光電科技導論(通識中心課程)

Chapter 5
多采多姿的雷射---雷射及其應用 I

成大光電

光電系

大綱

- 雷射的原理、構造和特性
- 雷射的歷史
- 雷射的種類介紹

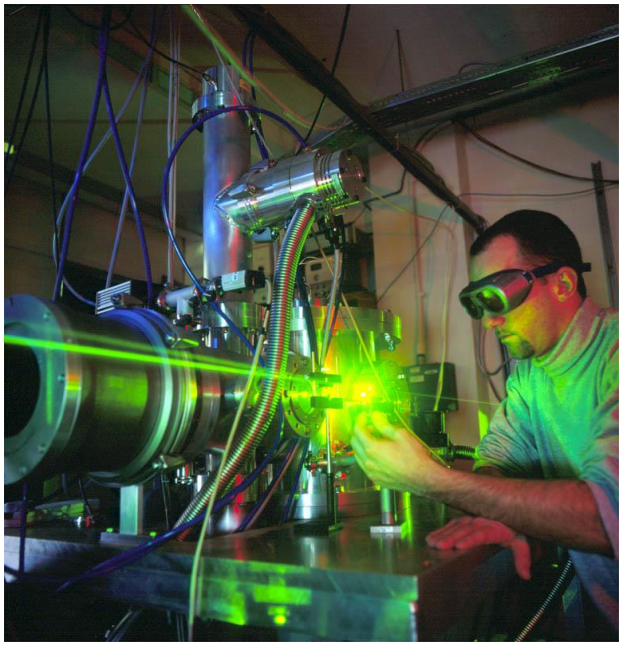
  依增益介值分類：氣態、固態、液態、半導體

  依雷射輸出方式分類：連續、脈衝式
- 日常生活的應用
- 醫學及工業應用
- 科學發展的應用

雷射的原理、構造和特性

- 受激放光
- 光放大器
- 光學共振腔

- 準直性
- 單色性



雷射是什麼?

LASER is the abbreviation of

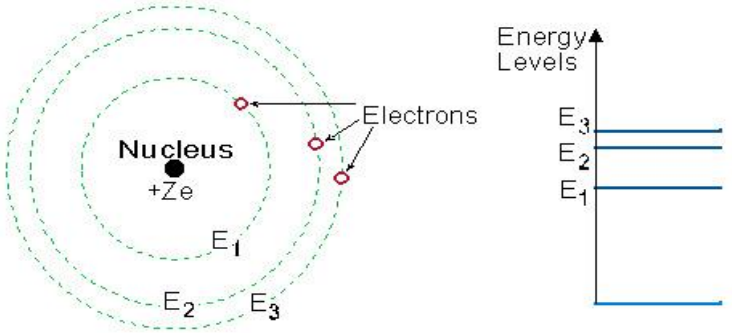
『***L****ight* ***A****mplification by* ***S****timulated* ***E****mission of* ***R****adiation*』

受激輻射之光放大

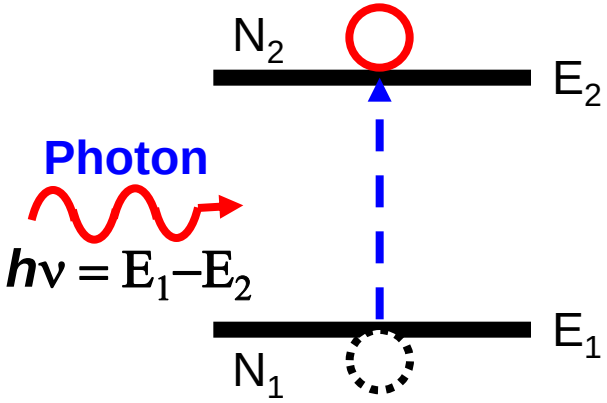
台灣音譯 ⇨ 雷射

大陸意譯 ⇨ 激光

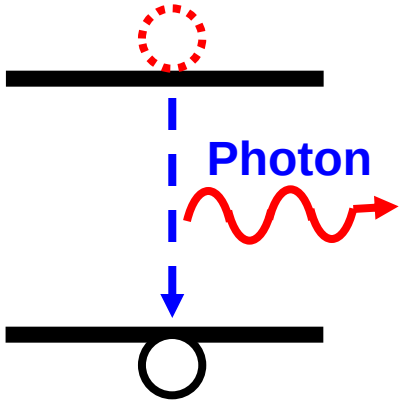
雷射理論介紹



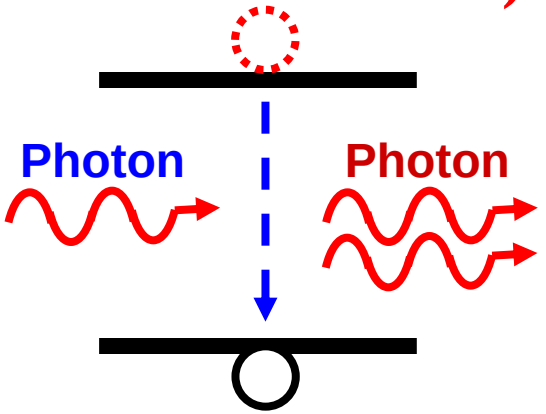
吸收 (absorption)



自發放光 (Spontaneous emission)



受激放光 (Stimulated emission)

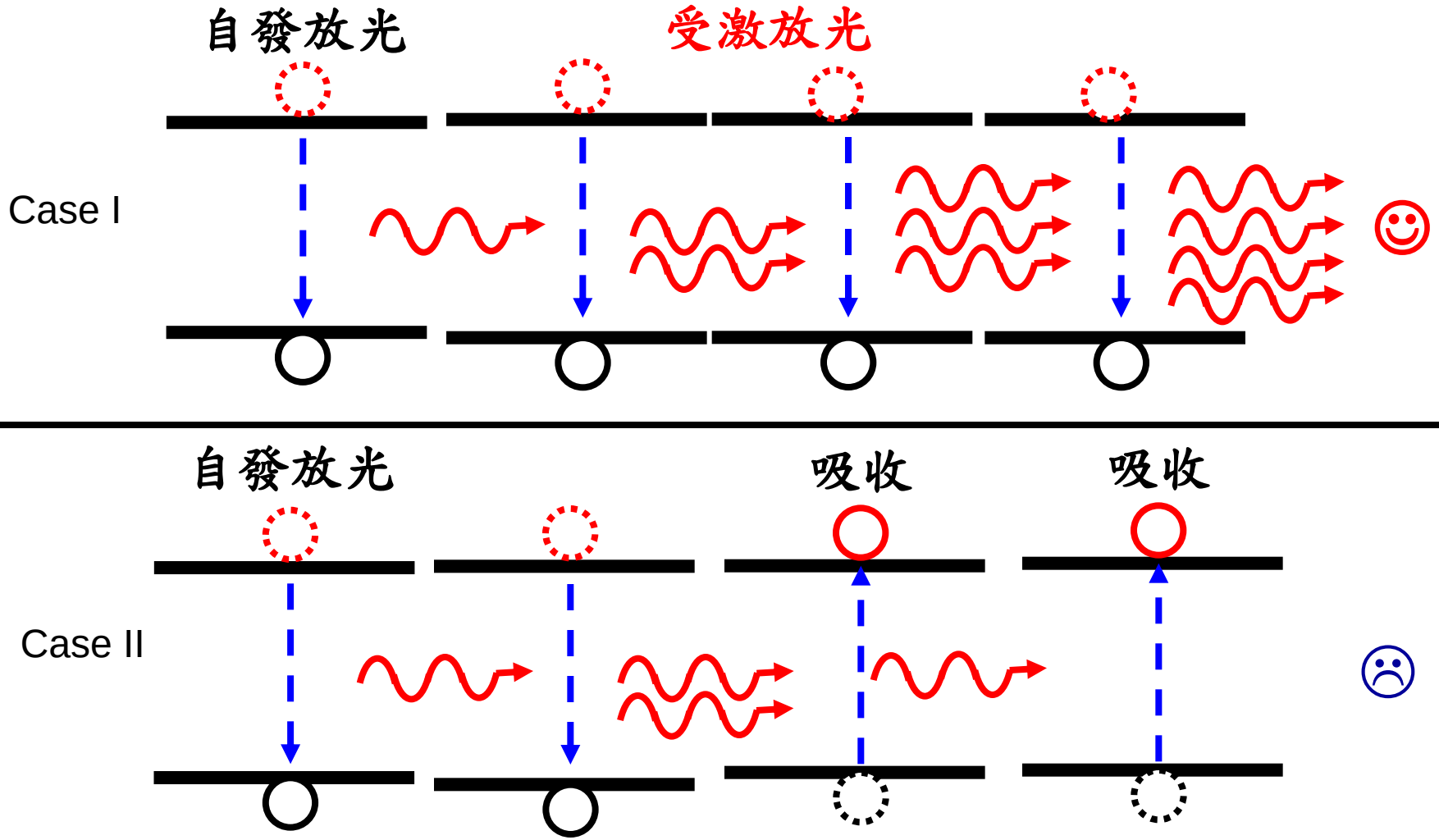


激發源（pumping source）：

激發源—將低能階的電子送到高能階。

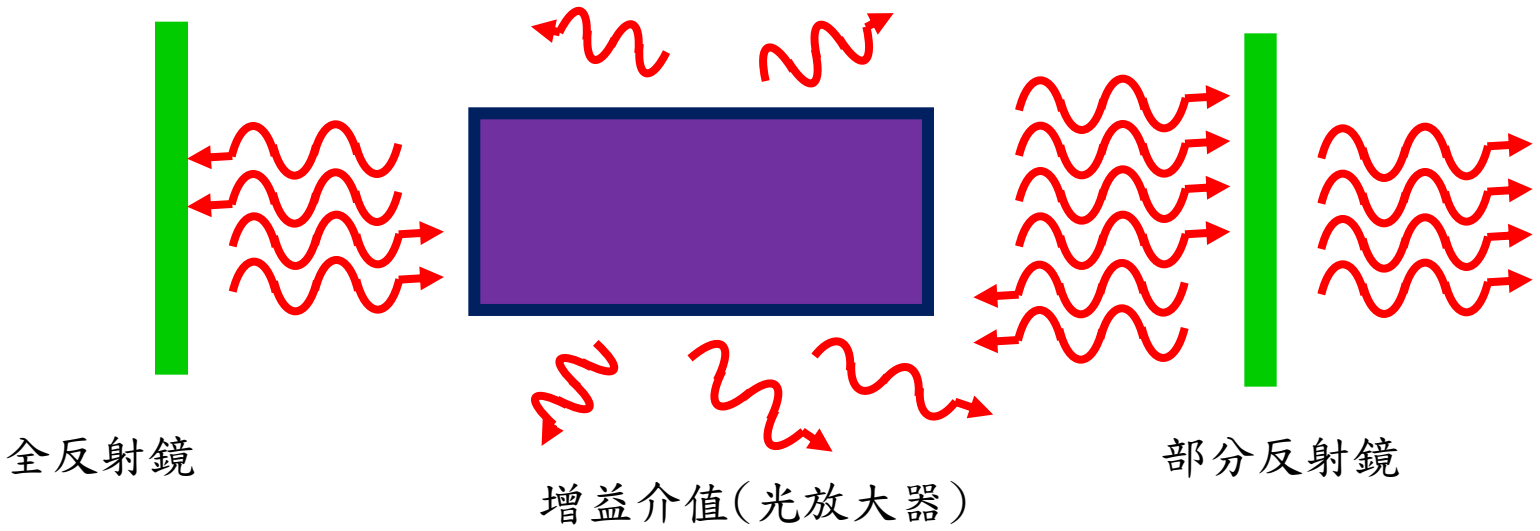
- 常見的雷射泵浦系統有電流驅動、加熱驅動，或用其他波長之雷射來驅動等方式
- 泵浦系統常產生大量的熱能，故需增加散熱裝置

光放大過程



- 光放大的操作條件： 上能階的原子數大於下能階原子數 (稱為居量反轉; Population inversion)

光學共振腔 (optical cavity/ optical resonator)



共振腔的功能

1. 限制雷射光的行進方向
2. 限制雷射的頻率
3. 增加放大器的作用長度

共振條件: $L=n\lambda/2$

組成雷射的三個基本要素

- **激發源（pumping source）：**

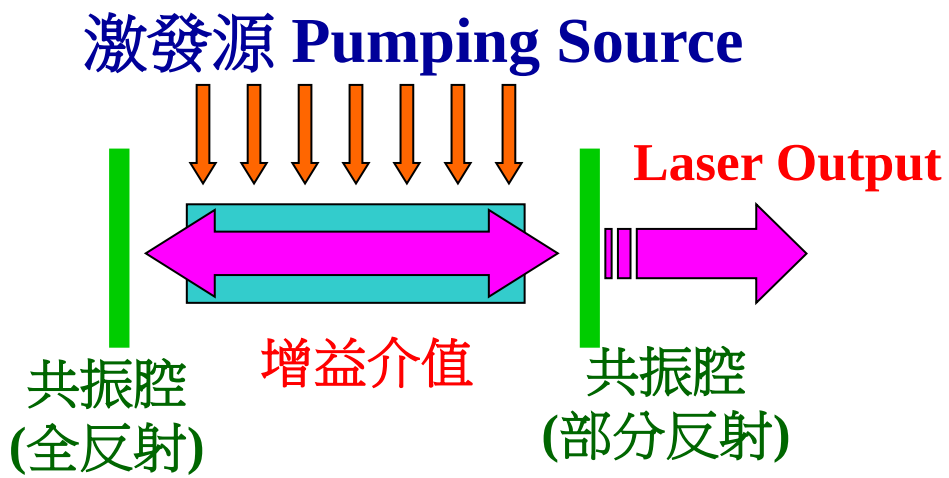
  把低能階的電子，激發使其成為高能階電子。供給能量的方式有電荷放電、光子、化學作用...。

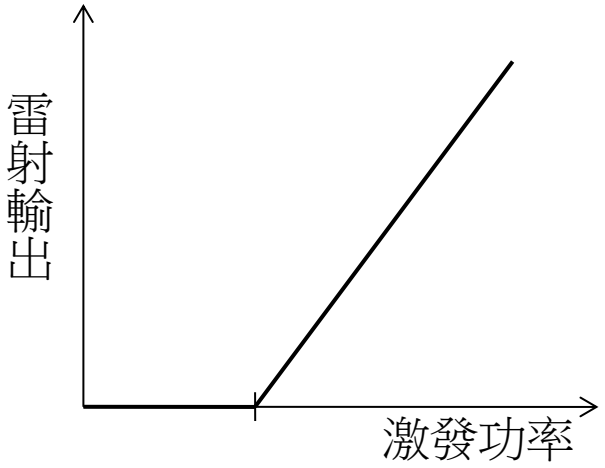
- **增益介質（gain medium）：**

  被激發、釋放光子的電子所在的物質，其物理特性會影響所產生雷射的波長等特性。

- **共振腔（optical cavity/optical resonator）：**

  光在腔內來回反射，目的是使被激發的光經過增益介質多次以得到足夠的放大，當放大到夠大時，雷射可發射出去。



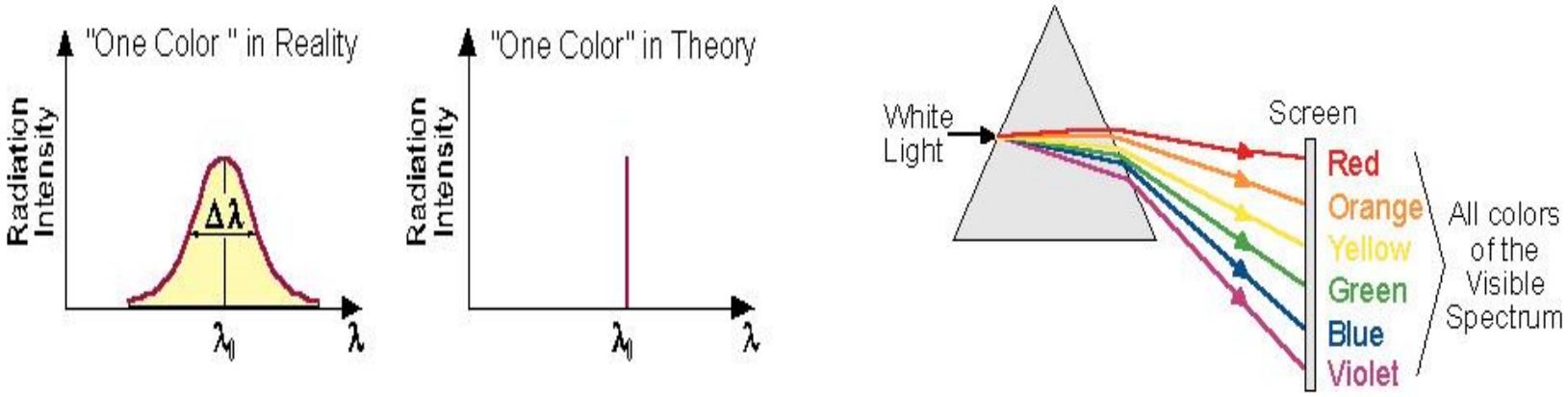


雷射光的輸出特性

- 單色性（monochromatic）
- 方向性（Directional）
  或稱準直性（Collimated）
- 高強度（High intensity）
- 同調性 (或稱為高度相干性,Coherent）

單色性（monochromatic）

整個產生雷射的機制中，只會產生一種波長的光。這與普通的光不同，例如陽光和燈光都是由多種波長的光合成的，接近白光。

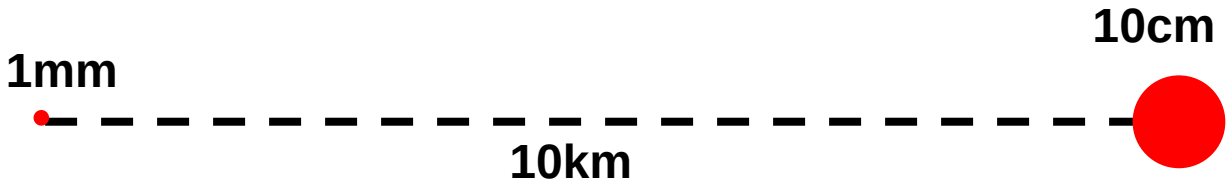


傳統光源與雷射的單色性之比較

光源	光譜線中心波長(nm)	△λ(nm)	△ν(Hz)
鈉燈	589.6	0.1	9×10^{10}
低壓鎘燈	643.8	0.0013	9.4×10^{8}
氦氖雷射	632.8	10^{-8}	7.5×10^{3}

方向性（Directional）

- 激發輻射之方向決定於入射光的行進方向；共振腔的構造又使光束往主軸集中。因此行進方向偏離主軸的光波不會顯著地放大，而且向側方逸出。放大後的雷射光束則很細很直。
- 對照：夜空中的探照燈光束直徑比 10cm 大得多。

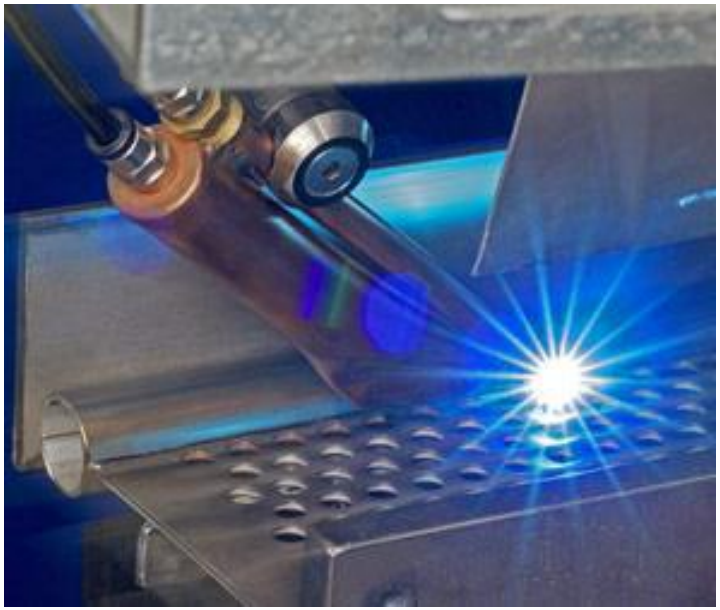


雷射的聚焦

- 點光源
- 平行光
- 點光源和平行光可以聚焦到很小的一點

高強度（High intensity）

- 高強度：光束攜帶的能量很多；能量集中在很小的截面積上。
- 激發輻射造成放大，共振腔又增高放大次數，且使光束截面縮小，雷射光的強度就高出傳統光束。光束很狹窄，並且十分集中，所以有很強的威力。相反，傳統燈光分散向各個方向轉播，所以強度很低。
- 光的強度（intensity）：每秒內通過1 平方公尺的光能量。亦稱為功率密度（power density）。



同調性(Coherence）

- 頻率和相位完全相同的光子。所謂「相位」相同，是指射出光子的波峰和波谷，所產生的光子群，有相同的方向、波長和相位，有如齊步前進的士兵。

- 同調性佳，才會出現干涉條紋。

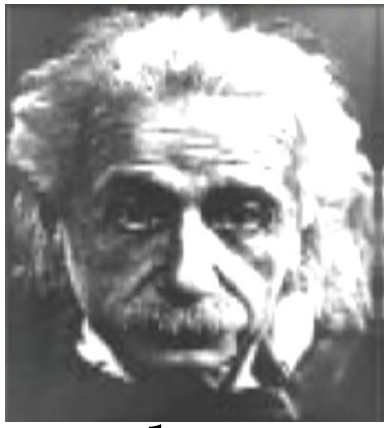
大綱

- 雷射的原理、構造和特性
- 雷射的歷史
- 雷射的種類介紹

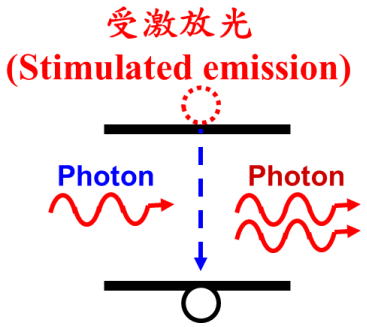
  依增益介值分類：氣態、固態、液態、半導體

  依雷射輸出方式分類：連續、脈衝式
- 日常生活的應用
- 醫學及工業應用
- 科學發展的應用

雷射發明演進史

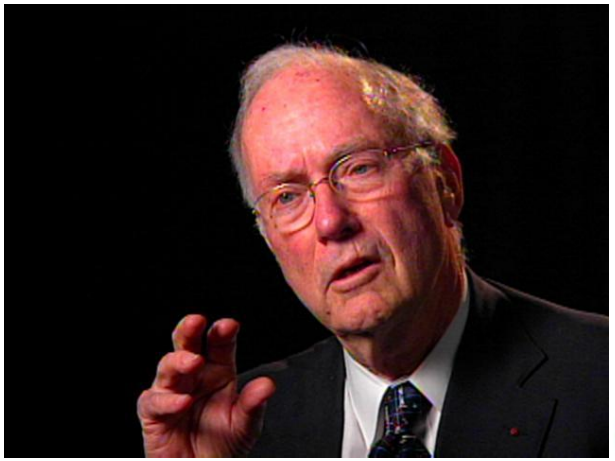


- 雷射的最基本原理:物質量子論
- 1900普朗克提出能量不連續的概念
- 1905愛因斯坦提出光量子論
- 1917愛因斯坦提出受激輻射(Stimulated emission)
- 1950E.M.Purcell 和 R.V.Pound實驗證實居量反轉

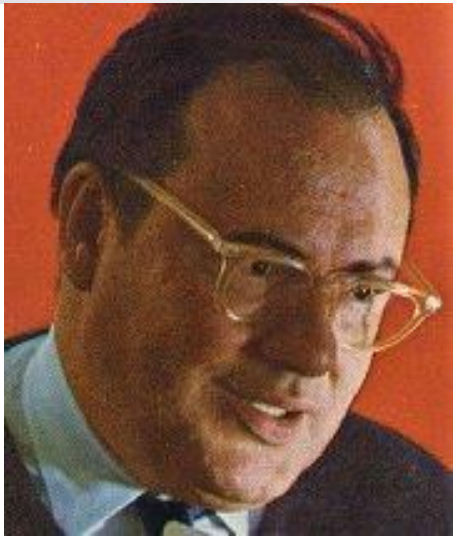


雷射發明演進史

- 1953年，湯斯(Charles H. Townes)和他的同事們製成了第一個微波量子放大器－鐳射(MASER; Microwave Amplification by the Stimulated Emission of Radiation)。



- 1958年，肖洛(Arthur Schawlow)與湯斯把微波量子放大器的原理推廣到可見光頻。

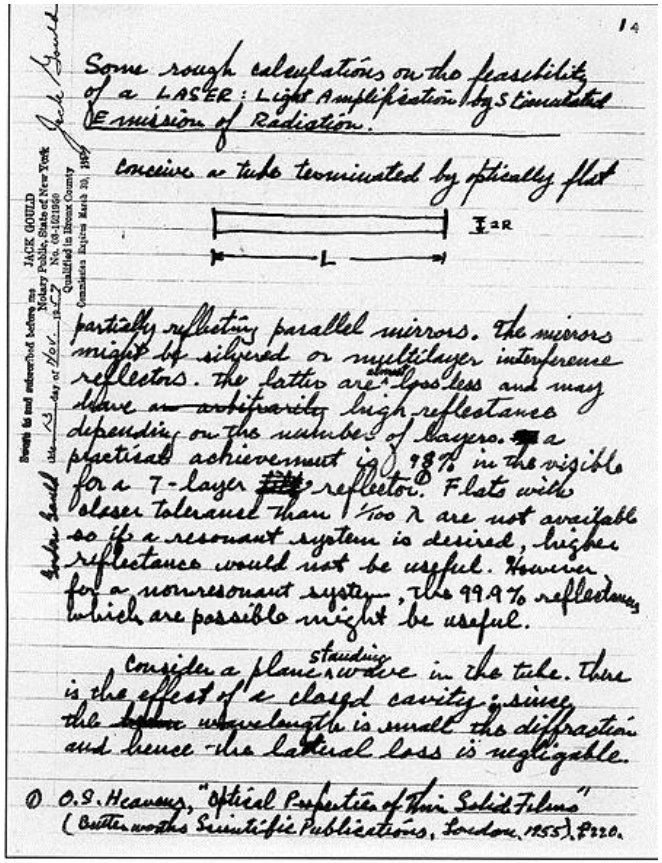


- 1960年，梅曼(Theodore Maiman)成功的製造了第一台紅寶石(Ruby Laser)雷射。

雷射發明的另一個故事...
Mr. Gordon Gould

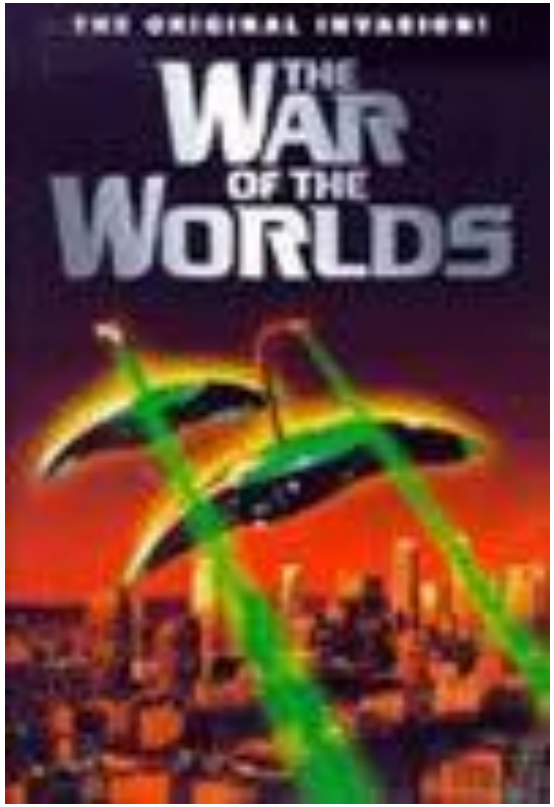
- "Some rough calculations on the feasibility of a LASER: Light Amplification by Stimulated Emission of Radiation“ on November 13, 1957.
- Gould曾於1957年在筆記本寫下有關雷射裝置的構想，可能是第一個完成雷射構想的人。雖然Gould立刻將此筆記拿去申請專利，但是當時律師告訴他要想得到專利，必須先將此構想實用化，所以Gould也就沒有申請了(直到1959年4月才申請)，坐失先機。
- Gould 因曾參加共黨外圍組織，被美國政府禁止參與雷射的研究，1987年才終於打贏雷射的專利官司。

November 13, 1957



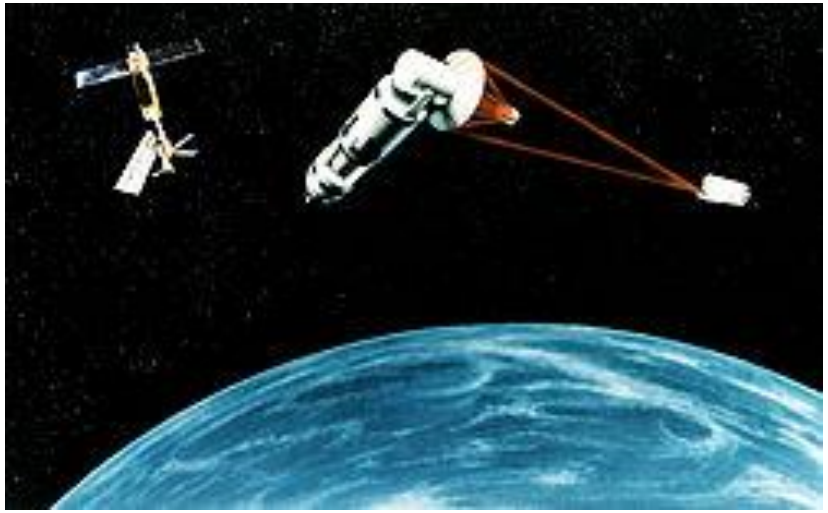
電影：火星人入侵地球 1953

- 雷射狂想曲…



美國對抗蘇聯的星際大戰(1983)

- 美國前總統雷根1983年的演說:….以各種手段攻擊敵方的外太空的洲際戰略飛彈和太空飛行器，以防止敵對國家對美國及其盟國發動的核武攻擊。希望利用外太空和地面部署高能定向武器（如微波、雷射、高能粒子束、電磁動能武器等）或常規打擊武器，能攔截來襲的飛彈。….



大綱

- 雷射的原理、構造和特性
- 雷射的歷史
- 雷射的種類介紹

  依增益介值分類：氣態、固態、液態、半導體

  依雷射輸出方式分類：連續、脈衝式
- 日常生活的應用
- 醫學及工業應用
- 科學發展的應用

雷射的分類（I）

- 依增益介值分類：氣態、固態、液態、半導體

- 氣態雷射Gas Lasers

  氦氖He-Ne (633nm), 氬離子Ar^+ laser(488nm, 514nm), 氦鎘He-Cd(325nm), 準分子Excimer Laser(KrF 248nm),
  二氧化碳CO_2 Laser(10600nm), 氮氣N_2 laser(337nm), …

- 液態雷射Liquid Lasers　染料Dye laser (tunable)
- 固態雷射Solid-State Lasers

  釹雅鉻(釹釔鋁*石榴石*,Neodymium doped yttrium Aluminum Garnet。化學式為Y3Al5O12：Nd3+，簡寫 Nd:YAG and,鈦藍寶石Ti:Sapphire laser(700-900nm tunable), …

- 半導體雷射Semiconductor Lasers

  GaAs, AlGaInP, GaN…

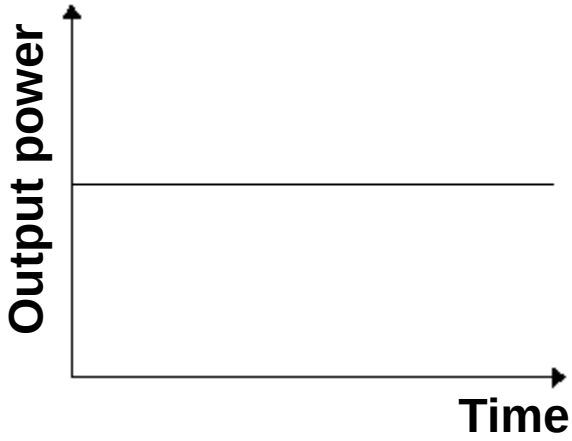
- 其他雷射 Other Lasers

  Free-Electron Laser, …

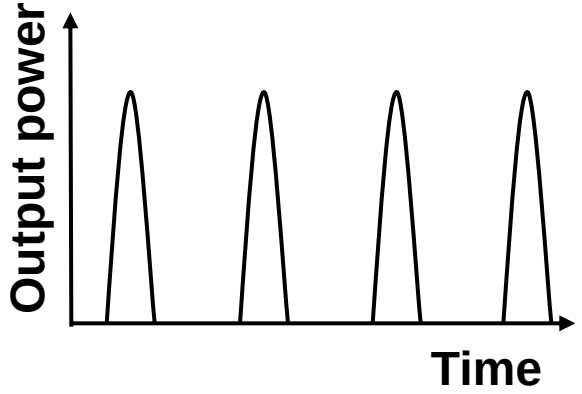
雷射的分類（II）

依輸出的方式

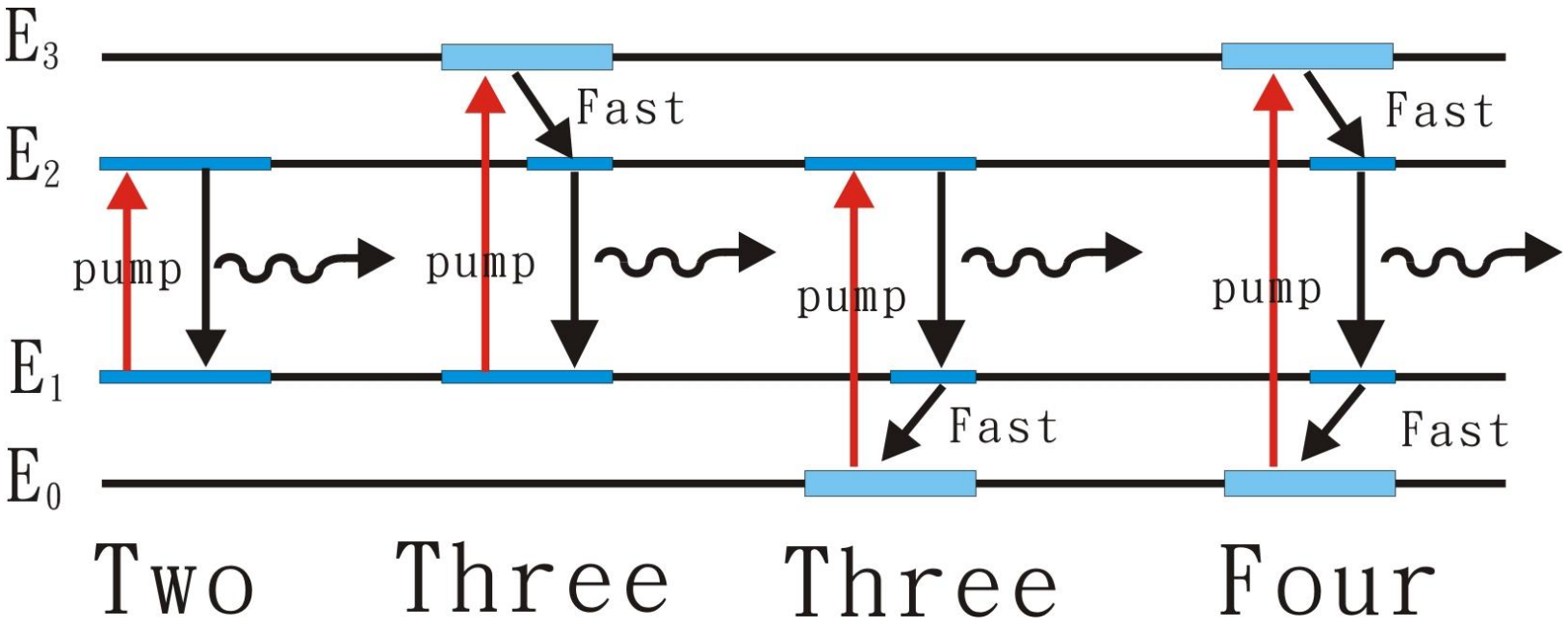
- 連續式Continuous wave (CW) laser:
  He-Ne, Argon, He-Cd, GaAs, …

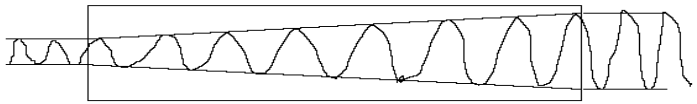


- 脈衝式Pulsed laser:
  Q開關Q-switched → Nd:YAG, Nd:YVO_4, …
  t_p > tens of picosecond
  鎖模Mode locked → Ti:Sapphire, Cr+: LiSAF, …
  t_p ~ several femtosecond➔ ultra short

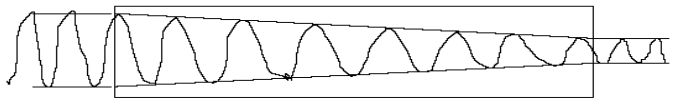


Two, Three or Four level system





$N_2 > N_1$ Amplify



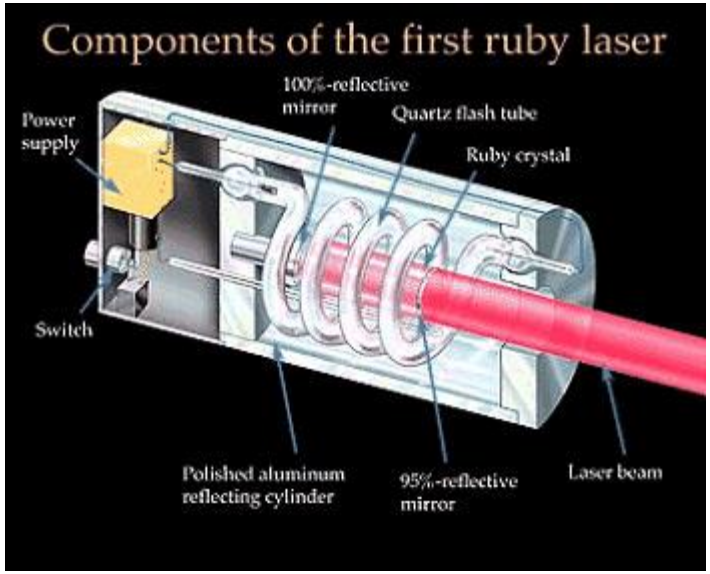
$N_2 < N_1$ Attenuate

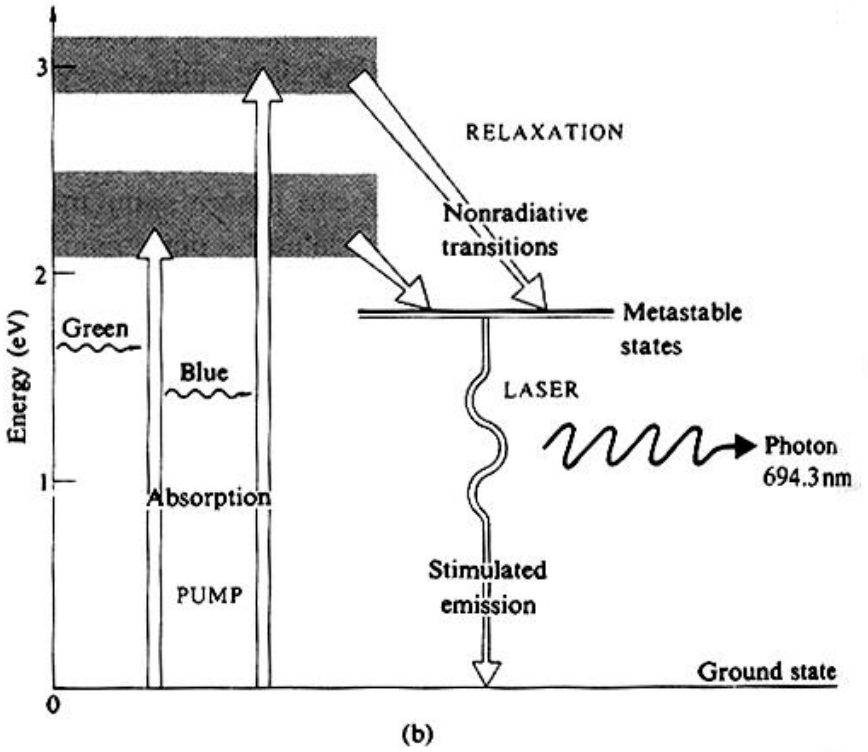
各式雷射介紹

紅寶石雷射 Ruby Laser

Invented in 1960 by Ted Maiman at Hughes Research Labs, it was the first laser.

Ruby is a three-level system, so you have to hit it hard.

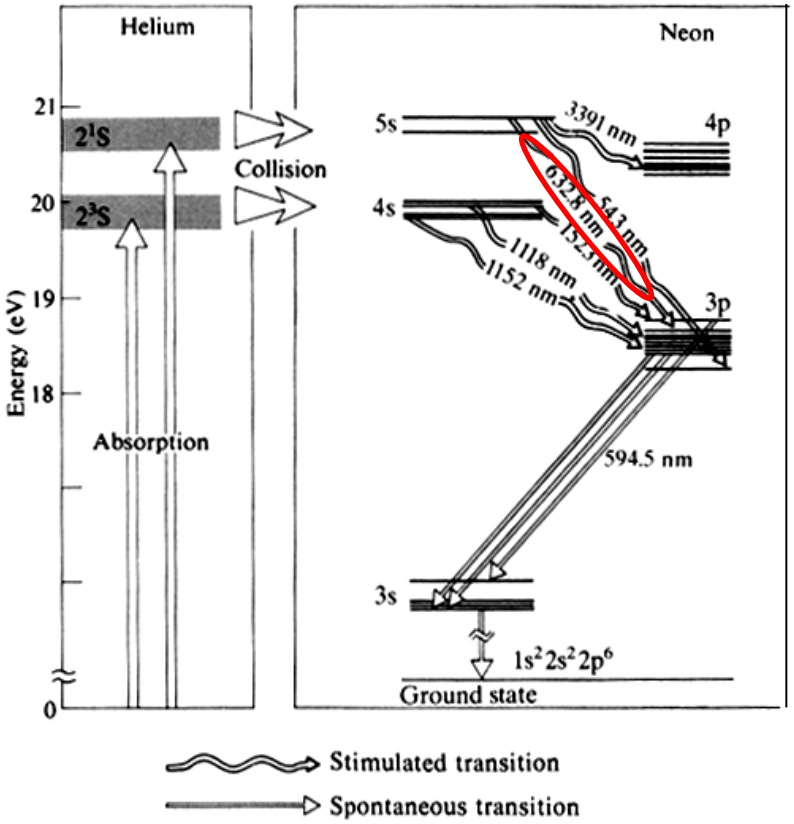


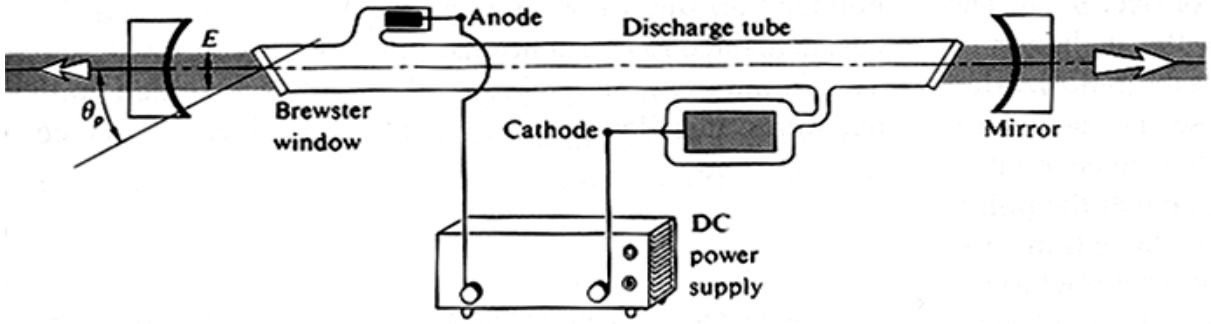


氦氖雷射Helium-Neon Laser

Energetic electrons in a glow discharge collide with and excite He atoms, which then collide with and transfer the excitation to Ne atoms, an ideal 4-level system.

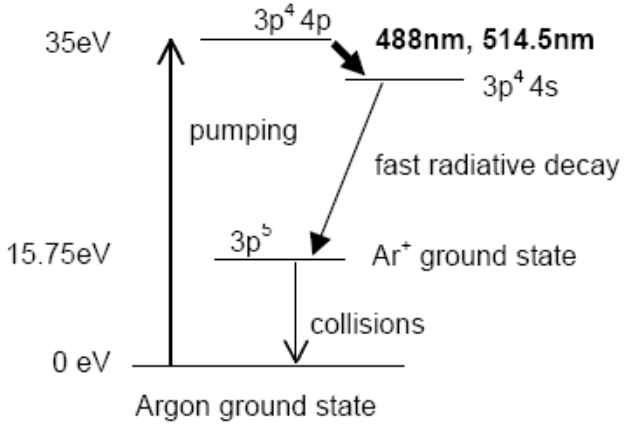
1960 - Dr. Ali Javan (associate of Charles Towne) succeeded in creating the first continuous wave laser. Today we call it a He-Ne (helium-neon) 632.6nm (red) gas ion laser. The lasing medium of ion lasers are stimulated electrically by DC high-voltage or RF excitation.





氬離子雷射 Argon Ion Laser

1964 - The Argon Laser was developed. The continuous wave 488nm/515nm (blue-green) argon gas ion laser was much easier to control and even better suited for retinal surgery. The lasing medium of argon gas ion lasers are stimulated electrically by DC high-voltage.



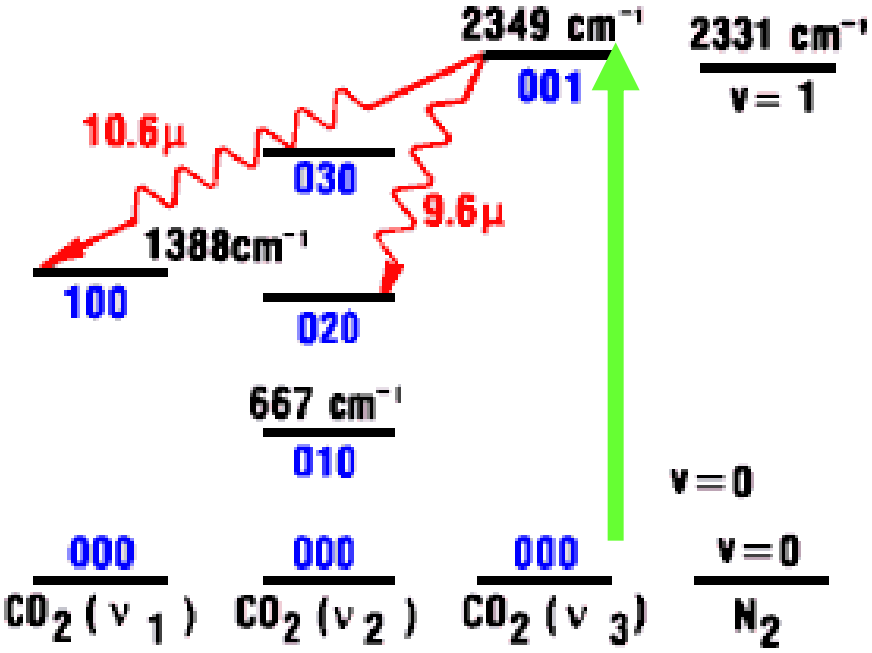
Argon ion laser lines:

Wavelength	Absolute Power
454.6 nm	.8 W
457.9 nm	1.5 W
465.8 nm	.8 W
472.7 nm	1.3 W
476.5 nm	3.0 W
488.0 nm	8.0 W
496.5 nm	3.0 W
501.7 nm	1.8 W
514.5 nm	10.0 W
528.7 nm	1.8 W

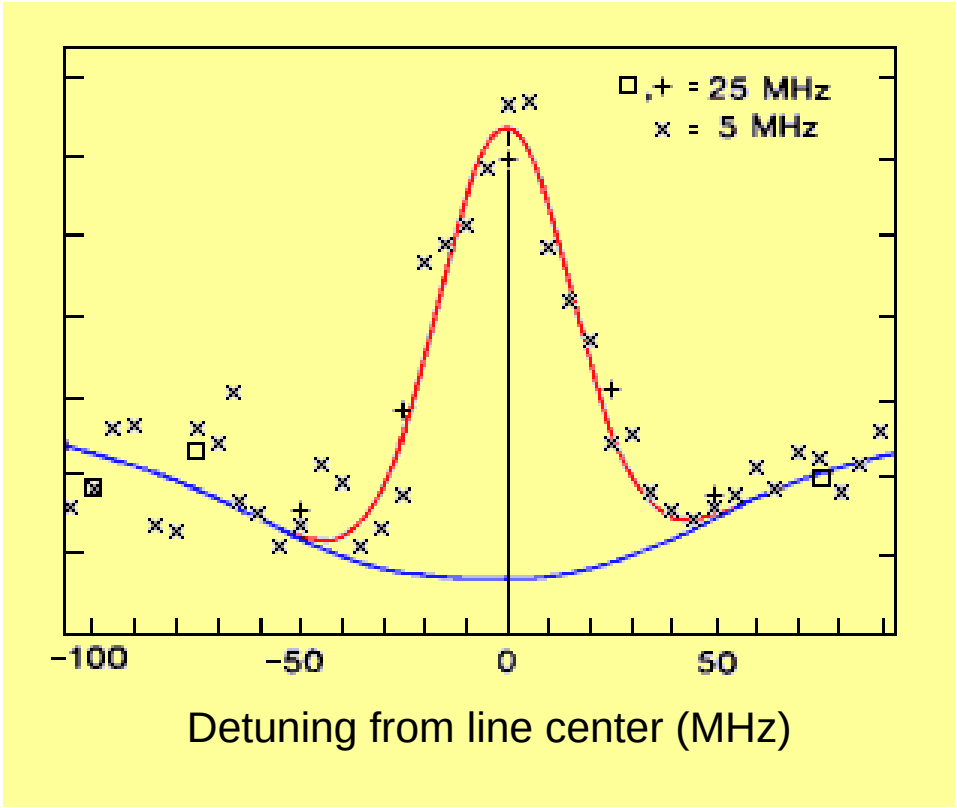
二氧化碳雷射Carbon Dioxide Laser

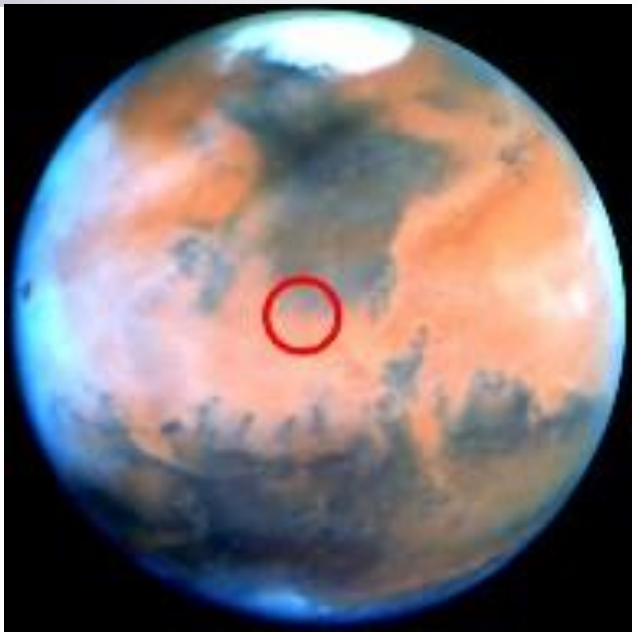
1964 - Kumar Patel invented the CO_2 (carbon dioxide) 10,064nm (far-infrared) gas ion laser. The lasing medium of CO_2 gas ion lasers are stimulated electrically by DC high-voltage or RF excitation.

The N_2 laser operates analogously. N_2 is pumped, transferring the energy to CO_2.



CO_2 laser in the Martian atmosphere





The atmosphere is thin and the sun is dim, but the gain per molecule is high, and the pathlength is long.

氦鎘雷射 Helium-Cadmium Laser

The population inversion scheme in HeCd is similar to that in HeNe's except that the active medium is Cd+ ions.

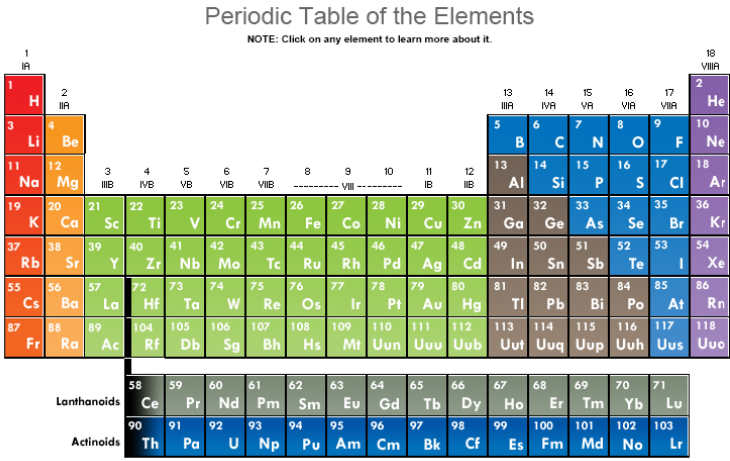
The laser transitions occur in the blue and the ultraviolet at **442 nm**, **354 nm** and **325 nm**.

The **UV** lines are useful for applications that require short wavelength lasers, such as high precision printing on photosensitive materials. Examples include lithography of electronic circuitry and making master copies of compact disks.

準分子雷射 Excimer Laser

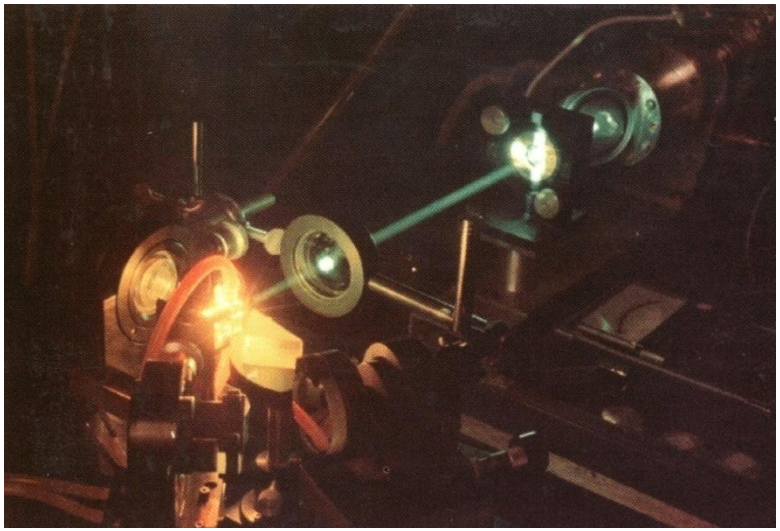
1975 - The Excimer Laser (noble gas-halide) was invented.

Excimer	Wavelength	Relative Power mW
Ar_2*	126 nm	
Kr_2*	146 nm	
F_2	157 nm	10
Xe_2*	172 & 175 nm	
ArF	193 nm	60
KrF	248 nm	100
XeBr	282 nm	
XeCl	308 nm	50
XeF	351 nm	45



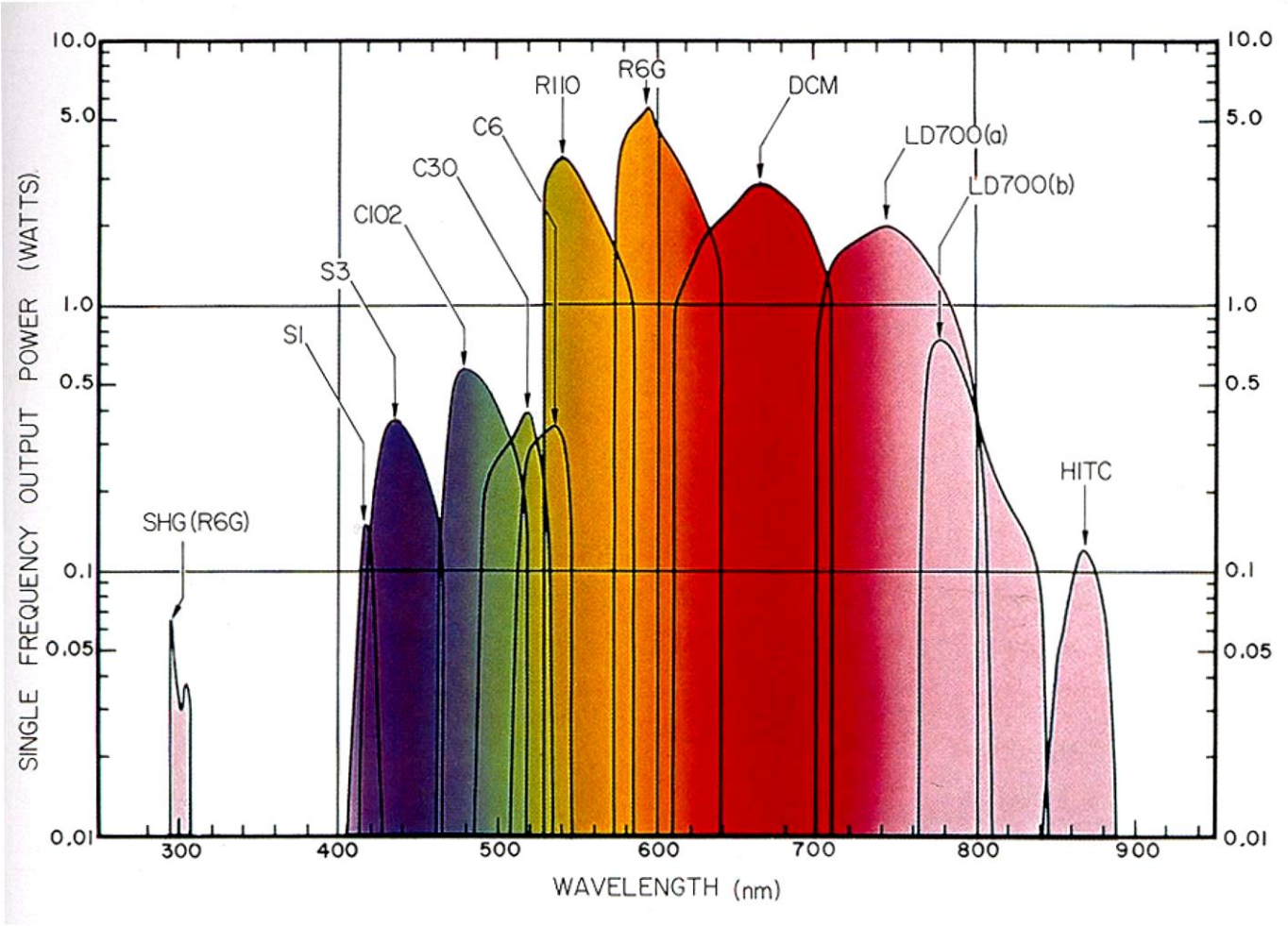
染料雷射 Dye lasers

1969 - The Dye Laser was introduced. The Pulsed Dye Laser was the first laser to produce selective light induced injury. It is used to treat a variety of blood vessel abnormalities such as port wine stains. Before the advent of this laser, these unsightly birthmarks responded poorly to treatment and available therapies often caused permanent facial scarring. The lasing medium of Dye lasers are stimulated optically by light (other lasers).



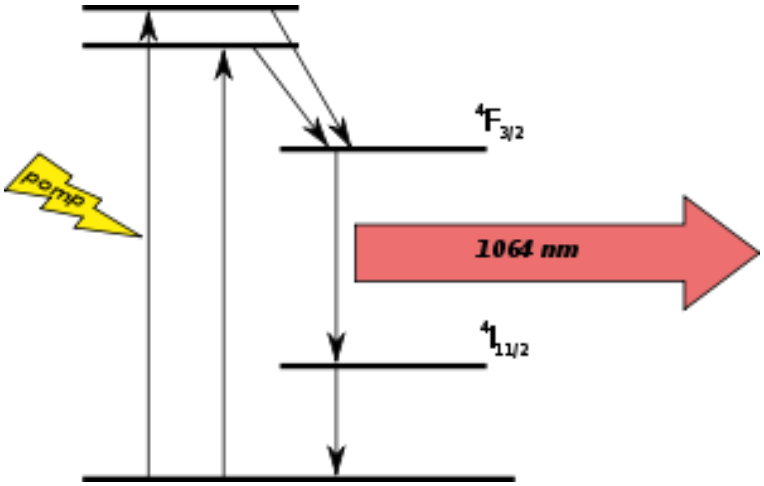
Dye lasers are an ideal four-level system, and a given dye will lase over a range of ~100 nm.

Dyes cover the visible, near-IR, and near-UV ranges.

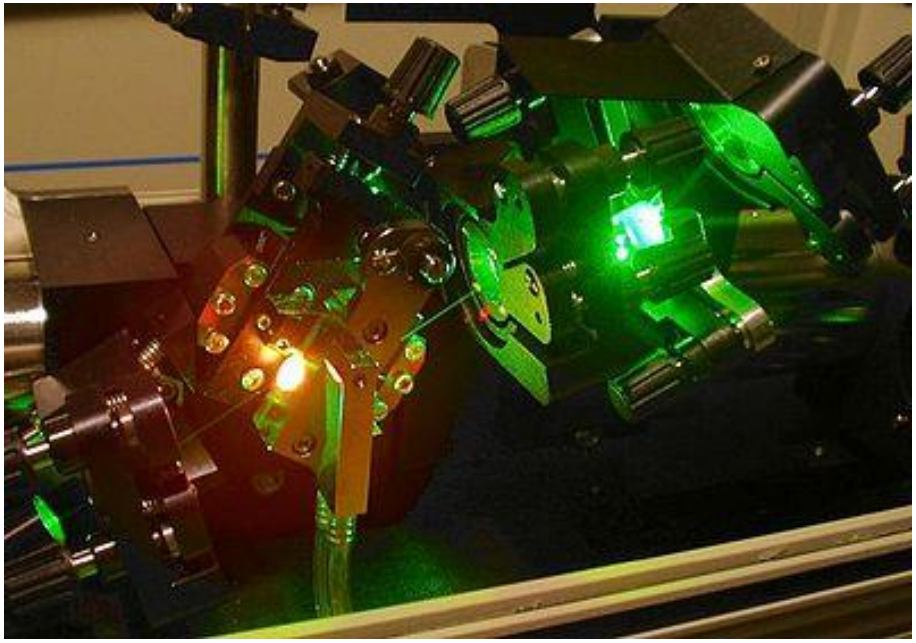


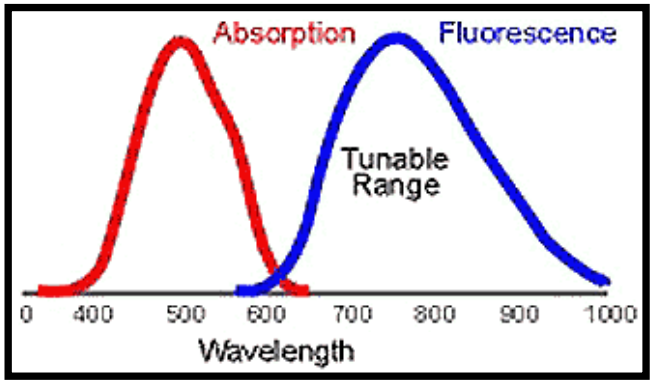
釹雅鉻雷射 Nd:YAG laser

- **1964** - The Nd:YAG (Neodymium doped, Yttrium Aluminum Garnett) 1,064nm (near-infrared) was developed in the same technology as the ruby laser. The lasing medium of YAG lasers are stimulated optically by light (flashlamps).
- The high-intensity laser may be efficiently frequency doubled to generate laser light at 532 nm, or higher harmonics at 355 and 266 nm.



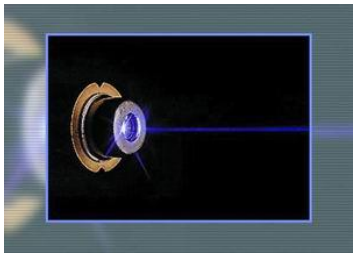
鈦藍寶石雷射Titanium: Sapphire (Ti:Sapphire)

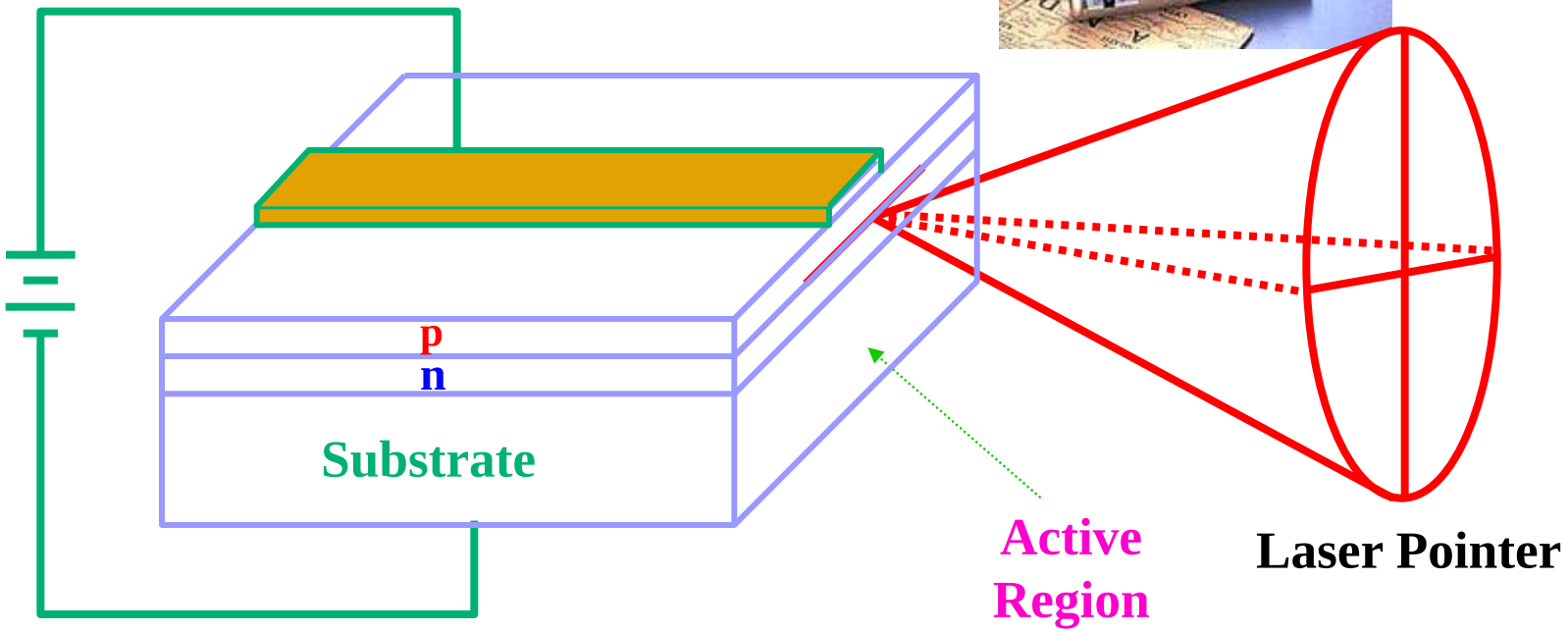




Ti:Sapphire lases from ~700 nm to ~1000 nm.

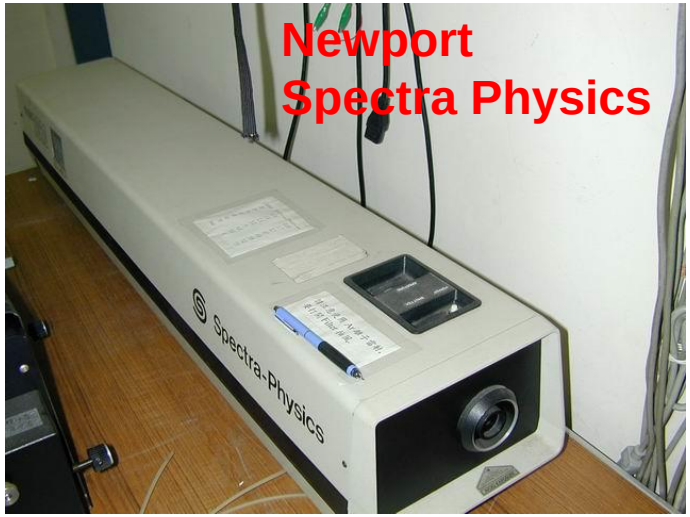
半導體雷射(Semiconductor Laser)





又稱為二極體雷射“**Diode Laser**”或是雷射二極體“**Laser diode**”

Laser profile



Argon Laser

CW Ti:Sapphire Laser

Argon Laser

Green-laser-pointer