

레이저의 원리와 종류

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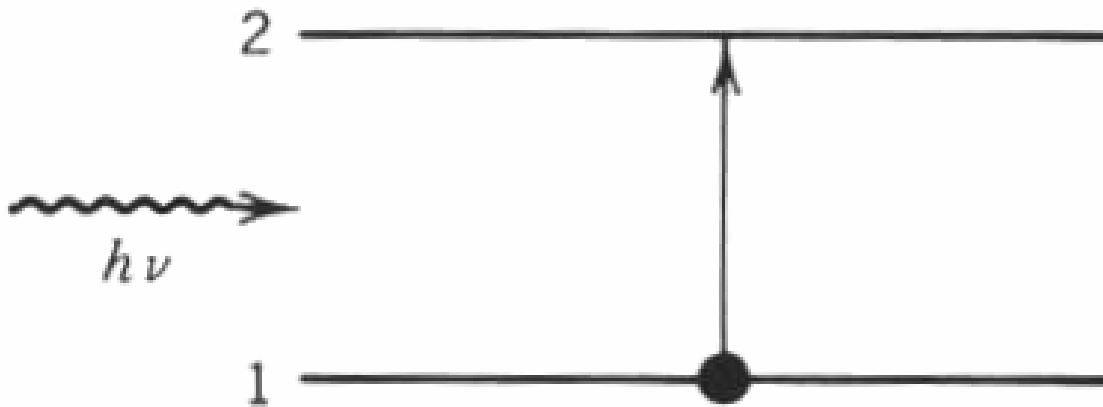


Laser의 특성

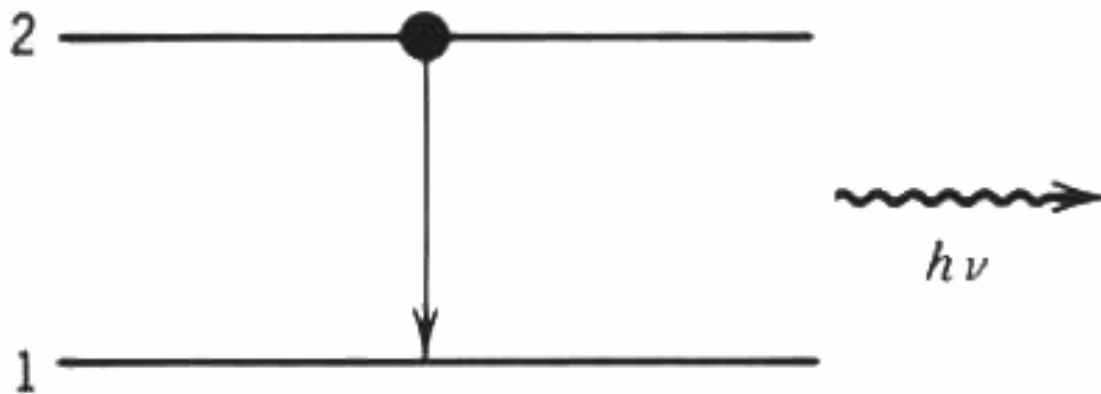
- 단색성
- 고휘도
- 지향성
- 가간섭성(Coherency)



흡수와 자발방출



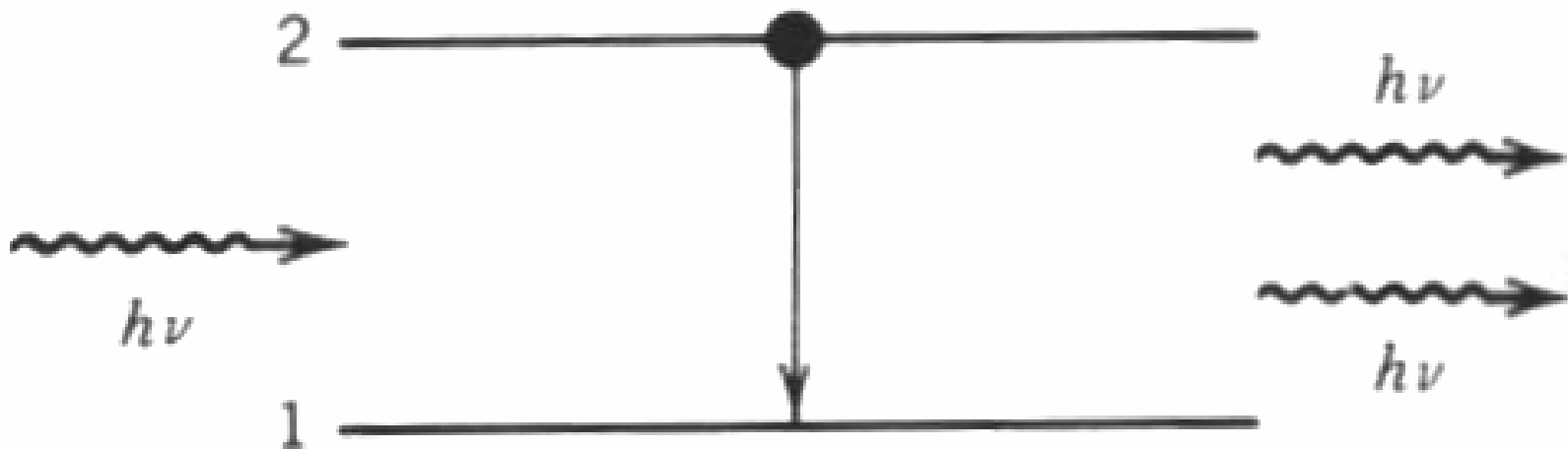
흡수(Absorption)



자발방출
(Spontaneous
Emission)

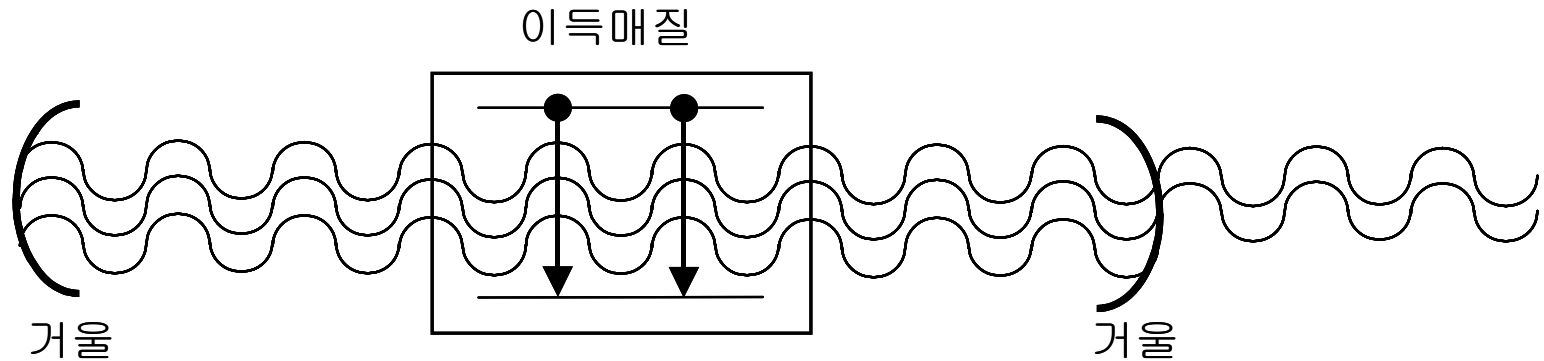


유도방출 (Stimulated Emission)



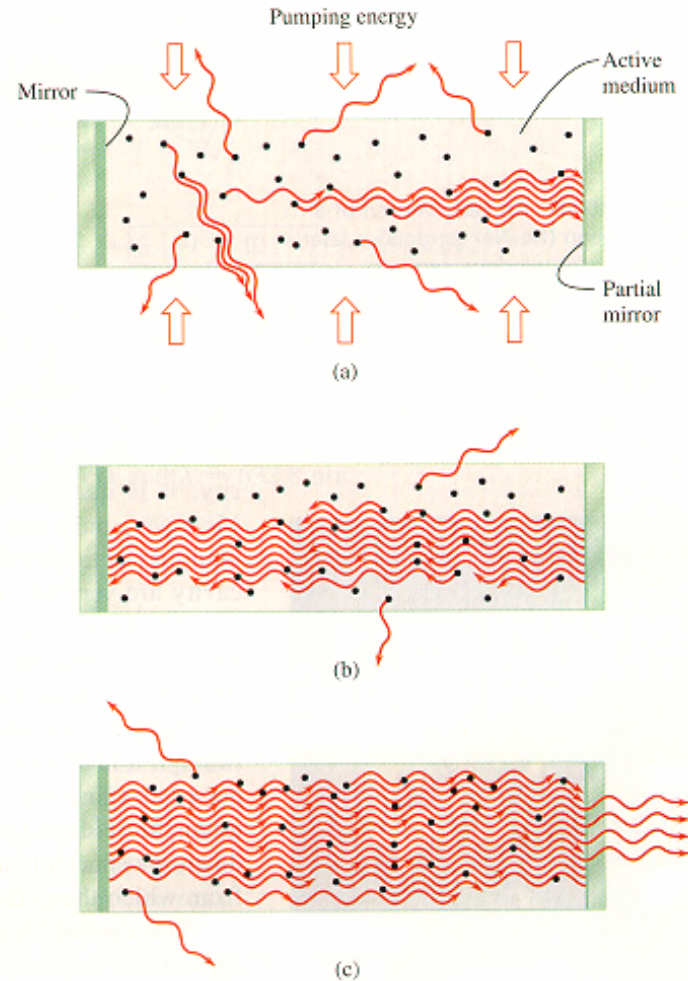
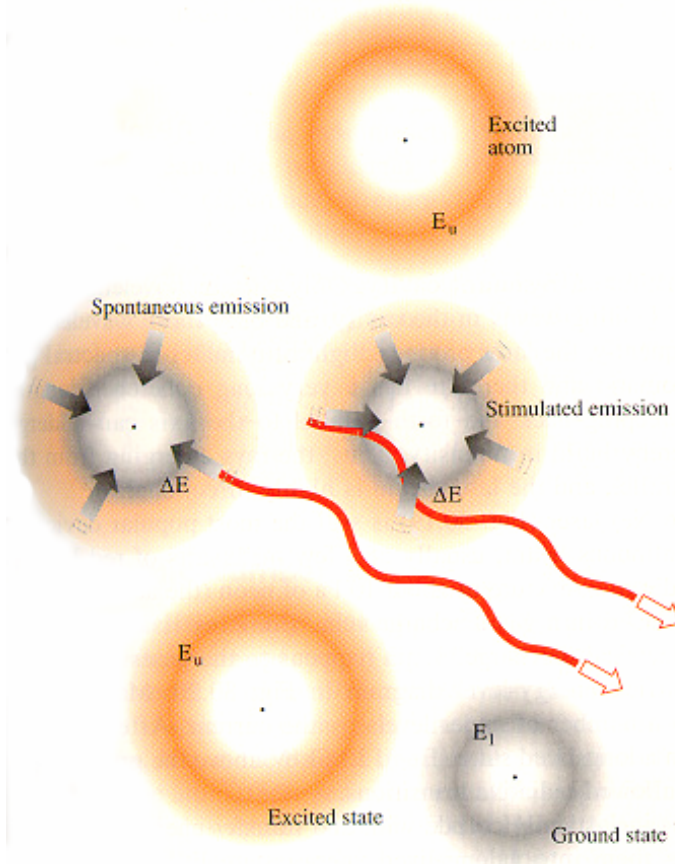
LASER

Light Amplification by Stimulated Emission of Radiation

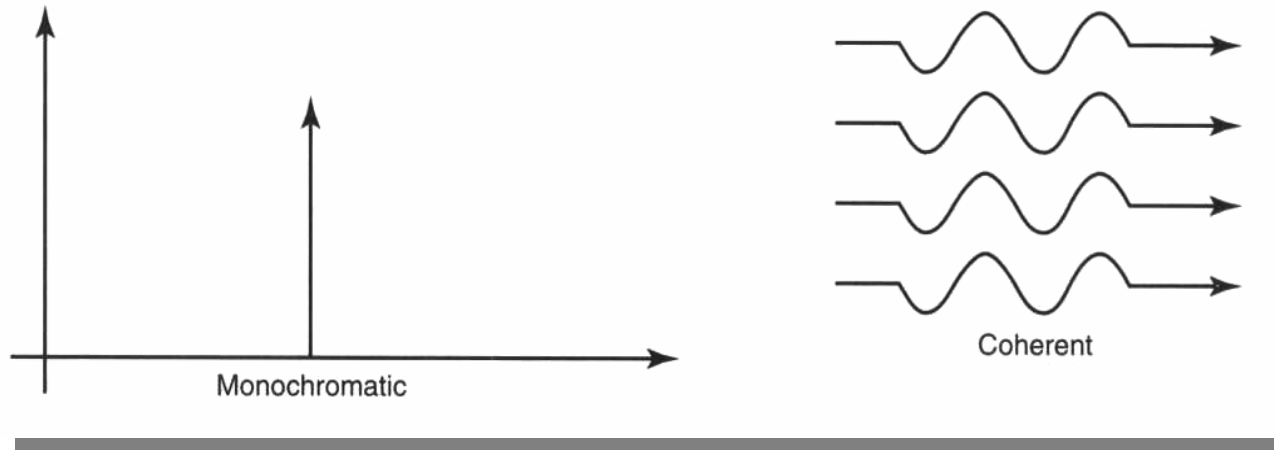


- 양자역학적인 광자와 물질사이의 상호작용을 이용한 광원

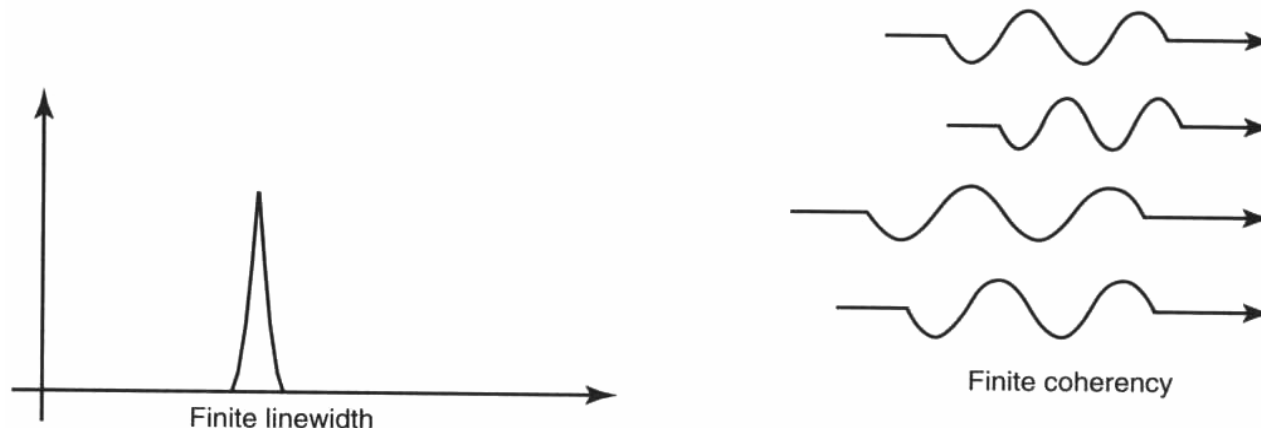
LASER의 개략도



Coherency



An ideal monochromatic source of light has a group of photons with exactly one frequency.
An ideal coherent source of light has a group of photons with the same relative phase.



Real laser sources are neither perfectly monochromatic nor perfectly coherent.
A real laser will have a finite linewidth and finite coherence.



Laser의 역사

- 1917 Einstein – Stimulated Emission
- 1940s Fabrikant – 박사학위 논문
- 1950s Townes, Weber, Prokhorov, Basov – MASER
- 1954 Gordon, Townes, Zeiger – 최초의 maser
- 1957 Gould – LASER 특허출원
- 1958 Schawlow, Townes – “Infrared and Optical Masers” 논문
- 1960. 5. 16. Maiman – 최초의 레이저 동작 (Ruby laser)
- 1960. 12. 12. Javan, Bennett, Herriott – 최초의 cw 레이저 동작 (He-Ne laser)
- ... laser flood



Laser가 늦게 발명된 이유

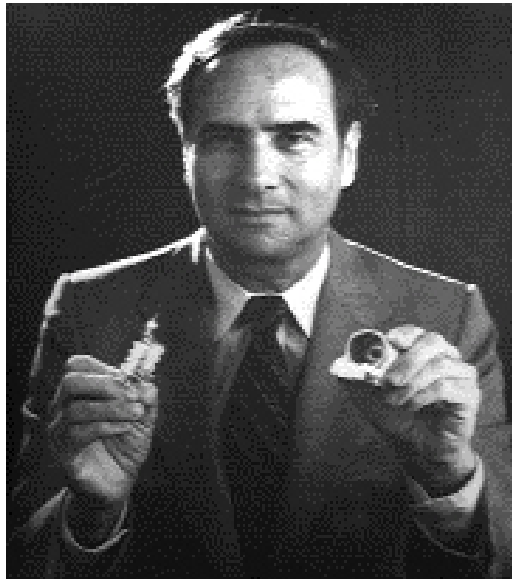


Charles H. Townes (1915-)

“대부분의 물리학자들은 전자공학과 증폭기에 대해서 몰랐었고, 전기공학자들은 대개 양자역학을 배우지 않았다. 하지만 제 2차 세계대전으로 인해 레이더 (radar) 개발을 위해 공학자들과 자연과학자들이 함께 일하게 되었고, 물리학자들이 전자공학에 접근할 수 있게 되었다.”



최초의 루비 레이저



- 최초의 레이저 : 1960년, Maiman이 만든 세계 최초의 레이저, 루비를 레이저 매질로 사용



Theodore Harold Maiman
1927-2007

Theodore Maiman, who demonstrated the world's first laser in May 1960, passed away on May 5, 2007, at the age of 79.

Other groups had already started trying to build lasers when Maiman decided to tackle the problem in mid-1959. He owed his quick success to a particularly elegant design and a keen understanding of the properties of the material he used, synthetic ruby.

Small enough to fit in his hand, the ruby laser worked on the first try—a rarity in cutting-edge research made possible by Maiman's knowledge of physics and his knack for engineering. The ruby laser changed the course of laser development; unlike the other types being developed at the time, it concentrated its power into pulses. Engineers soon tested pulsed lasers by blasting holes in razor blades and measuring their power in "gillettes" (the number of razor blades through which the laser could burn a hole). Physicists used pulsed lasers to discover new optical effects. Charles Townes, who received the 1964 Nobel Prize in physics for developing the maser-laser principle, called Maiman's laser "an important start to a tremendously important field of science and technology."

Born in Los Angeles and raised in Denver, Colo., Maiman learned electronics from his father, Abe Maiman, an electrical engineer for AT&T Corporation. After serving in the Navy, Theodore Maiman studied engineering physics at the University of Colorado and physics at Stanford under the theoretician Willis Lamb, who received the Nobel Prize in physics in 1955, months after Maiman received his doctorate.

Maiman settled at Hughes Research Laboratories, a California aerospace contractor owned by billionaire Howard Hughes. It was a hotbed of innovation, fueled by the Cold War military budget and powered by a staff of bright, intense and often colorful scientists. To keep ideas simmering, Hughes lured the famed physicist Richard Feynman from Caltech to give regular seminars.

Townes earlier had invented the maser, a microwave predecessor of the laser, at Columbia University in New York. Hughes's managers assigned Maiman to build a more practical version of the maser using microwave emission from chromium atoms in synthetic ruby crystals. An earlier version had weighed more than two tons, but Maiman built a ruby maser that weighed only two kilograms.

Maiman then turned his attention to the laser, proposed separately by Townes and Gordon Gould. Bell Labs and the Pentagon's Advanced Research Projects Agency had funded competing million-dollar programs to build lasers, but progress had stalled on the issue of finding a material that could store energy briefly, then be stimulated to emit the energy as a beam of light. Others had dismissed using ruby, claiming it didn't emit light efficiently enough. However, Maiman decided to see where the lost energy was going. He found that the earlier measurements were wrong.

Using his own data, Maiman calculated that he could make a marginal laser by illuminating a ruby rod with the most intense movie projector lamp on the market. Seeking a better demonstration, he decided to try exciting the laser with bright pulses of light, and his student assistant Charles Asawa suggested using a photographic flash lamp. Maiman then ordered three sizes of spring-shaped flashlamps, and started tests on the smallest. He inserted a fingertip-sized ruby rod inside the coiled lamp, then sealed the lamp and rod inside a machined aluminum cylinder.

Maiman and his assistant Irnee D'Haenens hooked up a power supply and measured pulses as they slowly cranked up the voltage. They saw the red ruby pulses suddenly grow brighter as the power crossed the threshold for producing a laser beam. It was a moment of triumph after months of intense effort.

Maiman presented an important report on the laser at an OSA meeting in fall 1960 [(paper TC1, "Stimulated optical emission in ruby," JOSA 50, p. 1134 (Nov. 1960)]; this may have been his first description of a laser at a scientific conference.

Maiman left Hughes less than a year after making the first laser, founding a company called Korad, which he headed for several years before being bought out. He later was a consultant for the aerospace firm TRW.

Throughout his career, Maiman received several scientific awards, including the Fannie and John Hertz Science Award, the 1984 Wolf prize, and the 1987 Japan prize. In 1976, Maiman received OSA's R.W. Wood Award, which recognizes outstanding discovery, scientific or technical achievement, or invention.

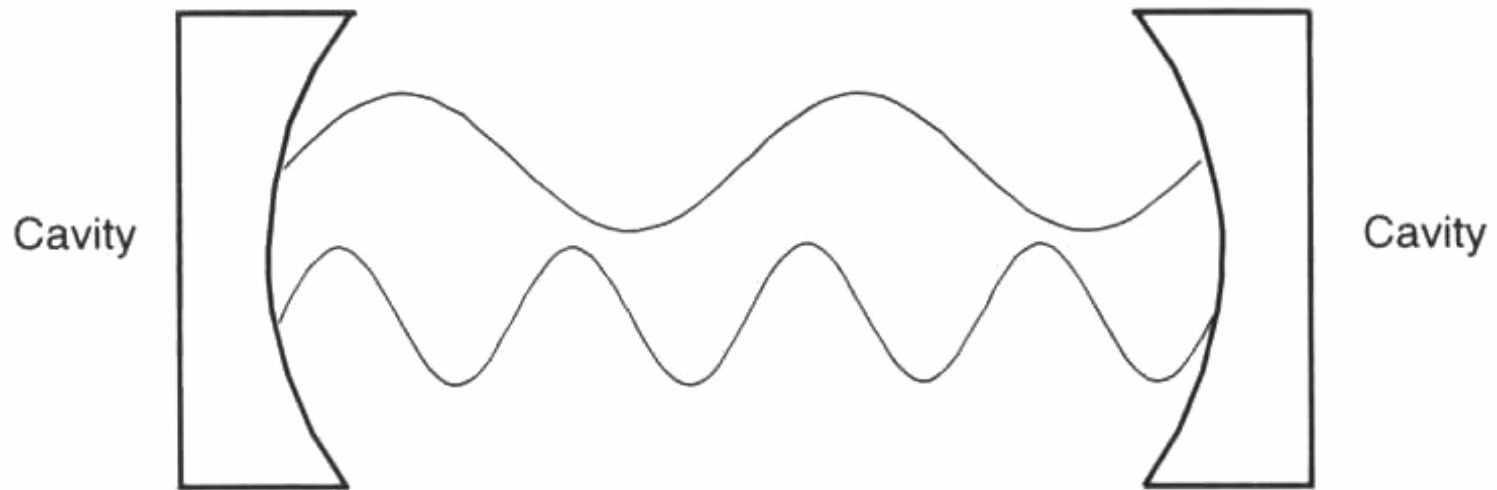
He was twice nominated for the Nobel Prize and was given membership in both National Academies of Science and Engineers. He received the 1983/4 Physics Prize and was inducted into the National Inventors Hall of Fame.

--Jeff Hecht

This tribute is adapted from an obituary that was published May 9, 2007, in the British newspaper The Independent.



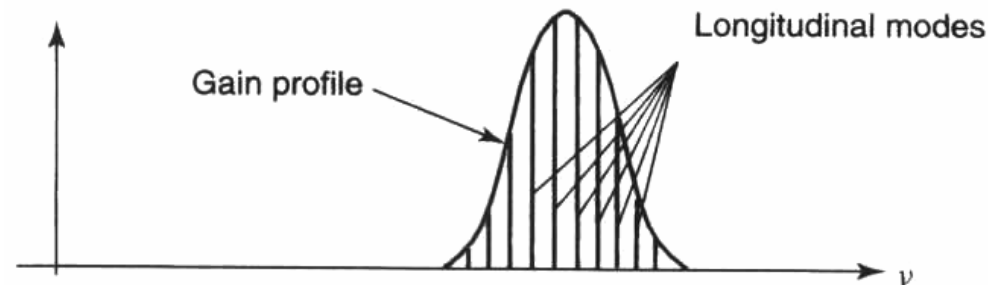
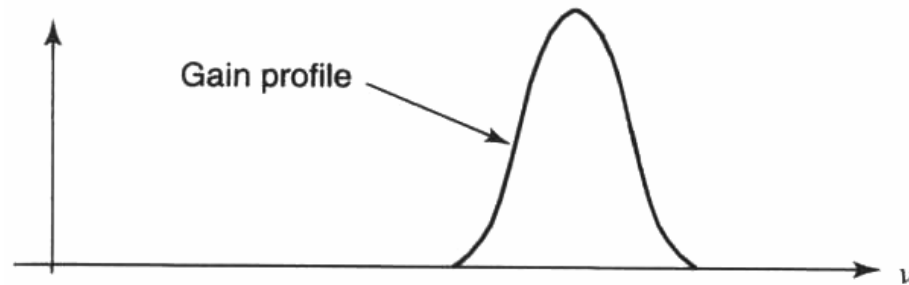
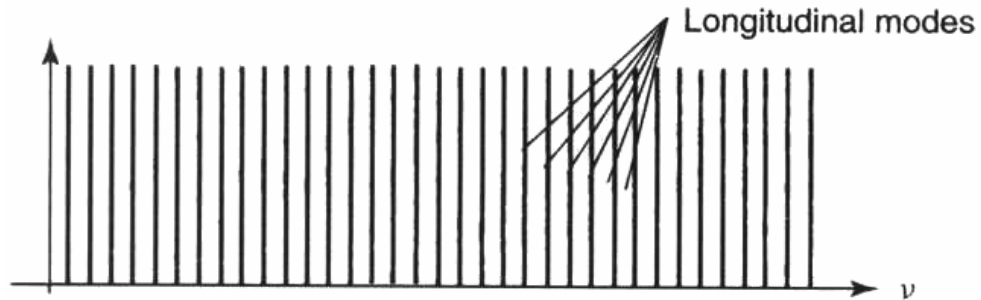
Laser Oscillation (I)



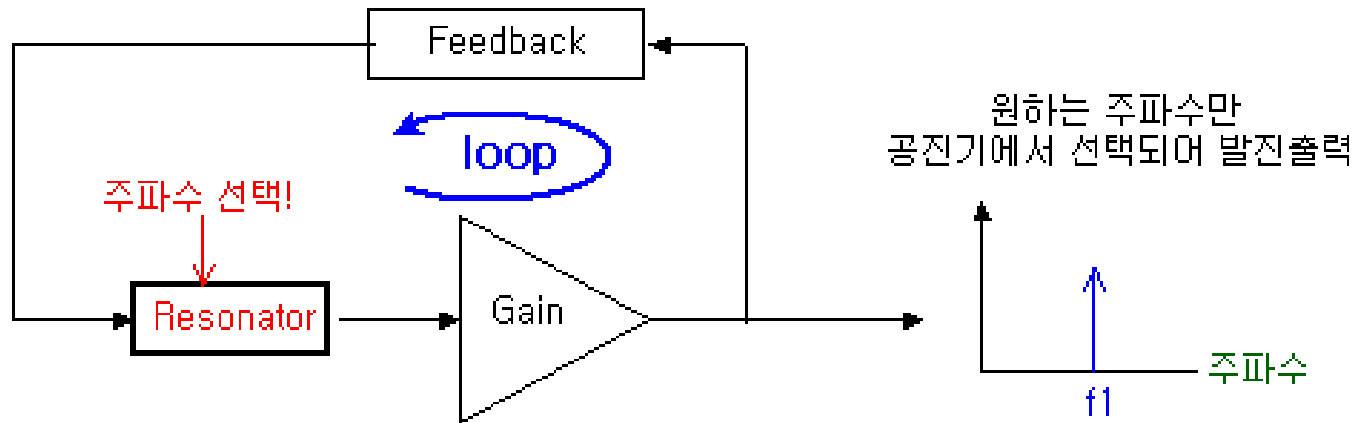
A laser can only lase at those wavelengths (longitudinal modes) for which an integral multiple of half-wavelengths fit into the cavity.



Laser Oscillation (II)

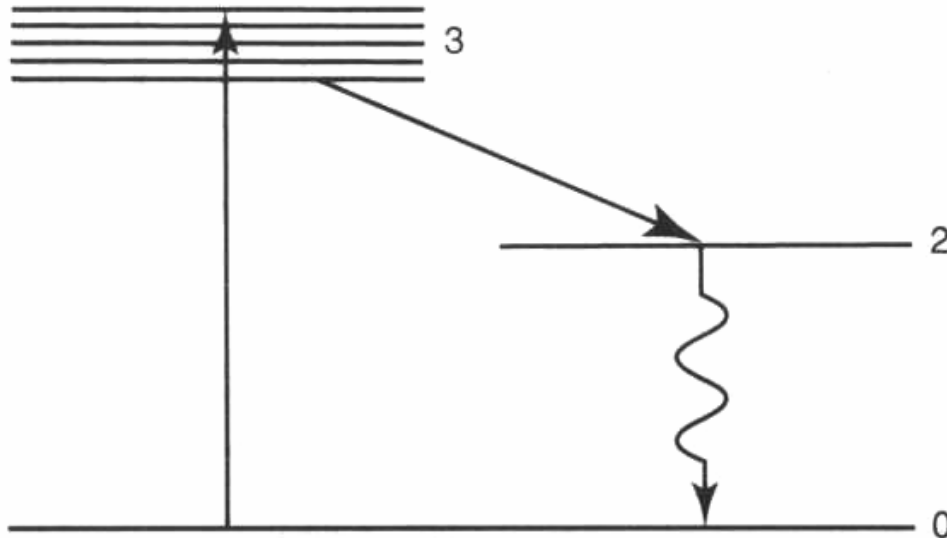


발진 회로와의 비교

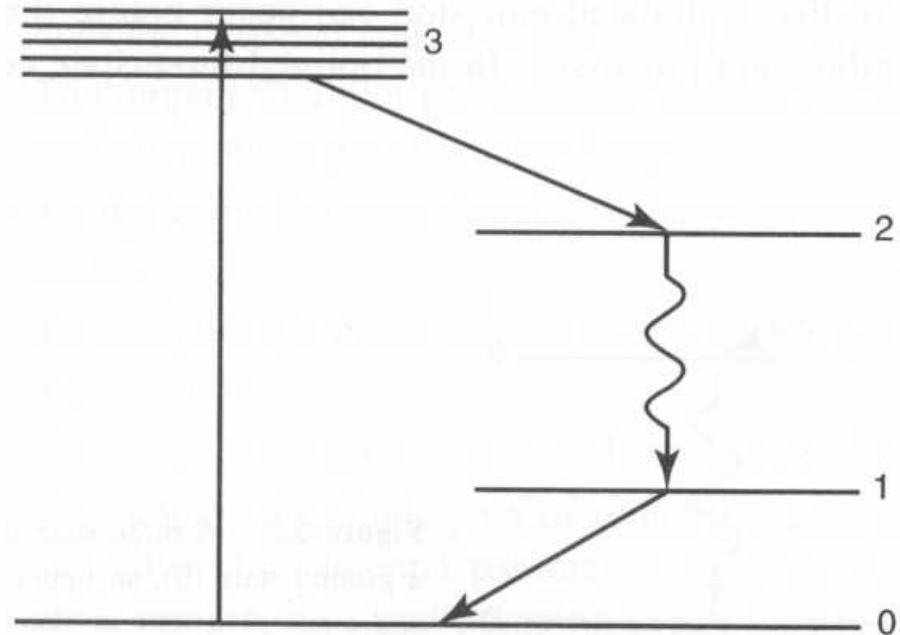


- Gain = 이득매질
- Feedback & 주파수선택 = 공진기 (거울)

3-준위 및 4-준위 레이저



A three-state laser consists of a ground state(0), an upper laser state(2), and a pumping state or states(3).



A four-state laser consists of a ground state 0, a pumping state(or band of states) 3, an upper laser state 2, and a lower laser state 1.



레이저 안전등급

	Hazard	Control
Class 1	The output is so low that the laser is inherently safe Or The laser is totally enclosed and it is safe by engineering design.	No control other than labelling
Class 2	These are visible CW and pulsed lasers where the protection can be afforded by the blink reflex of 0.25 s.	The laser head must be labeled. The beam should be terminated. No beams at eye level.
Class 3A	Class 2 is extended to exclude viewing with optical instruments.	Extra caution than class 2.
Class 3B*	This is a sub-class of 3B confined to visible lasers with less than 5 mW CW output.	Treated like 3A.
Class 3B**	Eye hazard from intra-beam viewing and from specular reflections.	A designated laser area and interlocks must be used. Eye protection required for exposed beams. Beam terminated.
Class 4	Hazard from diffuse reflection and possibly to skin	As for Class 3B** Protective clothing recommended.

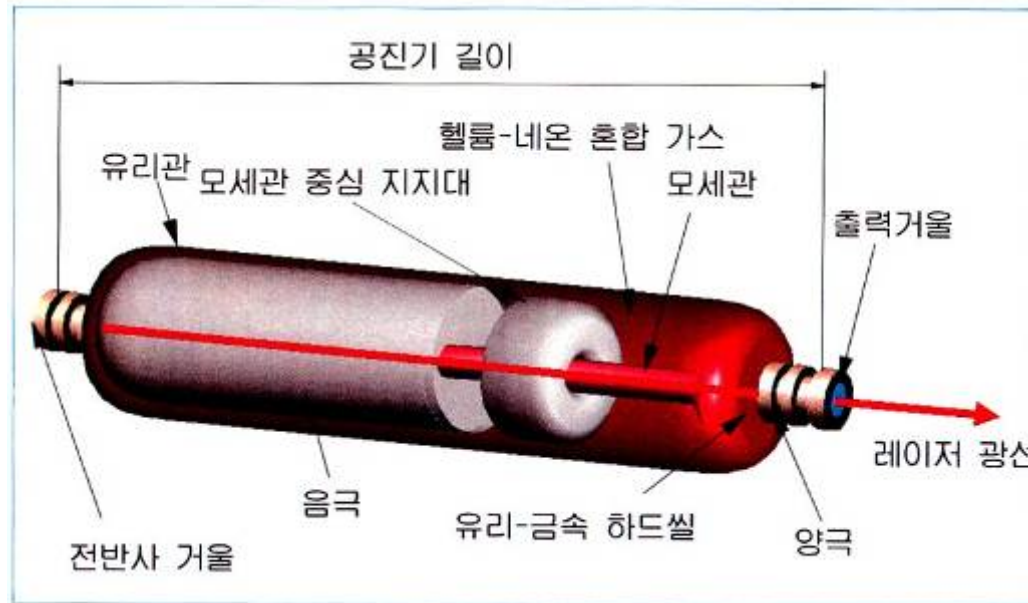


레이저의 종류

- 매질의 종류에 따라
 - 고체 : 루비 레이저, Nd:YAG 레이저, Ti:Sapphire 레이저, 광섬유 레이저, ...
 - 기체 : 탄산가스 레이저, 헬륨-네온 레이저, 아르곤 이온 레이저, 엑시머 레이저, ...
 - 기타 : 색소 레이저, 자유전자 레이저
- 발진 종류에 따라
 - 연속파(cw: continuous wave) 레이저
 - 펄스 레이저: ~ 펨토초 레이저 상용화
- 파장에 따라
 - 가시광선, 적외선, 자외선, ~X-ray



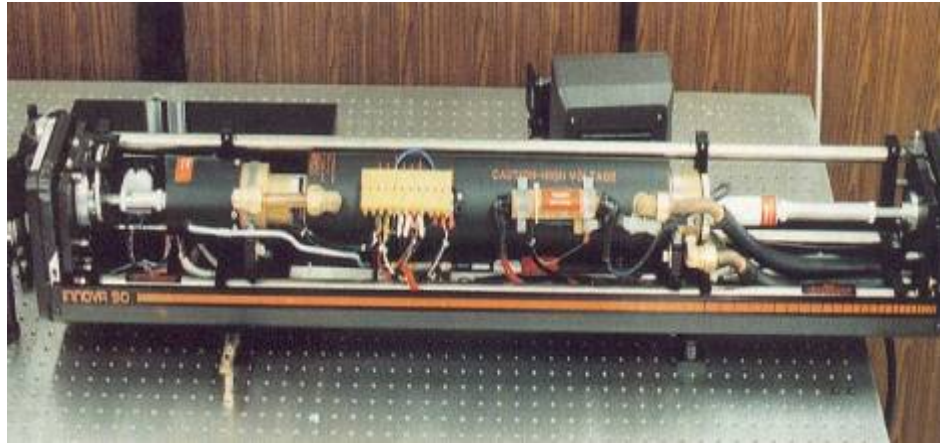
He-Ne Laser



- 1961년 Javan, Bennett, Herriott 세 사람은 헬륨(He)과 네온(Ne)의 혼합기체를 이용하여 최초로 1152.3nm의 적외선의 연속발진에 성공
- 오늘날에는 이 레이저는 수 밀리와트의 가시광선(632.8nm)을 발진하게 하여 실험실에서 간섭을 이용한 측정, 홀로그래피의 제작등에 널리 쓰고 있다.
- 0.8 torr의 He과 0.1 torr의 Ne의 혼합기체를 가늘고 긴 관속에 넣어두고 방전시킨다. 헬륨은 네온을 들뜨게 하는 매개물질로서 작용하여 실제의 발진은 네온에서 이루어진다.



Argon Ion Laser의 특징



- Ar-Ion레이저는 가스레이저로서 He-Ne 레이저와 유사
- Ar-Ion 레이저는 전리(ionization)와 여기(excitation)을 위하여 대단히 높은 전류가 인가되어야 한다.
- Blue-green범위에서 100W 이상을 공급할 수 있다.
- 이온레이저는 고전류 방전으로 여기되는데 높은 전류밀도는 기체를 이온화시키고 이온들을 고준위로 여기시킨다.
- 상위 레이저 준위가 36 eV로 매우 높다. ⇒ 강력한 여기가 필요하다.



Nd:YAG Laser의 특징



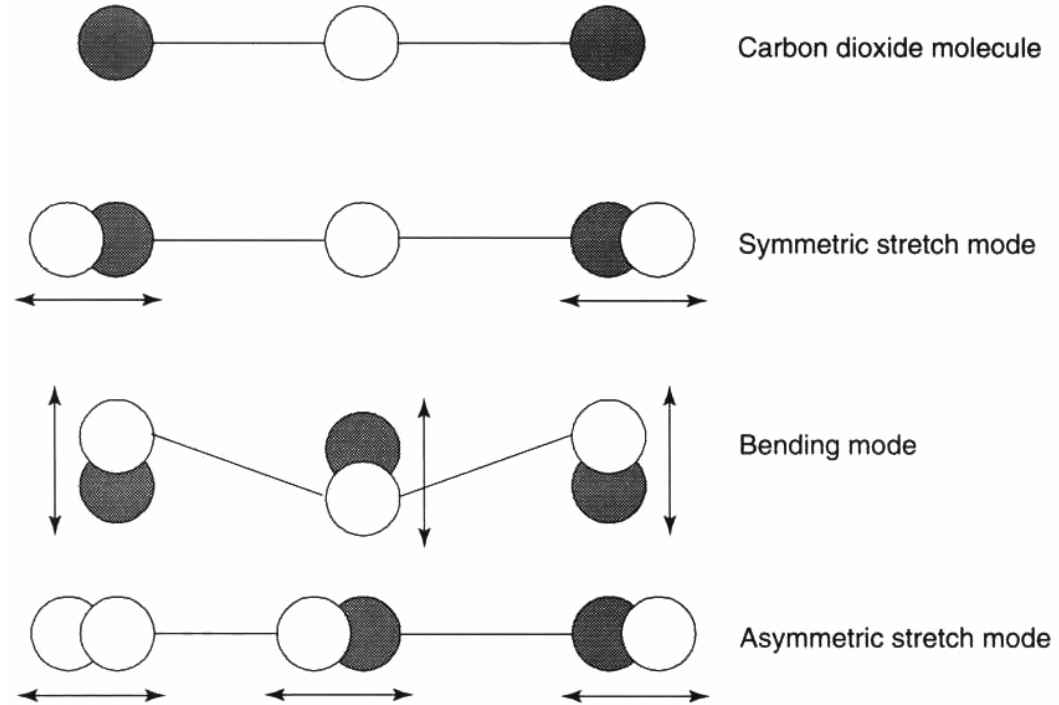
- YAG(yttrium aluminum garnet) 결정 안의 Nd가 레이저 물질
- Nd:YAG 레이저는 100W 이하의 연속파 혹은 수 MW의 짧은 펄스를 만들어내므로 응용범위가 상당히 넓다.
- 외부광원에 의해 여기
- 레이저 용접, 의료용, 핵융합



CO₂ Laser



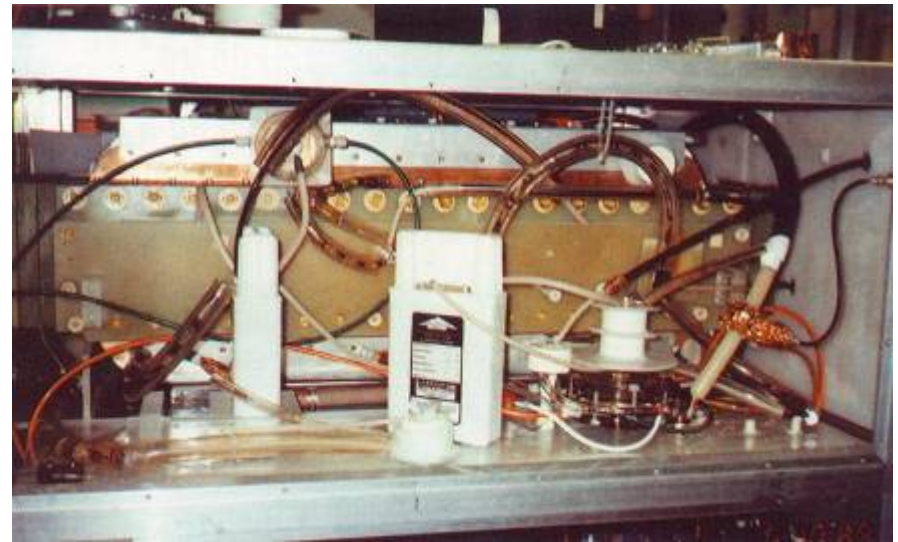
Carbon dioxide laser cutting system.



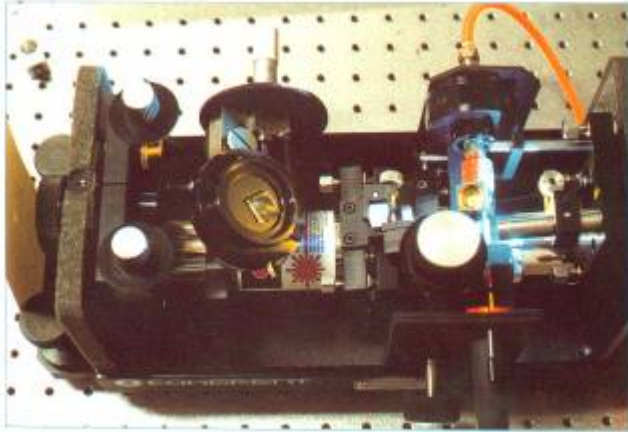
Normal modes of the carbon dioxide molecule.



Excimer Laser의 내외부



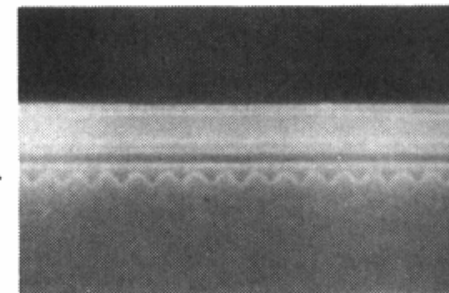
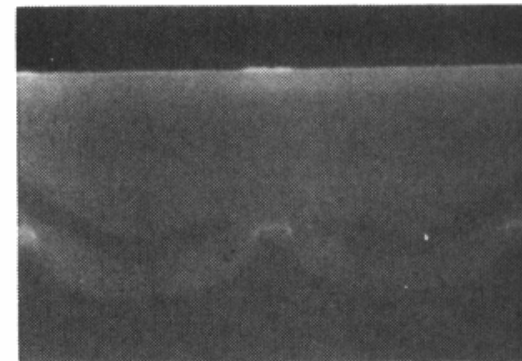
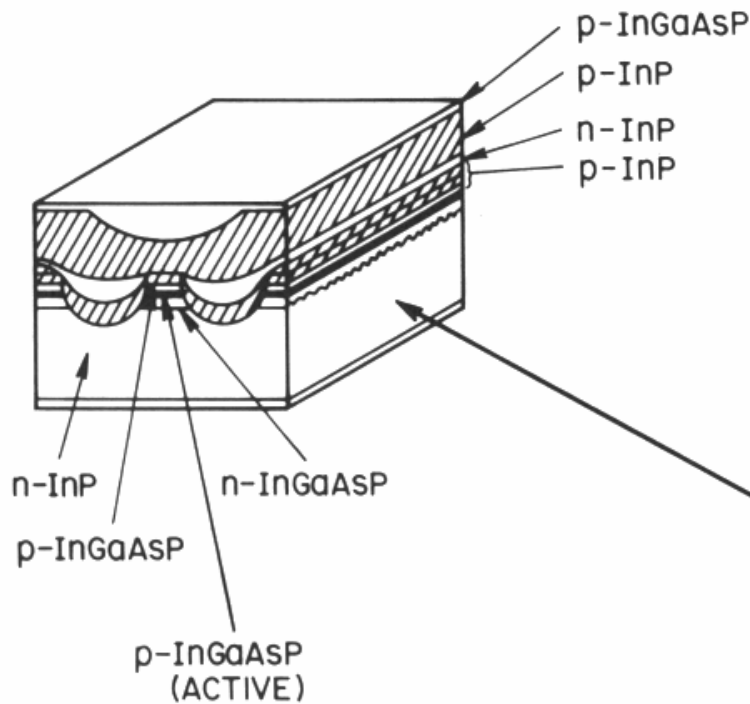
Dye Laser



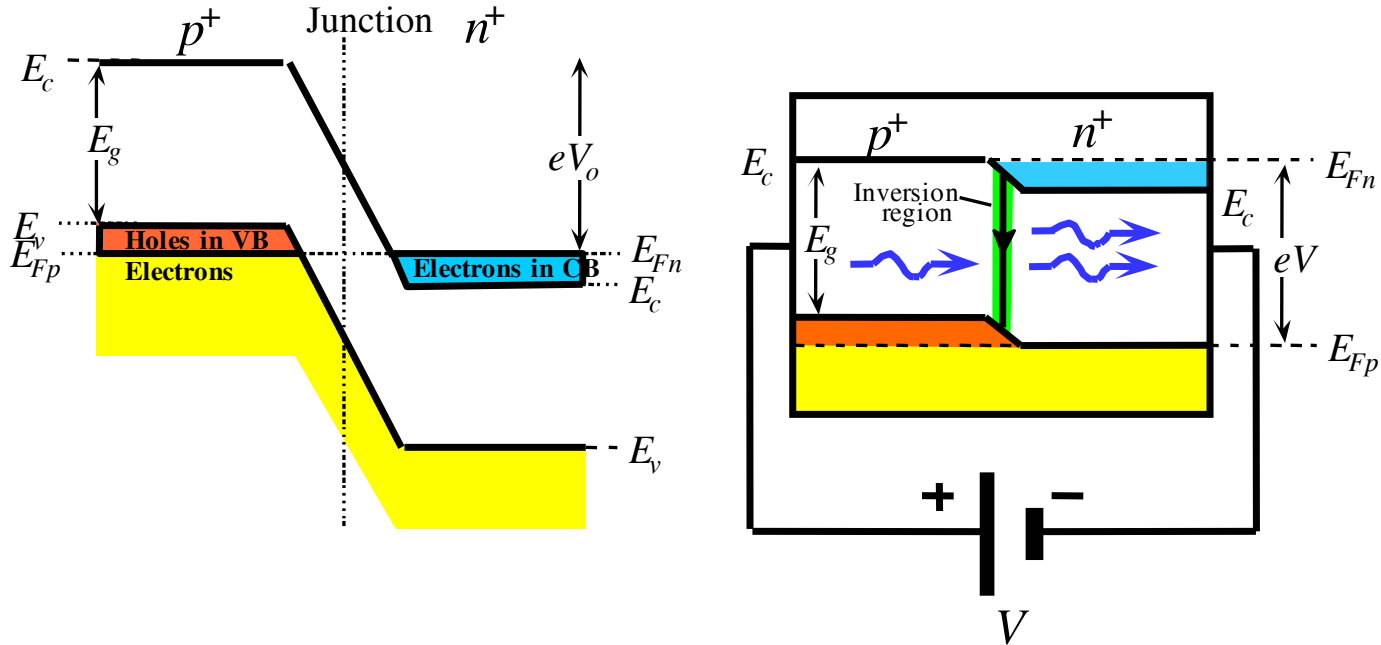
- 색소 레이저는 유기 색소 분자를 알코올 등에 용해 시켜 레이저 매질로 사용
- 액체 레이저
- 색소의 종류나 농도를 변화시켜, $0.3\mu\text{m} \sim 1.2\mu\text{m}$ 범위의 근자외선, 가시광, 근적외선의 넓은 범위에 걸쳐 연속 파장가변이 되는 레이저가 가능하다.
- 광여기 방법
- 극초단 펄스, 의료용



반도체 레이저 (DFB LD) 구조도



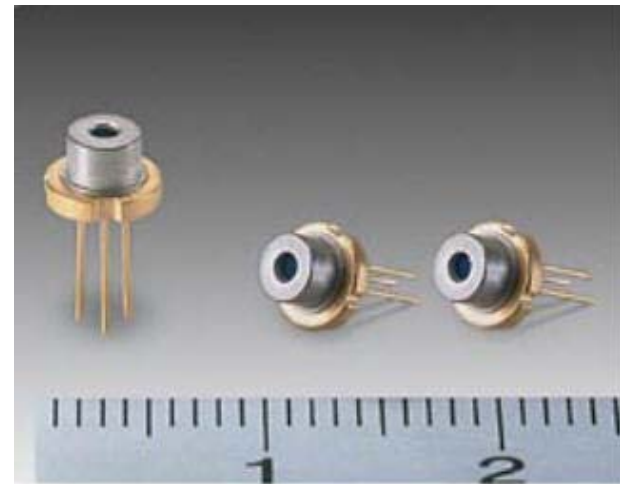
반도체 레이저의 원리



- 순방향 바이어스 pn 접합은 내부 포텐셜 (potential) 장벽을 낮추어서 접합의 한쪽에서 다른 쪽으로 전자를 흐르도록 만든다. 전자-홀 재결합을 하면서 전자가 전도띠 (conduction band) 에서 원자가띠 (valence band) 로 떨어질 때 밴드갭 (band gap) 에 해당하는 에너지가 광자로 방출된다.
- LED에서는 자발방출이 일어나지만 레이저 다이오드 (LD)에서는 유도방출이 일어나도록 제작된다.

반도체 레이저의 응용

- CD, DVD, 광통신, 의료용
- 현재 가장 수요가 많은 반도체 레이저는 780nm 파장대의 것으로 CD 구동장치의 광원으로 가장 많이 이용되고 있고, 800nm 대의 것은 Nd:YAG 레이저의 여기광원과 의료용으로, 1.3 μm 와 1.5 μm 의 레이저는 주로 광통신용으로 이용되고 있으며 최근 상품화가 된 670nm 대의 것은 헬륨-네온 레이저를 대신하는 용도로 사용



광섬유 레이저의 예

- Yb-doped double-clad fiber
 - Core diameter: 9 μm
 - NA: 0.11
 - Inner-cladding diameter: 150 μm
 - Low index coating: outer cladding
 - Cladding pump absorption: 0.8 dB/m
 - Fiber length: 10 m

