Diode Lasers for Medical Applications

White Paper

Lasers are widely used throughout the field of 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 wavelengths and power levels, compact rugged packaging, and superior (semiconductor) reliability when 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 medical applications that currently benefit from Coherent diode lasers.

Laser Diode Advantages

The diode laser is a monolithic semiconductor device that directly converts electrical energy into laser light. It also provides unique levels of power and wavelength scalability that combine to support a very wide range of medical applications. Selected wavelengths are enabled by different semiconductor compositions; the output wavelength can be set to be in the blue, green, red, or near and mid infrared ranges, with near-infrared devices generally offering the highest power levels. Other than a small gap between green and red, the majority of medically interesting wavelengths can be produced.

This wide choice of output wavelengths enables tailoring of the laser system 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 burst target cells, and so on. For every application, there is one or more optimum wavelength which delivers the best selectivity, i.e., where the laser produces a maximum effect while minimizing any unwanted collateral effects.

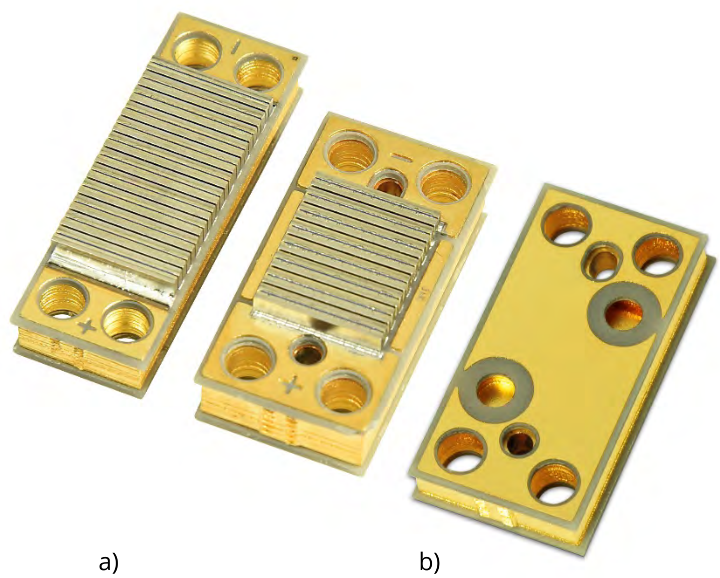

Figure 1: a) 8- and 12-bar stacks, suitable for industrial water cooling in long pulse (5-400 msec) operation for hair removal, b) Backside of such a stack, showing, in addition to the mounting and alignment holes, the water-inlet and -outlet, suitable for O-ring sealing.

The versatility of diode lasers is further enhanced by their power scaling: from single emitters at the watt level to bars emitting tens to hundreds of watts, all the way to stacks of bars delivering multiple kilowatts. Plus, diode lasers are more electrically efficient than any other laser type; in many cases >55% of the electrical input can be converted into useful laser output. However, they also generate heat, which could lead to a reduction in efficiency and output power, and hence to reduced lifetimes. For this reason, cooling is a key consideration in any diode laser and diode laser system. De-ionized water has previously been the industry standard since this provides the low electrical conductivity necessary. This unfortunately adds to the cost of operation. In addition, de-ionized water has to be controlled carefully, in order to prevent corrosion and leakage in the cooling micro-channels; the control of water conditioning further adds to the running cost. But micro-channel-coolers still offer the best thermal efficiency and hence support highest CW output powers.

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Coherent has successfully addressed this cooling vs. cost challenge by using an architecture that separates the cooling water from the electricity. This allows efficient cooling using only clean, industrial-grade water, lowering the cost of ownership. And avoiding DI water minimizes the need for careful control of the water condition. This simplifies infrastructure requirements, extends expected device lifetime, and lowers the cost of ownership further.

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. Except for applications requiring large area illumination, most Coherent 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 convenient fiber delivery for laparoscopic and robotic procedures, as well as enabling straight-forward connection to some type of handpiece with an imaging (e.g., telescope) capability. Conversely, some applications such as hair removal actually need large area illumination and our 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	X
	Tissue Tightening																		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	X													
	Wound Healing	X												X						
Surgical Treatment	Dental Treatment													X						
	Endovenous Treatment												X					X		X
	General Surgery												X	X		X	X	X	X	
	Microsurgery													X	X					
	Urology													X			X	X		

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Hair Removal

Hair removal is one of the most popular non-surgical aesthetic laser procedures worldwide. 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. Actively cooling the skin's surface during the procedure reduces the pain of the patient. Selectivity is further enhanced by optimizing pulse duration, so that the follicle cells are killed without causing thermal damage to the dermis – see figure 2. This requires a pulse width somewhere between 5 and 100 milliseconds, which is very simple to achieve with the fast on/off capabilities of diode lasers.

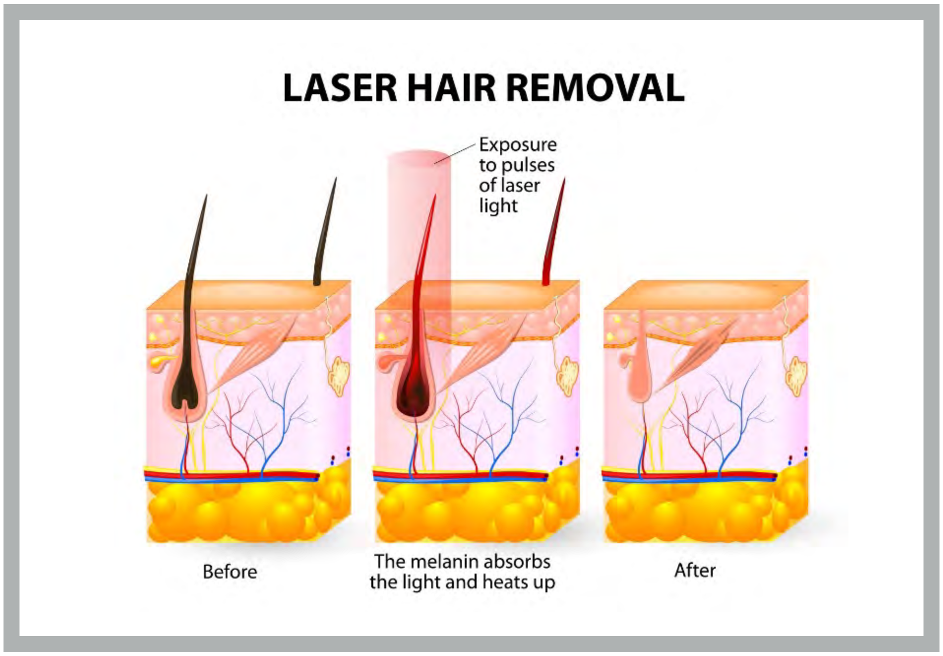


Figure 2: Laser hair removal schematically explained.

The specific wavelength requirements also serve to make diode lasers a great match for hair removal. The color in hair comes from 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. Thus, there is a wide potential wavelength window for this application between 600 nm and 1100 nm. System builders have converged on four diode laser wavelengths for this application: 755 nm, 808 nm, 940 nm, and 1060 nm. Their instruments typically combine up to three of these wavelengths since experience has shown that this type of multi-wavelength device yields the best results in the broadest range of patients, accommodating a wide variety of skin tones and natural hair colors.

These different wavelengths are generated by different diode laser materials and until recently, this has created difficulties for system builders because the slope (output versus current) was different for each of the wavelengths. Setting and maintaining a power balance was therefore often a challenge. Coherent has developed a unique semiconductor solution to this problem, so that all four wavelengths have nearly identical slopes and provide the same power per bar at the operating point / operating current – see figure 3. These are all packaged in an identical stack format, preferred by system builders in this application.

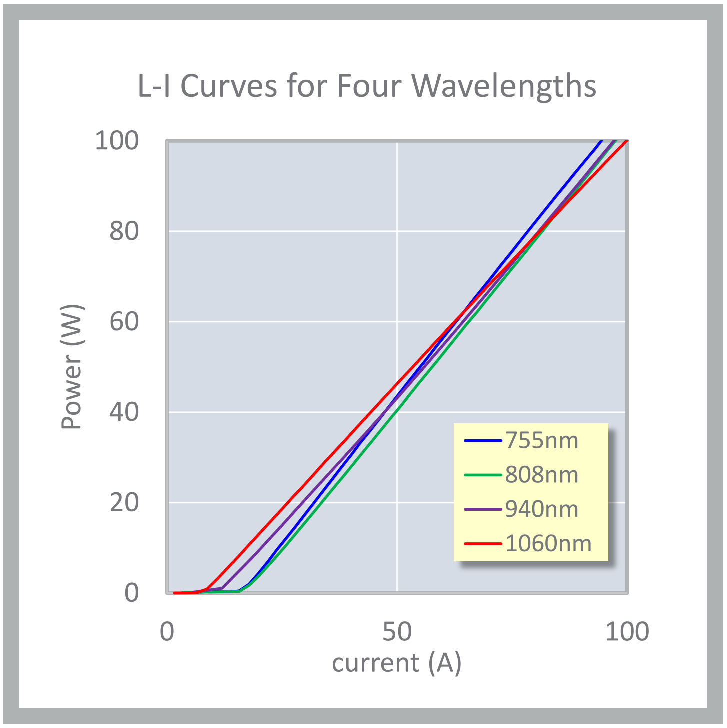


Figure 3: Coherent diode lasers at the four hair removal wavelengths all exhibit the same slope, simplifying power balance.

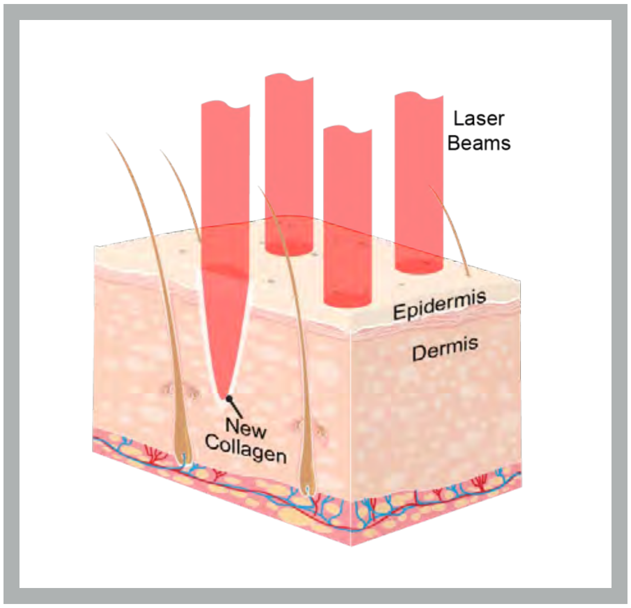
Other Aesthetic Procedures

Lipolysis (laser body fat removal) is a growing application for the transdermal application of light using 1060 nm via direct and fiber-coupled diode lasers. The 1060 nm light optimizes selectivity by maximizing the ratio of absorption in fat tissue versus absorption in water. At the appropriate intensity, this wavelength elevates the temperature in adipose fat tissue just below the dermis, resulting in cell degeneration. Over a period of a few weeks, the body then naturally removes the degenerated adipose tissue, giving the skin time to adjust and often avoiding the loose baggy skin appearance typically resulting from liposuction or some weight loss surgeries.

Discomfort and dermal damage are avoided by using surface cooling of the skin, as in hair removal. A novel tool serves both to implement the cooling and maximize process efficiency for fat removal. Specifically, the applicator provides an illuminated area of approximately 10x15 cm^2, water cooling to cool the illuminated skin, as well as a gold coated reflector to recycle some of the 1060 nm light which inevitably will be reflected from the skin. Coherent supports this application with a fiber-coupled diode laser module supplied with a detachable (800 microns diameter) optical fiber, simplifying system assembly, cleaning and service. Alternatively, 1210 nm can also be used for fat removal, as the fat absorption of this wavelength is relatively high compared to the water absorption.

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. 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 CO2 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.



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 940 nm diode laser endovenously.

Other aesthetic applications include acne treatment, primarily using blue-green lasers at either 450 nm or 520 nm, or 1470 nm which is highly absorbed on the skin's surface, and teeth whitening using 810 nm or 980 nm.

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.

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 in 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 absorbed less 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.

Photodynamic Therapy

In photodynamic therapy (PDT), a laser is used in conjunction with a chemical or pharmaceutical photosensitizer agent to cause selective cell degeneration. 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 photo-physical 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 used today 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 752 nm) 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) Coherent diode lasers are used in these systems.

Summary

The unique characteristics of 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 Coherent to offer products that are optimally matched 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.

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