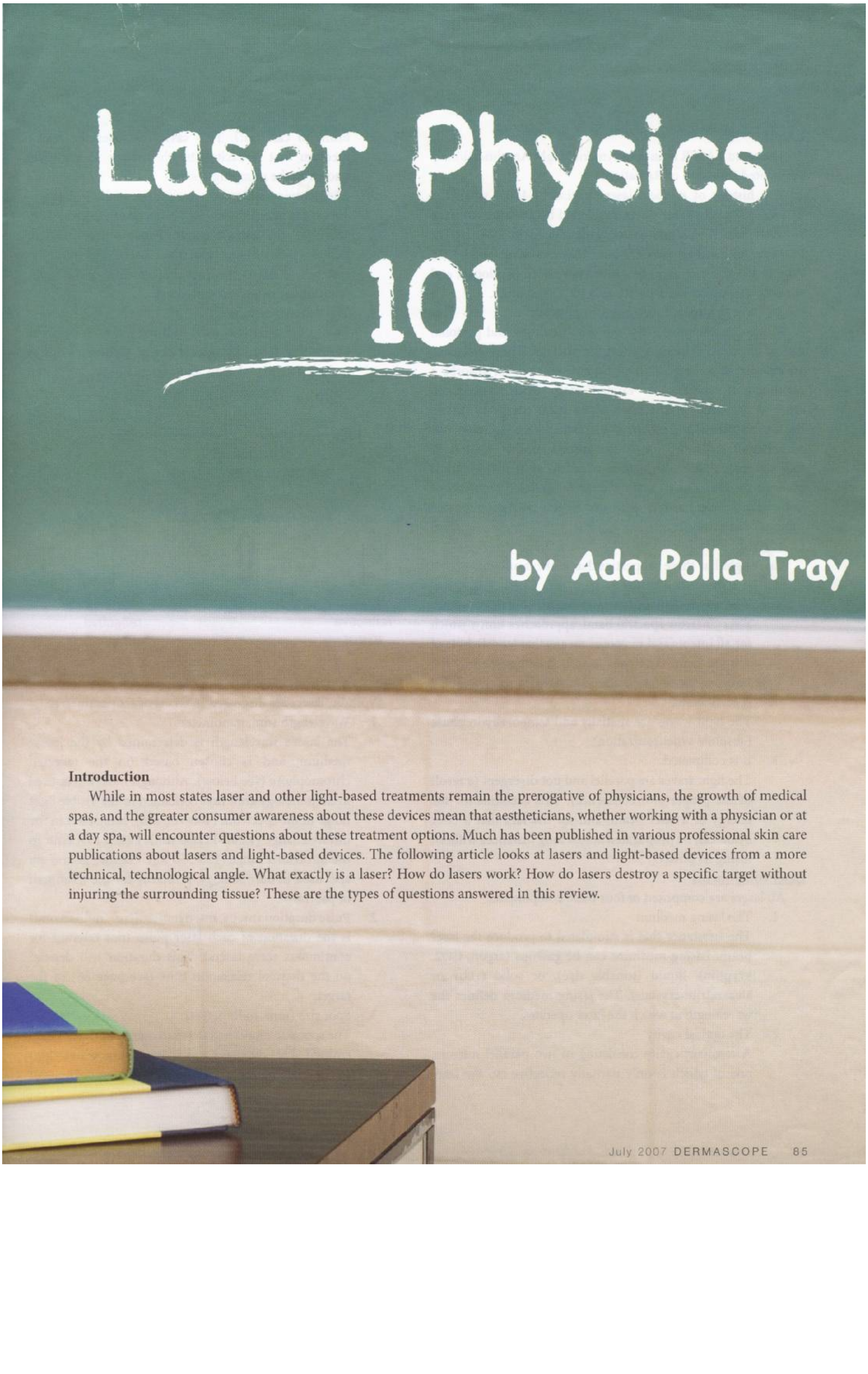
Laser Physics, Dermascope, July 2007



Laser Physics 101

by Ada Polla Tray

Introduction

While in most states laser and other light-based treatments remain the prerogative of physicians, the growth of medical spas, and the greater consumer awareness about these devices mean that aestheticians, whether working with a physician or at a day spa, will encounter questions about these treatment options. Much has been published in various professional skin care publications about lasers and light-based devices. The following article looks at lasers and light-based devices from a more technical, technological angle. What exactly is a laser? How do lasers work? How do lasers destroy a specific target without injuring the surrounding tissue? These are the types of questions answered in this review.

LASER

The word LASER is an acronym for "Light Amplification by Stimulated Emission of Radiation."

The history of medical lasers begins in 1960, when the first laser – a ruby laser – was developed by Dr. Maiman[1] (the Nd:YAG laser was simultaneously developed in 1960 by Dr. Johnson, followed by the CO2 laser that was developed by Dr. Patel in 1964). Since then, new lasers have been developed, and existing lasers have been continually improved upon.

Going back to basics: Electrons and photons

Atoms are composed of a nucleus (neutrons and protons) and of electrons floating around the nucleus. These electrons are usually in a "resting" stage. When an electron absorbs a photon, it is raised to an "excited" state. Once "excited", an electron can either emit a photon of similar energy to that of the one absorbed, and return to its resting stage (spontaneous emission of radiation), or it can absorb another photon. If this happens, that electron then needs to emit two identical photons to return to its resting stage (stimulated emission of radiation). A laser beam is generated by this reaction, repeated innumerable times.

Laser light

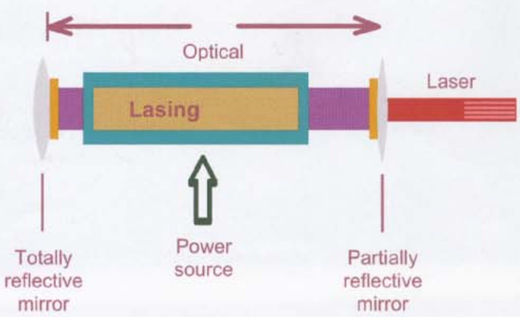
Laser light has three properties that make it unique:

1. It is monochromatic.
   The wavelength of the laser beam, contained within a very narrow spectral band, approaches unity, which for all intents and purposes means that laser light is of a single color. That wavelength is determined by the lasing medium (see diagram at right).
2. It is coherent.
   The light waves are spatially and temporally in phase (absolute synchronization).
3. It is collimated.
   The light waves are parallel and not divergent (a result of the property of coherence). This accounts for the energy of a laser beam, and for the fact that a laser beam can be propagated across long distances without losing its power.

Laser components

All lasers are composed of four basic components:

1. The lasing medium
   The substance that is stimulated to produce the laser beam. Lasing mediums can be gaseous (argon, CO2, krypton), liquid (tunable dye), or solid (ruby or alexandrite crystals). The lasing medium defines the wavelength at which the laser operates.
2. The optical cavity
   A resonant cavity consisting of two parallel mirrors, one of which is only partially reflective (so the laser beam to can exit). This cavity encloses the lasing medium that is excited by the power source, also known as the pumping system.
3. The pumping system
   This is the laser's power supply necessary to excite (i.e. stimulate) the lasing medium. Power sources include electricity, flashlamps, and other lasers. The pumping system will define the time characteristic of the beam (continuous or pulsed emission).
4. The delivery system
   This is the apparatus used to bring the laser beam to the patient from the optical cavity. Delivery systems include articulated arms and optical fibers.



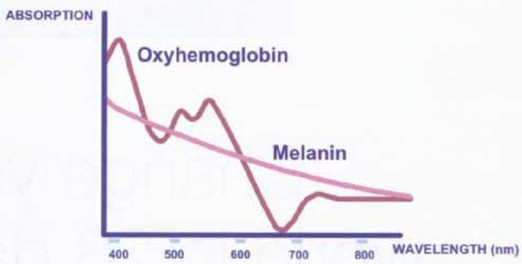
Laser parameters

Typically, lasers are discussed in terms of six parameters:

1. Wavelength (nm, nanometers)
   The laser's wavelength is determined by the lasing medium, and is chosen based on the targeted chromophore (see below). Although most lasers used in dermatology emit rays contained in the visible light range of the spectrum (400-700 nm), some emit in the infrared range (1,000-11,000 nm). Lasers that emit in the ultraviolet range (150-350 nm, excimer lasers) are also used in dermatology, primarily for the treatment of psoriasis.
2. Pulse duration (ns, µs, ms, nano-, micro-, millisecond) is the duration of each laser pulse (not relevant for continuous wave lasers). This duration will depend on the thermal relaxation time (see page 88) of the target.
3. Spot size (mm, millimeters)
   The spot size represents the diameter of the laser beam emitted. This diameter will influence the penetration of the beam in the tissue. Indeed, the larger the spot

size, the less the scattering of the photons inside the tissue, leading to a deeper penetration of the laser beam. A larger spot size will also enable a faster treatment time, as each pulse covers a greater area.

4. Fluence (j/cm2, joules per centimeter square)
   Fluence measures the energy delivered per unit area. As the fluence increases, so does the destructive force of the beam. Depending on the laser used, the fluence will vary between 3-150 j/cm2.
5. Irradiance (w/cm2, watts per centimeter square)
   Irradiance measures the rate of energy delivery per unit area, i.e. irradiance describes the intensity of energy delivery. A high irradiance induces fast heating of the chromophore. Q-switched lasers have the highest irradiance (mega- to gigawatt output).
6. Repetition rate (Hz, hertz)
   The repetition rate measures the number of laser pulses emitted per second. A higher repetition rate leads to increased treatment speed.



Laser types

While most often laser types are discussed in terms of what they can treat, it is important to recognize the broader categories of lasers.

1. Continuous wave (cw) lasers
   These emit a continuous beam and include the CO2 and krypton lasers. Pseudo-continuous wave lasers emit a beam in such close pulses that the effect on tissue is similar to that of a continuous wave laser. These lasers are used to coagulate tissue, as for example in the treatment of moles and warts.
2. Pulsed lasers
   Lasers that emit a beam in short pulses usually separated by 0.1-1 second. Pulsed lasers are more selective in their destructive effect than continuous wave lasers, and are used in selective photothermolysis.
3. Q-switched lasers
   Q-switching refers to the process of storing up laser energy in the laser cavity and releasing it in one single very short and extremely powerful pulse. This results in power outputs in the megawatt to gigawatt range, and allows for mechanical (versus thermal) destruction of the target. Such lasers are often used in the removal of tattoos.

Laser tissue interaction

Lasers are effective in the treatment of various skin conditions because of their interaction with tissue, which falls in the following categories:

1. Reflection: The beam is reflected off of tissue, with no clinical effect.
2. Transmission: The beam is transmitted through tissue, with no clinical effect.
3. Scattering: Intra-dermal molecules (for example collagen) induce a scattering of the beam's photons, thus reducing the efficiency of their progression towards the target.
4. Absorption: The beam's photons are absorbed by the chromophore. Once absorbed, the light energy is transformed into thermal or mechanical energy. According to the Grothus-Draper law, which governs all laser light-tissue interactions, light absorption is required for effect on tissue.

In dermatology, thermal, more rarely mechanical, energy is responsible for the laser's destructive properties. Thermal or mechanical energy is used to destroy the target that contains the chromophore. The speed at which the tissue is heated also has therapeutic properties:

1. Slow heating: this leads to the coagulation of tissue (thermal destruction).
2. Rapid heating: this leads to the vaporization of tissue (thermal destruction).
3. Extremely rapid heating (achieved by Q-switched lasers): this leads to the shattering or explosion of tissue (mechanical destruction).

The desired heating speed will be chosen according to the lesion to be treated and the necessity to protect the surrounding tissue. In addition to heating speed, the peak temperature is also a factor in obtaining the best possible treatment results.

Chromophores

Chromophores are molecules responsible for the color of a mass. These molecules absorb the energy of specific wavelengths. The most common chromophores encountered in dermatology are hemoglobin (which is targeted when vascular lesions are treated, including rosacea, leg veins, and Port Wine Stains), melanin (which is targeted during hair removal treatments, and for the removal of brown spots), tattoo ink (which is targeted during tattoo removal treatments), and water (which is targeted in most rejuvenating laser treatments).

Selective photothermolysis

The theory of selective photothermolysis was developed by Dr. Rox Anderson at the Wellman Laboratory of the Massachusetts General Hospital in 1983. This theory revolutionized the use of lasers in dermatology by stating that laser light of a specific wavelength can destroy a target containing the adequate chromophore without damaging the surrounding tissue. This theory is based on the concept of thermal relaxation time. The thermal relaxation time of a mass is the time required for it to cool down to the ambient temperature after having been heated (for most targets, this time is determined by their size and shape, varying between 10 nanoseconds for a tattoo ink particle and 100 milliseconds for a hair follicle). Selective photothermolysis suggests that if a mass is heated for a period shorter than its thermal relaxation time, there is not enough time for thermal diffusion to damage the surrounding tissue. Stated another way, if a mass is heated for a period shorter than its thermal relaxation time, the heat and resultant damage (necessary for successful treatment) is confined to the target alone and the surrounding tissue remains unaltered.

Intense Pulsed Light devices (IPL)

Intense pulsed light devices are not lasers. The two are indeed different from both a technology perspective and from a treatment perspective. The main difference between an intense pulsed light device and a laser is that the light of the former is non-monochromatic. While in the case of lasers, the lasing medium produces a single wavelength, and thus targets a single chromophore, IPL devices function with filters. Non-monochromatic light is created by an energy source, and then filtered. While IPL filters enable the therapist to select the range of wavelength best suited to a specific treatment, they do not enable the therapist to select a single wavelength: for example, a 585 nm IPL filter will filter out shorter wavelenghts, but not longer wavelengths. The therapeutic consequence is that a wider range of conditions can be treated with a single IPL device versus with a single laser (for example, both redness and brown spots can be treated with an IPL). In other words, an IPL is less specific in its effects. Some will argue that this lack of specificity makes IPL devices less effective, and more difficult to use (thus operator error is more likely).

Light Emitting Diodes (LED)

Light Emitting Diodes are neither lasers, nor IPL devices. The main difference between LEDs and lasers is that the light of the former is not collimated (but it is monochromatic); this means that the energy is divergent, and not focalized. The therapeutic consequence is that LEDs overall have a much lower energy output than lasers. LED treatments are still effective, however. Indeed, while the purpose of a laser is to selectively destroy a specific target (hence the need for a high energy output), the purpose of an LED is most often to stimulate (rather than destroy) a specific target, something that can be achieved with a lower energy. The main applications of LEDs are rejuvenation, photodynamic therapy, and cellulite reduction.

What device for what condition?

The number of light-based devices (whether lasers, IPLs, or LEDs) available today continues to increase regularly as new technologies are discovered and launched. The chart below provides an overview of some of the devices available today for the treatment of various conditions.

Hair removal	Pulsed alexandrite, pulsed Nd:YAG, diode lasers; IPL devices
Rosacea, broken capillaries (face)	Pulsed dye, pulsed Nd:YAG lasers
Pigmented lesions (brown spots)	Q-switched lasers (ruby, alexandrite, Nd:YAG)
Tattoos	Q-switched lasers (ruby, alexandrite, Nd:YAG)
Wrinkles	FRAXEL laser; intense pulsed light devices; diode 1450 nm, pulsed Nd:YAG, pulsed dye, erbium, ultra-pulsed CO2 lasers; photodynamic therapy (PDT)
Scars and stretch marks	FRAXEL, pulsed dye lasers, pulsed Nd:YAG, diode 1450 nm
Veins, dilated capillaries of the legs	Pulsed dye, pulsed alexandrite, pulsed Nd:YAG lasers
Acne	Diode 1450 nm, pulsed dye lasers
Angiomas	KTP, pulsed dye, pulsed alexandrite lasers
Seborrheic keratoses, various skin tags	KTP, erbium, ultra-pulsed CO2 lasers
Cellulite	LED devices

References:

Maiman,T.H.: 1960, Nature, 187, 493.

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