LASER

EINSTEINS EQUATIONS (OR) EINSTAINS CO- EFFICIENTS :

It is the expression for probability for stimulated emission of radiation to the probability for spontaneous emission of radiation under thermal equilibrium.
Let us consider E_1, E_2 be the energy states and N_1, N_2 be the no of atoms per unit volume .

N_2 ———————————— E_2

N_1 ———————————— E_1

Let $\rho(\upsilon)d\upsilon$ is the radiation energy per unit volume between the frequency range of υ and $\upsilon+d\upsilon$

ABSORPTION:
An atom in the lower energy state E_1 can absorb radiation and get excited to the state E_2

The probability of rate of occurrence of absorption transition $1\rightarrow2$ would be proportional to N_1 and $\rho(\nu)$

$\therefore$The number of atoms under going absorption per unit volume per second from level E_1 to E_2

$$N_a = N_1\,\rho(\upsilon)B_{12}$$

Where B12 represents probability of absorption per unit time. It is known as Einstein's co-efficient of absorption probability per unit time

STIMILATED EMISSION:
When an atom makes transition E_2 toE_1 in the presence of external photon whose energy equal to (E_2-E_1) then stimulated emission takes place .
The probability of rate of occurrence of absorption transition $2\rightarrow1$ would be proportional to N_2 and $\rho(\nu)$

$\therefore$The number of stimulated emission per unit volume per second from levels E_2 to E_1

$$N_{st} = N_2\,\rho(\upsilon)\,B_{21}$$

B_{21} is represents probability of stimulated emission per unit time. It is known as Einstein's co-efficient of stimulated emission probability per unit time

SPONSTANEOUS EMISSION: An atom in the level E_2 can also make a spontaneous emission by jumping in to lower energy level E_1.
The probability of rate of occurrence of absorption transition $2 \rightarrow 1$ would be proportional to N_2

$\therefore$ The number of spontaneous emission per unit volume per second from levels E_2 to E_1

$$N_{sp} = N2A_{21}$$

A_{21} represents probability of spontaneous emission per unit time. It is known as Einstein's co-efficient of stimulated emission probability per unit time

Under steady state $(dN / dt) = 0$

$\therefore$ No of atoms under going absorption per second = no of atoms under going emission per second

$$\therefore\ N_1 \rho(\upsilon) B_{12} = N_2 \rho(\upsilon) B_{21} + N_2 A_{21}$$

$$N_2 A_{21} = N_1 \rho(\upsilon) B_{12} - N_2 \rho(\upsilon) B_2$$

$$= \rho(\upsilon)(N_1 B_{12} - N_2 B_{21})$$

$$\Rightarrow \rho(\upsilon) = N_2 A_{21} / (N_1 B_{12} - N_2 B_{21})$$

$$= A_{21} / [(N_1 / N_2) B_{12} - B_{21})]$$

$$= (A_{21} / B_{21}) [1 / \{(N_1 / N_2)(B_{12} / B_{21})\} - 1] \quad \rightarrow (1)$$

Since , from law of distribution we know that

$N_1 / N_2 = \exp(E_2 - E_1) / k_B T = e^{h\upsilon / kT}$ Here $K_B = K$ & $(E_2 - E_1) = h\upsilon$

Substituting N1 / N2 in equation 1

We get

$$\rho(\upsilon) = (A_{21} / B_{21}) [1 / \{(e^{h\upsilon / kT})(B_{12} / B_{21})\} - 1] \quad \rightarrow (2)$$

From Planck's radiation formula

$$\rho(\upsilon) = (8\pi h\nu^3 / c^3) [1 / (e^{h\upsilon / kT}) - 1] \quad \rightarrow (3)$$

from equation (2) and (3)

$$(A_{21} / B_{21}) = (8\pi h\nu^3 / c^3)$$

$$(B_{12} / B_{21}) = 1$$

For stimulated emission to be predominant, we have

$$A_{21} / B_{21} << 1$$

POPULATION INVERSION:

Under ordinary condition s of thermal equlibrium, The no of atoms in higher energy level is less than the no of atoms in lowest energy level. So that there is negligible Stimulated emission compared with absorption.

By some means, if the number of atoms in higher energy state be made sufficiently larger than the number of atoms in lower energy state, then the stimulated emission is promoted.

The situation in which the number of atoms in higher energy state exceeds the number of atoms in lower energy state is known as Population inversion

A light photon (frequency ν) is incident on an atom which is already in excited energy state E_2 This atom decays to a lower energy state E_1, emitting a photon of frequency ν . the emitted photon is in perfect coherence .

If these two photons are incident on two other atoms in the state E_2 then they give rise to the emission of two more photons. Thus resulting in four coherent photons. This process continues and the intencity of light beam increases exponentially. This increase in intensity is known as "Light Amplification"

Population inversion is achieved by pumping the atoms from the ground level to the higher energy level through optical (or) electrical pumping.

The method of raising the particles from lower energy state to higher energy state is called "Pumping".

Different methods of atomic excitations are adopted in different types of LASER

1. Excitation by Strong source of light – optical pumping
2. Excitation by electron impact – electrical pumping
3. Excitation by Chemical reaction –Chemical pumping
4. Excitation by Supersonic gas expansion – gas dynamic pumping etc.

The states of system, in which the population of higher energy state is more in comparison with the population of lower energy state, are called "Negative temperature state".

A system in which population inversion is achieved is called as an active system.

DIFFERENMT TYPES OF LASES:

1. Solid state laser - Ruby laser, Nd-YAG laser
2. Gas laser - He-Ne laser, CO2 laser
3. Semi conductor laser - GaAs laser

RUBY LASER:

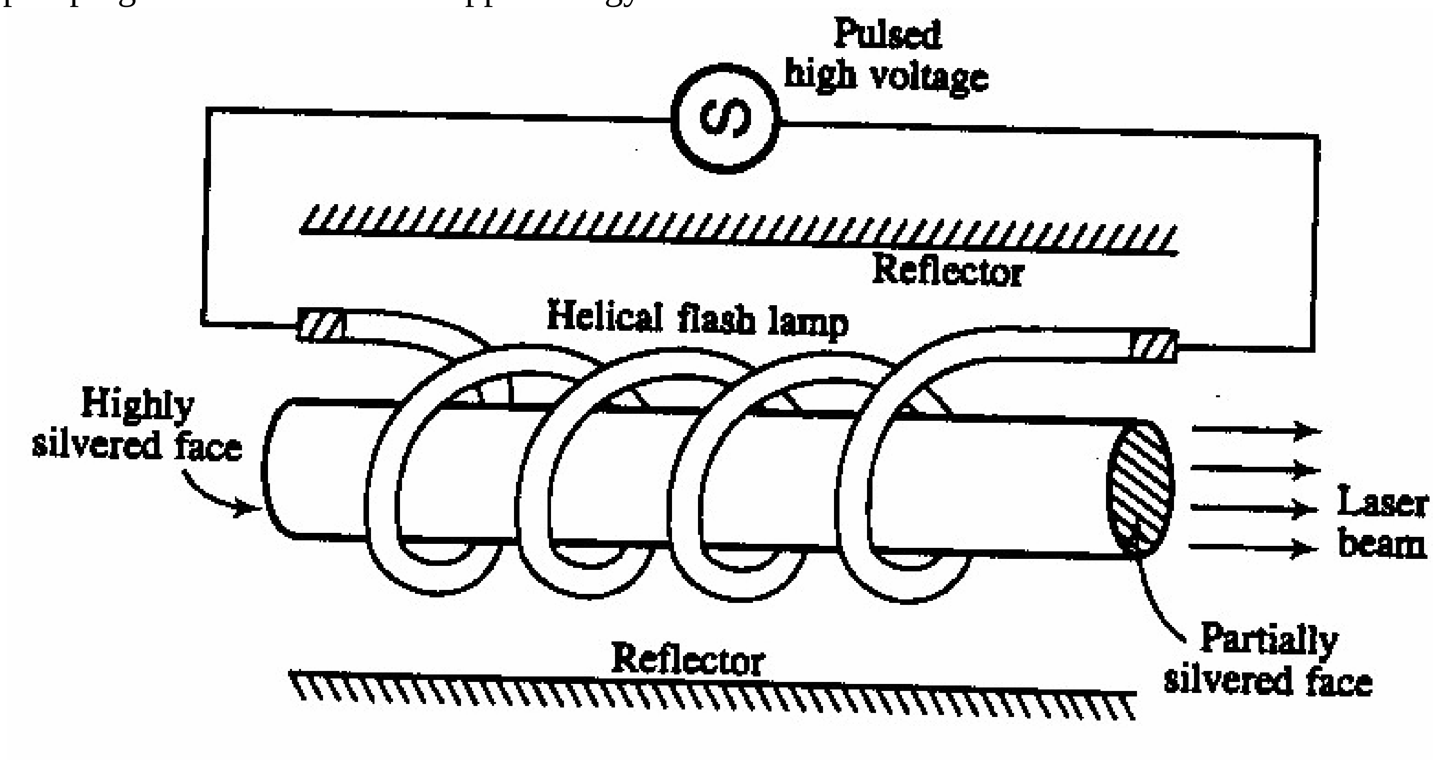
Ruby laser is a three level solid state laser having very high power of hundreds of mega watt in a single pulse it is a pulsed laser.

The system consists of mainly three parts

1) ***ACTIVE MATERIAL:*** Ruby crystal in the form of rod.
   Ruby → Crystalline Al_2O_3 + Cr (0.05%)
2) ***RESONANT CAVITY:*** A fully reflecting plate at the left end of the ruby crystal and partially reflecting end at the right side of the ruby crystal both the surfaces are optically flat and exactly parallel to each other.
3) ***EXCITING SYSTEM:*** A helical xenon flash tube with power supply source.

CONSTRUCTION: In ruby laser, ruby rod is a mixture of Al_2O_3+Cr_2O_3. It is a mixture of Aluminum oxide in which some of ions Al^{+3} ions concentration doping of $Cr^{+}3$ is about 0.05% , then the colour of rod becomes pink. The active medium in ruby rod is Cr^{+3} ions.

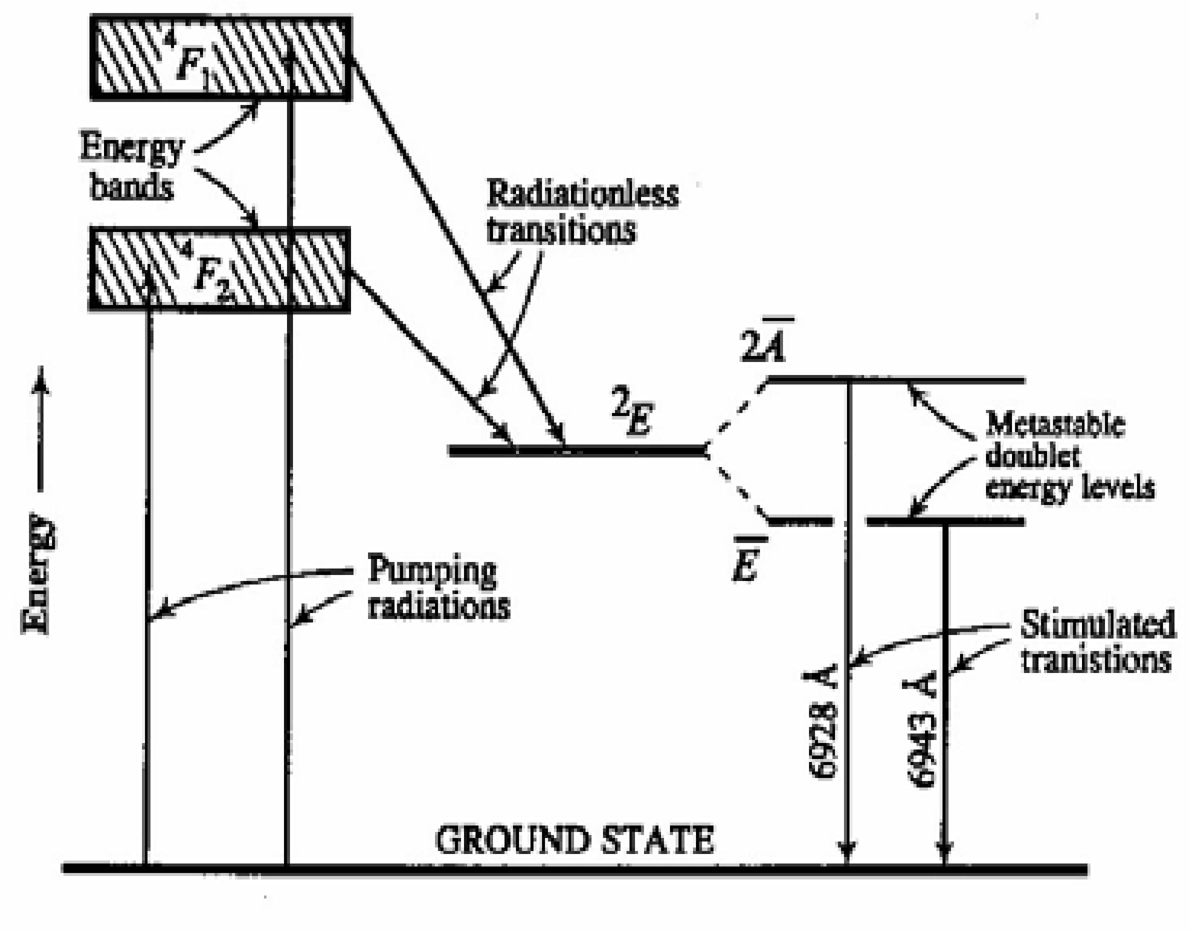
The length of the ruby rod is 4cm and diameter 5mm and both the ends of the ruby rod are silvered such that one end is fully reflecting and the other end is partially reflecting.
The ruby rod is surrounded by helical xenon flash lamp tube which provides the optical pumping to raise Cr^{+3} ions to upper energy level.



RUBY LASER

The chromium atom has been excited to an upper energy level by absorbing photons of wave length 5600A^0 from the flash lamp. Initially the chromium ions (Cr^{+3}) are excited to the energy levels E_1 to E_3 , the population in E_3 increases.
Since the life time of E_3 level is very less (10^{-8}Sec). The Cr^{+3} ions drop to the level E_2 which is matastable of life time 10^{-3}Sec.The transition from E_3 to E_2 is non-radiative.
Since the life time of metastable state is much longer, the no of ions in this state goes on increasing hence population inversion achieved between the excited metastable state E_2 and

the ground state E_1.



ENERGY LEVEL DIAGRAM OF Cr^{+++} IN A RUBY CRYSTAL

When an excited ion passes spontaneously from the metastable state E_2 to the ground state E_1. It emit a photon of wave length $6993A^0$ this photon travel through the ruby rod and if it moving parallel to the axis of the crystal and it is reflected back and forth by the silver ends until it stimulates an excited ion in E_2

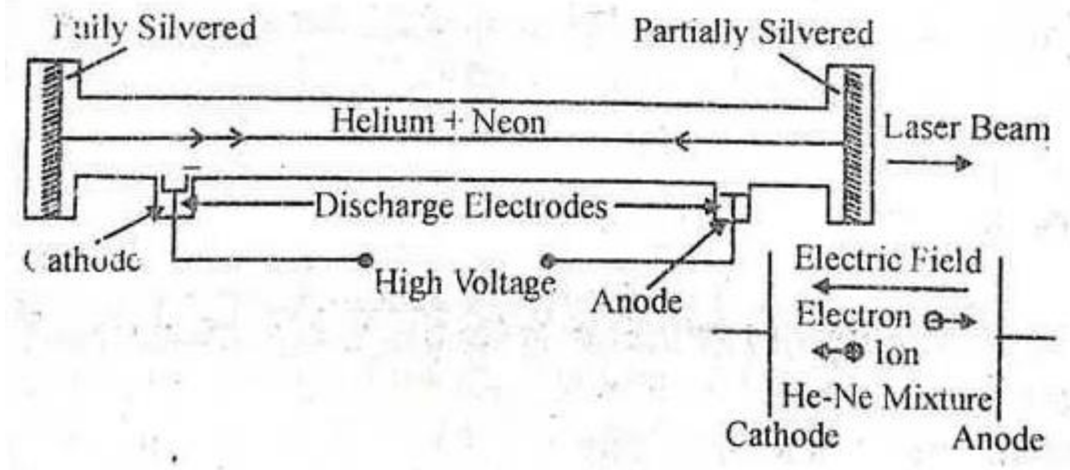
The emitted photon and stimulated photon are in phase the process is repeated again and again finally the photon beam becomes intense; it emerges out through partially silvered ends. Since the emitted photon and stimulating photon in phase, and have same frequency and are traveling in the same direction, the laser beam has directionality along with spatial and temporal coherence.

IMPORTANCE OF RESONATOR CAVITY: To make the beams parallel to each other curved mirrors are used in the resonator cavity. Resonator mirrors are coated with multi layer dielectric materials to reduce the absorption loss in the mirrors. Resonators act as frequency selectors and also give rise to directionality to the output beam. The resonator mirror provides partial feedback to the protons.

He- Ne Laser

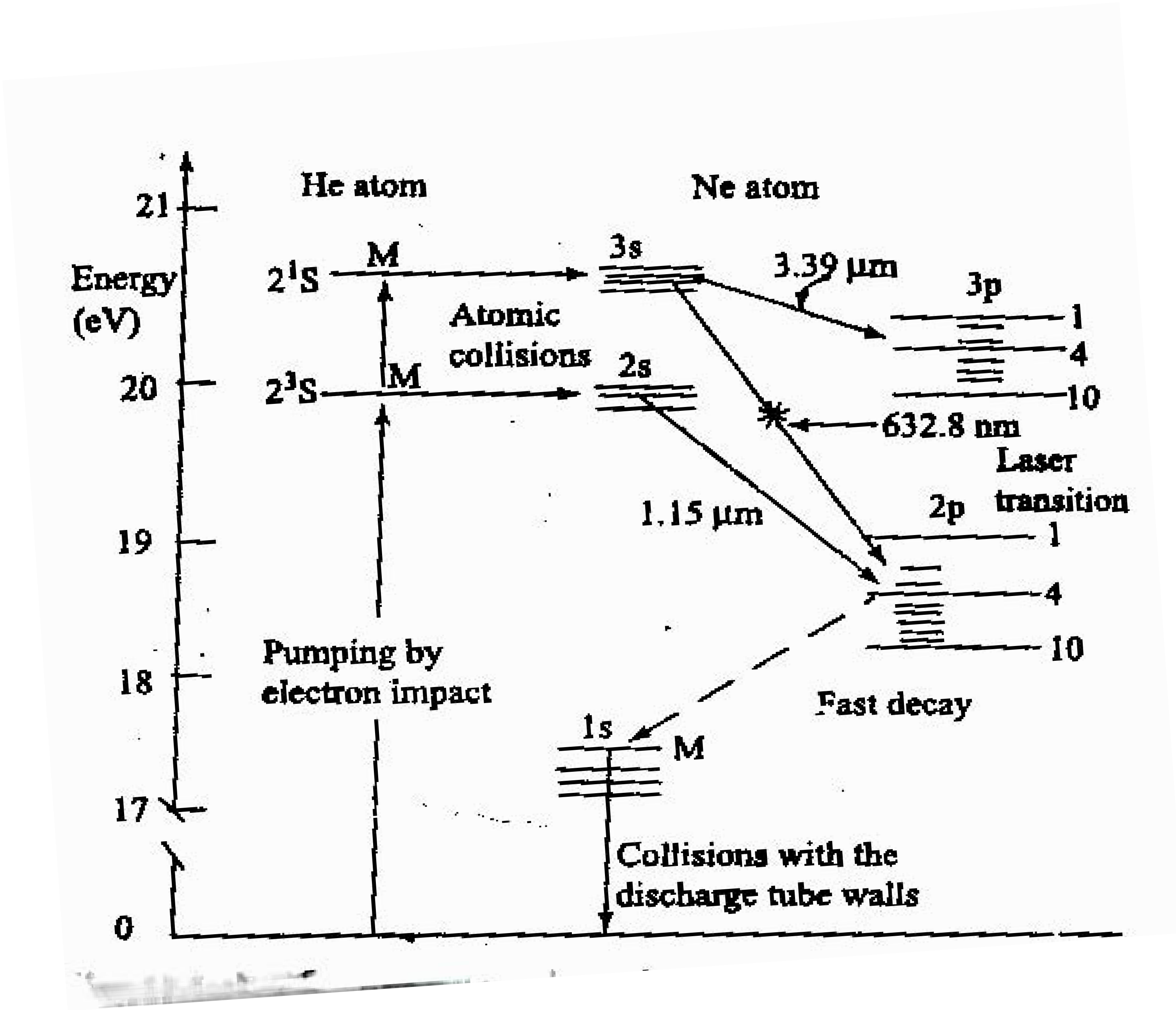
CONSTRUTION:

He - Ne gas laser consists of a gas discharge tube of length 80cm and diameter of 1cm. The tube is made up of quartz and is filled with a mixture of Neon under a pressure of 0.1mm of Hg. The Helium under the pressure of 1mm of Hg the ratio of He-Ne mixture of about 10:1, hence the no of helium atoms are greater than neon atoms. The mixtures is enclosed between a set of parallel mirrors forming a resonating cavity, one of the mirrors is completely reflecting and the other partially reflecting in order to amplify the output laser beam.



WORKING:

When a discharge is passed through the gaseous mixture electrons are accelerated down the tube these accelerated electrons collide with the helium atoms and excite them to higher energy levels since the levels are meta stable energy levels he atoms spend sufficiently long time and collide with neon atoms in the ground level E_1 . Then neon atomsare excited to the higher energy levels E_4 & E_6 and helium atoms are de excited to the ground state E_1



Since E_6 & E_4 are meta stable states, population inversion takes place at there levels. The stimulated emission takes place between E_6 to E_3 gives a laser light of wave length 6328A^0 and the stimulated emission between E_6 and E_5 gives a laser light wave length of 3.39μm. Another stimulated emission between E_4 to E_3 gives a laser light wave length of 1.15μm. The neon atoms undergo spontaneous emission from E_3 toE_2 and E_5 to E_2. Finally the neon atoms are returned to the ground state E_1 from E_2 by non-radeative diffusion and collision process. After arriving the ground state, once again the neon atoms are raised to E_6 & E_4 by excited helium atoms thus we can get continuous ou put from He-Ne laser. But some optical elements placed insides the laser system are used to absorb the infrared laser wave lengths 3.39μm and1.15μm. hence the output of He-Ne laser contains only a single wave length of 6328A0 and the output power is about few milliwatts .