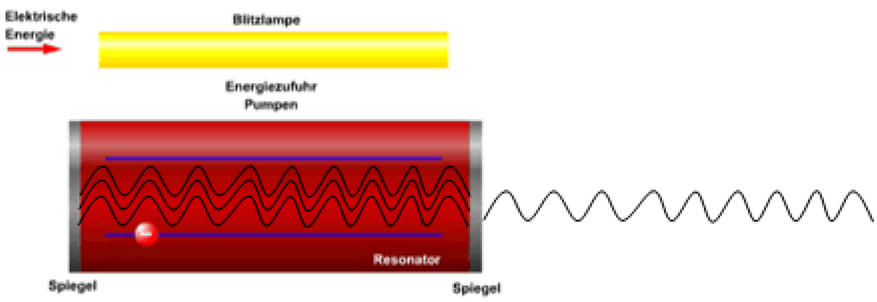
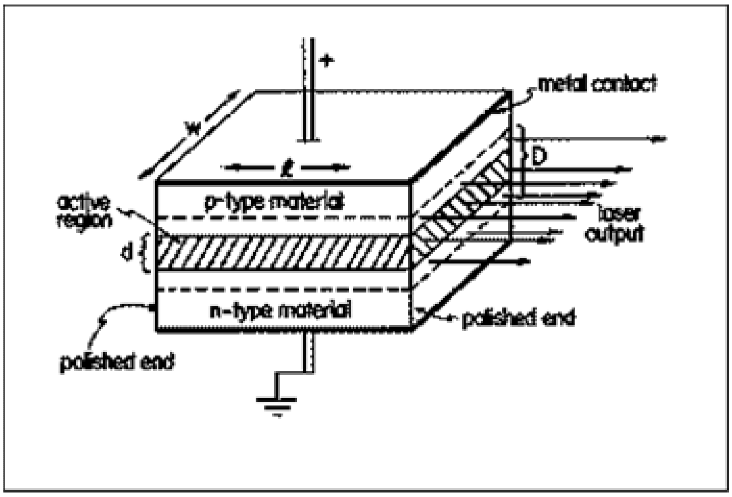
The evolution of the diode laser

In modern dentistry applications, two different types of laser occupy dominant positions: gas lasers and solid-state lasers. The first of these categories includes the Co_2 laser (10 600 nm) and the argon laser (480 + 515 nm), while examples of the solid-state laser are the Nd:YAG (1064 nm), Er:YAG (2940 nm), Er:CrYSGG (2780 nm) and the diode laser (mainly 810 and 980 nm). As the name suggests, gas lasers use gas mixtures as their active laser medium whereas solid-state lasers usually employ a crystal as their active laser medium. In classic solid-state lasers, the laser medium takes the form of an optical crystal which is excited by a flashlight (a process known as “pumping”). The laser crystal and flashlight are located in a unit known as a resonator, a chamber comprising 2 mirrors between which the laser process takes place. At a low percentage rate, one of these mirrors is permeable to laser light, enabling usable light energy to be disengaged from the process. A fundamental property of this design principle involves a certain level of laser energy being stored in the resonator which can be released in a very short pulse. The shorter the energy release time (i.e. the pulse time), the lower the thermal impact of the laser beam. In eye surgery applications, tissue can be removed by very short pulses of laser light to correct vision defects, and this can be done without damaging this tissue with heat. In the world of dentistry, manufacturers of Er:YAG lasers are committed to achieving the shortest possible pulse times. This increases the removal rate for hard tooth material while at the same time reducing the sensation of pain.



Bildertext: Electrical energy Flashlight
Energy supply, pumping
Mirror Resonator Mirror

Semiconductors or diode lasers occupy a special position among solid-state lasers. These do not have a resonator in any conventional sense of the term because the laser medium takes the form of a semiconductor chip. In keeping with all semiconductors, the diode laser has a p-layer and an n-layer. The laser beam is generated precisely in the boundary layer between the p-layer and n-layer. The great advantage of this is that you do not need any flashlights for optical pumping. Instead, the laser element can be excited directly with electrical current. This gives rise to a very high efficiency rating of approx. 35 % (comparison with YAG laser: approx. 1-5 %). For this reason, diode lasers do not require large cooling units and can be built in relatively compact, lightweight units.



Bildertext
Fig. 15 Diagram of a laser diode

A minor disadvantage of the diode laser is that no meaningful levels of energy can be stored due to the absence of a resonator chamber. This means that the laser can only be “on” or “off”. For this reason, diode lasers are typically operated in continuous or CW (continuous wave) mode.

Diode laser technology first started being used in the early 1980’s in the context of what became known as therapy lasers. They were also known as soft lasers or LLLT lasers (low level laser therapy). The spectrum ranges from 1 mW at 635 nm – equivalent to a standard laser pointer – up to 200 mW at 810 nm. Everyone is free to form their own judgement about the possible differences in operating method.
Around about 1995, the first diode laser devices made their appearance, with a power rating of roughly 6 W at 810 nm. For the first time, it was now possible to utilise the thermal effect of diode laser radiation. Numerous clinical studies proved that superlative results could be achieved with diode laser radiation in the 1.0 Watt range when applied to the decontamination of periodontal abscesses and to root canal work. This is due to the good absorption characteristics of the laser light in gram-negative and positive bacterial cells at this wavelength. The accompanying high absorption rate for haemoglobin observed means that, at higher energy levels, surgical incisions can be made using these systems, accompanied by an almost complete absence of bleeding. As time went by, other meaningful possible applications were added and these are now considered to be clinically secure. As a typical example, we would point to the treatment for periodontal implants (“periimplantitis”) which has been superbly documented by a wide range of universities around the world.

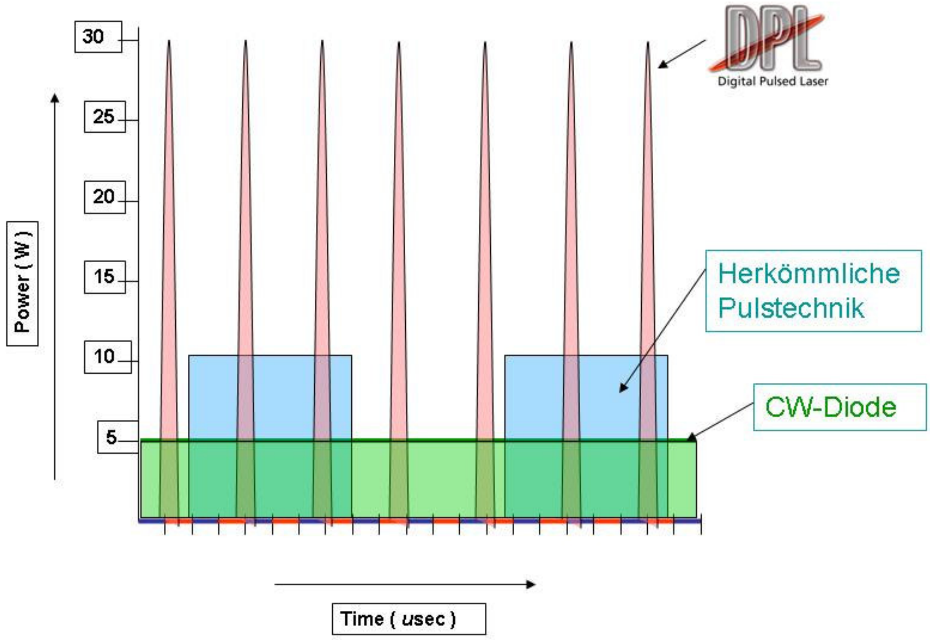
To further improve performance in the surgical sector, it was appropriate to boost the output power of the diode laser. Initial tests with 10 and 15 Watt diodes demonstrated as early as 1999 that success could not be achieved simply by increasing the light energy. A power rating of about 3-4 Watts CW led fairly rapidly to carbonisation of the tissue. Due to the resultant toxic by-products, this effect is therefore undesirable. In addition, wound healing and the sensation of pain are both adversely affected. The cause of this carbonisation is not therefore related to wavelength, instead it can be traced to the timing characteristics of the laser. Since the laser is continuously enabled, this gives rise to a continuous increase in tissue temperature. The burned tissue also exhibits a higher absorption coefficient than healthy tissue. As a consequence, this rise in temperature is disproportionately high.

If you wish to further increase the cutting speed – without damaging the tissue through severe carbonisation, there is only one way left open: simulation of the pulse characteristics of a solid-state laser, e.g. the Er:YAG. Since the diode laser source, as described at the outset, is not able to "store" energy in any significant amounts, the laser diode needs to be able at all times to generate the desired pulse power. The CW performance of the laser diode therefore corresponds to maximum pulse power.

Initial tests were conducted in 2000 with an 810 nm diode laser, an output rating of 20 W and minimum pulse times of approximately 50 nanoseconds (millionths of a second). In this process, the time between 2 pulses was set to between 100 and 450 nanoseconds, equivalent to a mean power rating of 2.0 – 6.7 W.

The histological and practical results were very promising indeed. Compared with a CW diode laser of the same power rating, the necrosis zone in the cut section was almost halved while, at the same time, cutting speed was increased substantially.

Based on these results, work commenced in 2002 on the development of a 30 W diode laser (Elexxion) with a minimum pulse duration of just 9 nanoseconds (millionths of a second). Up to 20 000 pulses per second can be issued across a variable range and, at appropriate pulse widths, the calculated mean power rating was restricted to a maximum of 10 watts. Technical implementation of these short pulses at the high pulse power rating of 30 W necessitated the development of a completely new digital electronic activation system. This type of pulsing process is also referred to as the digital pulsed laser (DPL®) technique. Furthermore, fibre applicators with a special coating had to be developed, capable of withstanding these loadings. Nevertheless, it is still virtually impossible to cause tissue burns, provided that the power settings defined by Elexxion (the manufacturer) are complied with.



Bildertext

Standard pulse technology
CW diode

Clinical trials have demonstrated that a cutting speed in soft tissue can be achieved which actually outperforms a Co_2 laser. At the same time, this laser light cuts more gently than ever before. Previous objections to diode laser surgery ("cutting with a hot glass needle") can now be refuted very credibly indeed.

Something which works so effectively in surgical situations ought to be equally effective in paradontology and endodontics. For the last ten years, these sectors have been using diode lasers with power ratings of 1.0 W for decontamination work. This restricted power rating is chosen to prevent undesirable thermal effects from arising. It is conceivable, through the use of extremely short 30 W pulses, to improve effectiveness substantially without entailed undesirable side effects. Initial clinical trials are now in progress.

We shall see what the future holds. In 5 years time, we might already be working with 50 or even 100 W diode lasers. One thing is for certain though: the future of the diode laser is already in its infancy.

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