盪需要條件是 **放大、回授、調整**  
**機制**

示意圖

系統通常包含了放大的機制



# Laser的類型

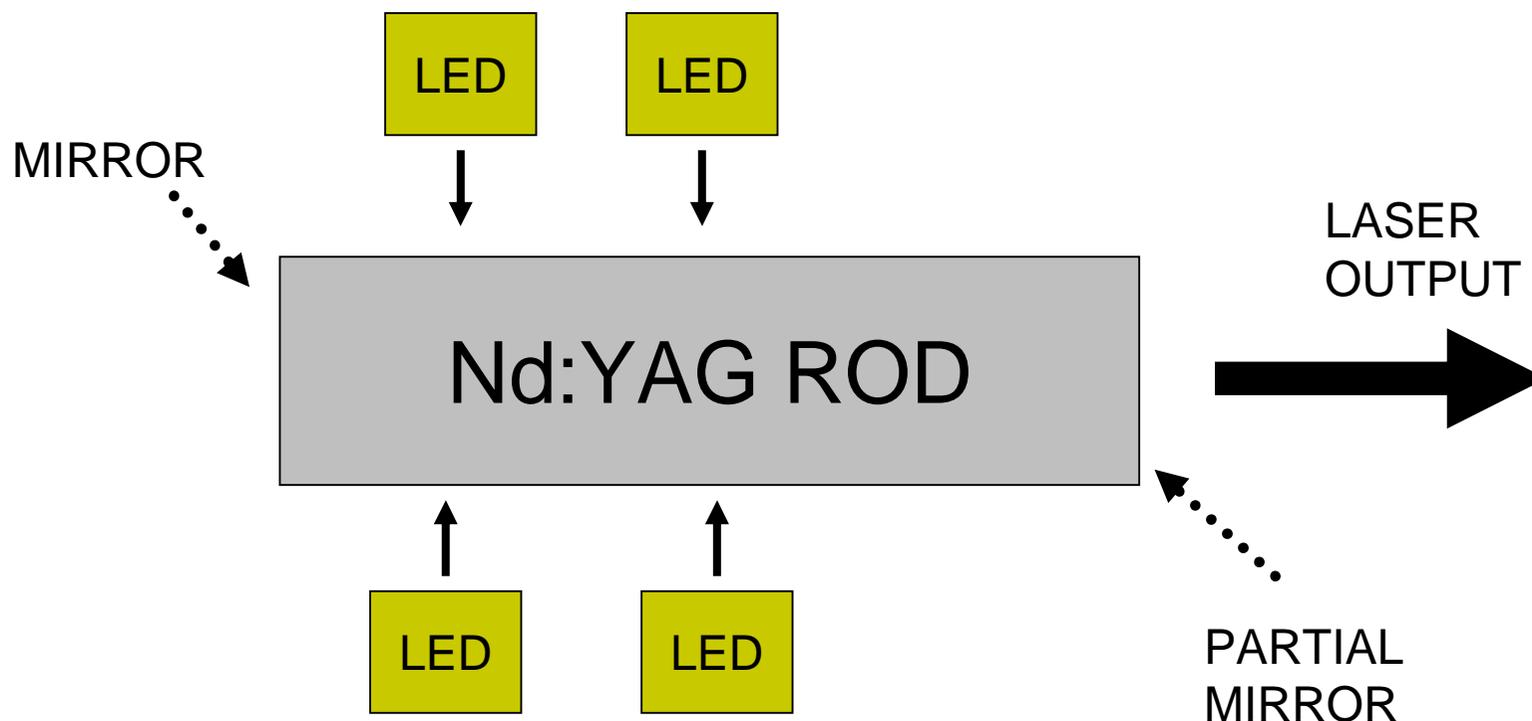


- Nd:YAG Laser
- HeNe Laser
- Laser Diode
- DFB Laser
- DBR Laser

# Nd:YAG Laser



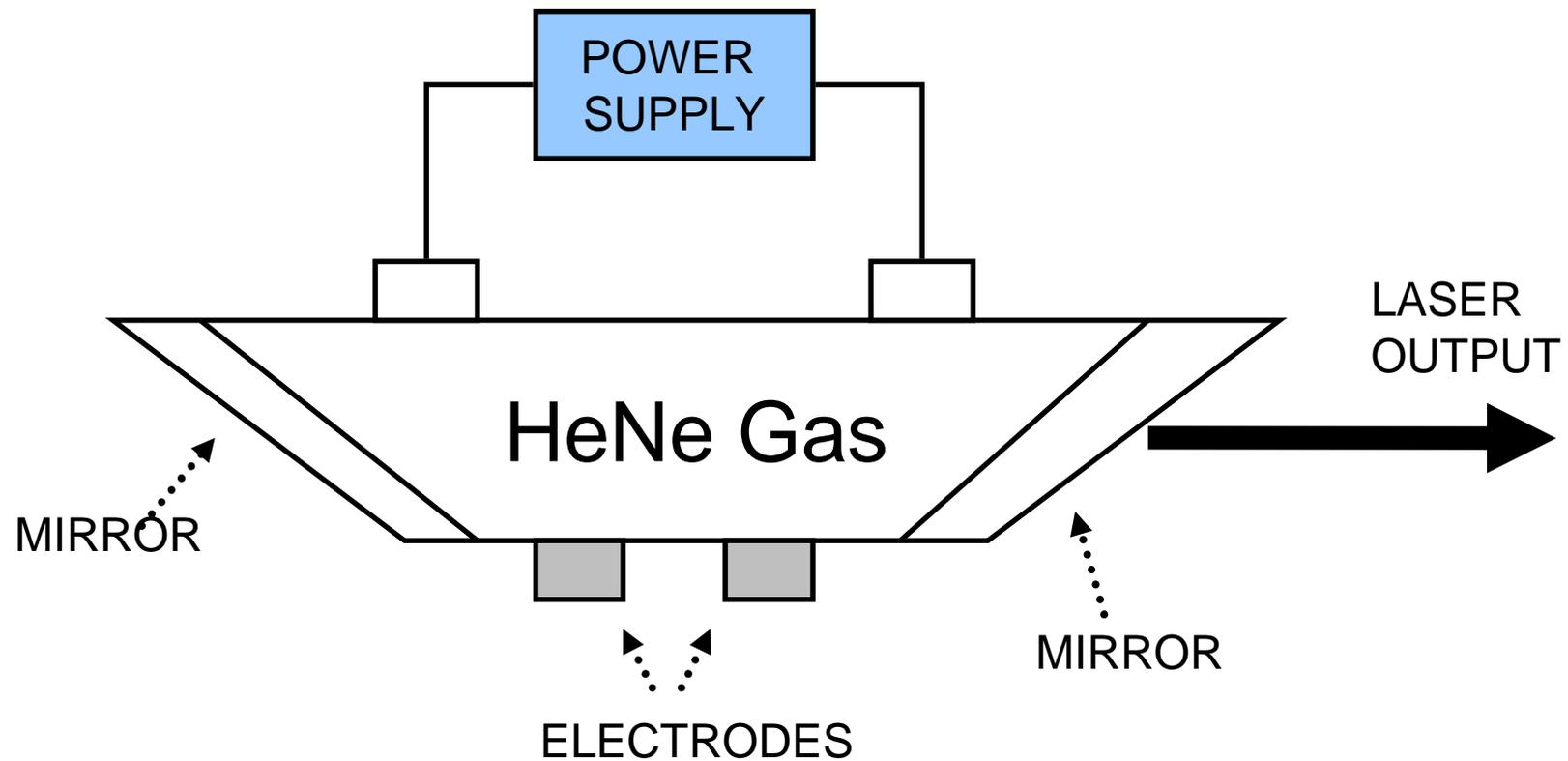
- LED提供輸入功率
- Nd:YAG為主動性材料，提供放大機制
- MIRROR提供回授回授機制



# HeNe Laser



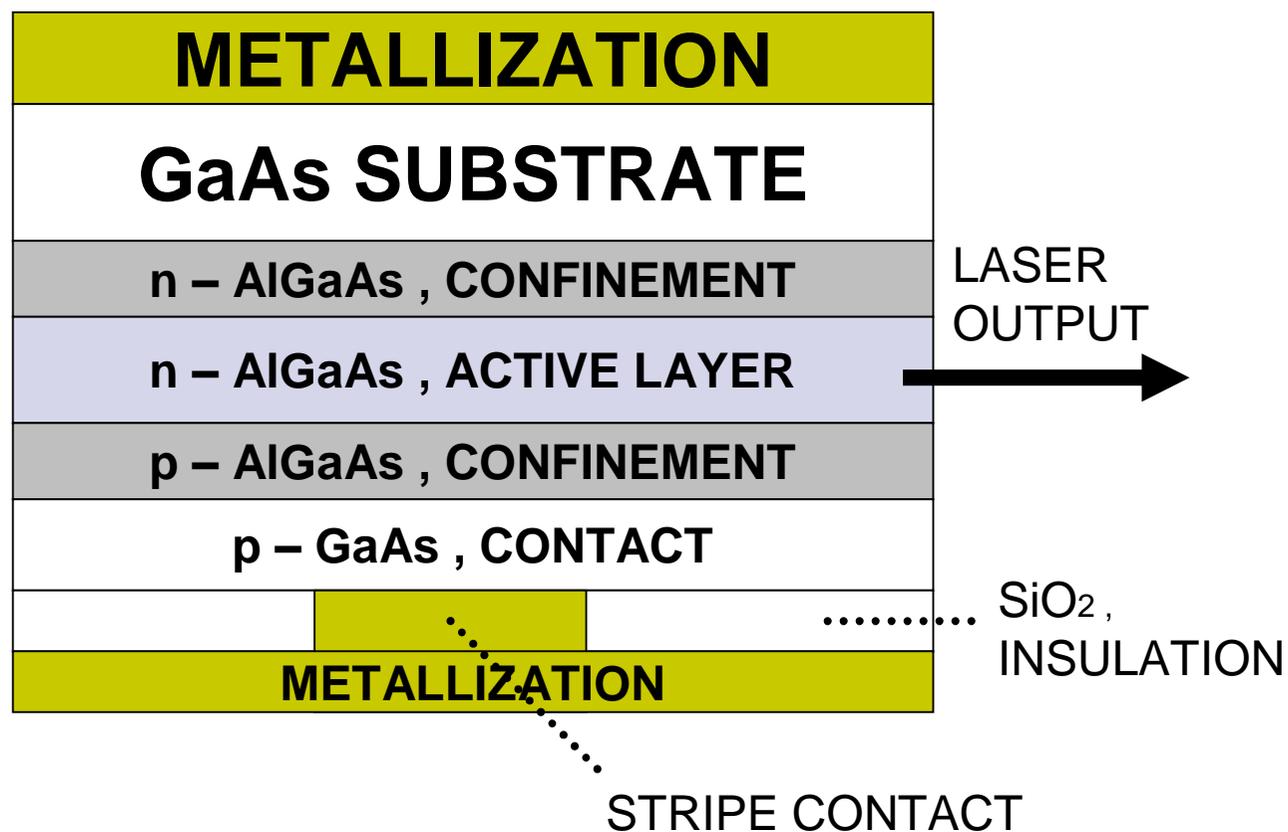
- HeNe Gas 提供放大機制
- MIRROR 提供回授機制



# Laser Diode



- 以下為雙異質結構的 AlGaAs laser diode

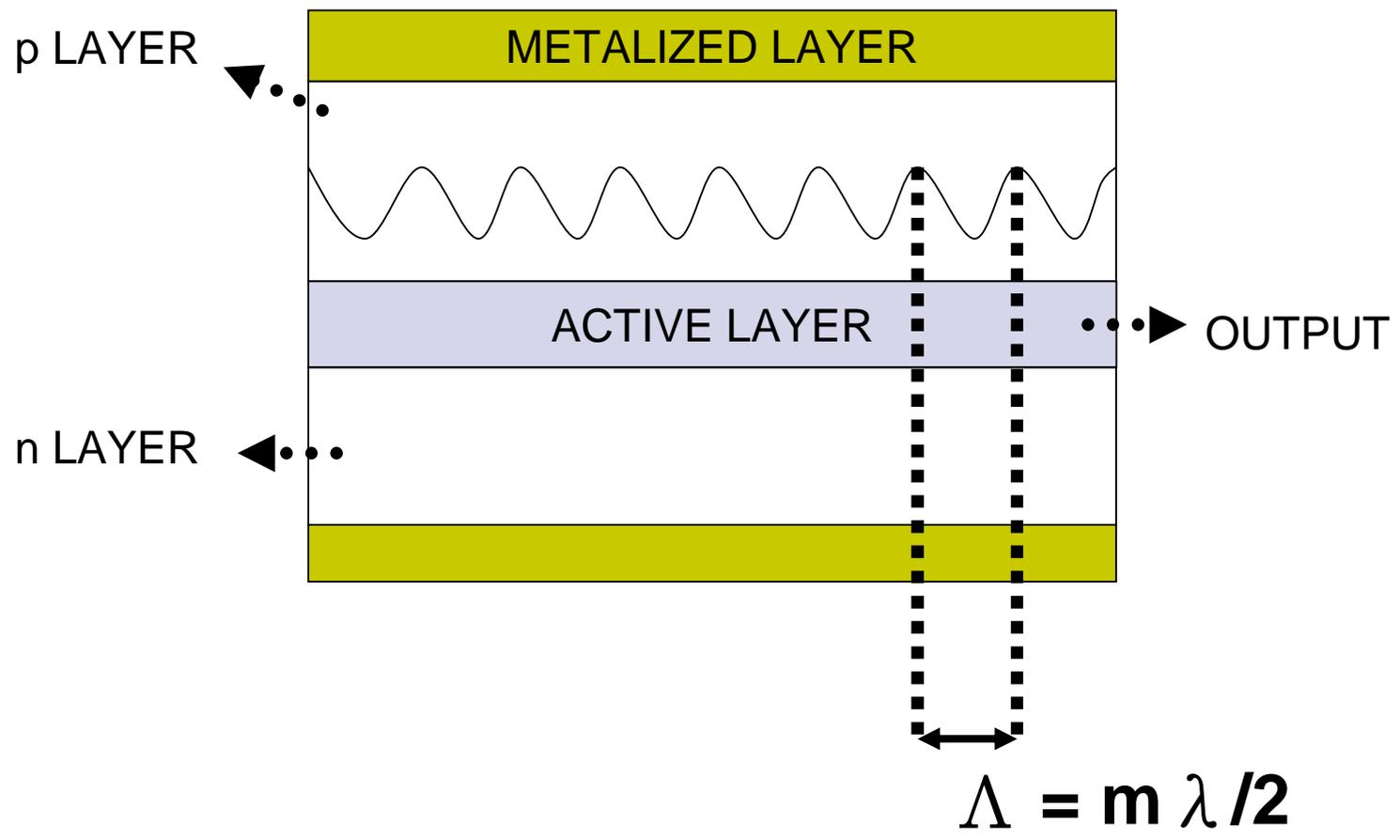
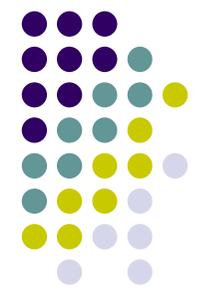




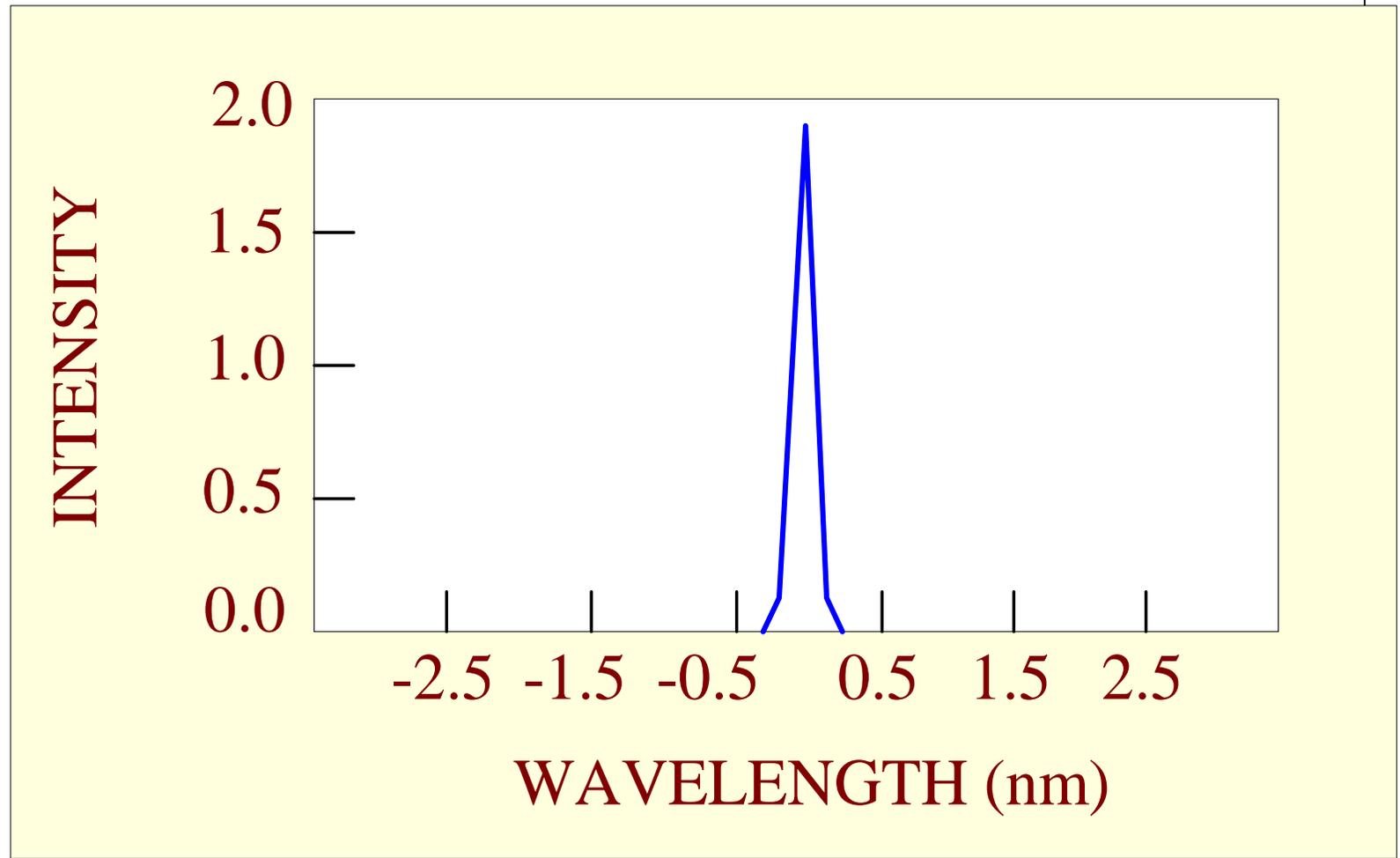
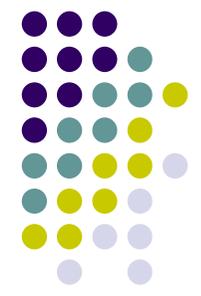
# DFB Laser

- DFB, Distributed-FeedBack
- 利用光柵( grating )達到濾波( filter )功能，使Laser輸出近乎單一波長的光
- 可調整光柵的空間週期，選擇輸出光之中心波長
- Bragg's law  $\Lambda = m \lambda / 2$   
 $\Lambda$ : 光柵週期  
 $\lambda$ : 輸出光波長  
 $m = 1, 2, 3, \dots$

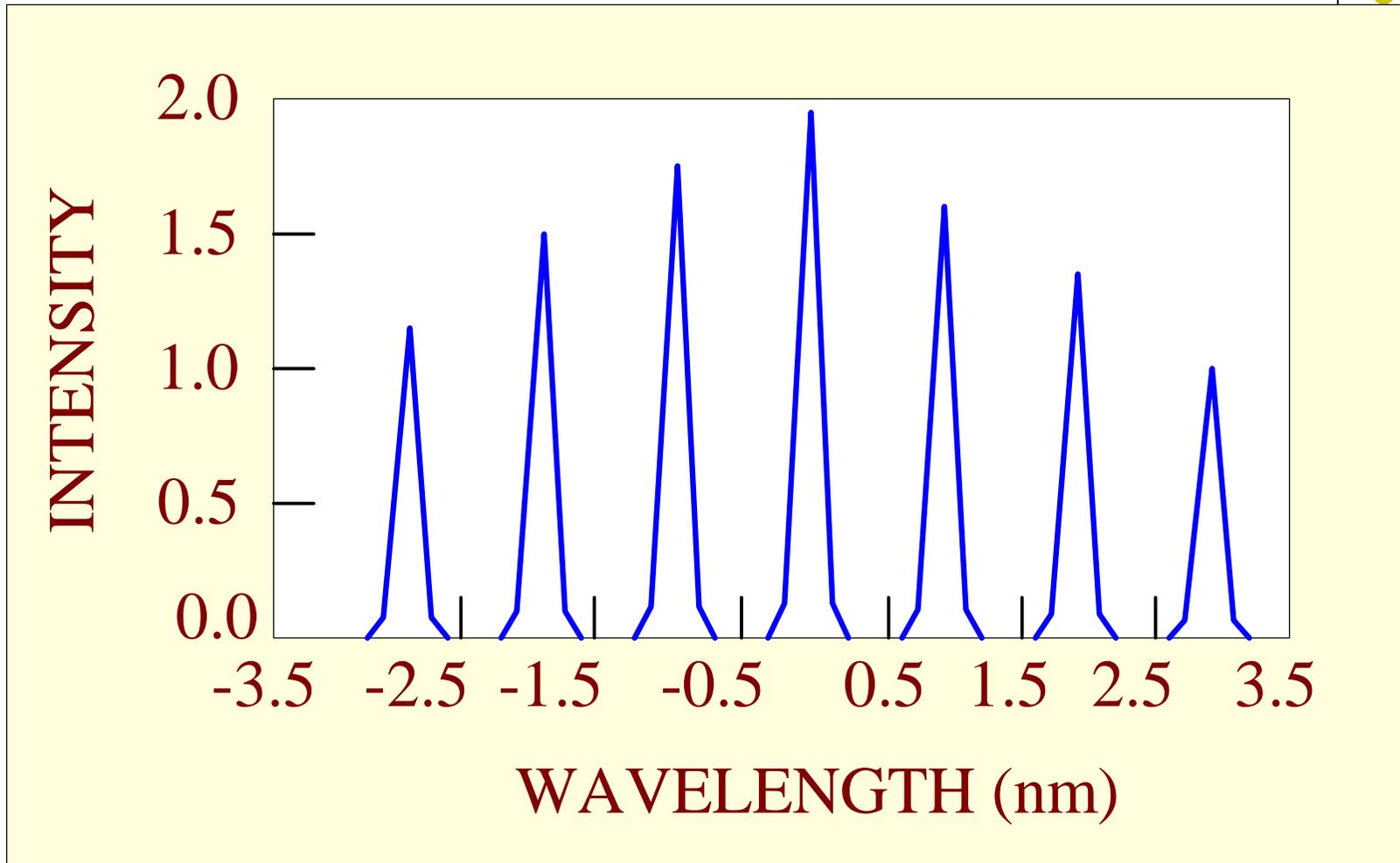
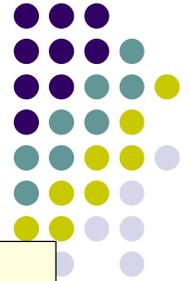
# DFB結構



# DFB LD 輸出頻譜



# FP Laser 頻譜

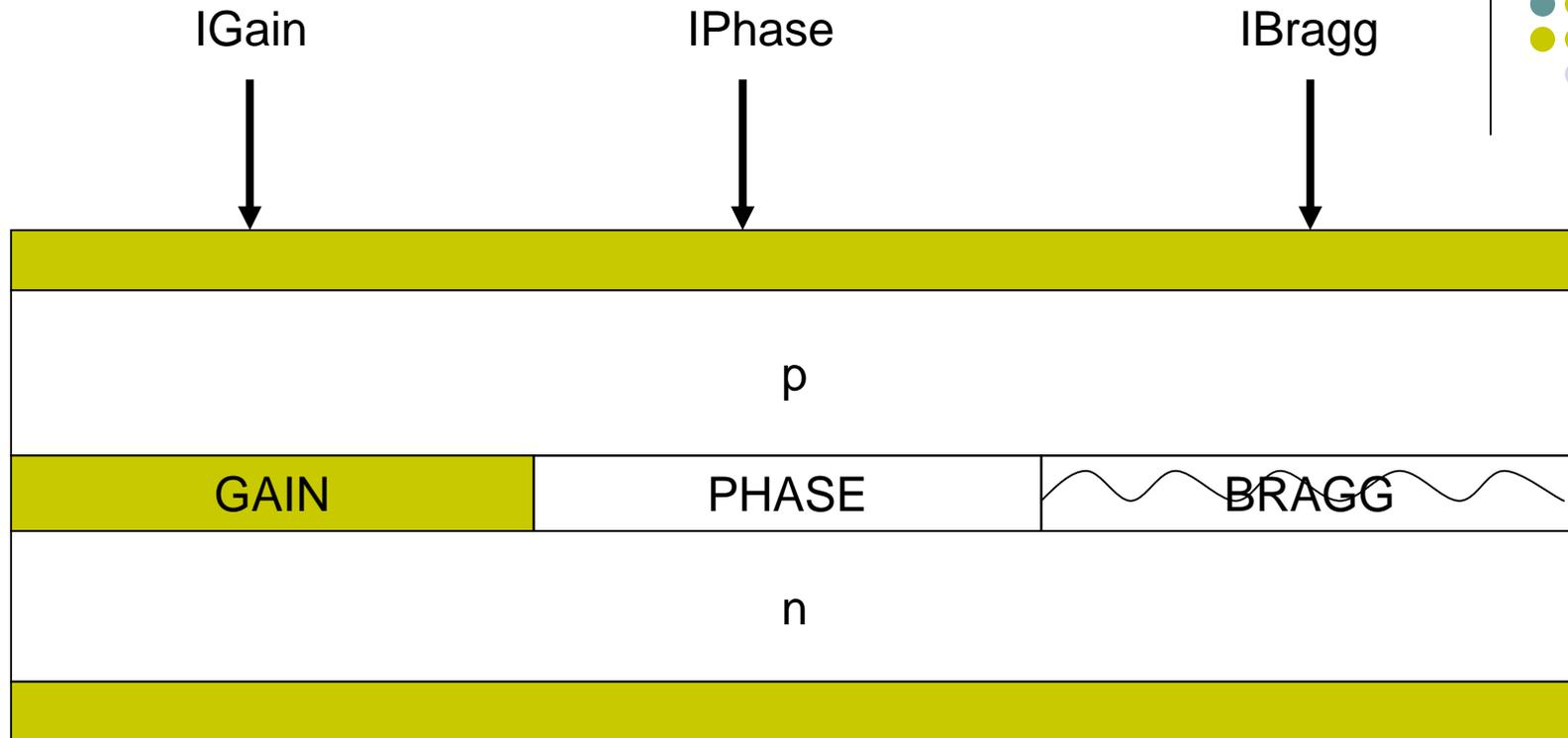




# DBR Laser

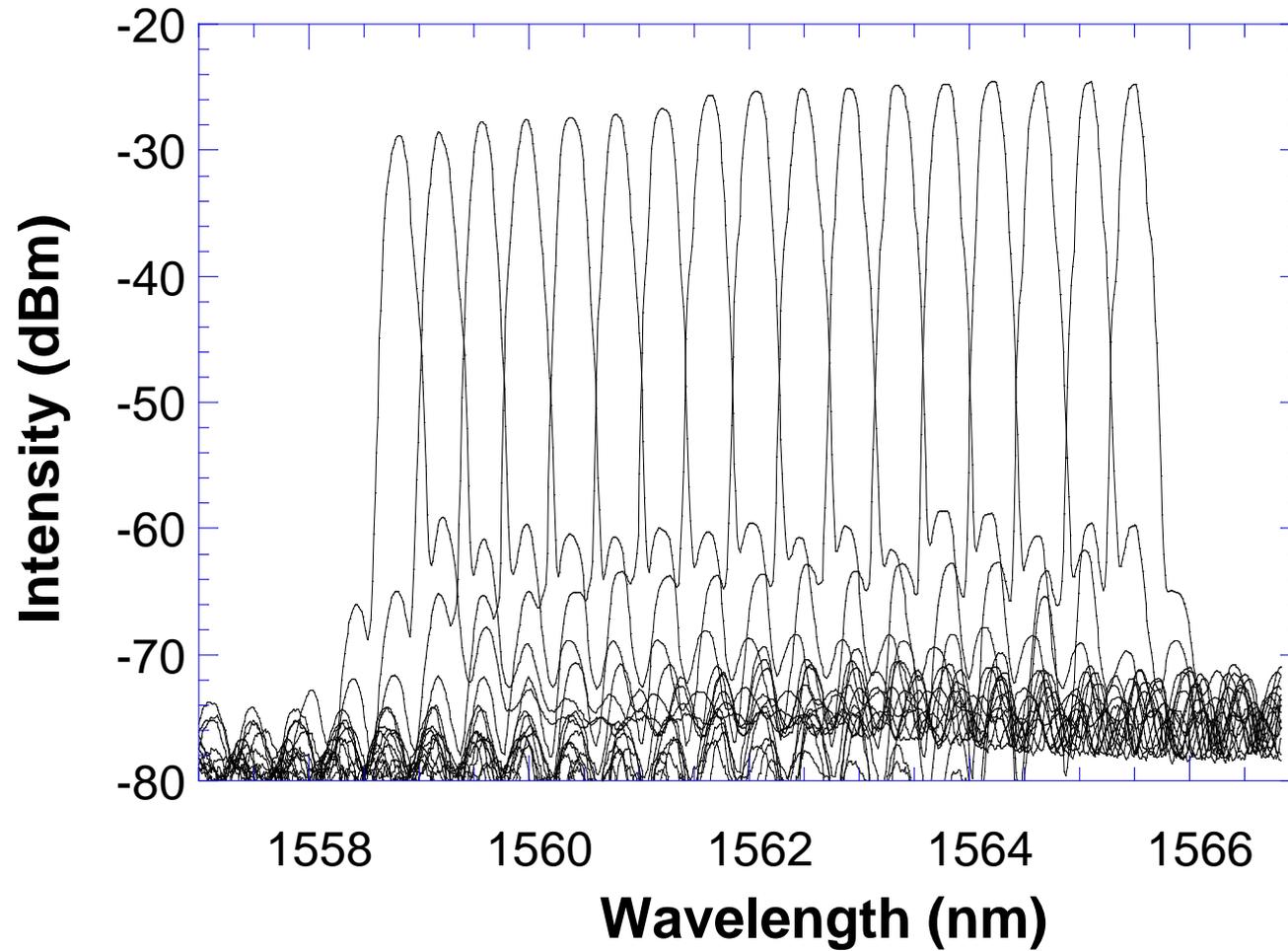
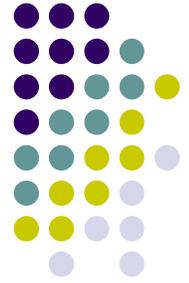
- DBR, Distributed Bragg Reflector
- DBR原理與DFB相似，其特色在於擁有一種輸出波長調整機制
- DBR的Active region中，設計了三個的區塊分別為：gain, phase, Bragg。藉由三個輸入電流分別控制此三個區塊，達到調整輸出波長和功率的目的

# DBR的結構



- IGain控制輸出光功率
- IPhase控制回授
- IBragg控制輸出光波長

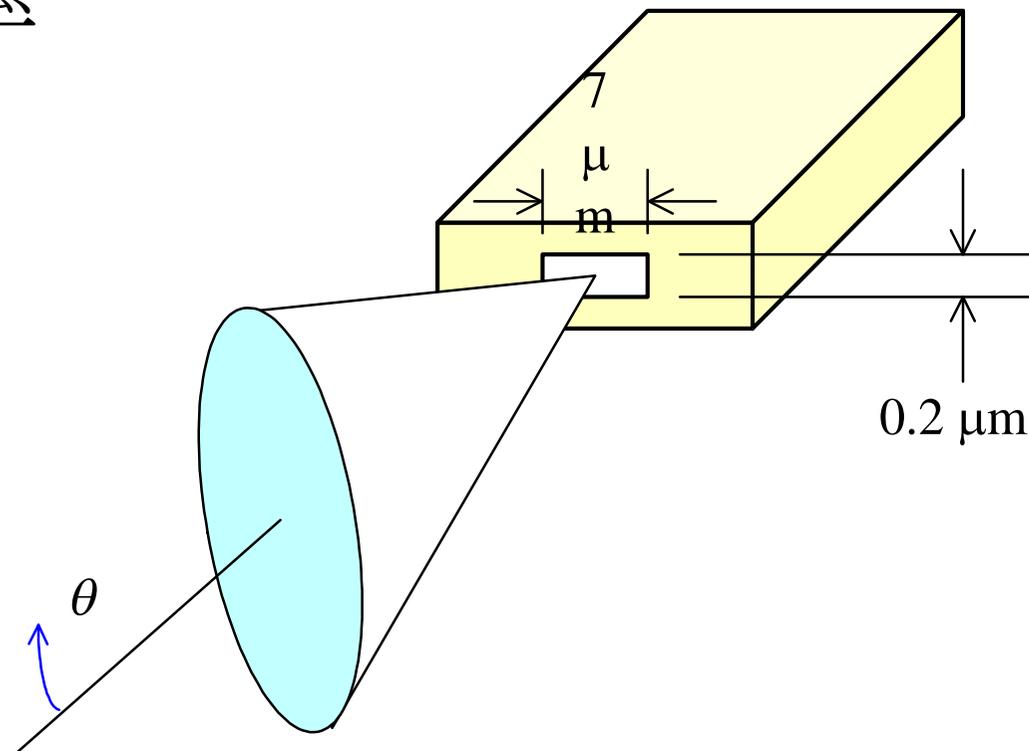
# DBR輸出頻譜



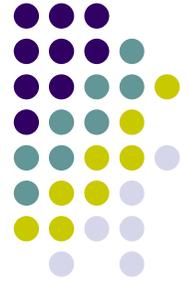
# Radiation Pattern



- **Laser** 輻射圖形不是對稱的
- 越小的收斂角使得耦合到光纖時更有效率



# Laser 應用於調變

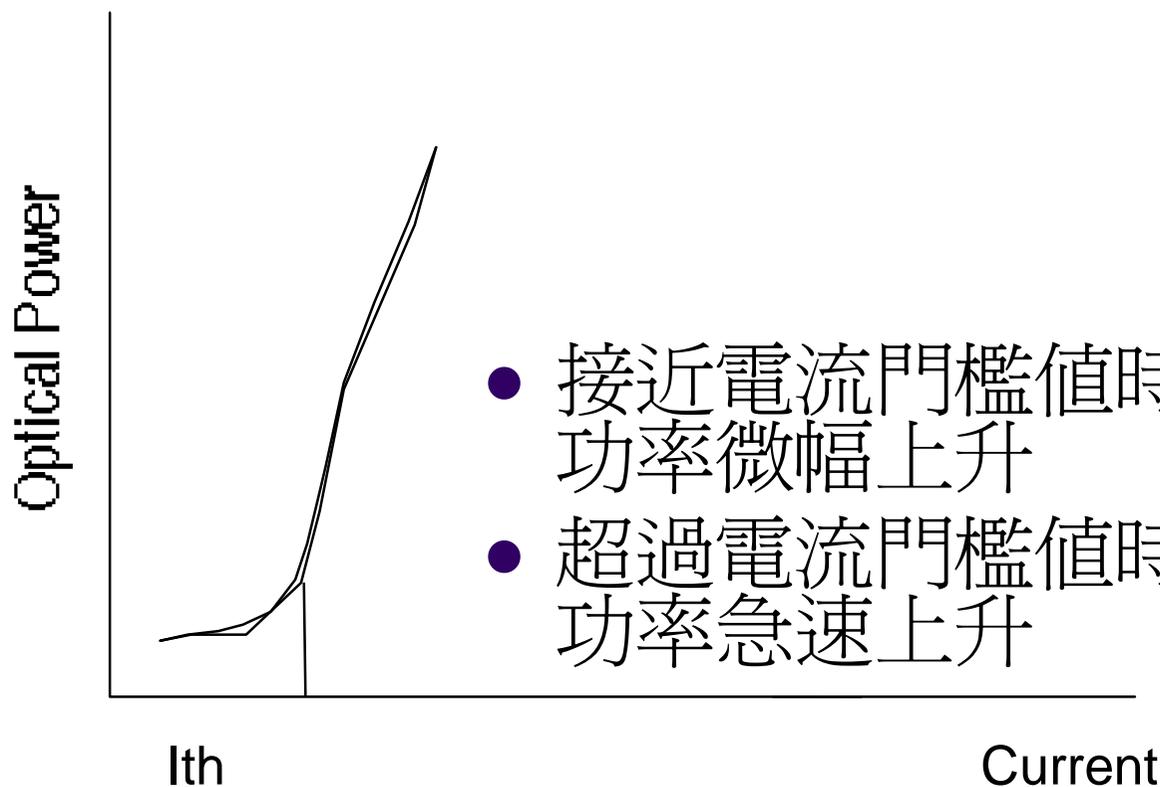


- Laser diode 的操作特性
- 類比調變
- 數位調變
- 直接調變
- 外部調變



# Laser Diode的操作特性

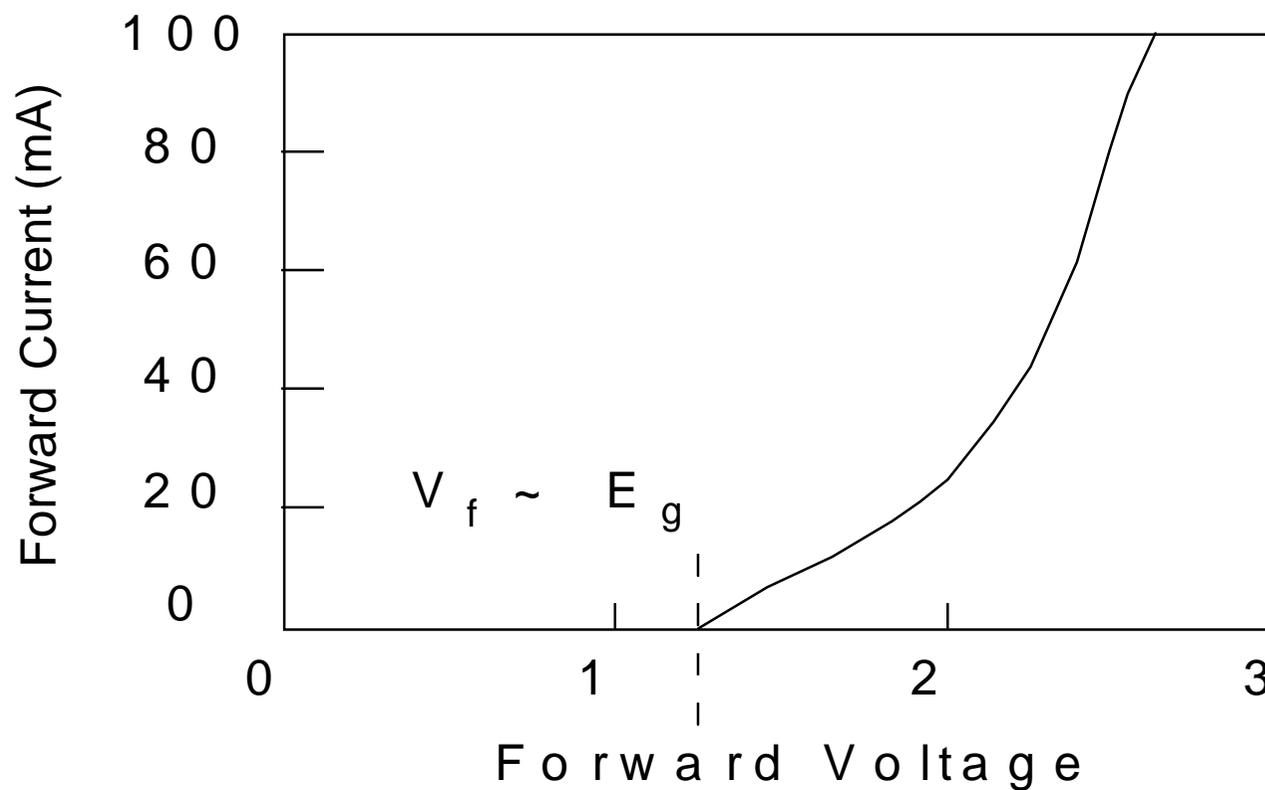
## Power-Current relationship



- 接近電流門檻值時，光功率微幅上升
- 超過電流門檻值時，光功率急速上升



# Laser Diode的操作特性

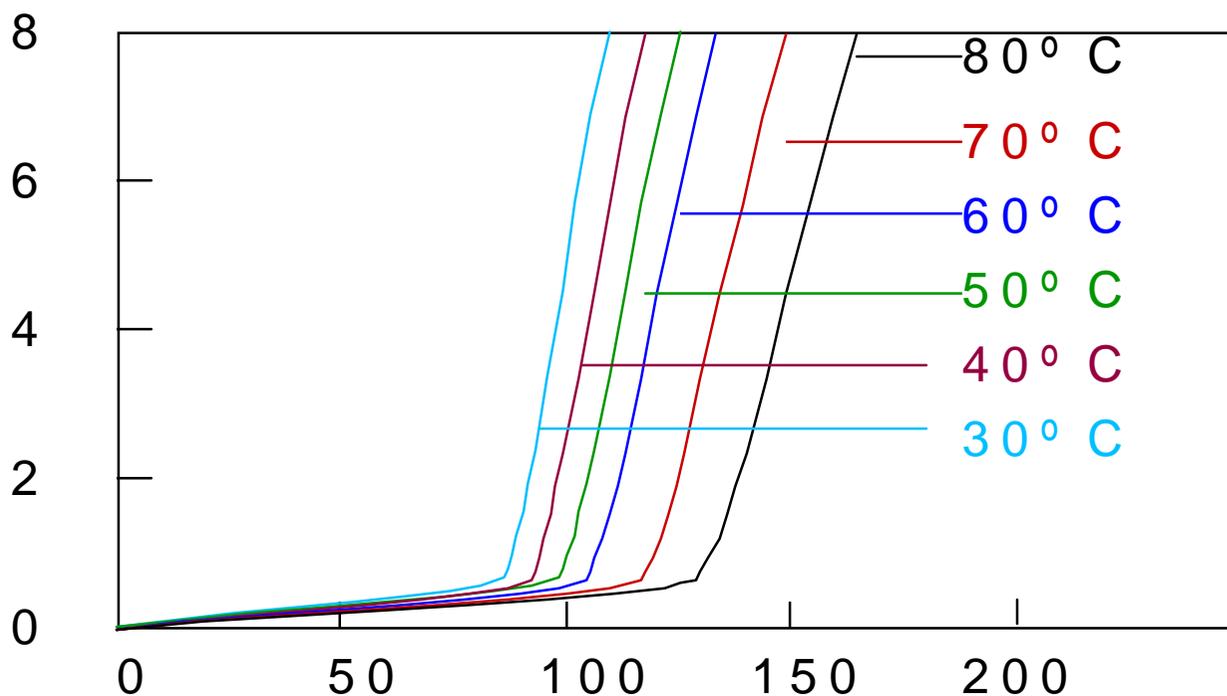


Typical voltage-current characteristics for a laser diode



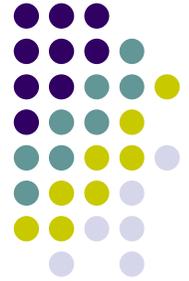
# Laser Diode的操作特性

## Temperature dependence



- 當溫度升高時，門檻電流值亦升高

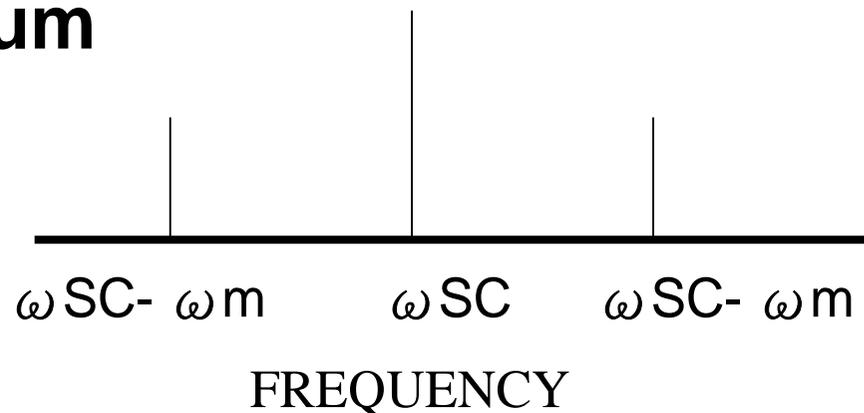
# 類比調變



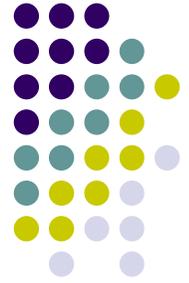
## AM/IM

- $P = P_0 + P_s ( 1 + m \cos \omega_m t ) \cos \omega_{sc} t$
- 訊號紀錄於載波振幅
- $m \leq 1$ ， $m$ 為調變因子

## Spectrum



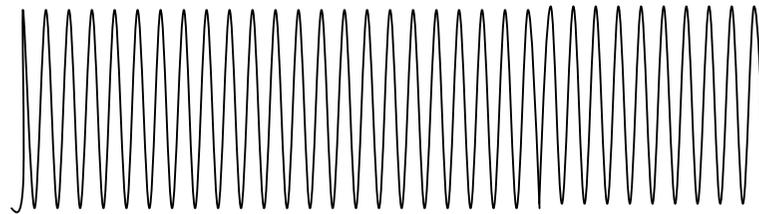
# 類比調變



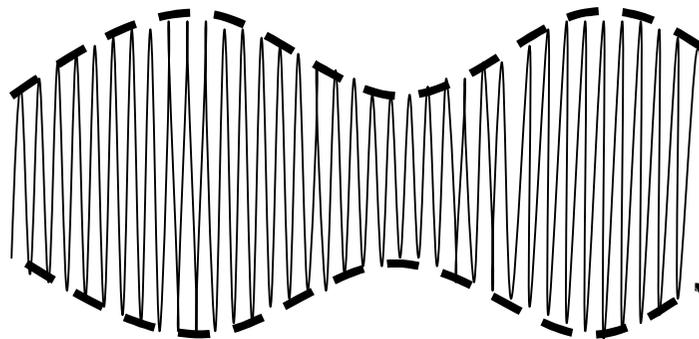
AM/IM



BASEBAND

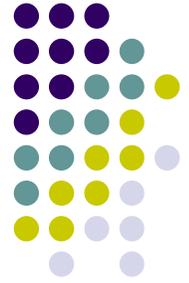


SUBCARRIER



AMPLITUDE-  
MODULATED  
SUBCARRIER

# 類比調變



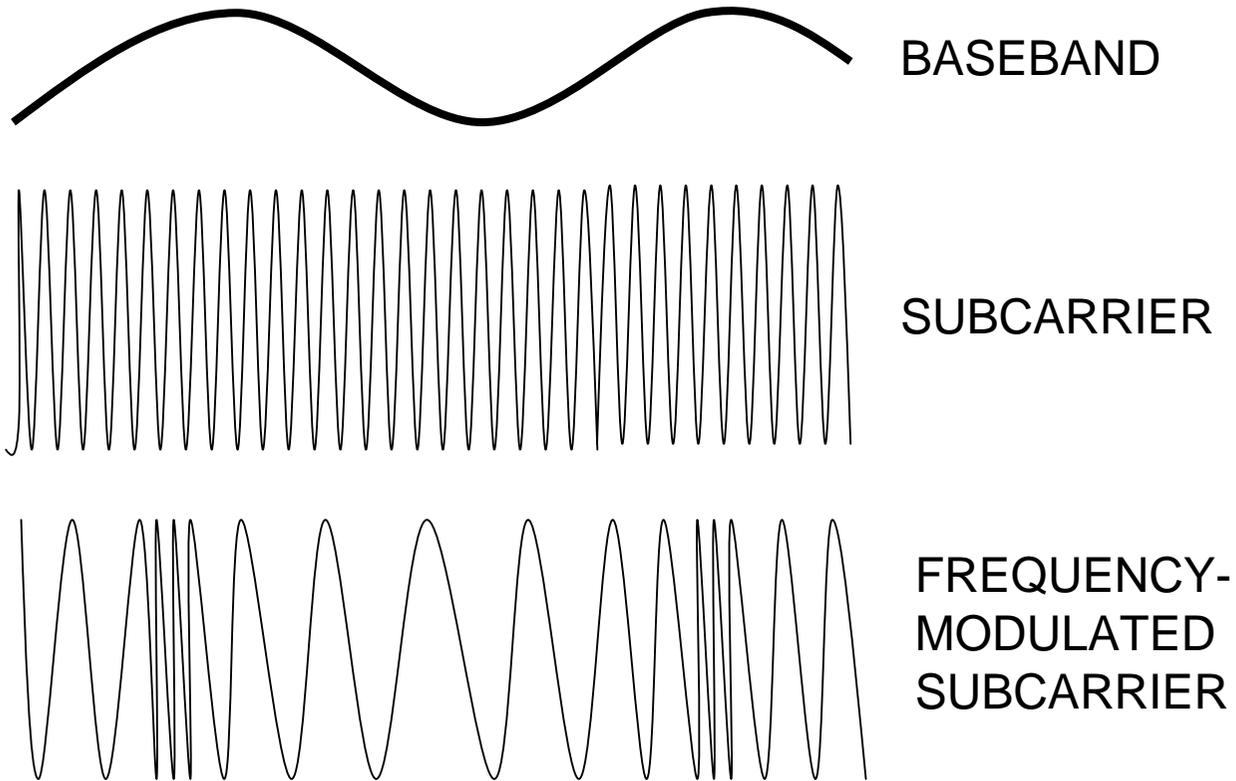
## FM/IM

- $P = P_0 + P_s \cos ( \omega_{sc} t + \beta \sin \omega_m t )$
- 訊號紀錄於載波頻率
- $\beta$  為調變因子

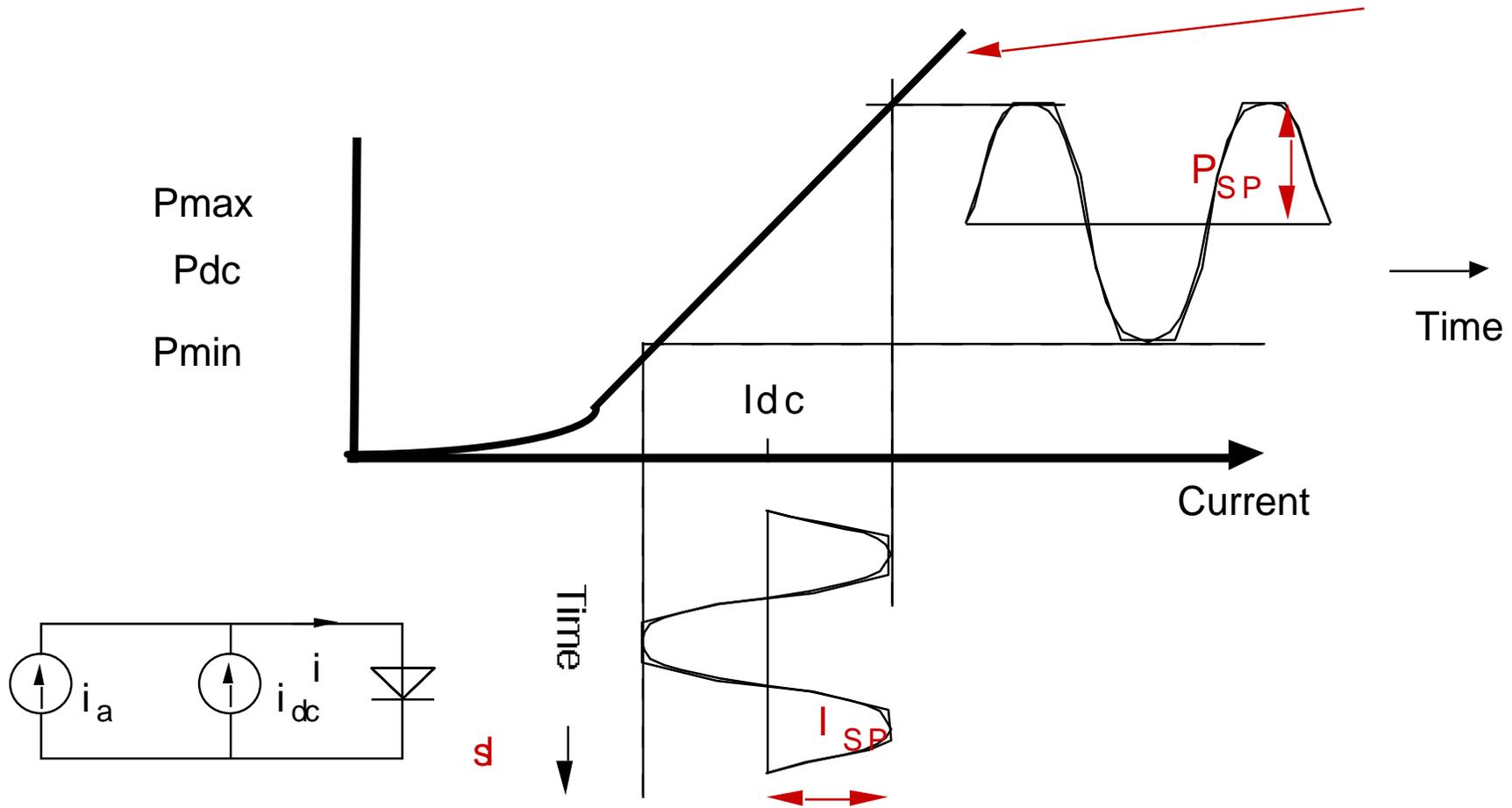
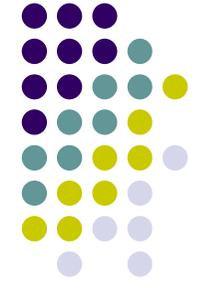
# 類比調變



## FM/IM



# 類比調變

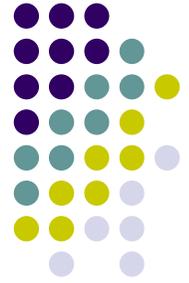


# 數位調變



## 數位調變 VS. 類比調變

- 數位調變的頻寬需求較大，而利用 Laser 及 LED 調變可提供足夠的頻寬，光纖及光檢測器亦提供足夠的頻寬
- 類比調變易受 Laser 及 LED 的非線性特性影響，造成失真
- 數位調變可使用錯誤更正碼技術，改善信號失真情形



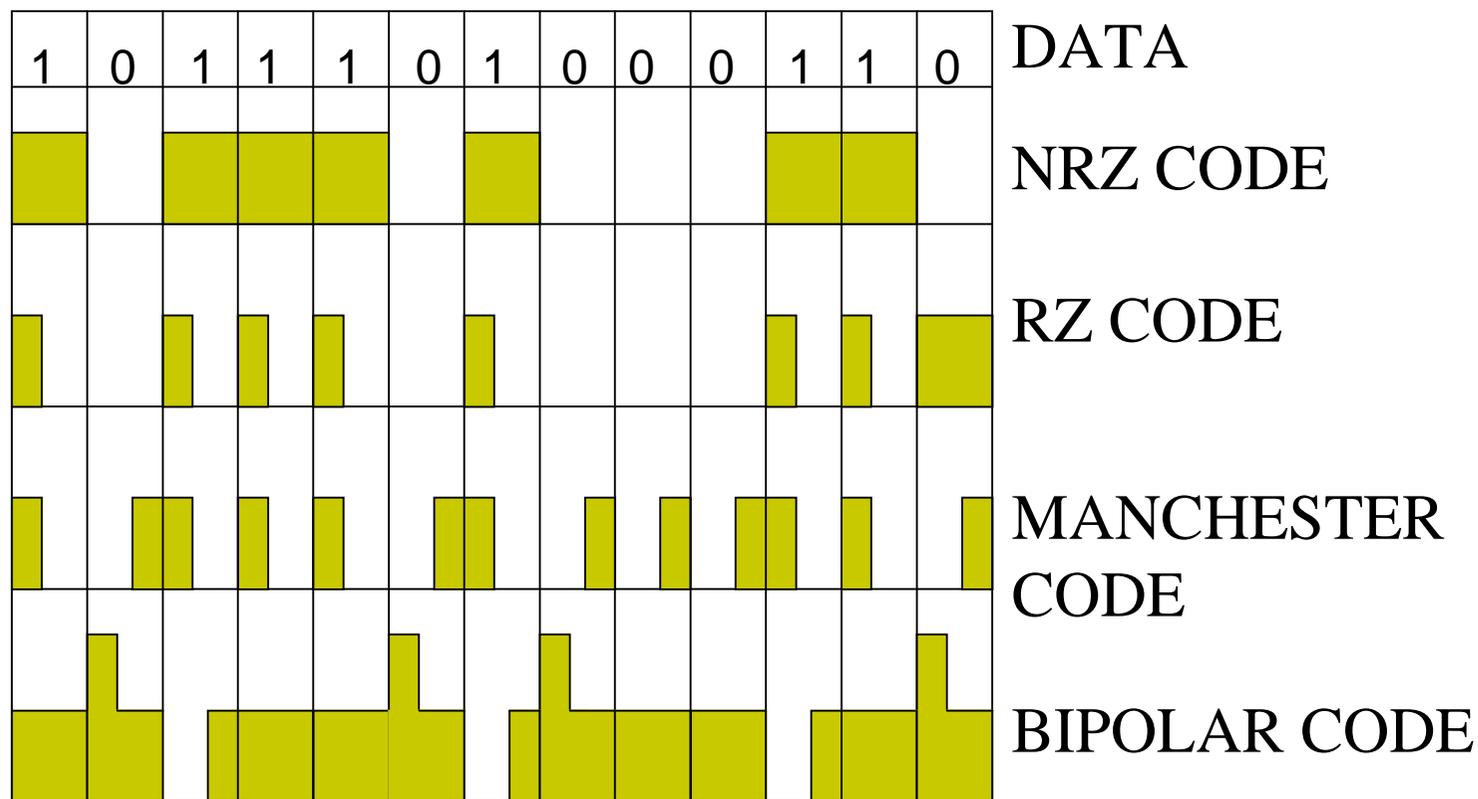
# 數位調變

- 光纖數位系統相容於非光纖之數位系統，類比則否
- 數位系統可利用資料壓縮技術，節省頻寬
- 大致上，數位品質優於類比

# 數位調變



## PCM





# 數位調變

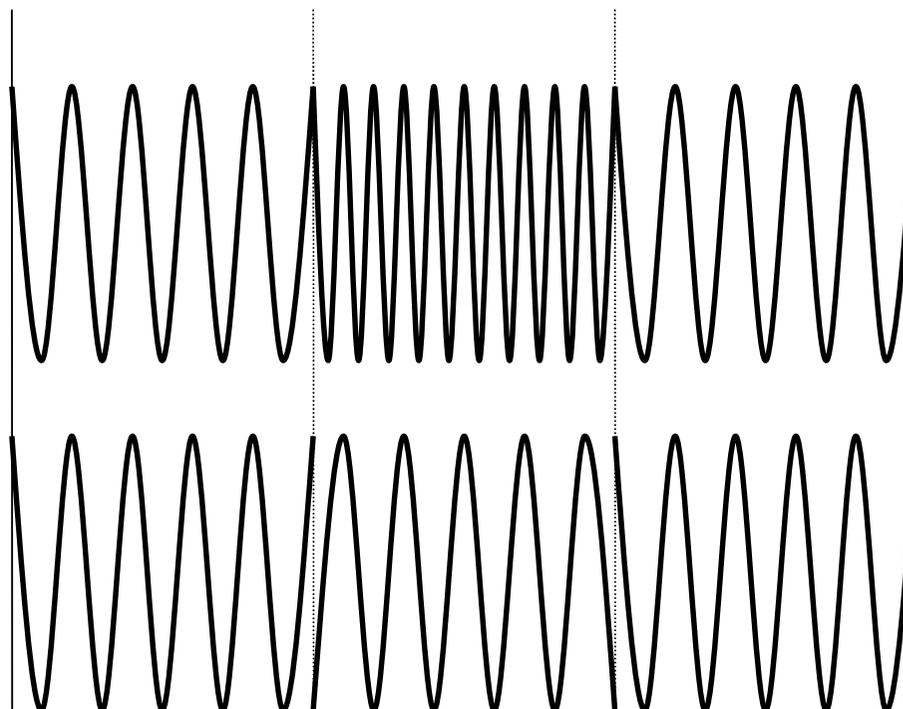
## FSK/PSK

0

1

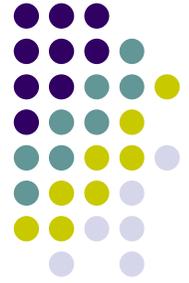
0

利用頻率調  
變1或0



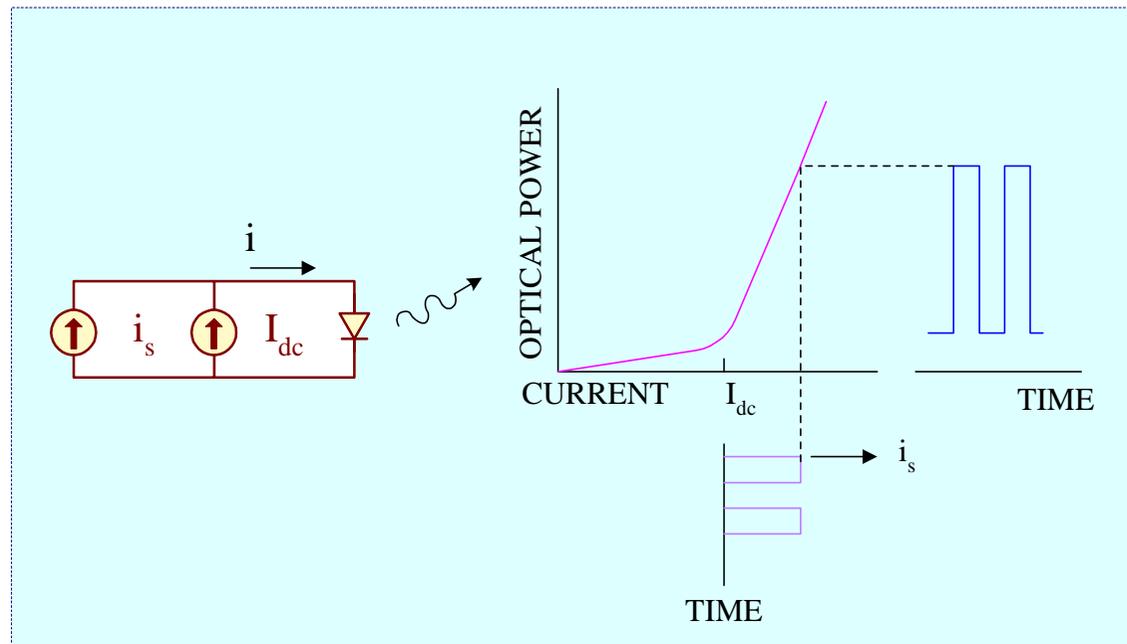
利用相位調  
變1或0





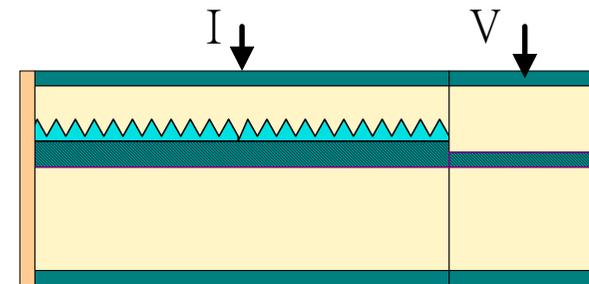
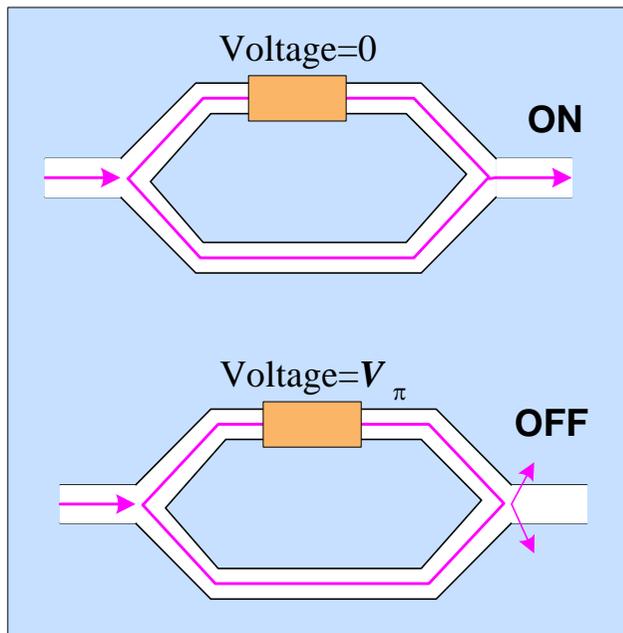
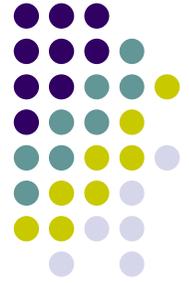
# 直接調變

- 利用電流調變將訊號加載在**Laser**光源
- 調變方式簡單
- 引起 **frequency chirp** 使得傳輸距離受到限制



# 外部調變

- 調變速度快
- 減少frequency chirp 現象

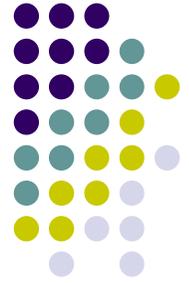


Integrated EA modulator



- 動機與目的
- 光纖通信簡介
- **Laser** 特性與應用
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# PIN-TIA特性與應用



- Photodiode 的基本參數
- I-V特性
- PIN
- Current-to-Voltage Converter

# Photodiode的基本參數



Responsivity ,  $\rho$

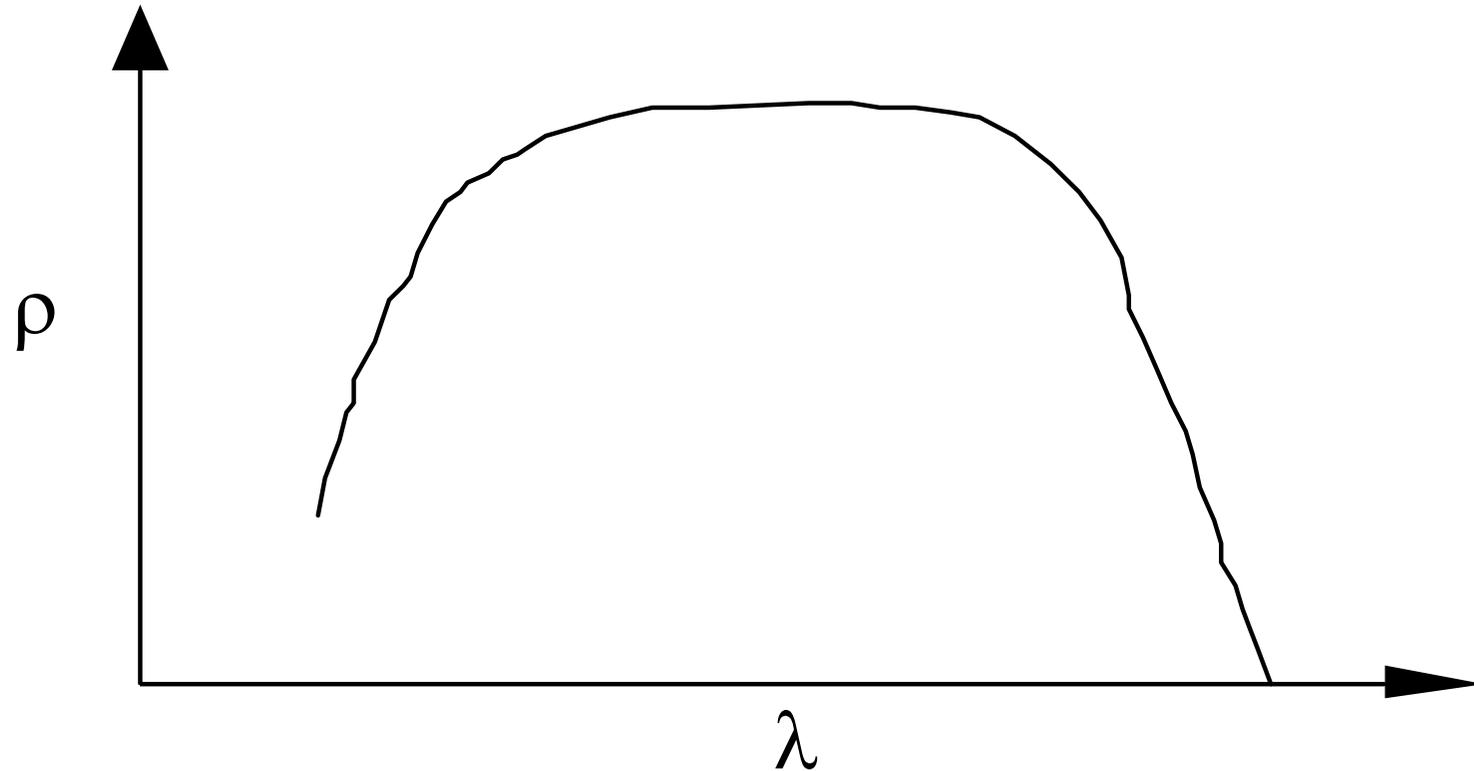
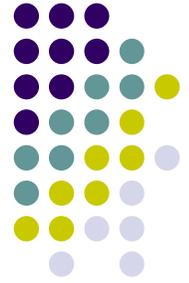
定義

$$\rho = i / P \text{ ( amperes / watt )}$$

$i$  : 輸出電流

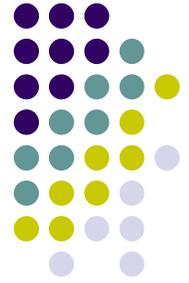
$P$  : 輸入光功率

# Spectral response curve



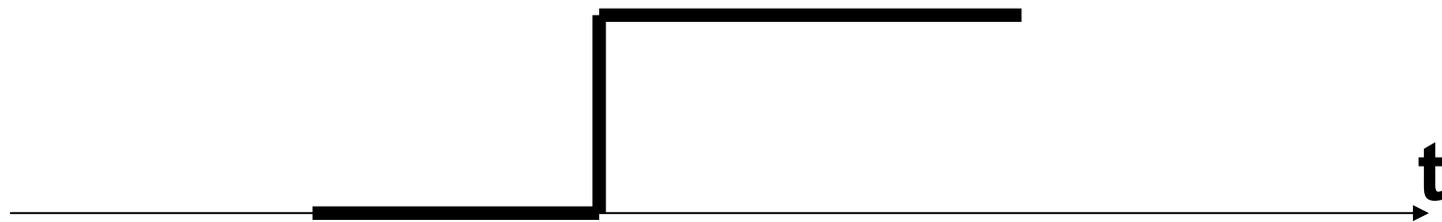
因為responsivity隨著波長而改變。所以在不同的頻譜區段必須使用其適合的檢光器。

# Photodiode的基本參數



## Rise Time , $t_r$

- 輸入一步階訊號，輸出波形將會有延遲的現象。rise time之定義為，輸出訊號功率值由10%變化至90%間的時間差。

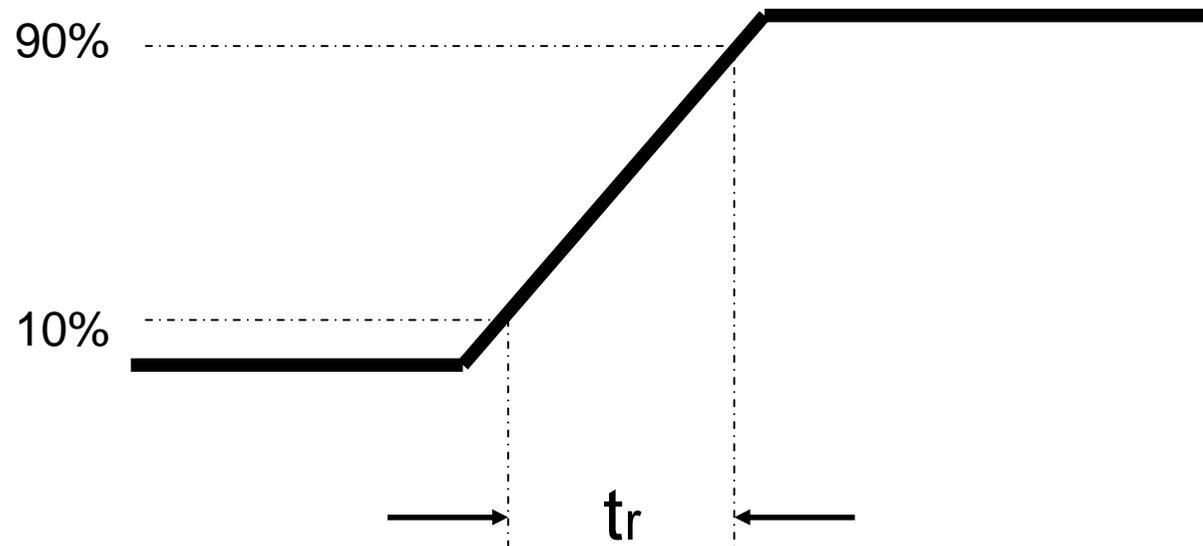


輸入訊號波形

# Photodiode的基本參數



## Rise Time , $t_r$



檢光器之輸出電流波形



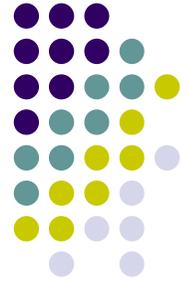
# Photodiode的基本參數

## Rise Time , $t_r$

- **Rise time** 決定了檢光器的**3-dB**調變頻寬。操作在此頻率下時，檢光器的電訊號功率是在低頻操作下之功率的一半。  
( 前提為兩者輸入功率相同 )

$$f_{3\text{-dB}} = 0.35 / t_r$$

( 3-dB調變頻寬 )



# Photodiode的基本參數

## 截止波長

- 為了要產生電子電洞對，輸入光能量必須超過材料之帶溝( band gap )能量。其數學表示如下：

$$\lambda_c = 1.24 / w_g$$

**wg : band gap energy**

**$\lambda$  : wavelength**



# Photodiode的基本參數

## 響應速度

響應速度受限於暫態時間( transit time )，即自由電荷越過空乏層之時間。

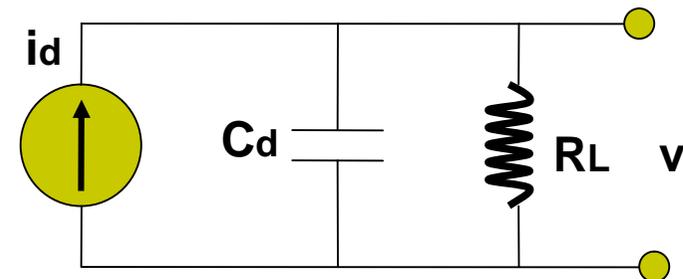
- 自由電荷通過空乏區的速度與二極體偏壓大小成線性正比。
- 空乏電容也是影響響應速度之因素。二極體之高頻等效電路如下

# Photodiode的基本參數

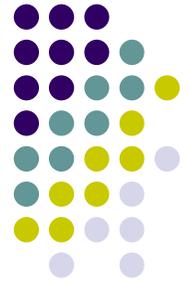


$$t_r = 2.19 R_L C_d$$

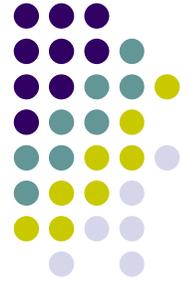
$$f_{3\text{-dB}} = 1 / 2 \pi R_L C_d$$



# I-V特性



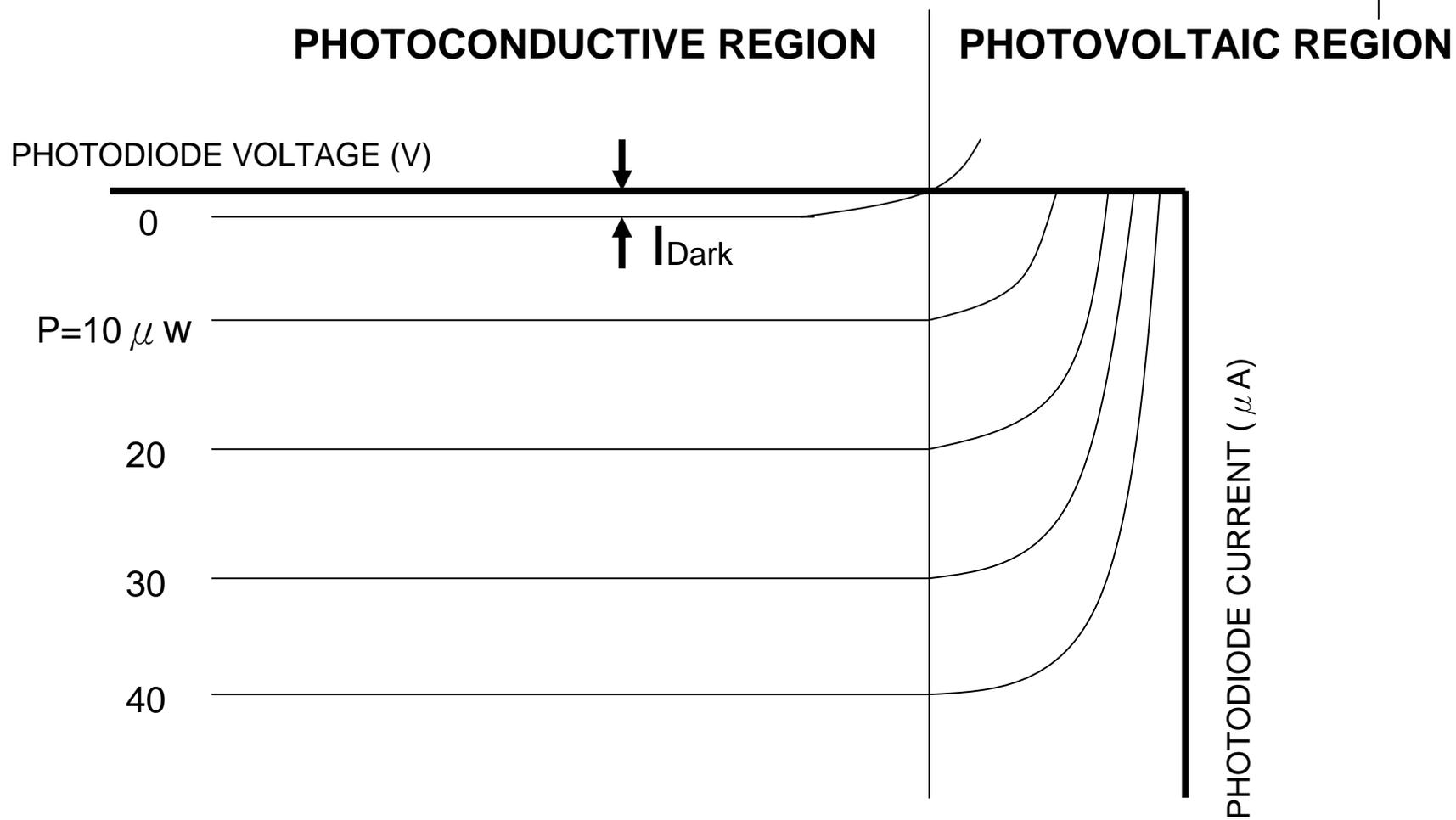
- 順向偏壓時，工作於PHOTOVOLTAIC REGION。此區可運用於太陽能電池，但並不使用在光纖通訊的檢光器中。
- 逆向偏壓時，工作於PHOTOCONDUCTIVE REGION。在此工作區中，輸出電流正比於輸入光功率。光纖通訊的檢光器操作在此工作區

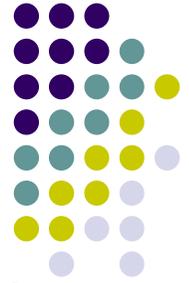


## I-V特性

- 當沒有光功率輸入時，逆向偏壓的二極體中存在一微小的逆偏電流，稱為暗電流( dark current )。
- 暗電流是由自由電荷載子在二極體中的熱產生所造成的。也稱為漏電流或是飽和電流。
- 暗電流有熱相依性，靠近適溫增加十度時大約會增加一倍的暗電流量

# I-V特性圖



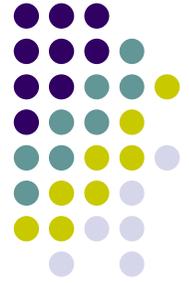


# PIN

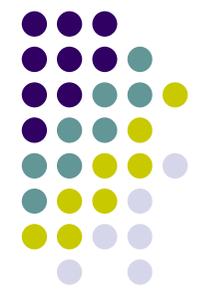
- PIN是一種光二極體，也是光通訊系統中最長被使用的檢光器
- 其名稱由其結構組成而來，相較於PN二極體，PIN多了一層 intrinsic layer，使得入射光子被吸收的機率增加，大幅改善了responsivity

<b>P type semiconductor</b>	<b>Intrinsic semiconductor</b>	<b>N type semiconductor</b>
---------------------------------	------------------------------------	---------------------------------

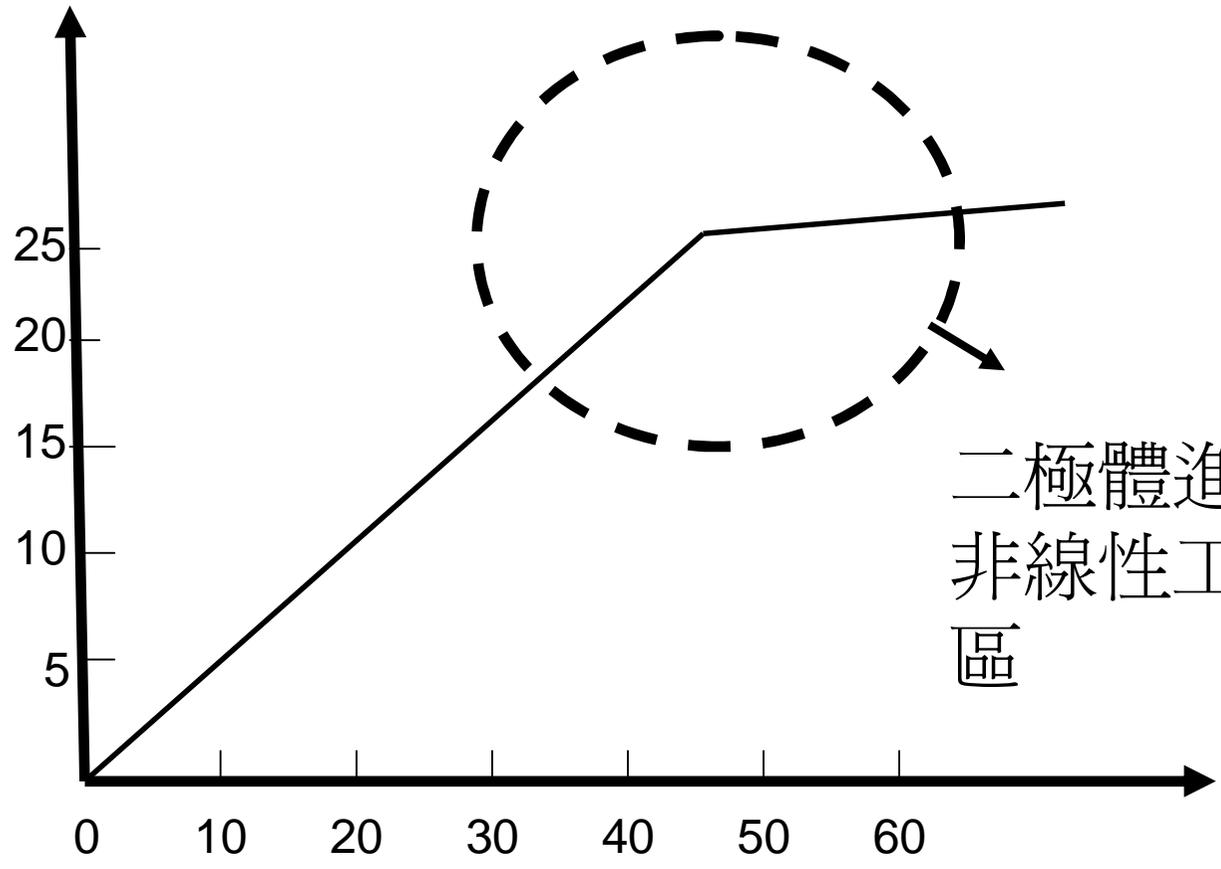
# Current-to-Voltage Converter



- 當輸入功率越大時，二極體輸出電流亦愈大。由下圖簡易的PIN電路可知，在二極體上的壓降將會越來越小。導致二極體進入非線性工作區，進而影響了檢光器的效能。



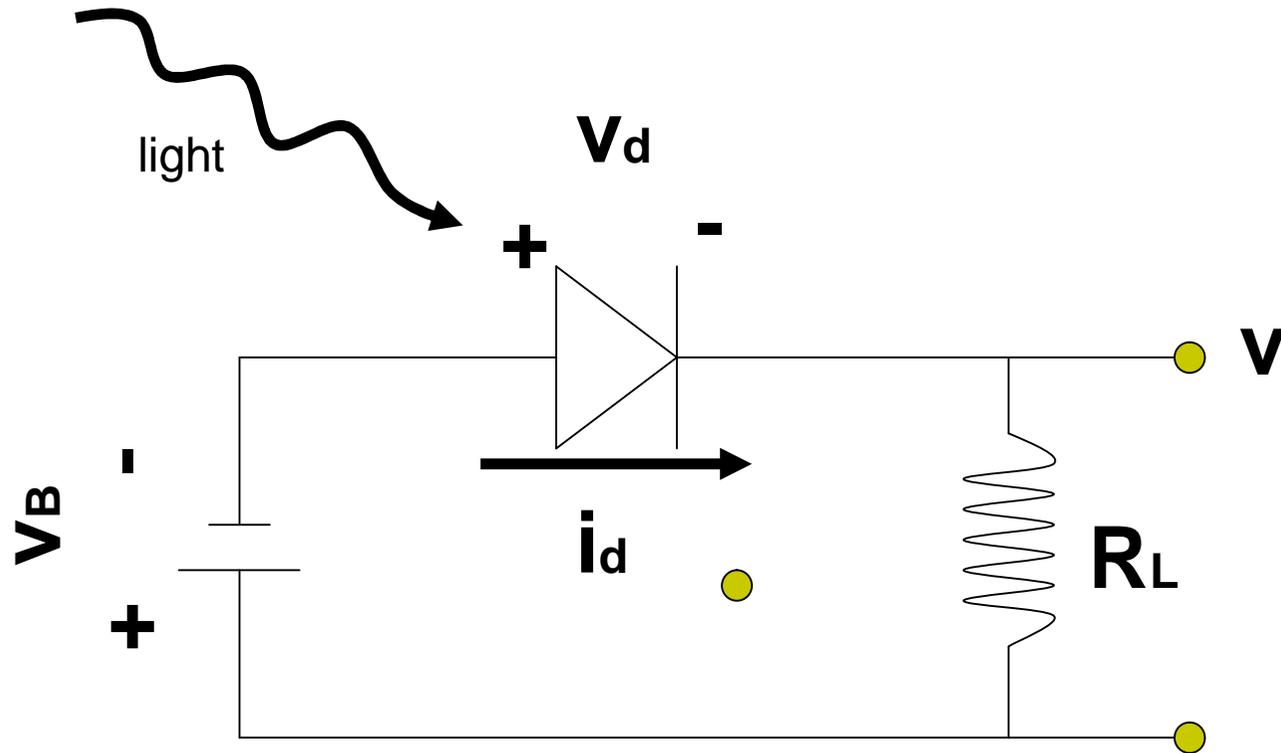
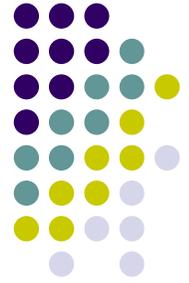
OUTPUT VOLTAGE



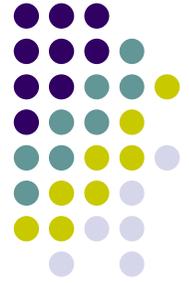
二極體進入  
非線性工作  
區

OPTICAL POWER

# Simple PIN Circuit



# Current-to-Voltage Converter



- 利用放置current to voltage converter來改善上述的問題
- Current to voltage converter是由一個操作放大器加上一個回授電阻所組成

# Current-to-Voltage Converter

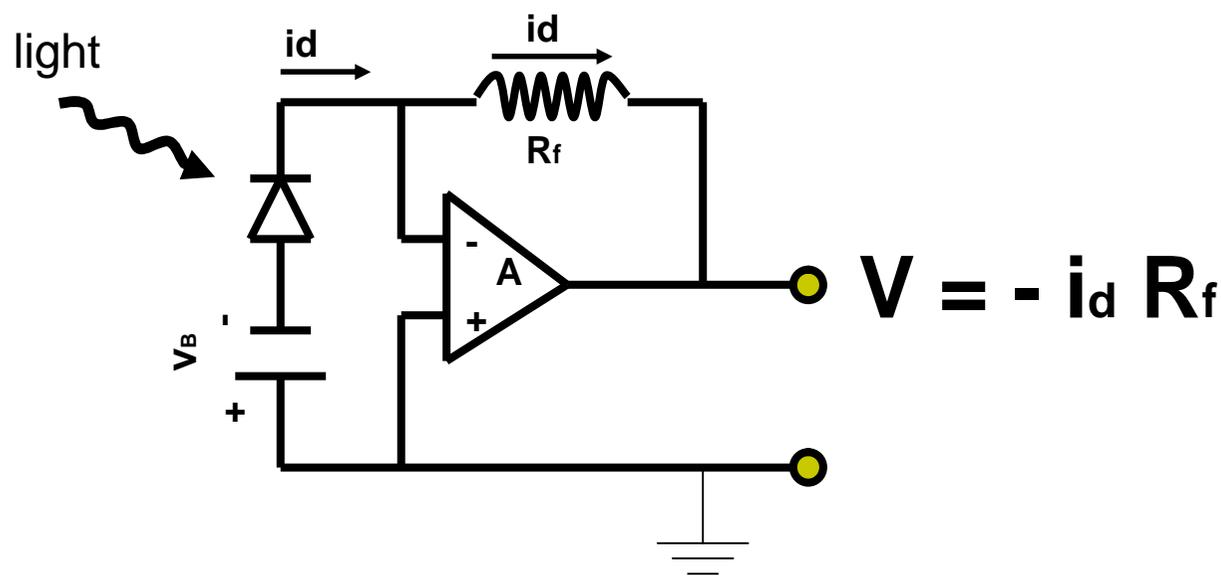


- 高增益操作放大器的輸入端幾乎沒有壓降，所以電池的所提供的壓降將全部由二極體接受，因此二極體的工作區便被定位在線性的Photoconductive區內
- 高增益操作放大器的輸入端幾乎沒有電流，所以輸出電流會流過回授電阻，輸出電壓則將正比於輸出電流，達到了電流轉換成電壓的目的



# PIN-TIA Simple Circuit

- TIA( TransImpedance Amplifier )是一種 Current to Voltage Converter，簡易圖示如下



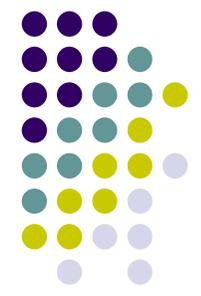
# 光傳送接收模組量測結果與討論



**12.5GHz Error detector**

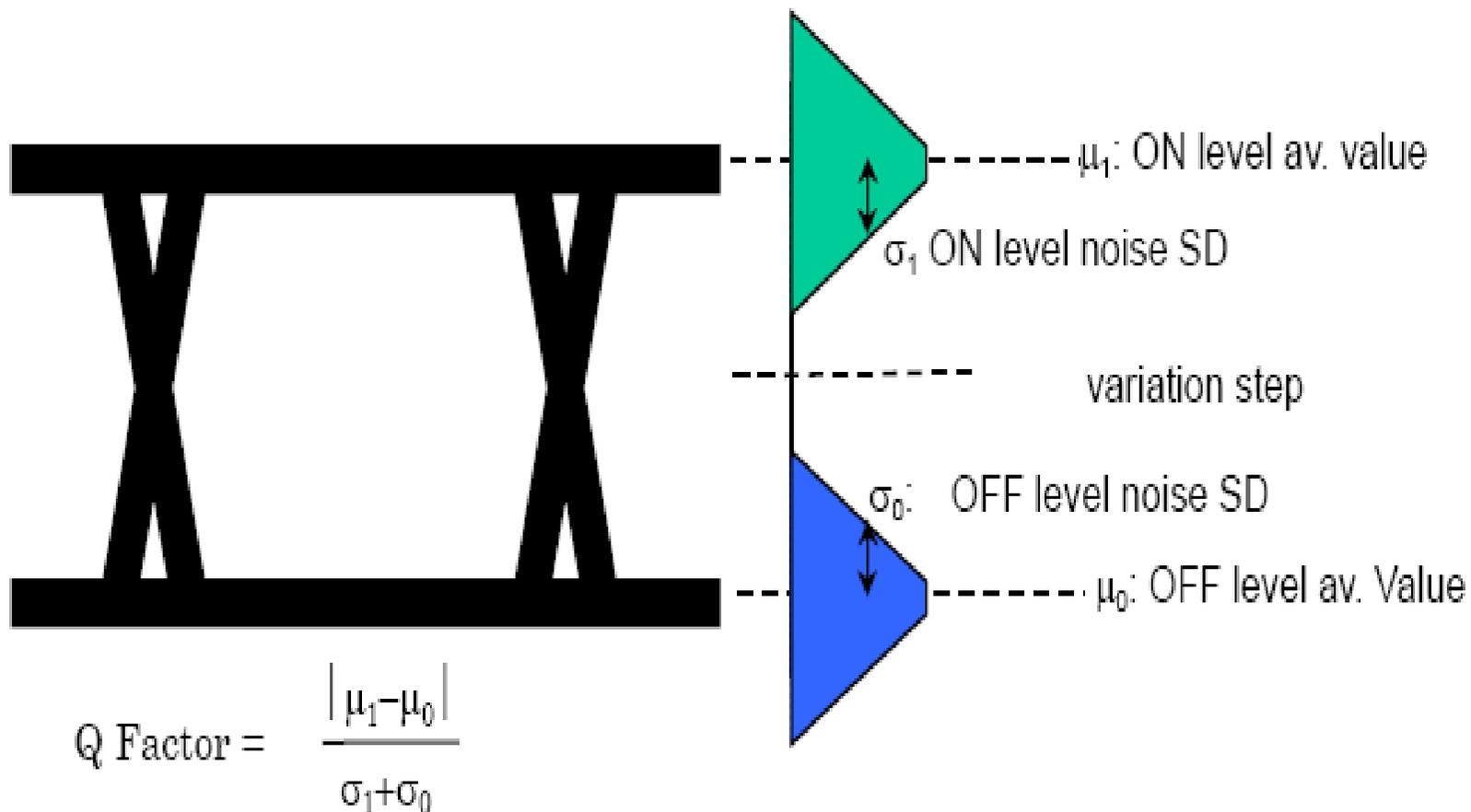


**12.5GHz pulse  
pattern  
generator**





# Q factor 定義 (1)



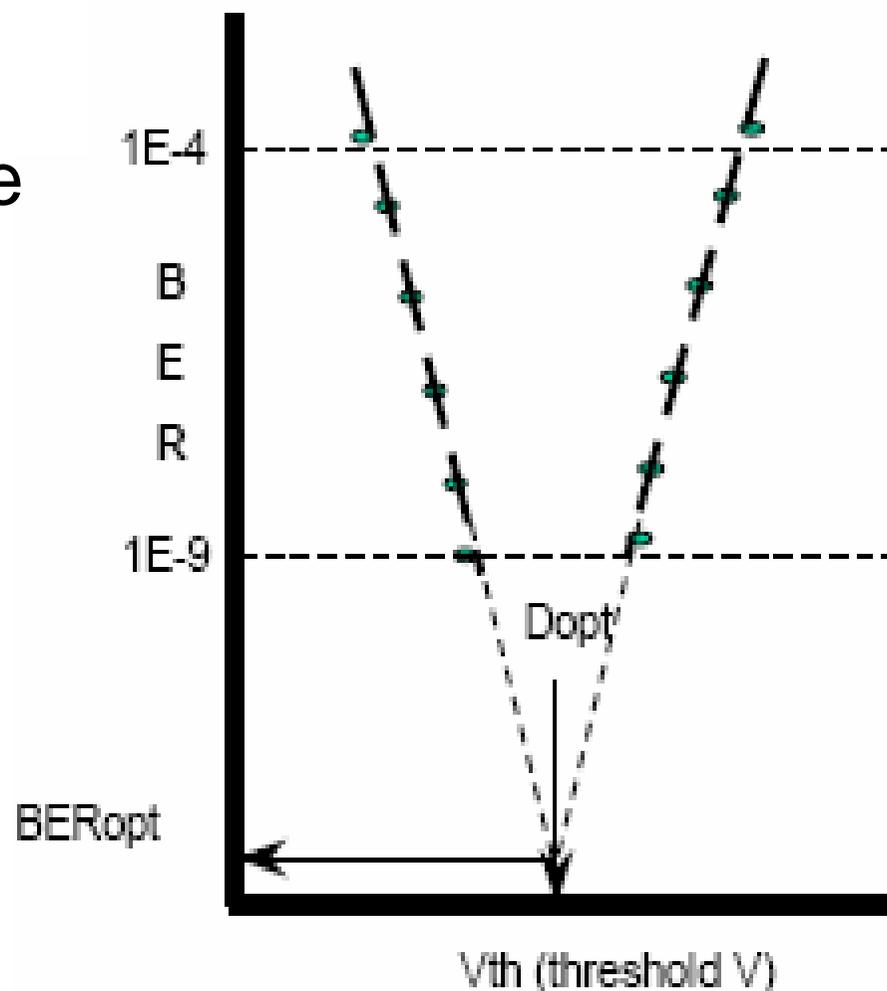


## Q factor 定義(2)

The Q factor is used to predict the minimum bit error rate (BER<sub>opt</sub>) and the threshold voltage (D<sub>opt</sub>) at that time.

$$BER = \frac{1}{\sqrt{2\pi}} \frac{\text{Exp}(-Q^2/2)}{Q}$$

$$D_{opt} = \frac{\sigma_0 \mu_1 + \sigma_1 \mu_0}{\sigma_1 + \sigma_0}$$

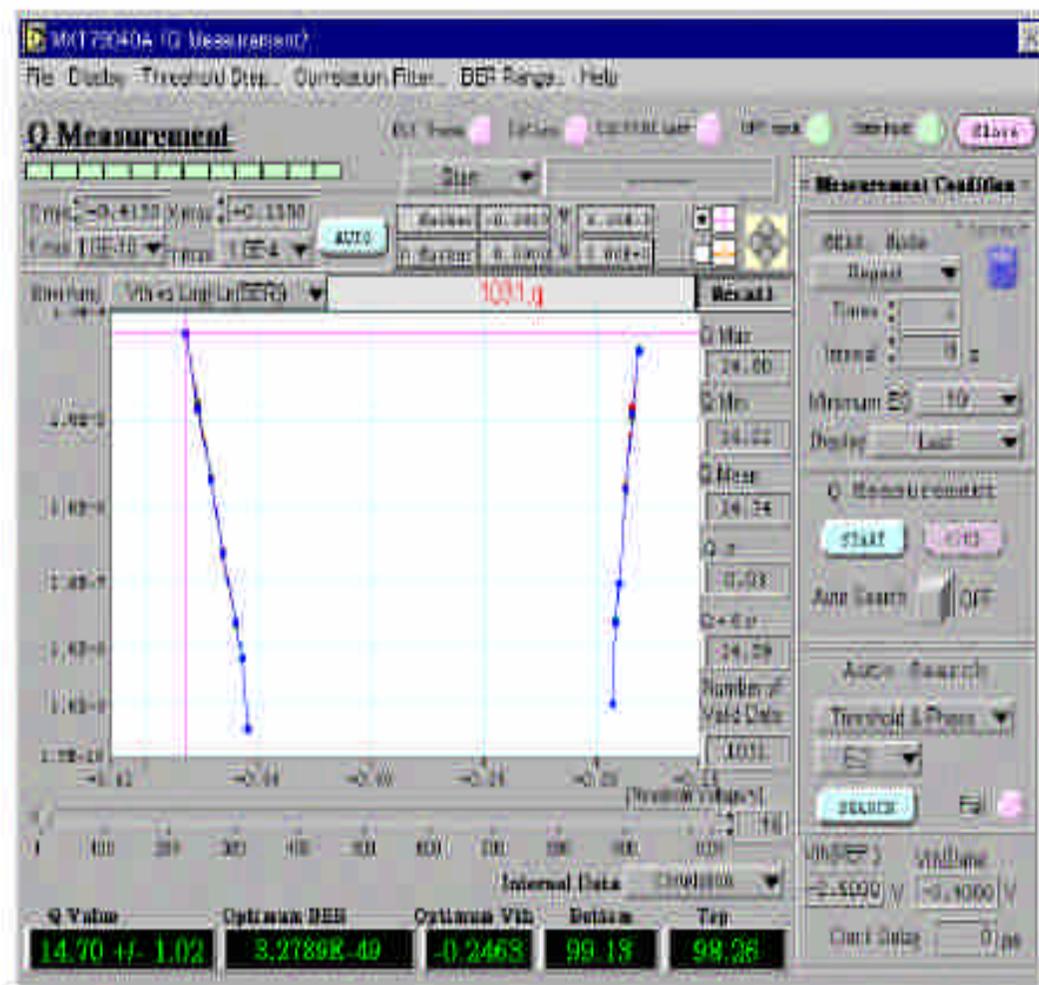


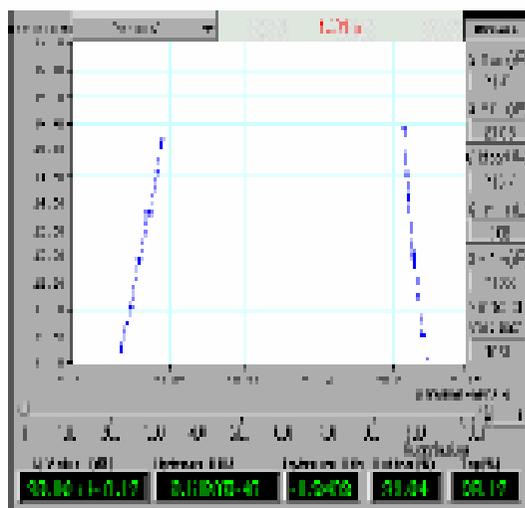
# 量測結果表示方法



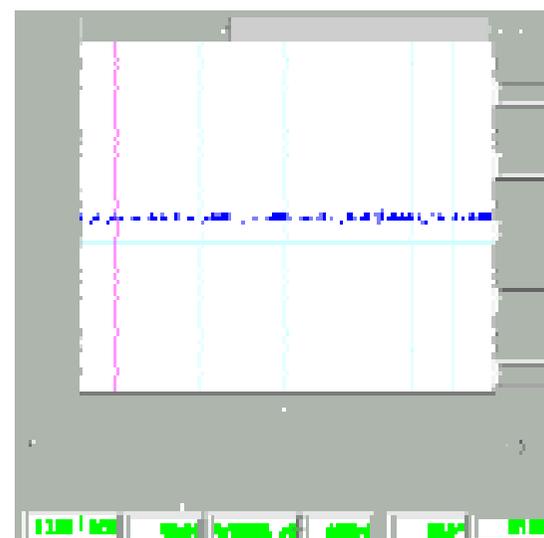
量測結果可以有  
下列幾種圖示：

- 1) Threshold voltage vs.  $\text{Log}(\% \text{Ln}(\text{BER}))$
- 2) Threshold voltage vs.  $\text{Log}(\text{BER})$

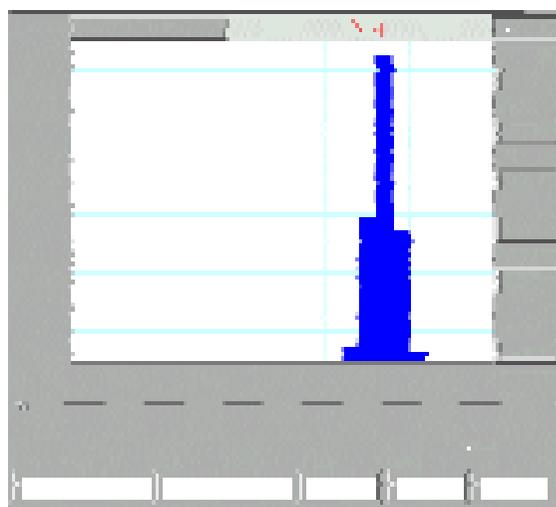




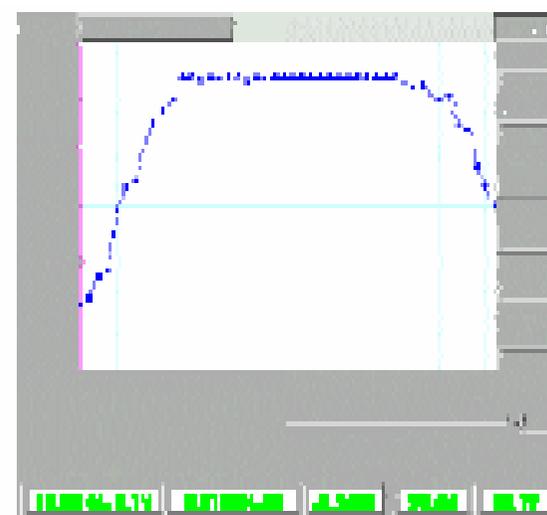
Threshold voltage vs. Q factor



Measurement times vs. Q factor



Histogram

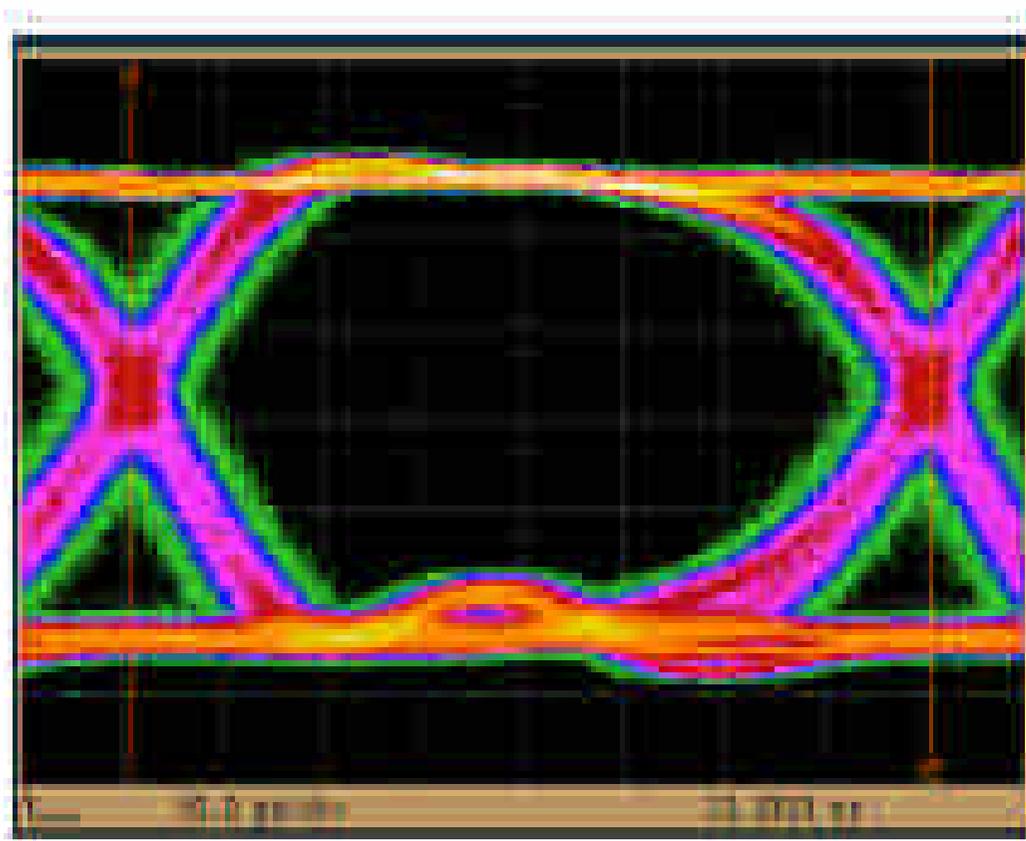


Clock phase vs. Q factor

# 使用取樣示波器觀察眼形圖



眼形圖的量測是一種用來評估數位訊號品質的典型方法。通常是利用數位示波器進行眼形圖的量測。

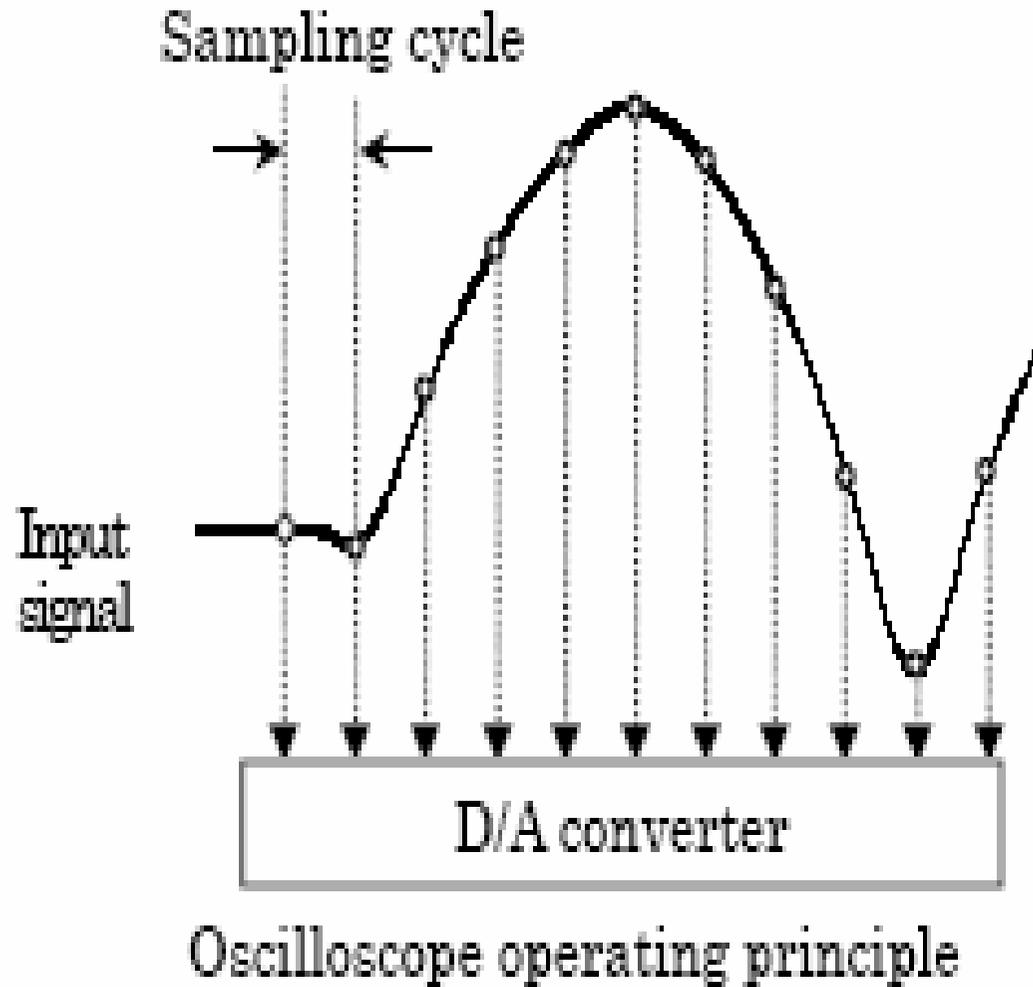


Eye-Diagram observed by oscilloscope

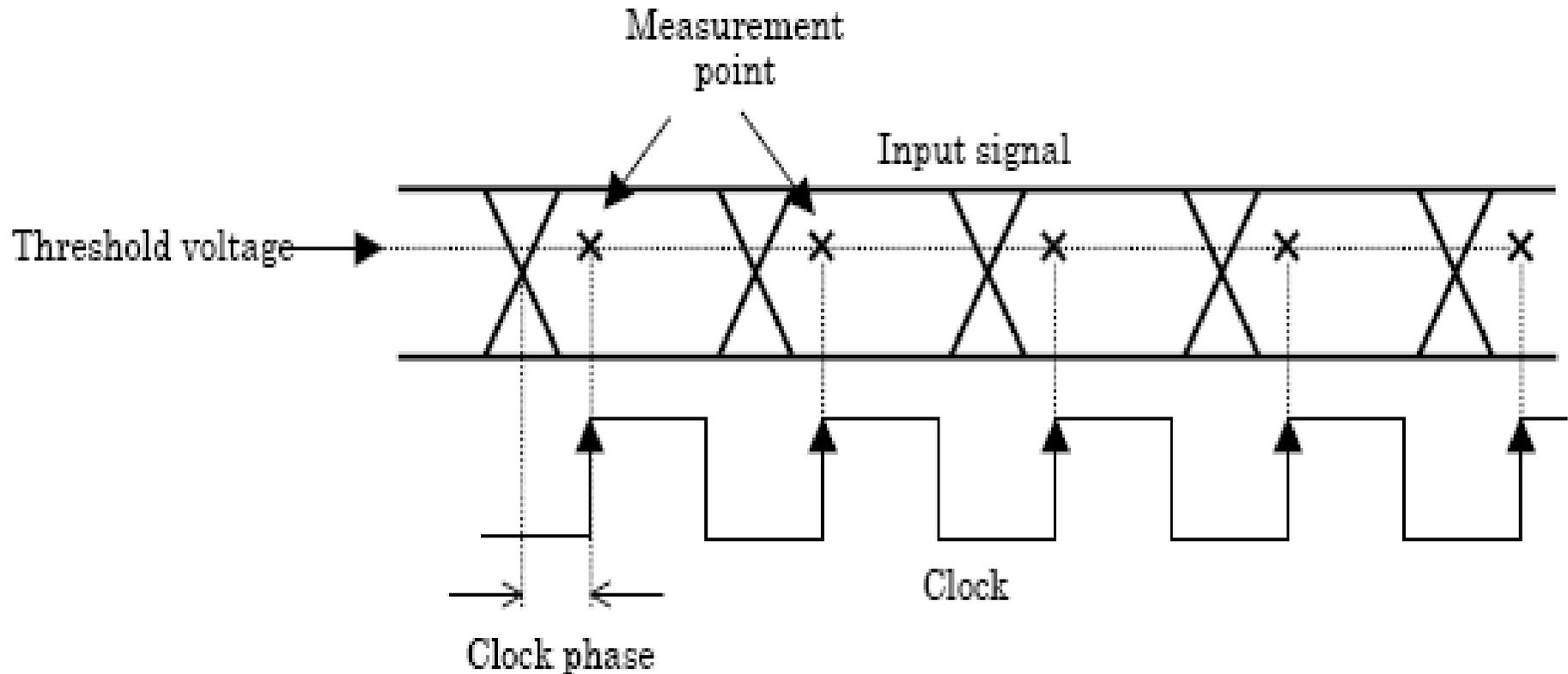
# 示波器量測原理



輸入為類比電壓波形轉換成數值表示，在指定的取樣週期內並儲存到內部記憶體，需要的取樣速度超過今日最快的A/D轉換器。



# 利用眼形圖的量測進行誤碼率測量



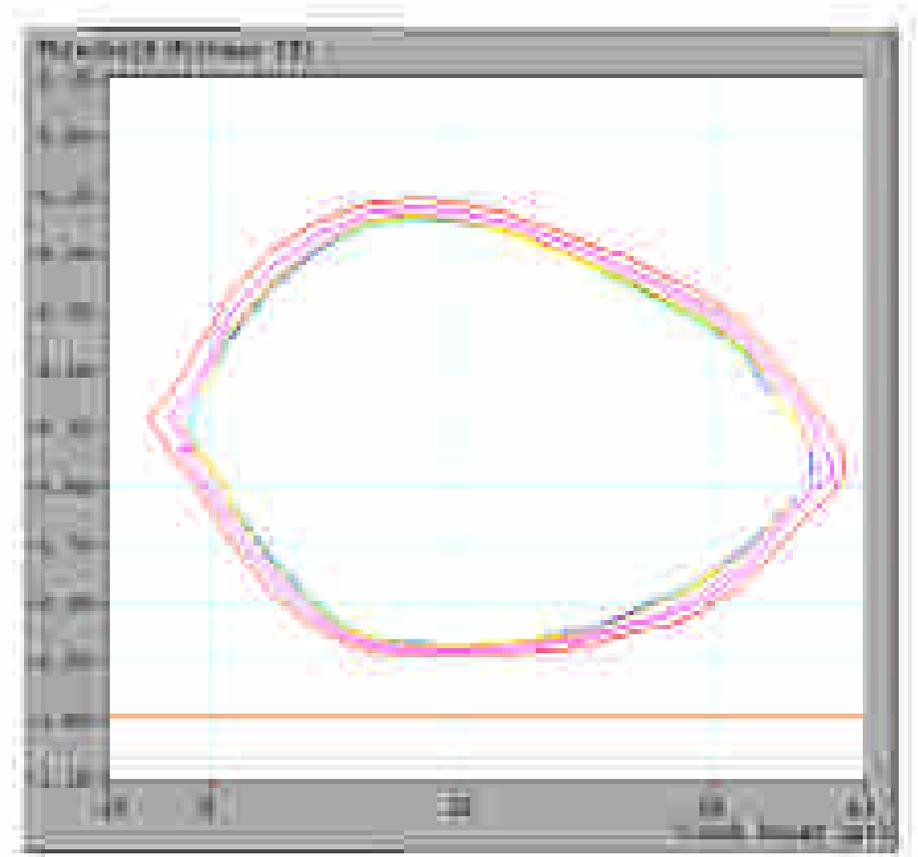
在錯誤的偵測中，誤碼率的量測是透過每個眼圖中，調整適當的clock phase 與 threshold voltage 設定出量測點作判斷。

# 使用誤碼率量測繪製眼形圖



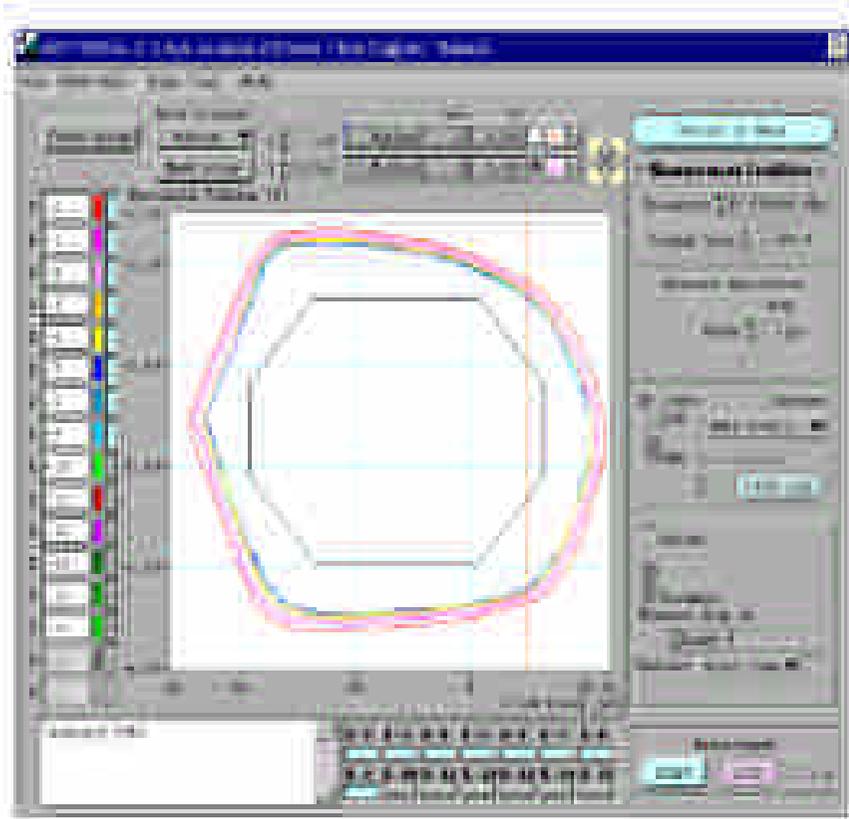
**At eye-diagram-based bit error rate measurement, the clock phase and threshold voltage are varied and the bit error rate at any position in the eye pattern is measured as a bit error rate contour.**

**Any combination from E2 to E15 can be chosen as the contour.**

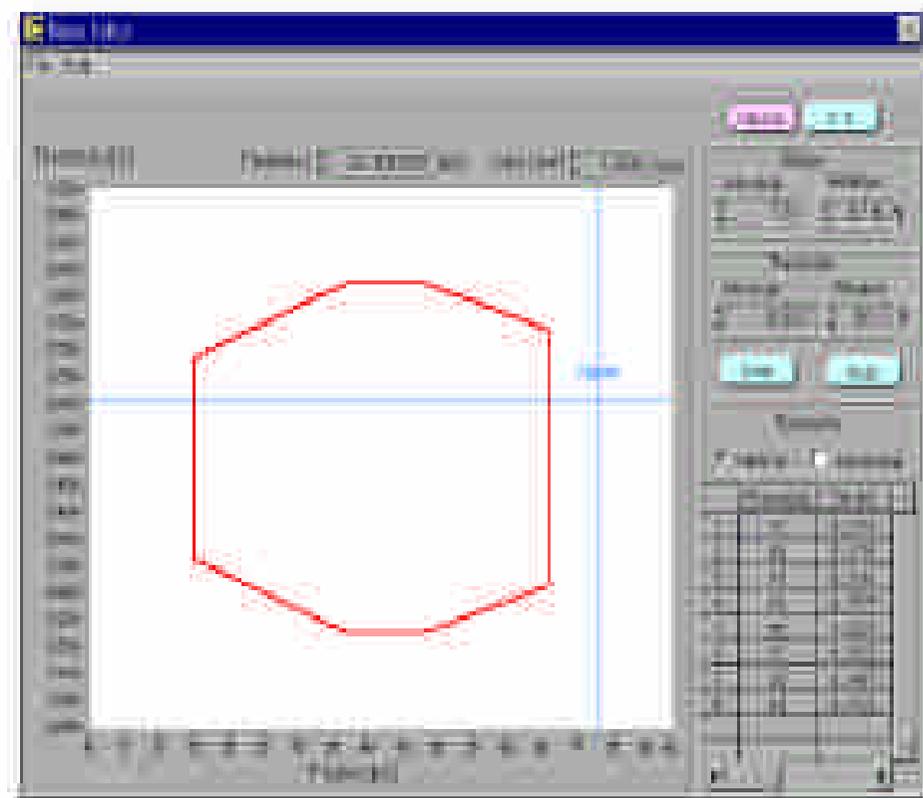


Eye-Diagram based on bit error rate

# Signal Quality Pass/Fail Evaluation based on Eye Diagram Measurement



Template display



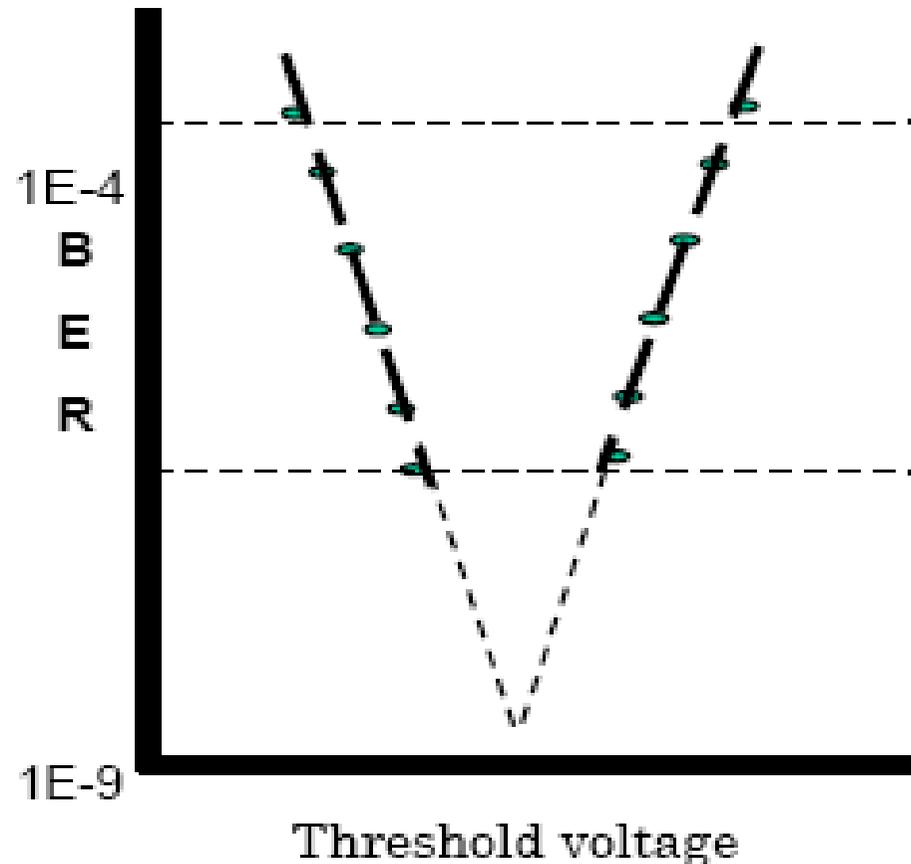
Editor screen of template

# High-speed Eye Diagram Measurement using Q factor

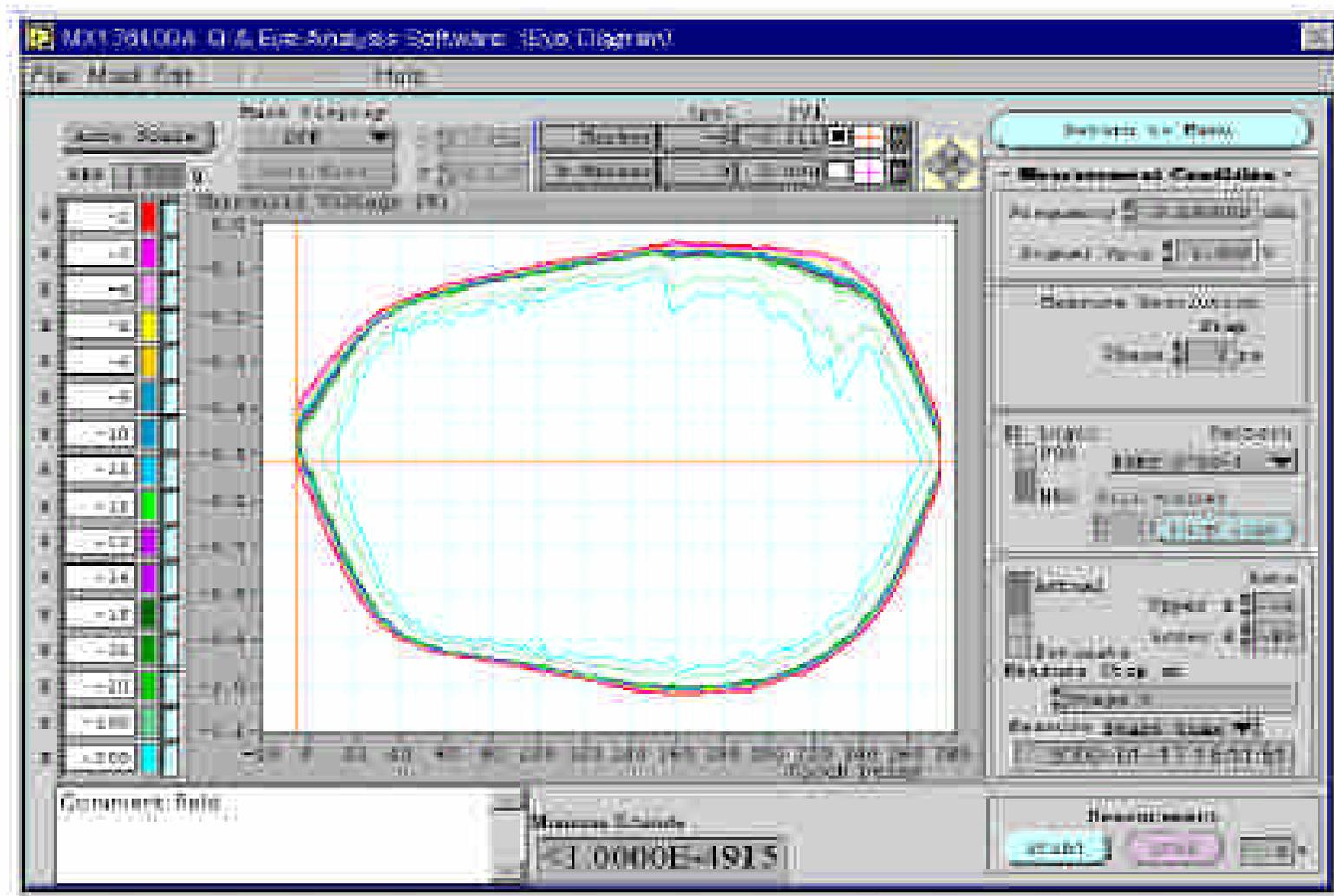


By measuring the Q factor, the bit error rate of low rates that cannot be presently measured can be predicted.

$$BER(D) = \frac{1}{2} \left[ \frac{e^{-\frac{(\mu_1 - D)^2}{2\sigma_1^2}}}{\left(\frac{\mu_1 - D}{\sigma_1}\right)\sqrt{2\pi}} + \frac{e^{-\frac{(\mu_0 - D)^2}{2\sigma_0^2}}}{\left(\frac{\mu_0 - D}{\sigma_0}\right)\sqrt{2\pi}} \right]$$



By using the Q factor, any bit error rate diagram up to E-4915 can be displayed



# Eye Margin Measurement



The screenshot displays the MXI 76400A Q & Eye Analysis Software interface. The main window shows an eye diagram with a central white oval representing the signal's eye. The diagram is overlaid with a grid and measurement lines. A vertical double-headed arrow on the right side of the eye is labeled "Threshold" with a value of "0.000 V p-p". A horizontal double-headed arrow at the bottom of the eye is labeled "Phase" with a value of "0 ps p-p".

The software interface includes a menu bar with "File" and "Help". A "Return to Menu" button is located in the top right corner. The "Measurement Conditions" panel on the right contains the following settings:

- Frequency Set: 12.50000 GHz
- Measure Resolution: Phase  $\frac{\Delta}{\Delta}$  1 ps, Threshold  $\frac{\Delta}{\Delta}$  0.010 V
- Measure Direction: Threshold & Phase
- Measure Rate: 1-15
- HD Condition: Phase  $\frac{\Delta}{\Delta}$  0 ps, Threshold  $\frac{\Delta}{\Delta}$  -0.500 V
- Measure: Start Time

A "START" button is located at the bottom right of the interface.