Successful Laser Module Specification

Whitepaper

PRO PHOTONIX

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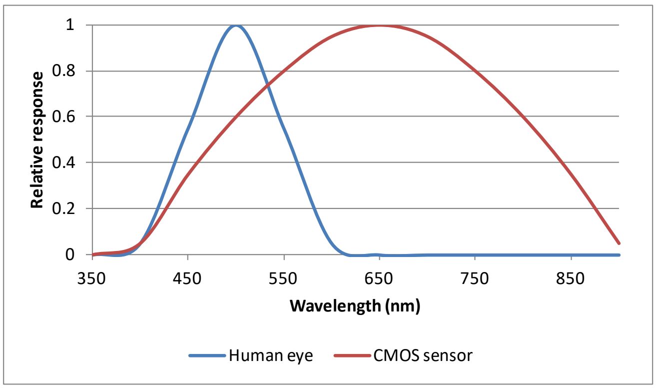
The task of selecting or specifying the ideal laser module for an OEM application can seem daunting. If optimal performance is to be achieved, many design aspects need to be taken into account including wavelength, output power control, laser safety, life expectancy, operating environment, power supply and size limitations. Some of these are independent but others have to be considered in relation to one another and trade-offs may need to be made based on performance priorities and cost constraints. Here we describe a 7-element design approach to deliver the best possible OEM laser module solution.

1. Wavelength Selection

At the core of laser module design is the selection of an appropriate laser diode and one of the most important considerations is laser diode wavelength.

The human eye is more sensitive to green light than to other colors so, for maximum apparent brightness when viewed by the human eye, green lasers are preferred e.g. at 520nm. Applications include patient positioning in medical or dental equipment, targeting for security and defense, and use in industrial alignment operations.



Spectral response of the human eye in daylight conditions and a typical monochrome CMOS camera sensor

As shown in the image above, most machine vision cameras are more sensitive to red light at around 650nm. For these applications a red wavelength may be most appropriate. Lasers in the infra-red are used where invisibility is an advantage, and newer model cameras used in machine vision applications are increasingly sensitive in the NIR (near infra-red). Other sensors are wavelength specific or may be paired with optical filters to reduce the effect of daylight or artificial light, either for observation by the human eye or where a camera is used. Other wavelengths offer performance advantages in applications such as biomedical analysis, fluorescence or sorting where materials being tested or analysed respond only to light of a very specific color including 450nm or 488nm. Also, a range of wavelengths is essential for color mixing; for example in RGB (red/green/blue) projectors.

Laser diodes used in high quantities, for example in consumer or telecoms applications, are typically lower cost devices. These include 405nm blue-violet lasers for Blu-ray, red for optical disc drives, and near IR for laser printers or telecoms. When specifying a laser for a more specialized application there may be significant cost benefit in selecting a wavelength commonly used in these high volume applications.

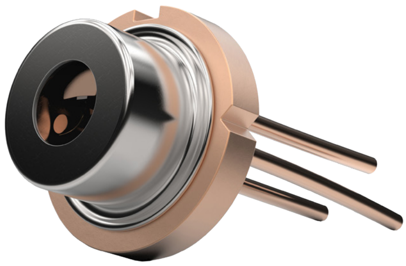
For any application it is important to understand the range of suitable wavelengths and not to restrict wavelength selection without proper analysis.

2. Output Power Considerations

Optical output power, typically expressed in mW (milliwatts) or W (watts) is the absolute measure of brightness and one of the most important factors in laser module design.

This parameter is closely linked to both performance in the application and predicted laser lifetime under a given set of operating conditions. Both are likely to be improved by the selection of a laser module rated for higher output power so it may be tempting to select one with an unnecessarily high optical output for the specific application. With higher optical output power there are important safety and cost considerations.

For safety reasons the maximum output power of a laser module design may need to be limited for a particular application. Some lasers are designed for use in cutting and welding applications and deliver such high power that they can never be inherently safe and must be physically isolated from the user for safety reason. At the other extreme are medical applications such as retinal imaging or pilot lasers for eye surgery requiring laser modules which are eye-safe and have total output power in the <0.4mW range.



Laser diodes, and by inference laser module designs incorporating them, may be rated for several thousand hours of continuous use at a specific output power and temperature. With ideal heat dispersion, the laser will stabilise at the same temperature as the operating environment. But heat dispersion is rarely ideal. It relies on effective thermal conduction between the laser diode semiconductor chip and a suitable heat sink via other elements of the laser module design and the equipment into which it is mounted. Operating a laser module in higher temperature conditions than it is rated for, or with inadequate heat sinking may significantly reduce its life and affect performance.

Durability is important where field replacement of the laser module will be costly, inconvenient or impossible, or where failure is unacceptable e.g. in safety-critical applications. In these cases it may be advisable to over-specify the laser module in terms of rated output power to ensure longer laserlife. For applications where only a very short life is needed (e.g. a disposable device) it may be possible to reduce cost by using a laser module rated for a lower output power with an expectation that the diode will have a life of a few hours or days.

Laser module life will be extended if used infrequently and for short periods, or pulsed, rather than continuously, 24/7. Pulsing the laser will extend its life approximately in inverse proportion to its duty with effectively no penalty for switching i.e. a laser pulsed with 50% duty will last almost twice as long as one driven continuously, with the same output power and in the same environment.

Compact Laser Diode Module

Where space for the laser module in its operating environment is constrained, a laser module incorporating a semiconductor laser diode in a very small package may be the only option. Laser diodes with <1W output will typically be packaged in a TO can either 9mm, 5.6mm, 3.8mm or 3.3mm in diameter. A larger can allows for more efficient heat transfer from the semiconductor chip. So the largest laser diode package compatible with the allowable laser module size should be used to ensure output stability and long service life.

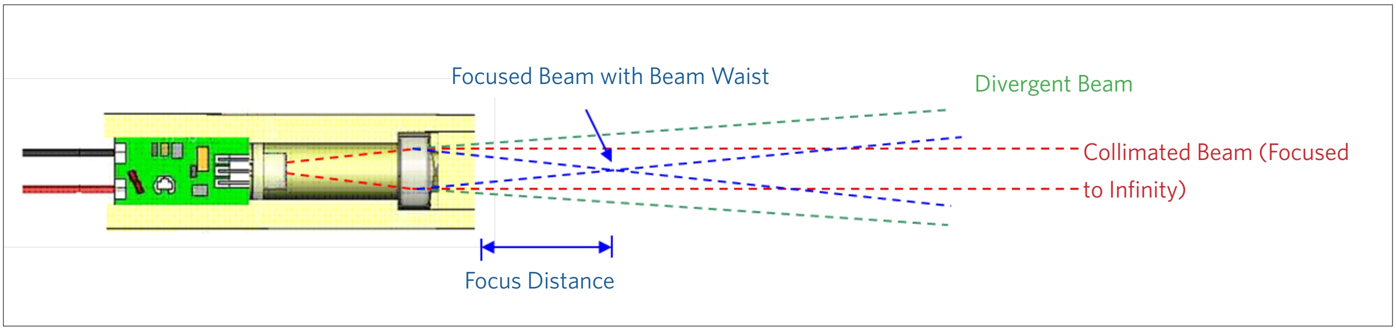
3. Optical Design

Once the most suitable laser diode has been selected based on wavelength, optical output power and dimensions, an optical configuration incorporating one or more lenses will be designed to deliver a beam with the required size and shape at the working distance or over a working distance range.

TO-can laser diodes emit diverging elliptical beams which, for almost every OEM application, will need to be collimated or focussed. The difference in the divergence angles in the two directions perpendicular to the axis of propagation, (the axis along which the beam travels), and astigmatism (a difference in the apparent point source origin of the beam in those two dimensions) in the semiconductor diode chip results in a beam shape that is not only elliptical but changes with increasing distance from the laser diode.

In some applications, a collimated beam is needed. A perfectly collimated beam is the same size regardless of distance from the point of emission from the laser module. In practice, the beam will increase in size to some extent with distance from the laser module, and the rate of this increase is a measure of how well collimated the beam is.

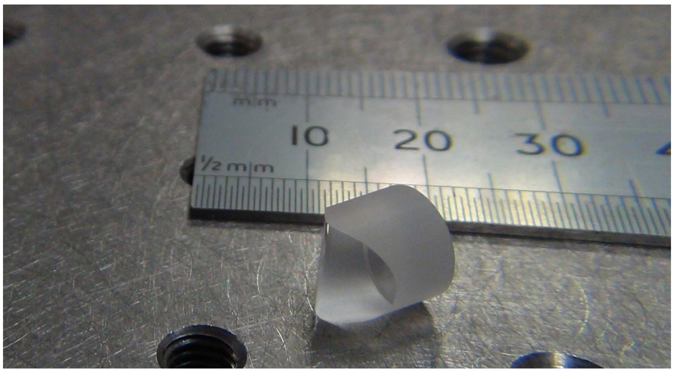
To meet the needs of other applications, the beam may be focussed to the smallest possible size at a specific working distance. Optics can be selected to provide a small beam diameter at this "beam waist". The beam will converge between the laser module and the beam waist, and diverge again after it, and the extent to which the beam maintains the same size either side of the beam waist is described as its depth of focus. Greater depth of focus provides a wider range of working distances.



With a simple, low cost optical design there will be a trade-off between beam size and depth of focus. A smaller diameter beam at the beam waist will have a shorter depth of focus and vice versa. More complex optical designs using two or more lenses allow more precise control of beam size and degree of collimation. Where necessary, correcting optics can be used to make the beam more circular but there will be a cost penalty and loss of optical output power due to the added optics. For many applications, an un-circularised, elliptical beam is satisfactory and economical.

Several methods can be used to convert an elliptical beam laser to a line generator. The most suitable method will depend on the quality of the line needed for the application.

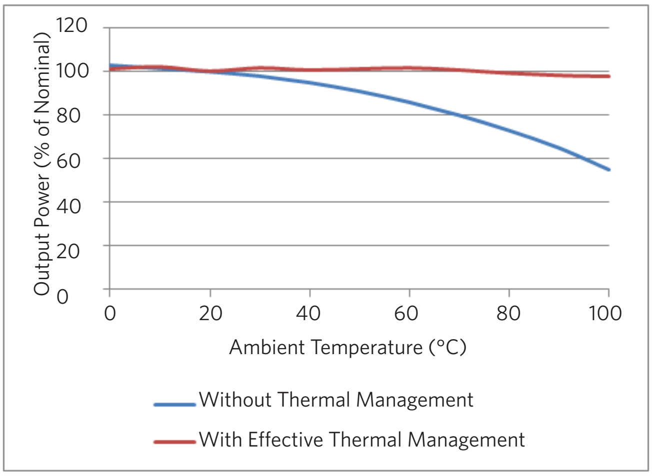
A cylindrical line-generating lens will produce a line which is brighter and thicker at the centre, tapering towards the ends with a Gaussian intensity distribution. This line is likely to be perfectly suitable for many visual alignment applications.



Where a line with much greater uniformity along its length (in terms of line thickness and intensity) is required, more sophisticated optical designs will be needed. Precise 3D measurement applications typically have this requirement. More complex beam shapes can be achieved using diffractive optical elements. Projected patterns include multiple lines, grids, dot arrays and a wide variety of custom designs for specific applications.

4. Thermal Management

The operating environment will affect the temperature of the laser module and the laser diode inside. In turn those factors will determine the stability of the laser output as well as its useful life, so thermal management is an essential consideration. As a minimum, the design of a laser module and the system in which it is used should provide adequate dissipation of heat from the laser diode semiconductor chip. This will normally involve metal-to-metal contact between the laser diode can and the external environment.



Variation in operating conditions (especially temperature) may cause variation in output power, wavelength or beam shape. Thermally induced changes in output power or wavelength are characteristic of the laser diode whereas beam shape variation may be associated with expansion or contraction of optical and mechanical components. In applications where a high degree of performance stability is required (as with many analytical and metrology applications) and the operating environment cannot be controlled, the laser module may need to include design features to stabilise optical output.

For optimal thermal stability in the most critical applications, the laser diode temperature will be controlled using thermoelectric cooling (TEC) incorporated into the laser module design. The impact of effective thermal management is illustrated in the chart below.

5. Mechanical Aspects

When it comes to mechanical design, almost any form factor can be achieved (see examples in the image below). A laser module is an assembly of multiple component parts including a semiconductor laser diode, one or more optical components, and electronics to control the laser diode output and protect the diode from electro-static discharge (to which these devices are extremely sensitive). These components are enclosed within a mechanical package which must keep the optical elements aligned and precisely positioned relative to one another under normal operating, storage and transport conditions, provide protection e.g. against water and dust ingress, allow heat dissipation from the laser diode and protect the whole assembly from mechanical damage. Brass is a suitable material for many applications where lower cost is critical and electrical isolation is not necessary. Depending on the laser diode used, the package may need to provide electrical isolation between components and the clamp or bracket with which the laser module is mounted. Anodized aluminium provides electrical isolation as well as a more aesthetically attractive finish in a range of colours.

Mechanical packages can be tailored to individual OEM applications

Cylindrical laser module designs allow for simple clamping with adjustment by rotation and, by moving the laser module forwards or backwards in the clamp, some degree of working distance adjustment.

Many alternative geometries and mounting methods can be provided to fit specific OEM applications. As well as the design of mechanical parts, the quality of their manufacture is critical to the performance of the laser module especially in controlling the precise alignment of optical components. Most users prefer the position of optics within the laser module to be adjusted and factory set for collimation or focus. This ensures reliable optical performance without risk of misalignment caused by shock or vibration in use.

Where more focus adjustment is required, by an OEM or end user, this feature can be provided in the design of the package but the more complex designs may be more costly, and a focus-adjustable laser module is likely to be larger than one that is factory set.

Very often, dimensional constraints in the OEM's own product design mean that a laser module should be as small as possible. The introduction of smaller laser diode packages, with the current trend from 5.6mm TO-can as standard, towards 3.8mm or 3.3mm diameter can sizes, is allowing the design of very small laser modules with a high level of functionality.

When space limitations do not allow for a laser module incorporating all components in a single package, it may be possible to use one extremely small package containing the laser diode and optics, plus a second containing the driver circuit located some distance away where more space is available. These two elements will be connected by electrical cable.

Fiber PRO Laser

Alternatively, a fibre coupled laser design, with the laser diode and control circuitry in a larger package remote from the very small optical device may be used. A wide range of optical fibres and fibre connector types are available. Although optical efficiency will be reduced when a laser diode is coupled through an optical fibre to the focusing or collimating optics, the beam emitted from an optical fibre is circular rather than elliptical which will be an advantage for some applications.

Custom label designs fixed to the body of the laser module or the cable, or laser-engraved markings, allow rapid part identification and traceability.

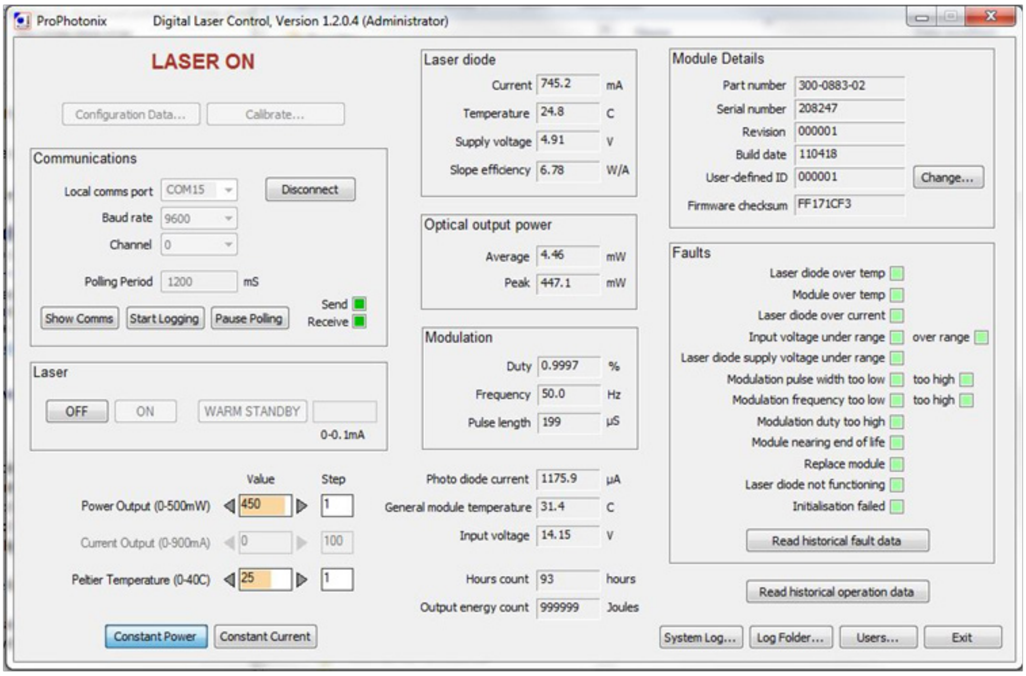
6. Drive Electronics

The majority of laser module designs include drive circuitry to control and stabilize output power under a range of operating conditions and over the life of the part.

Automatic power control (APC) in combination with a built-in photodiode maintains constant output from the laser module while connected to a DC power supply with voltage within a specified range. When a laser diode without this in-built photodiode feature is used in the laser module design, other methods of limiting the impact of environmental changes and aging of the laser diode and other components will often be required (such as an integrated external photodiode).

A feature to enable the user to adjust laser output power by varying the voltage applied to a second input cable may be incorporated into the driver design. Other optional electronic features include a facility to pulse laser output at frequencies up to several MHz using a TTL (transistor-transistor logic) trigger input.

A wide range of digital control and monitoring features may also be incorporated into the drive electronics allowing the user to control and monitor laser module performance. For example, total output power, pulse frequency and pulse duration may be



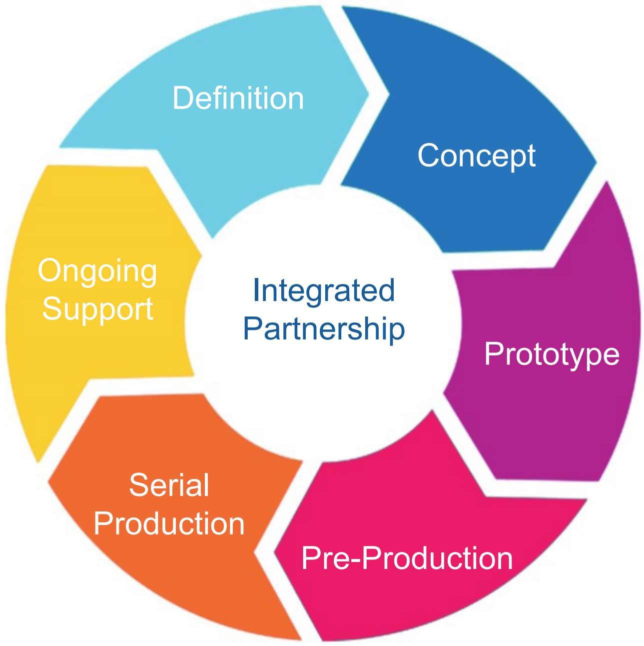
Digital features enable user control and monitoring of laser module performance

controlled through a digital interface (an example of which is illustrated here), performance data may be stored or output for long-term performance monitoring and preventative maintenance scheduling, and a flag may be raised as the laser reaches near end of life.

7. Partner Selection

Successful design of an OEM laser module and development of its associated manufacturing and test processes invariably require a close partnership between the OEM and laser design and manufacturing teams. The laser manufacturer's ability to move the development process forward rapidly will depend on a number of factors including depth and breadth of experience in laser module design, availability of component parts such as laser diodes and lenses ideally from stock, in-house facilities for mechanical component manufacture and the readiness of a team with experience in the full range of engineering disciplines.

Very rarely, a suitable laser module can be designed on paper to precisely and very economically meet the needs of a specific application, and taken straight into high volume manufacture. More typically, there will be one or more phases of prototyping and qualification, and the laser module manufacturer should be capable of moving through this process quickly and efficiently. Laser manufacturer and OEM will work closely to specify the laser module as clearly as possible at the start of the development process and maintain communication throughout, refining the specification based on performance evaluation.



The Laser Module Design Cycle

Alongside laser module design, the manufacturer will need to perfect production and test processes to maximize product quality and consistency, and minimize waste, achieving the lowest possible part cost whether in single digit quantities or hundreds of thousands of units per year.

Once the laser module is in routine manufacture, the OEM and laser manufacturer will continue to work together, monitoring performance and identifying improvements and cost saving opportunities for the current and next-generation product.

A quality laser manufacturer will have robust quality management systems in place throughout their business and be approved to international quality standards. Laser modules will be manufactured consistently and to the highest quality standard with appropriate in-process and release inspection procedures. The manufacturer will also agree the batch, or individual part records to be maintained or supplied with the product, to allow traceability and verification of product performance.

Effective and efficient laser module design for OEM applications requires careful consideration of many factors each of which influence cost as well as performance. The ideal outcome can only be delivered by an experienced, specialist laser module design team working in close partnership with the OEM's own engineers. The specification and design process will be simplified and brought to a more successful conclusion by careful consideration of the seven design elements discussed here.

To learn more about our Laser Capabilities, download the Custom Laser Solutions brochure: