On the Potential Role of the High Power Diode Laser in Modern Dentistry

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It is being increasingly realised by many that there is much to be said for the more extensive deployment of lasers to perform a wide variety of tasks. Within the fields of science, engineering and medicine, lasers have, and still are replacing existing equipment and tools as well as, perhaps more importantly, being used to carry out unique functions that were hitherto not possible. Moreover, this evolutionary cycle has advanced a stage further with technologically mature lasers now being superseded by more contemporary lasers. This is particularly true of the contemporary diode laser.

Since its advent in 1962, the diode laser, despite its inherent advantages, has up until recently only found its way into a limited number of applications. Such applications were, and still remain generally those where only a small amount of laser power is required. Applications of this nature are dominated by the longer wavelength diode laser devices (950-1500 nm) which are used almost entirely in telecommunications systems, without question the most predominant application area comprising 60% of all diode laser sales. Shorter wavelength diode laser devices (650-800 nm) account for almost all of the remaining market share, 35%, being used chiefly in items such as CD audio systems, CD-ROM and laser printers. Nonetheless, today the diode laser forms by far the largest single segment of the world-wide laser market, some 57%. Rapid and continuous enhancement of diode laser material and fabrication technology over the last decade has increased the average power output of the devices by two fold each year, giving rise today to the commercial availability of diode lasers delivering output powers in excess of 50 mW - the High Power Diode Laser (HPDL). Indeed, output powers of up to 120 W for single 10 mm experimental diode bars have been reported. As has been mentioned earlier, such improvements in, amongst other things, output power has resulted in HPDLs already beginning to replace traditional lasers in many application areas.

For some time now HPDLs have been used in the field of ophthalmics, where the HPDL has almost completely replaced the argon laser in eye treatments such as retinal coagulation. Similarly, optically coupled diode lasers delivering high power in the 50 W range are beginning to replace Nd:YAG lasers in many common surgical applications. As a direct result of this laser interchange, HPDLs are now being employed more widely within medicine, being used extensively in: ear, nose and throat operations; infertility treatment; prostate enlargement surgery and photodynamic therapy (PDT). What is more, the efficacy of the HPDL within surgery has been recognised to such a degree that they are now used in more complex surgical procedures such as: microarterial surgery; aorta surgery; welded skin grafts and general laser tissue welding. Even more complex surgical applications in the form of nerve repair have been investigated and shown to have reasonable potential. Within dentistry a number of different types of lasers are employed across a broad applications base, principally CO_2, Er:YAG and Nd:YAG lasers. The typical applications of these dental lasers are in endodontic surgery, tooth whitening, periodentics, cavity preparation and soft tissue treatment. At the present time the only reported application of the HPDL within dentistry has been for specifically treating dental gum disease.

To understand why the HPDL is superseding established lasers it is extremely important to be aware that the HPDL has many unique distinguishing features that afford the laser beneficial characteristics that the traditional laser work horses, the CO_2 and Nd:YAG lasers, simply do not possess. A major asset of the HPDL is its ability to emit at a range of short wavelengths by altering the drive current and/or the operating temperature, which in effect allows the HPDL output to be wavelength tuned. In this way, not only is the versatility of the HPDL increased, but also its material coupling efficiency. Furthermore, because the output wavelength can be tuned, better material coupling can be maintained throughout the process as the material properties and characteristics alter, ensuring that higher processing speeds may be obtained. Additional versatility comes from the fact that almost unlimited output power can be achieved by optically combining or stacking laser diode units. The HPDL is inherently reliable and extremely efficient, often in excess of 30% overall efficiency. The power requirement of HPDLs in comparison with other lasers is very low indeed, requiring only a normal mains supply. Coupled with the fact that only simple cooling techniques are required means that on the whole, the running costs of the systems are considerably less than those of other lasers. The running costs of HPDLs are also reduced by the simple nature of their operation. Generally, except for the cooling fan, only electrical components constitute the construction, thus they are virtually maintenance free. In addition, the coupling and collecting optics involved are fully encapsulated, ensuring maintenance free and adjustment free operation. The intrinsic durable nature of HPDLs allows them to be portable. This means that not only can HPDLs be used for on-site applications, but can be easily integrated into existing machinery, readily automated or even incorporated into a robotics system. Table 1 gives a summary comparison between the HPDL, CO_2 laser and the Nd:YAG laser.

Table 1. Comparison of laser materials processing beam sources.

Attribute	**HPDL**	**Nd:YAG**	**CO_2**
Max. Output Power	multi kW	<3 kW	<20 kW
Operating Voltage	<100 V	<1000 V	< 10 kV
Wavelength	0.68 - 0.93 μm	1.064 μm	10.6 μm
Watts/Lasing Volume	1000 W/cm^3	50 W/cm^3	1 W/cm^3
Efficiency	30 - 60%	1 - 3%	5 - 10%
Lifetime	20000 - 100000 hrs.	10000 hrs.	10000 hrs.
Maintenance	None	Every 200 hrs.	Every 500 hrs.
Fibre Delivery	Y	Y	N
Portable	Y	N	N
Price/Output Watt	~£150 @ 50 W	~£90 @ 50 W	~£35 @ 50 W

Such advances in manufacturing technology and the inherent advantages notwithstanding, the proliferation of the HPDL into more application areas, especially dentistry, has been held in check by its prohibitively high price, currently around £150 per W at high level compared with £35 and £90 per W at the same level for CO_2 and Nd:YAG lasers respectively. However, this picture is almost certain to change as the 30-50% p.a. price reductions that HPDLs enjoy continue. Price reductions of this magnitude are possible for the HPDL due to the fact that semiconductors, and hence diode lasers, can be mass produced. Consequently, large economies of scale fuelled by demand can be realised by manufacturers. Therefore, diode lasers have the potential to become extremely inexpensive, probably less than £6 per W. In contrast, a reduction in the price per W of the more established dental lasers is not expected. More succinctly, even if sales of these laser systems increase by orders of magnitude in volume to the tens of thousands, then the price of the units would still be nowhere near as low as those of any HPDL-based systems simply by virtue of them not possessing the same propensity for mass production. Notably, it is believed that demand for HPDLs will be due in no small part to the intrinsic application flexibility of the HPDL. The general HPDL system offers a level of application flexibility that is, and will probably remain, unparalleled by any other laser system. This unique flexibility is clearly apparent when one considers the D60 HPDL produced by Diomed Inc. which emits at a wavelength of 810nm ±20nm with an output power of 60 W. Whereas CO_2, Nd:YAG and other laser systems are primarily fabricated for dedicated fixed position tasks (e.g. the Opus 20 CO_2/Er:YAG for dentistry and the Electrox Scorpion Nd:YAG for materials processing), the D60 has been used by the author for: the surface modification of metals, ceramics and bio-materials; metal forming; paint stripping; ceramic and rock marking and plastics welding, despite the fact the D60 is marketed by Diomed as a surgical laser. Such application flexibility will clearly help drive down the price of HPDLs; for if the same laser unit can be employed by the scientist, the engineer, the surgeon and the dentist, then the volume of sales is bound to increase.

It is accepted by many that the influence diode lasers will have on the laser market and the already broad laser applications base cannot be understated. Put simply, the changes effected by diode lasers will be analogous to those seen in computing when microchips replaced valves and transistors. The ensuing huge proliferation of laser availability and the enlarged laser applications base resulting from this veritable technological revolution will impact discernibly in every field of science, engineering and medicine. As such, the emergence of the HPDL as not only the principle laser of choice for dentists, but the preferred tool of choice is a distinct future possibility.