# Introduction

Shortly after their development, lasers were referred to as a solution eagerly looking for a problem. Lasers progressed rapidly as an omnipresent part of modern technology and procedural medicine. Recent advances in lasers and fiber optics make them ideally suited to travel through routes in human body where no hand or scalpel has gone before. With its widespread use of small-diameter endoscopic instruments, urology has been positively influenced by this technology, perhaps more so than any other medical subspecialty ***(Gross et al., 2013)*.**

Laser is an acronym that stands for light amplification by the stimulated emission of radiation. Albert Einstein proposed the concept of stimulated emission of radiation in 1917.Not until 1960, however, was this theory put to use by T.H. Maimen to produce the first visible light laser. He used a synthetic ruby crystal with silver –coated ends surrounded by a flash tube to produce light energy. Subsequently, researchers tested many new substrates or lasing materials, leading to diversity in their clinical application ***(Lacono et al., 2012)***.

Surgeons currently using lasers seek 4 different effects thermal, mechanical, photochemical, and tissue-welding effects (which is actually mediated through thermal energy).The most common utilization is the thermal effect. Light energy is absorbed and transformed into heat. This results in the denaturation of proteins at 42-65ºC. The shrinkage of arteries and veins at 70 ºc, and cellular dehydration at 100 ºc. Once water has completely evaporated from tissue, the temperature rapidly rises, carbonization then occurs at 250 ºc, and, finally, vaporization occurs at 300 ºc ***(Malek et al., 2005)***.

The mechanical effect results, for example, when a very high power density is directed at a urinary calculus and a column of electrons is freed rapidly at the stone surface. This creates a plasma bubble that swiftly expands and acts like a sonic boom to disrupt the stone along stress lines ***(Fuch et al., 2007).***

The photochemical effect refers to the selective activation of specific drug or molecule, which may be administered systemically but is taken up in selected tissues. By activation of the molecule or drug by a specific wavelength of light, the molecule is transformed into a toxic compound(s), often involving oxygen-free radicals that can cause cellular death through destruction of DNA crosslinks. This is a novel approach to destroying superficial skin or mucosal malignant and premalignant lesions. Lasers are ideally suited because of their power and specific wavelength ***(Woo et al., 2008).***

Finally, the tissue-welding effect is derived by focusing light of a particular wavelength to induce collagen cross-linking. By adding proteinaceous materials (eg, 50% human albumin, also known as tissue solder) directly to the tissue edges to be welded or a chromophore that absorbs at laser´s wavelength, increased tensile strength and decreased peripheral destruction can be achieved ***(Jaeger and krambeck., 2013).***

## LASER types and current clinical applications

- For soft-tissue incision (eg, uretheral strictures, posterior urethral valves, endopyelotomy, bladder neck contractures), use holmium:yttrium-aluminium-garnet HO:YAG, neodymium:yttrium-aluminium-garnet Nd:YAG, or kalium titanyl phosphate KTP.
- For resection and ablation (eg, benign prostatic hyperplasia, T, chondylomata, penile carcinoma, bladder and skin hemangiomata), use Nd:YAG, Ho:YAG, KTP:YAG, semiconductor diode, or $CO^2$.
- For lithotripsy use Ho:YAG, (frequency doubled double-pulse Nd:YAG) FREDDY, Pulsed dye, or Alexandrite.
- For tissue welding (eg, vasovasotomy, hypospadias, strictures, diverticula, or fistulas, pyeloplasty, bladder augmentation and continent urinary diversion) use diode, KTP, Nd:YAG, $CO^2$ ***(Jaeger and kramback., 2013).***

## Upcoming technology

The future of lasers in urology looks bright. New laser systems continue to enter the urology clinic that are more powerful, more compact, more versatile, and less expensive than the previous lasers, providing the urologist with the means to develop new minimally invasive laser applications in urology and improve on existing applications. Such as the 100 W Ho:YAG and 120 W KTP lasers, have resulted in more rapid and efficient incision or vaporization of prostate tissue. Even more compact and efficient laser technologies, Such as fiber lasers, may replace current solid state lasers ***(Fried and Matlaga, 2012).***

# Aim of the Work

To review the current uses of laser technology in urology and highlight the update in this technology and how it will influence the practice of urology in future.

# LASER FROM PHYSICIST'S POINT OF VIEW

Laser is an acronym for ‘‘light amplification by stimulated emission of radiation. The envelope ‘‘light radiation’’ shows that escaping energy is simply light of a defined wavelength and direction. This light is created by a quantum mechanical principle of ‘‘stimulated emission’’ of radiation of an excited laser medium (active media: gas, crystal, glass, dye). Excitation of the laser medium can be achieved by various principles (eg, excitation by photons from a flash lamp). Some of the excitation photons are absorbed by the active medium, leading to an increased energy level (excited states). According to the theory of spontaneous emission, these excited states return to the ground state, statistically releasing a photon at a characteristic wavelength. If these spontaneously emitted photons hit another excited laser medium ion, it stimulates the excited ion to return to the ground state by emitting a further photon with the same wavelength and direction of propagation. This is called stimulated emission of radiation ***(Gratzke et al., 2007).***

The emitted wavelength is defined by the active components of the lasing medium. For purposive excitation of the laser medium, it is embedded into an optical resonator, a set of mirrors within the optical axis of the laser medium redirecting emerging photons into the laser medium for further amplification of the laser radiation. One of the resonator mirrors shows a reflectivity at the laser wavelength of nearly 100% (high reflector), and the other one is partially transparent to allow laser radiation to exit from the resonator (output coupler).

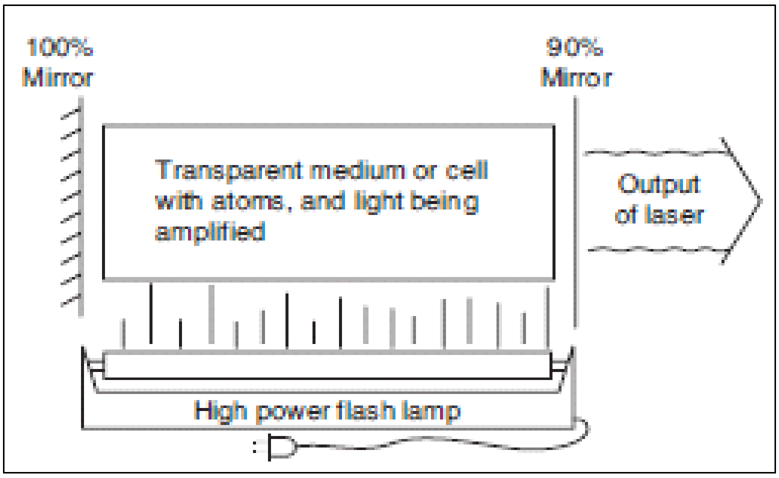


**Figure (1):** Complete laser system, showing elements responsible for energy input, amplification, and output ***(adapted from Peter W. Milonni and Joseph H. Eberly Laser physics 2$^{nd}$ ed 2010).***

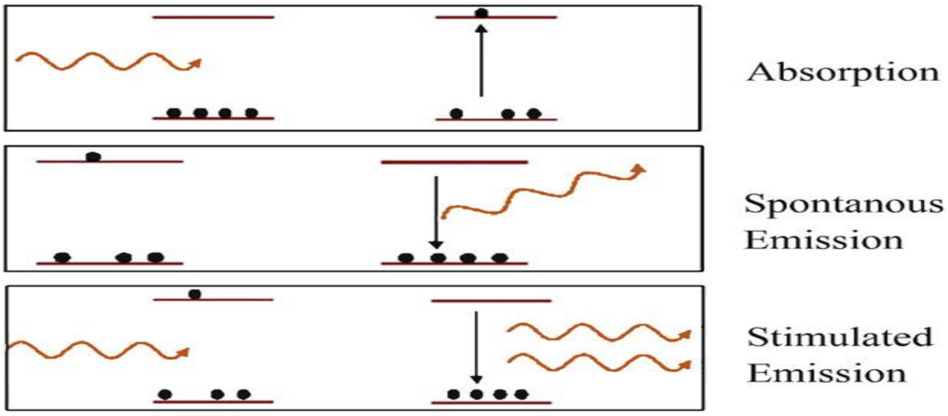


**Figure (2):** Spontaneous and stimulated emission of radiation ***(Thorsten et al., 2012).***

Laser radiation is emitted from the resonator in a continuous wave or pulsed manner depending on the construction of the laser device (eg, excitation source, characteristics of the laser medium) or the presence of additional optical elements, such as a Q-switch. Q-switching is a technique to generate short high-peak power laser pulses by modulating the cavity Q factor (cavity loss) of the laser resonator. It comprises an optoelectronic shutter that is embedded within the laser resonator. This shutter is periodically opened and closed. When the shutter is closed (low-cavity Q factor), stimulation of emission is suppressed, but the population inversion reaches a large value due to the ongoing excitation process. When the shutter opens (high-cavity Q factor), spontaneously emitted photons start oscillating within the resonator leading to release of stimulated emission. The larger the population inversion, the higher the Q-switch pulse peak power. The Q-switch pulse terminates with depletion of the population inversion ***(Thorsten et al., 2012).***

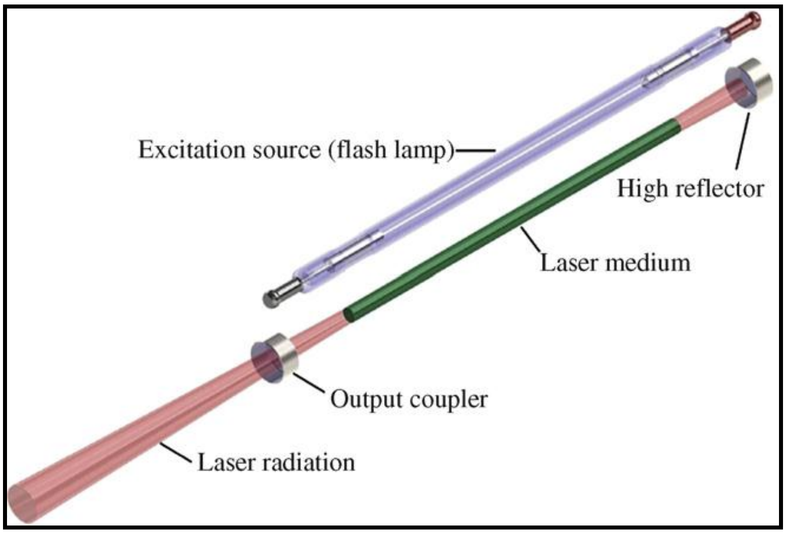


**Figure (3):** Optical resonator with excitation source (flash lamp). Green bar: laser medium; right end: high reflector; left end: output coupler; red beam: laser radiation ***(Thorsten et al., 2012).***

The 3 characteristics differentiate between laser light and natural light:

1- Coherence (the photons are all in phase)

2- Collimation (they travel parallel with no divergence)

3- Monochromaticity (they all have the same wavelength and, therefore, the same color if within the visible light spectrum. ***(Stein and Kendall, 1984).***

Physical properties of a laser can be described using 4 key concepts: energy, power, influence, and irradiance.

- Energy describes the amount of work accomplished and is measured in joules.

- Power refers to the rate of energy expenditure and is measured in joules per second, or watts (1 J/s = 1 W). The total energy applied to a given tissue is a function of the power multiplied by the duration of time the tissue is exposed.
- The influence, otherwise known as power density, describes the amount of energy delivered per unit area ($J/cm^2$) and is far more important in determining a laser's effect on tissues than total energy delivered.
- Irradiance is a term used to describe the intensity of a laser beam, and it is measured in watts per square centimeter. Irradiance is also inversely proportional to the square of the spot size radius. Lenses or optical fibers can manipulate the influence or power density of a laser. Lenses focus or defocus a beam to change spot size even when the laser is kept at a constant distance from tissue ***(Gross et al., 2007).***

## Laser–tissue interaction:

Laser–tissue interaction tissue properties, combined with the wavelength of laser light used, further affect the quality of the laser-tissue interaction. Examples of tissue properties include the density, degree of opacity (eg, quantity of pigments), water content, and blood supply of the tissue. The more dense or opaque a tissue is, the greater the degree of absorption of light energy and the greater the degree of transformation to heat. Molecules, proteins, and pigments may absorb light only in a specific range of wavelengths. Hemoglobin, for example, absorbs light energy that has a wavelength as high as 600 nm and is translucent to light beyond this range. (The argon laser produces light of 458-515 nm and, therefore, is heavily absorbed by hemoglobin.) Water also absorbs in a specific wavelength range, beginning with a small amount of absorption from 300-2000 nm, at which point the degree of absorption increases rapidly and continues for several thousand nanometers. The $CO_2$ laser produces light in the far infrared spectrum, at 10, 600 nm. This is heavily absorbed by water contained in tissue and, therefore, does not penetrate deeply. Local blood circulation affects the degree of laser energy absorption via 2 mechanisms.

1- The absorptive properties of individual blood components (eg, hemoglobin, water) differ and interact with light in specific wavelength ranges.

**2-** The circulating blood acts as a heat radiator by transporting absorbed thermal energy away from the site of delivery. Tissue composition and molecular absorption are among several other factors that play into the laser end effect ***(Gross et al., 2007).***

The Nd:YAG laser, for example, produces light in the near infrared region (1060 nm) and penetrates to a depth of approximately 5-10 mm in most tissues (at its wavelength, Nd:YAG is not absorbed by hemoglobin or water in any significant quantity). The $CO_2$ laser with a wavelength of 10, 600 nm (longer wavelength, thus should penetrate more deeply) penetrates only to a depth of less than 0.1 mm because its wavelength is very highly absorbed by tissue water. Ultimately, laser energy and tissue characteristics interact in a complex manner that determines the degree of absorption, penetration, reflection, and scattering of laser energy.Surgeons currently using lasers seek 4 different effects: thermal, mechanical, photochemical, and tissue-welding effects The most common utilization is the thermal effect, whereby light energy is absorbed and transformed into heat. This results in the denaturation of proteins at 42-65°C, the shrinkage of arteries and veins at 70°C, and cellular dehydration at 100°C. Once water has completely evaporated from tissue, the temperature rapidly rises, carbonization then occurs at 250°C, and, finally, vaporization occurs at 300°C ***(Bhatta et al., 1998)***.

The mechanical effect results when a very high power density is directed at a urinary calculus and a column of electrons is freed rapidly at the stone surface. This creates a plasma bubble that swiftly expands and acts like a sonic boom to disrupt the stone along stress lines.

There may be *a* photochemical effect, based on the selective photoactivation of a specific drug and its transformation to a toxic compound(s). The laser is an ideal source of light for photoactivation, because of its power and specific wavelength. The formation of toxic metabolites results in cellular death through the intracellular production of singlet oxygen, which generates free radicals and peroxides that damage cellular elements such as DNA and mitochondria. Thermal effect The principal light–tissue interaction encounters reflection, scattering, and reemission, which together result in photon and light distribution within the tissue and absorption by tissue chromophores. Light distribution and absorption affect the optical penetration in a wavelength-dependent manner For thermal laser–tissue effects, absorption is the most important factor ***(Teichmann et al., 2007).***

Energy absorption leads to excitation of a molecule, which results in a temperature increase. Thermal alteration may lead to coagulation, vaporization, or carbonization. To predict these effects, a number of `variables are relevant including the wavelength and the type of radiated tissue, especially the amount of target chromophore.These variables define the effects of the laser radiation. displays the absorption coefficient of tissue chromophores (water and hemoglobin) in the wavelength range from 0.1 mm up to 100mm, showing that the absorption of water ranged over eight orders of magnitude. Additionally, the optical penetration depth in the chromophore is displayed (right y-axis). In prostate tissue treatment, mainly two chromophores are of interest: the hemoglobin molecule in red blood cells and the intra cellular water. Taking a given wavelength (eg, 500 nm;) Absorption spectrum of prevailing body chromophores.

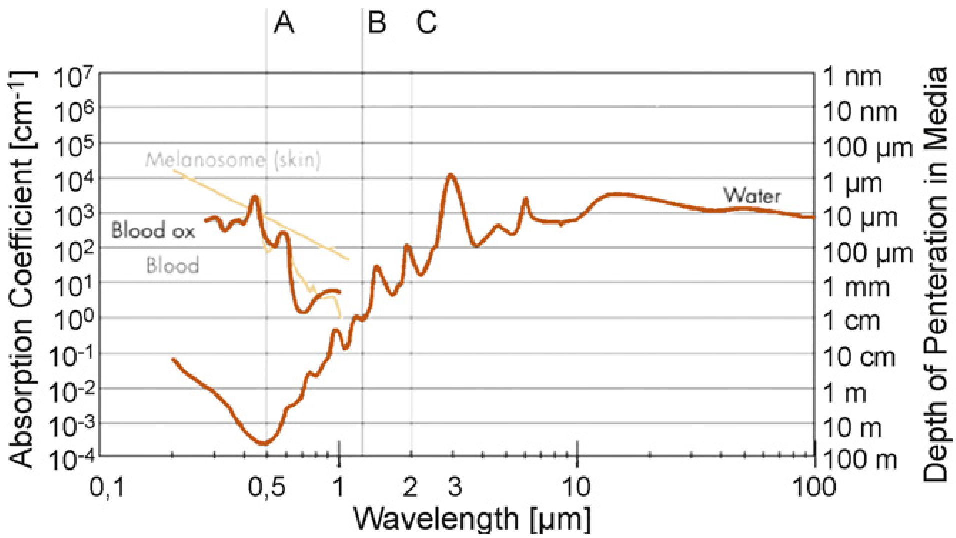


**Figure (4):** Chromophore absorption at laser radiation of (a) 500 nm, (b) 1300 nm, and (c) 2000 nm ***(Thorsten et al., 2012).***

Coefficient and also the penetration depth depend on the type of radiated tissue. Because the laser wavelength is absorbed by red blood cells, the absorption coefficient is high, leading to shallow penetration of about 100 mm. In contrast, the same wavelength has a very low absorption coefficient in intracellular water, causing a penetration depth of approximately 30 mm. Alternatively, one can take a given chromophore (eg, water) and examine absorption coefficient and optical penetration depth as a function of the utilized wavelength. The penetration depth in water at a wavelength of 1300 nm is within the centimeter range whereas the penetration depth at a wavelength of 2000 nm is <500 mm.

The laser–tissue effect of any given wavelength for the displayed chromophores blood and water can be estimated.

Thus changing either wavelength or targeted tissue alters laser–tissue interaction.

After generating laser radiation and aligning it into tissue, it must be understood what happens with the radiated tissue. Once laser radiation is absorbed, optical energy is converted into thermal energy, resulting in increasing tissue temperature. The volume of heated tissue correlates with the absorption of the laser wavelength. Once the tissue is heated high enough to denaturize protein without reaching the boiling point, coagulation necrosis occurs. Continuous temperature increases above the boiling point lead to vaporization ***(Westenberg et al., 2004).***

However, laser–tissue interaction usually is a mixture of both. With any laser, heating of the targeted tissue causes vaporization of a certain amount of superficial tissue once the critical boiling point is reached. Underneath this layer, tissue heats up but the temperature stays below the boiling point and causes coagulation necrosis. The combination of vaporization and coagulation follows a simple principle: A high absorption coefficient within the targeted tissue confines the generation of heat to the surface of the tissue leading to a low penetration depth. Consequently, lasers emitting a wavelength with a high absorption coefficient predominantly affect the tissue surface. Providing sufficient laser power, the temperature of the irradiated tissue will increase rapidly above the boiling point. Only a small proportion of the delivered energy causes