

# An Introduction to Industrial Laser Sources

The aim of these few paragraphs is to introduce some of the more common industrial laser types and to attempt to put them into some sort of order so that the inexperienced reader can at least broadly familiarise himself with the main technologies.

Along the way, a number of specialist terms will be introduced; whilst there is insufficient space here to fully explain them, the reader may be encouraged to further explore the internet once it becomes clear which which terms are likely to be of interest to him.

The language used here is intended to be as jargon-free as possible, without introducing inaccuracy. Fundamental terms used include:-

- Basic and derived SI units:

- Seconds (and subdivisions, each one thousandth of the previous: milli-, micro-, nano-, pico- and femto-; denoted ms,  $\mu$ s, ns, ps, fs)
- Metres (with the same subdivisions as above, note a micrometre is often referred to as a 'micron')
- Joules, being the measure of energy
- Watts (and the term for 1,000W, a kilowatt, kW), being the measure of power or energy per second

- Physical quantities:

- Wavelength (which is the distance between adjacent peaks of a wave, whether in water or electromagnetism, here measured in nanometres (nm – a millionth of a millimetre). The range of wavelengths being considered here extends from infrared (IR) to ultraviolet (UV) and can be visualised in figure 1.
- Mode Quality. A laser with good mode quality can be focused to a smaller spot, and achieve a greater power *density* than one with poor mode quality. There are a number of measures of mode quality, the one we will use here is  $M^2$  ("M squared"). A notional, perfect laser beam has an  $M^2$  of 1; real laser beams with  $M^2$  close to 1 are usually referred to as single mode lasers. At the other extreme, high  $M^2$  (10 or above) lasers are generally referred to as multimode lasers.

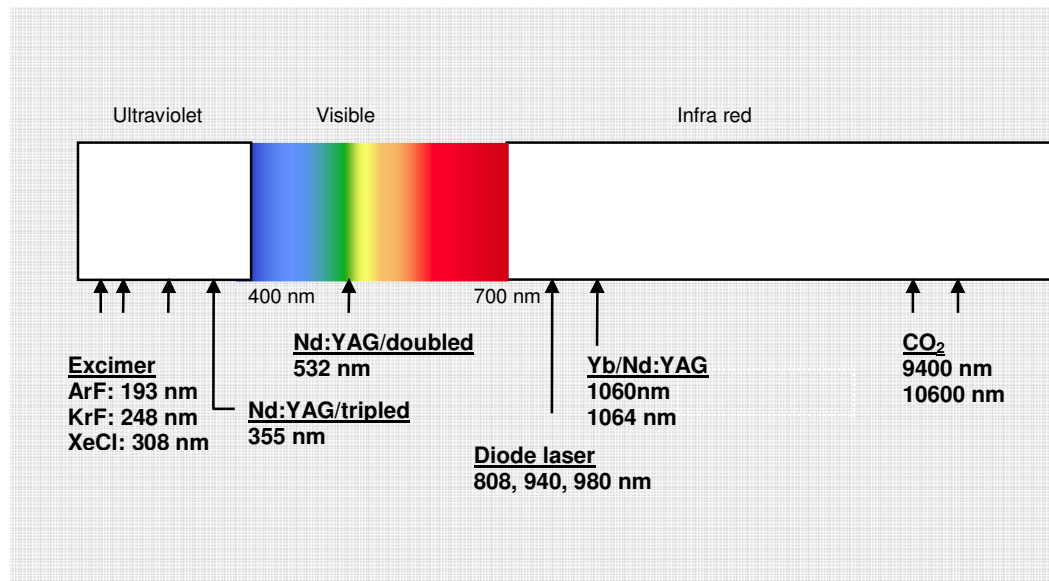


Figure 1 : common industrial laser wavelengths

- Elements or compounds:

- Carbon dioxide or  $\text{CO}_2$  – the gas that we all breathe out, found naturally in air. Laser action can take place between its vibration energy levels
- Two 'rare earth' elements: Ytterbium (Yb) and Neodymium (Nd). Laser action can take place between their electronic energy levels
- Two commonly-used crystals which act as convenient solid hosts for the above elements: 'YAG' (Yttrium Aluminium Garnet) and 'Vanadate' or ' $\text{YVO}_4$ ' (Yttrium Vanadate)

Of the many varieties of industrial lasers available today most are either based upon gas or solid state technology; that is to say that the medium within which the laser action takes place is either a gas or a solid. The laser 'light' to emerge from a source has the characteristics of being highly directional and essentially monochromatic (single wavelength). These 'coherent' characteristics distinguish laser light from other sources with which we are familiar, such as sunlight and man-made sources such as incandescent light bulbs or fluorescent tubes. The reason why laser light is so different is indicated by the words behind the acronym – light **amplification by stimulated emission of radiation**; the laser is an amplifier – it is a device that gives you much more of the energy that you start with. Such a device needs a source of power and all the lasers described require regular or continuous 'charging' – in laser-speak – 'pumping'.

Such a beam of light can be focused to a tiny spot using a lens or curved mirror – resulting in an extremely intense focused spot. This focus can then be manipulated by a variety of optical and mechanical techniques and used to process materials, be it to cut, weld, ablate, harden, mark, expose or engrave.

### **Gas Lasers**

The two most important industrial gas lasers are  $\text{CO}_2$  and Excimer lasers, and these happen to occupy the extremes of the wavelength range under consideration.

Excimer ('Excited Dimer') lasers use halogen dimers (e.g.  $\text{F}_2$ ) or rare gas halides (e.g. ArF or XeF) as the laser medium, pumping is by electric discharge through the gas. The output in the UV part of the spectrum (usually at discrete wavelengths between 157nm and 351nm) and as such has a very short absorption wavelength in most materials. The lasers are pulsed, delivering up to about a Joule of energy in a pulse duration of around 10ns. Such pulses are often imaged through a mask and used in the micro-machining of thin layers of organic or ceramic materials by ablation.

$\text{CO}_2$  lasers were the first laser to be applied to a commercialised industrial application – die board manufacture, wherein fine cuts are made in wooden forms to allow blades to be accurately inserted to produce a tool to press out cardboard boxes.  $\text{CO}_2$  lasers also rely on electric discharge pumping, through a mix of nitrogen, helium, hydrogen and of course carbon dioxide. The laser output is more commonly continuous, but can be pulsed. The output is in the infrared part of the spectrum, around  $10\mu\text{m}$  wavelength and average powers in excess of 10kW are commercially available. There are several distinct types of  $\text{CO}_2$  lasers available – sealed, semi-sealed and flowing gas. The highest power lasers are fast flow lasers and use a turbine to force the gas mix from storage bottles through the laser. The lowest power ones (less than a kW) are entirely sealed – a waveguide or slab geometry, requiring no gas supplies other than a factory refill every few years. An intermediate technology, based on the slab format is sealed and able to deliver multikilowatts of power, but it requires a single small gas bottle (lasting for months), which is used to refill the chamber every few days.

Unlike most of the solid state lasers that follow, the UV and IR gas lasers described above cannot be delivered by fibre optic. One of the attractions of the near IR and green lasers below is that these wavelengths have negligible losses when transmitted down flexible fibres, which is most convenient, particularly if using robot manipulation to bring the laser power to the workpiece.

## Solid State Lasers

The first laser, demonstrated by Theodore Maiman in 1960 was a solid state ruby laser, the ruby crystal was pumped by a flashlamp. Today, some of the most important industrial solid state lasers are based around the rare earth element, Neodymium (Nd). The Nd atoms displace a small percentage of the atoms in a suitable host crystal lattice to make a single crystal of rare earth doped laser medium – common hosts are YAG and YVO<sub>4</sub> ('Vanadate'). These Nd:YAG and Nd:YVO<sub>4</sub> lasers are optically pumped, either by arc lamps or by laser diodes.

Until recently, the commercial world of these lasers was dominated by one crystal geometry: the rod. Rod-shaped crystals of perhaps 15:1 aspect ratio, the size of a pen, have served industrial laser users well for over 30 years, however they do have a drawback: the quality of the laser beam generated can be compromised by the inherent difficulty of extracting the heat produced during operation. Heat from within the body of the rod has to be removed by water cooling the surface of the rod; this is not an ideal process. It is easier to cool extremely long rods (i.e. fibres) or extremely short rods (i.e. discs) and in recent years industrial lasers based on these two geometries have begun to reach the market.

Glass fibres are doped with a rare earth element, often Ytterbium (Yb) and pumped with laser diodes to produce commercial fibre laser modules of up to a few hundred Watts of *continuous wave* (cw) power at 1060nm – 1070nm, with  $M^2$  close to 1. These fibres are sometimes bundled together to produce multimode outputs of 10kW and beyond. Such fibre lasers can also have pulsed outputs.

Thin discs of Yb:YAG crystal are also diode laser pumped to produce cw powers of up to several kW, which are multimode, but of better beam quality than equivalent rod-format lasers. Single mode versions of these disc lasers can produce around 100W of power with excellent beam quality, close to 1, which can be '*Q-switched*' – more on Q-switching later.

The majority of solid state lasers supplied today are, however still rod-based. For industrial purposes these can be classified as cw, pulsed and Q-switched. Of these the highest average power is available from cw (Nd:YAG) solid state rod lasers. These can be pumped by diode lasers or by arc lamps and overlap in performance with the Disc and Fibre lasers mentioned above, albeit with somewhat lower beam quality (higher  $M^2$ ).

Pulsed lasers are normally flashlamp-pumped. Conventional noble gas-filled glass lamps, have been used for optically pumping solid state lasers of various types for decades. Usually Krypton is used for cw arc lamps and Xenon for pulsed ones. Each high energy pulse of white light from the tube produces a laser pulse from the Nd:YAG rod. Typical outputs from these lasers are up to 100J or so per pulse and pulse durations are in the range of a millisecond (ms) – most typically between a tenth of a ms and ten ms (0.1ms – 10ms). These industrial pulsed YAG lasers can operate at repetition rates from single pulses up to several thousand pulses per second ('several kHz'), subject to maximum average powers of several hundred Watts.

Another means of generating pulsed outputs from many types of laser is Q-switching. Put simply, this process involves briefly halting the laser process, so that energy is effectively built up within the laser medium, and then releasing this stored energy in a short, powerful pulse, before once more stopping the output to repeat the process. Whilst a simple mechanical block could perform such a task, the favoured means of interrupting the laser action in cw pumped solid state lasers is acousto-optic deflection. A mechanical block could simply soak up the light (photons), so that the 'snowball' process ('positive feedback') of power build-up that is fundamental to laser action is halted. The acousto-optic Q-switch works in a very similar way: the Q-switch itself is a block of quartz that is vibrated at a high frequency. The interaction of these vibrations and the laser light passing through the crystal (by diffraction) causes the light to be 'dumped' rather than contribute to the laser process. The appeal of acousto-optic Q-switching is that the Q-switch can be precisely controlled by microprocessor at very high frequency (on-off rates).

Q-switched Nd:YAG and Nd:YVO<sub>4</sub> rod-lasers are often operated at thousands or tens of thousands of pulses per second (Hz) and can achieve peak powers of more than a thousand times the cw or average power that a given laser is capable of. Such lasers are usually capable of delivering average or cw powers in the range of tens to hundreds of Watts. These high peak powers, albeit lasting for only very brief pulses [typically in the range of a few nanoseconds (ns) up to a microsecond (μs)], can be very valuable for specific material processing applications.

A summary of pulse durations from several solid state laser technologies is shown in figure 2

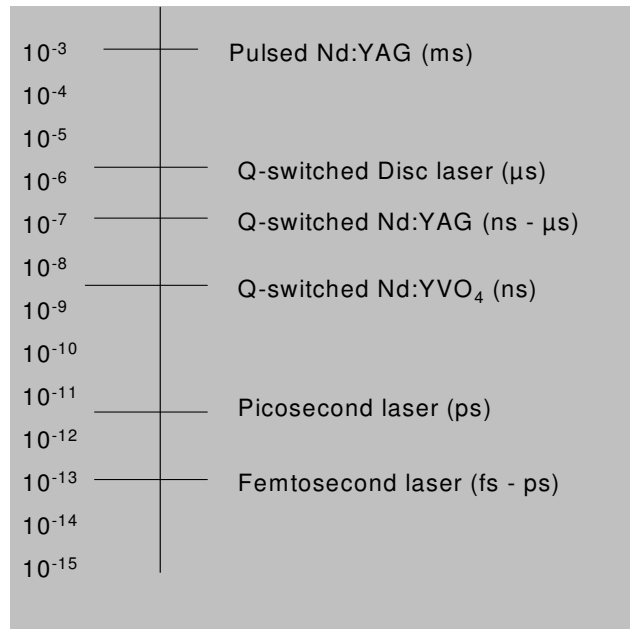


Fig. 2: pulse widths from various solid state lasers

The very short pulse lasers – pico/femtosecond sources – offer the potential to perform some tasks so quickly that negligible residual thermal effects remain after the laser process. Whilst exciting, such lasers are very rare within mainstream ‘industrial laser processing’.

Another approach to improved materials processing, be it cutting, marking or surface modification, is to attempt to tailor the laser wavelength so that it is better absorbed by the material to be processed. The rod-type, Q-switched, diode pumped solid state (DPSS) lasers described above have the characteristics of high peak power and comparatively good mode quality. This type of laser, operating at near infrared wavelengths can have its output wavelength modified with a reasonable conversion efficiency. Certain crystals, when inserted into the laser, exhibit ‘non-linear’ effects which cause, for example, the fundamental wavelength of Nd:YAG (1064nm) to be converted into half this wavelength (533nm, green) – known as ‘frequency doubling’. Frequency tripling (to 355nm) and frequency quadrupling (to 266nm) is also available from commercial laser suppliers, these wavelengths are in the ultraviolet region of the spectrum. Conversion efficiencies in the region of 10% to 60% are commonly offered, generally the higher order conversions are less efficient. Other than improved absorption, these shorter wavelengths can also bring the advantage that they can be focused to a smaller spot owing to the fact that the focused spot size is directly related to wavelength. These frequency-doubled and frequency-tripled wavelengths can also be seen in figure 1.

The last solid state laser type to be introduced has already been mentioned: diode lasers. Thanks to their applications in telecommunications and in every CD/DVD player, this is the laser type manufactured in the largest unit volume. Diode lasers consist of a p-n junction of

semiconductor material, based for example on Gallium Arsenide (Ga As). Such tiny 'chips' resemble Light Emitting Diodes ('LEDs'), but are able to emit coherent laser light at one of a number of wavelengths from red (around 660nm) to near IR (980nm). However, the output from each tiny element is limited to a fraction of a Watt and for industrial applications many such independent elements are created in a row on a semiconductor strip or 'bar'. A bar can output up to a few hundred Watts. Further, these bars can be assembled into stacks, having a continuous wave output of several kilowatts. Such sources are compact, highly efficient (as much as 50% 'wallplug to optical' efficiency) and have little or no maintenance. There is however a limitation to their application and that is that such sources are necessarily *not* coherent sources – that is to say that in practice they cannot be focused as tightly as the other laser types discussed here. Diode lasers are ideal efficient pump sources for other laser types, but are usually only used directly in applications that do not require high power density, such as heat treatment, plastic welding or conduction-limited metal welding.

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30<sup>th</sup> January 2006