- Number of pulses per second (pps), which is called frequency (f) of the pulses.
- Period (T): the time interval between two equivalent points on adjacent pulses, i.e., the time interval between two adjacent pulses. The mathematical relation between the period and frequency of the pulses is:

$$T=1/f$$

Note that, the frequency of the pulses (f) also called the pulse repetition rate (prf), has no connection to the frequency of the wave (ν) determined by its wavelength (λ).

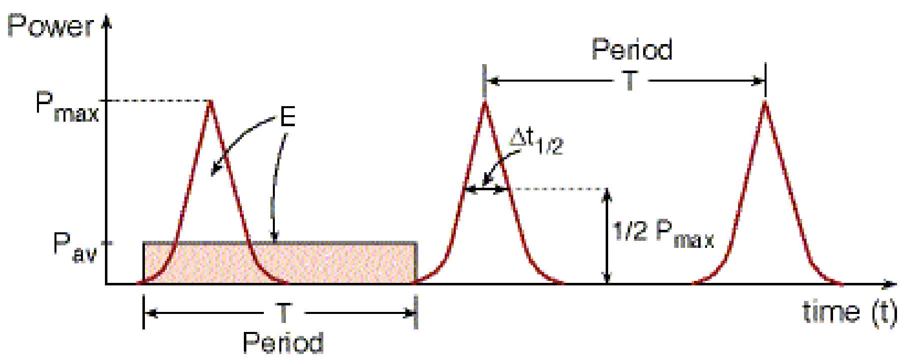



**Figure 1.5: Periodic laser pulses as a function of time.**

- Duty cycle (D.C.), is the relative part of the time that the pulse is "On" from the total time.

$$D.C.= \Delta t_{1/2}/T$$

- Average power ($P_{av}$): it is a measure of the rate at which the energy is emitted from the laser during one complete period

$$P_{av} = E_p.f = E_p/T$$

- Peak power ($P_{max}$), is the maximum emitted power and may be approximated by dividing the energy of the output pulse by pulse duration

$$P_{max} = E_p/\Delta t_{1/2}$$

Hence, the definition of the duty cycle becomes:

$$D.C= \frac{\Delta t_{1/2}}{T} = \frac{E_p/P_{max}}{E_p/P_{av}} = \frac{P_{av}}{P_{max}}$$

Energy of a single pulse **($E_P$)=** $\Delta t_{1/2} \times P_{max}$

This approximation, which is accurate for triangular pulse, is used as a good approximation for all laser pulses.

**Ex.** Q switched Nd: YAG laser produced 100 mJ in pulses. The duration of each pulse in 20 ns at prf of 10 Hz. Calculate the average power, the peak power, period and the duty cycle of this laser.

T= 1/f= 1/10= 0.1 s

$$P_{av} = E_p / T = 100 \times 10^{-3} / 0.1 = 1 \text{ W.}$$

$$P_{max} = E_p / \Delta t_{1/2} = 100 \times 10^{-3} / 20 \times 10^{-9} = 5 \text{ MW.}$$

$$D.C = \Delta t_{1/2} / T = 20 \times 10^{-9} / 0.1 = 2 \times 10^{-7}$$

Or, $D.C = P_{av} / P_{max} = 1/5 \times 10^6 = 2 \times 10^{-7}$

Now, the following parameters are also of interest:

- Power density (Irradiance): refers to the power of the laser per unit area.

  **Irradiance= power/area** $\quad (\mathbf{W/cm^2})$

- Energy density (Fluence): is the irradiance multiplied by the exposure time, measured in joules/ $cm^2$.

  $$\textbf{Fluence} = \frac{\textbf{power} \times \textbf{time}}{\textbf{area}} \qquad (\mathbf{j/cm^2})$$

## 1.7.2 Laser efficiency

The ratio between the amount of energy out to energy in is defined as the operating laser efficiency. It is common to express the laser efficiency in percent.

$$\textbf{Laser efficiency} = \frac{\textbf{Output power}}{\textbf{Input power}} \times \mathbf{100\%}$$

$$\eta = \frac{P_{out}}{P_{in}} \times 100\%$$

Most lasers have low efficiency, even as low as parts of a percent.

### 1.7.3 Operating wavelength

Lasers must be able to operate on wavelengths appropriate to the system being designed. The operating wavelength of a laser depends on the materials used for lasing and on the geometry of the laser cavity. Lasers have covered radiation at wavelength ranging from IR range to UV and even soft x−ray range.

## 1.8 Differences between different lasers

Each laser differs from another laser in one or moe of the following:

1. The output wavelength.
2. Time duration of the laser outputs ( pulsed or CW ).
3. Power output levels.
4. Operating efficiency.
5. Coupling between the active medium and the pumping source.
6. Cooling system.

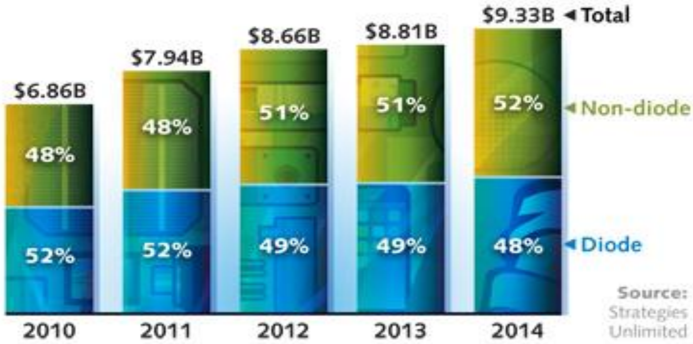
## 1.9 Choosing the right laser

The choice of laser for any application depends upon the specific needs:

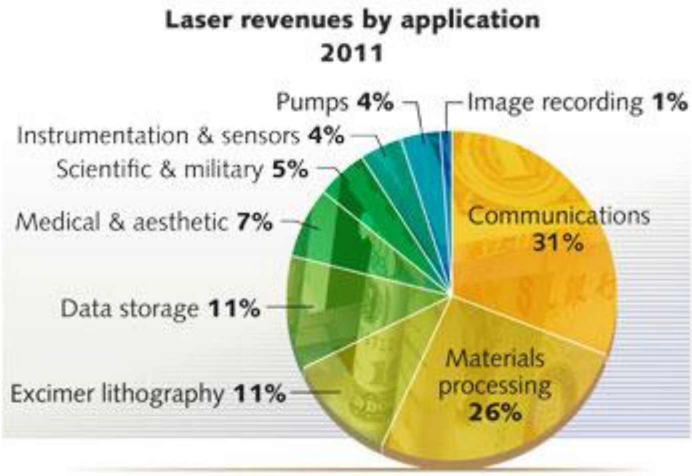
1. Power.
2. Wavelength (color),and possible need for wavelength tunability.
3. Continuous beam or pulses.
4. Beam quality.
5. Reliability.
6. Ruggedness.

## 1.10 Worldwide Commercial Laser Revenues

Commercial revenues exceeded predictions; Excimer lithography, materials processing, scientific and military, and medical applications



total half the applications. Many major laser markets are connected to materials processing by lasers. Optical data storage has significant market.




## 1.11 Classification of lasers

The laser world is really rich and interesting that laser research has produced a variety of improved and specialized laser types, optimized for different performance goals, including:

- new wavelength bands
- maximum average output power
- maximum peak pulse energy.
- maximum peak pulse power.
- minimum output pulse duration.
- maximum power efficiency.
- minimum cost.

Thousands of lasers have been invented, but only a much smaller number have found practical applications in scientific, industrial, commercial, and military applications.

Lasers can be divided into groups according to different criteria:

1. The state of matters of the active medium: solid, liquid, gas, or plasma.
2. The spectral range of the laser wavelength: visible, infrared (IR), ultraviolet (UV), X−ray spectrum.
3. The characteristics of the radiation emitted from the laser (i.e., by operating mode: continuous wave (CW) or pulsed).

4. The excitation (pumping) method of the active medium: Optical pumping, electrical pumping, etc.

5. The number of energy levels which participate in the lasing process.

Since the active medium determines most of the laser properties, it is convenient to divide lasers into four main groups depending on the physical nature of the active medium employed. Thus we have gas lasers, solid state (doped insulating) lasers, semiconductor lasers and dye lasers.

Various lasers will be outlined and studied with respect to the lasing process involved, details of the laser itself (lasing medium, cooling requirements), the structure of each laser, power sources and the function of each basic part and critical component of laser.

## QUESTIONS

1. What are the laser parameters that could be determined by the active medium?
2. How could we control the amount of power extracted through the output coupler?
3. Complete the following table ( see table 1 ) for gas laser spectra?
4. What regions of the electromagnetic spectrum are involved in:
   (a) electronic transitions, (b) vibrational transitions, and (c) rotational transitions in gas lasers?
5. Explaine why each of the following lasers has the corresponding bandwidth: He-Ne laser( narrow bandwidth), $N_2$ laser( relatively broad-band output), and Dye laser( a continuum output band).
6. Why do ion lasers have many lasing lines?
7. Why do $N_2$ and Cu vapor lasers operate strictly in pulsed mode?
8. What are the optical criterions upon which the HR & OC mirrors could be selected in commercial lasers?
9. What are the parameters that must be optimized for maximum efficiency of pulsed or CW laser operation?
10. On what parameters do the operating wavelength depend?
11. What are the main differences between different lasers?
12. What are the specific needs upon which the choice of laser depend?
13. What are the different performance goals upon which laser types are optimized?
14. What are the different criteria upon which laser types are divided into groups?