Diode Lasers Enable Diverse Therapeutic Applications

Lasers are widely used throughout medicine, from diagnostic imaging and clinical testing to surgical treatments and the latest aesthetic procedures. For therapeutic medical procedures, in particular, diode lasers have now become the dominant laser type in use. This is because these workhorse devices provide lower cost of ownership, a wider choice of output wavelength and power, compact, rugged packaging, and superior (semiconductor) reliability as compared to other laser types. In this article, we briefly examine the main features and advantages of typical diode laser types and then survey some of the leading therapeutic applications that currently rely on them.

Diode Laser Advantages

The diode laser is a monolithic semiconductor device that directly converts electrical energy into laser light. By using different semiconductor compositions, the output wavelength can be set to be in the blue, green, red, or near and mid infrared, with near-infrared devices generally offering the highest power levels. This wide choice of output wavelengths enables the laser system to be tailored to best match the needs of each specific application, e.g., to maximize blood coagulation, to tighten collagen, to maximize tissue ablation, to maximize penetration depth in soft tissue or to limit it to surface treatment, to bursts target cell, to kill dental pathogens, and so on. For every application, there is one or more optimum wavelength bands which delivers the best selectivity, i.e., where the laser produces a maximum effect while minimizing any unwanted collateral effects.

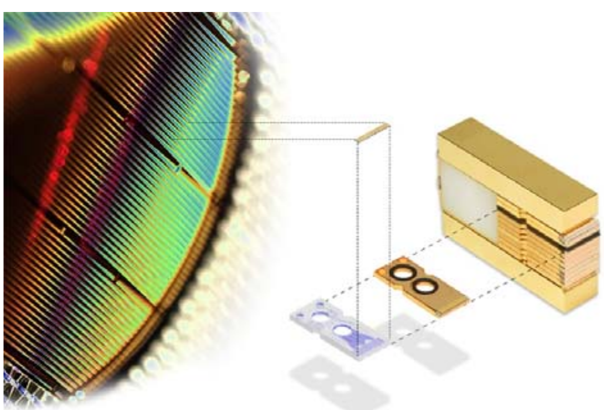

Figure 1: *Power scaling in diode lasers. A water-cooled diode laser bar typically contains a section of wafer with up to 40 emitting facets. Integrating multiple bars into a two-dimensional stack provides a simple modular route to even higher power.*

In terms of output power, a typical, individual diode laser emitter might produce at most a few watts (~5-15 W). However, a well-established modular architecture enables easy scaling to high powers. For example, numerous emitters can be fabricated on a single monolithic semiconductor array or bar with a total output of several 10s of watts or higher. This is more than sufficient for most medical applications. The combination of multiple bars into a stack (see Figure 1), or the use of multiple stack combinations by spatial-, polarization, or wavelength-multiplexing, enables applications requiring even higher power. Coherent also uniquely offers a fourth very useful format where several single emitters are arranged in a single package and efficiently combined together. Some representative examples of these different OEM formats and power levels are shown in Figure 2.

Figure 2: *To support diverse therapeutic applications optimally, Coherent supplies packaged diode lasers with a variety of scalable power* levels *and OEM package types, including fiber coupling.*

In addition to their compact, rugged packaging, diode lasers also offer the highest electrical efficiency of any laser type; in some cases up to >55% of the electrical input can be converted into laser output power, minimizing the carbon footprint of any medical system as well as its cooling requirements. Another important advantage of diode lasers is that their output wavelengths (from 405 nm up to ~2.3 μm) are deliverable through low-cost glass fiber optics. To simplify their use, most diode laser products packaged for the medical market include some type of fiber coupling; they are supplied in a pre-aligned package with a standard fiber output connector, or with a pigtailed (attached) fiber–. This eliminates alignment challenges for the system builder and allows simple fiber delivery for laparoscopic and robotic procedures, as well as enabling straightforward connecting to some type of handpiece with a focusing (e.g., telescope) capability. Conversely, some applications such as hair removal actually need large area illumination and modules without fiber coupling match this purpose.

Applications	Type	Wavelength [nm]																		
		405	450	635	652	670	689	752	766	794	810	915	940	980	1064	1210	1320	1470	1550	1940
Aesthetics	Acne Treatment		x															x		
	Hair and Wrinkle Removal								x		x	x			x	x				
	Laser Skin Resurfacing										x	x								
	Lipolysis														x	x				
	Pigmented Lesions										x		x	x						
	Tooth Whitening										x			x						
	Varicose Vein Removal												x							
Diagnostics	MRI									x										
Photodynamic Therapy	Age-Related Macular Degeneration						x	x												
	Cancer Treatment			x	x	x														
	Wound Healing	x												x						
Surgical Treatment	Dental Treatment													x						
	Endovenous Treatment												x							
	General Surgery													x	x		x	x	x	x
	Microsurgery													x	x					
	Urology													x			x	x		

Table. *A summary of the wavelengths of diode lasers that Coherent provides to support diverse medical therapeutic applications.*

Hair Removal

As illustrated schematically in Figure 3, laser hair removal is one of the most popular non-surgical aesthetic procedures, particularly in the U.S. Like other aesthetic laser procedures, selectivity is a paramount concern – obtaining maximum efficacy (killing the hair follicle) without damage or scarring of surrounding tissue, and with minimum discomfort to the patient.

The color in hair is due to the presence of melanin, which absorbs visible and near-IR light, from approximately 320 nm to 1200 nm. Conversely, blood absorbs most strongly at wavelengths below 600 nm, and the water that is omnipresent in soft tissue starts to absorb strongly at wavelengths longer than 1100 nm. There is thus a wide potential wavelength window for this application between 600 nm and 1100 nm. Actively cooling the skin surface during the procedure enhances selectivity. By optimizing pulse duration, the follicle cells are killed without causing thermal damage to the dermis. This translates into an optimum pulse width between 10 and 100 milliseconds, which is very simple to achieve with the fast on/off capabilities of diode lasers.

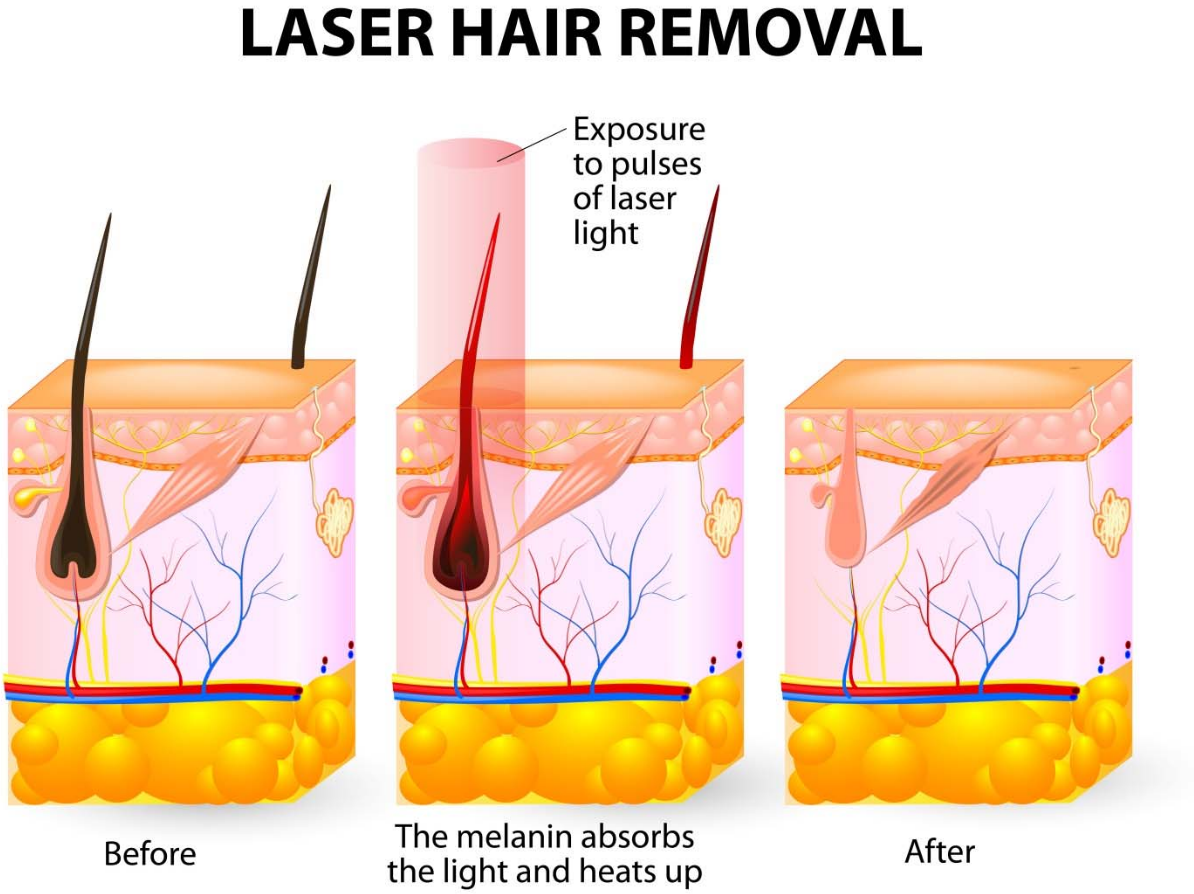

Figure 3: *Laser hair removal schematically explained.*

Diode lasers operating at 760 nm dominate the hair removal market. This wavelength was selected to match the output of the alexandrite laser, which was formerly widely employed in this application. However, managing the trade-off between follicle and dermis damage becomes more difficult at this wavelength in darker-skinned patients due to the increased melanin in the skin. But, by using shorter pulses (e.g., 30 ms or less) and longer wavelengths, hair removal is successful on darker skin types. Coherent provides diode lasers – usually packaged stacks – at both 808 nm and 1060 nm (as well as 760 nm) for this purpose.

Other Aesthetic Procedures

Lipolysis (laser body fat removal) is a growing application for the transdermal application of light using 1060 nm direct and fiber coupled diode lasers. The absorption of 1060 nm light by adipose fat tissue elevates temperature and causes cell death. Discomfort and dermal damage are avoided by using surface cooling of the skin, as in hair removal. Over a period of a few weeks, the body then naturally removes the dead adipose tissue.

Skin tightening is another popular aesthetic procedure. Often performed as a standalone treatment or as an adjunct after lipolysis to tighten the skin following adipose removal, it works through the heating and consequent photocoagulation (tightening) of collagen. The use of diode lasers at 1210 nm for this procedure minimizes any absorption by melanin in the skin. Conversely, wrinkle removal and skin resurfacing depend on the laser light being absorbed by the dermis cells and shorter wavelengths enable efficient melanin absorption. These skin resurfacing and wrinkle removal procedures are often performed using 810 and 915 nm, although some system manufacturers prefer 1550 nm where water absorption (rather than melanin absorption) is the dominant mechanism.

Yet another variant of skin resurfacing uses a 1550 nm diode laser together with an infrared CO_2 laser at 10.6 µm, in a procedure called "fractional resurfacing" - see Figure 4. In this two-pronged approach, the CO2 laser is focused to a small spot and pulsed as the spot is moved across the skin, resulting in myriad small holes in the skin. The purpose of the 1550 nm diode laser is to cause photocoagulation of the collagen. The combination of softening and tightening is also used in a less publicized "vaginal rejuvenation" procedure.

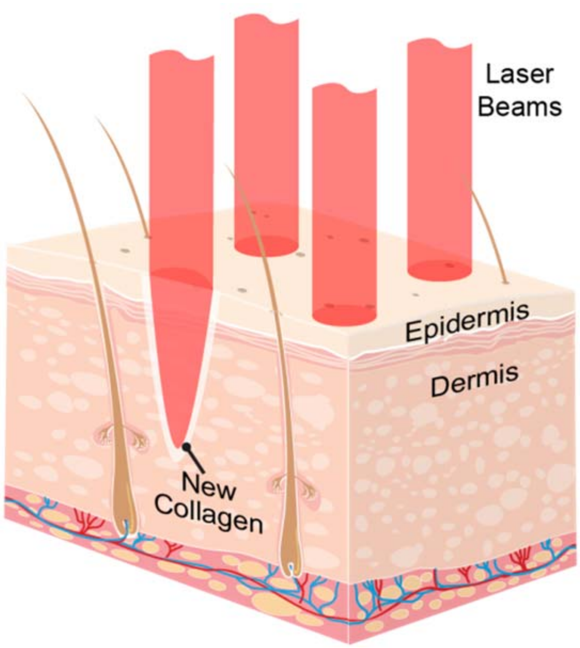

Figure 4: *In Fractional Resurfacing, a matrix of laser spots removes damaged tissue but leaves the intervening area intact to promote recovery. A diode laser at 1550 nm then tightens the underlying collagen.*

Most varicose vein removal is still a non-laser application, but even these procedures are beginning to change. Smaller veins that feed a larger varicose vein are often treated transdermally using 940, 980 or 1470 nm diode lasers. Larger veins are then treated using conventional surgical means or sometimes by using a 9XX nm diode laser endovenously.

Other aesthetic applications include acne treatment, primarily using blue-green lasers at either 450 nm or 520 nm, and teeth whitening using 810 nm or 980 nm.

Surgical Application Example – Treating Benign Prostate Hyperplasia

Like many other age-related conditions, Benign Prostate Hyperplasia (BPH) is a problem affecting a growing segment of the male population as life expectancy continues to increase. In a procedure called transurethral resection of the prostate (TURP), laser light is fiber delivered through the urethra, and the laser surgery site is actively cooled with flowing saline. Typically two diode laser wavelengths are used: 980 nm and 1470 nm. Both lasers are used to remove soft tissue primarily by heating the water within cells and causing them to burst. As noted earlier, strong laser absorption by water occurs at wavelengths longer than 1200 nm. So 1470 nm is absorbed very efficiently by soft tissue, including prostate tissue. In contrast, 980 nm is more weakly absorbed and consequently penetrates deeper. The 980 nm at a higher power level removes tissue quickly. This is followed by more precise removal of tissue using the 1470 nm wavelength.

Diode lasers are also used in general surgeries to destroy soft tissues. Generally, 1470 nm or shorter wavelengths are preferred; longer wavelengths are absorbed too strongly by water, and hence their penetration depth is too shallow in most cases.

Photodynamic Therapy

In photodynamic therapy (PDT), a laser is used in conjunction with a chemical or pharmaceutical photosensitizer agent to cause selective cell death. The photosensitizer is given to the patient systemically, locally or topically with the goal of causing preferential accumulation in the target cell type. When the photosensitizer is illuminated by laser light, it undergoes a photophysical or photochemical transformation that creates some type of toxic species – usually a type of reactive oxygen – that kills the host cell. Further selectivity is enabled by locally directing laser light. When originally introduced, PDT was seen as a potential silver bullet for treating a broad range of cancers. Instead, PDT is today used to treat only a few selective cancer types and has actually found more success in treating non-malignant ailments.

Red wavelengths (635 nm, 652 nm, 670 nm, and 752nm) are common in PDT. First, this matches the light absorption spectrum of common photosensitizers, many of which are porphyrin derivatives. Just as important, these red wavelengths penetrate deeper through soft tissue than blue or green wavelengths.

PDT is also sometimes used to treat the wet form of age related macular degeneration (AMD), although improved pharmaceutical options are reducing the use of PDT for this purpose. Here, the photosensitizer Visudyne is injected in the patient and accumulates in blood vessels in the retina. The laser then acts to seal the leaking vessels that are obscuring the retina. Coherent diode lasers with longer wavelengths beyond the normal retina response are typically used in the treatment, specifically 689 nm. Power levels as low as 0.5 watt are generally sufficient.

PDT is also used for wound healing, although there is some debate about the true efficacy of it for this purpose. Both violet (405 nm) and near-IR (980 nm) diode lasers are used in these systems.

Dental Applications

Lasers have long been touted as useful tools for dentistry, with the promise of replacing the mechanical drill that cause stress in many dental patients. While some lasers are now used to drill hard tissue, another less-publicized, but very successful, dental application is the use of diode lasers, usually at 980 nm, to cut and disinfect gums and soft tissues in the mouth. A typical example is to perform deep root sterilization where the laser kills bacteria and seals the wound with a blood clot, enabling some regeneration of the gum line. Here the usual power level is 10 watts, and the light delivery system is a fiber handpiece.

Summary

The unique characteristics of the diode lasers, including small size, high electrical efficiency and semiconductor reliability and longevity, have led to their widespread adoption in diverse therapeutic medical applications. Just as important, the unique ability to scale both the power and wavelength of diode lasers, together with the option of either free space or fiber delivery, enables manufacturers to offer products that are optimally suited to the needs of specific medical procedures. The end results are better outcomes, higher patient satisfaction, shorter treatment time, as well as shorter hospital stays, and reduced costs.