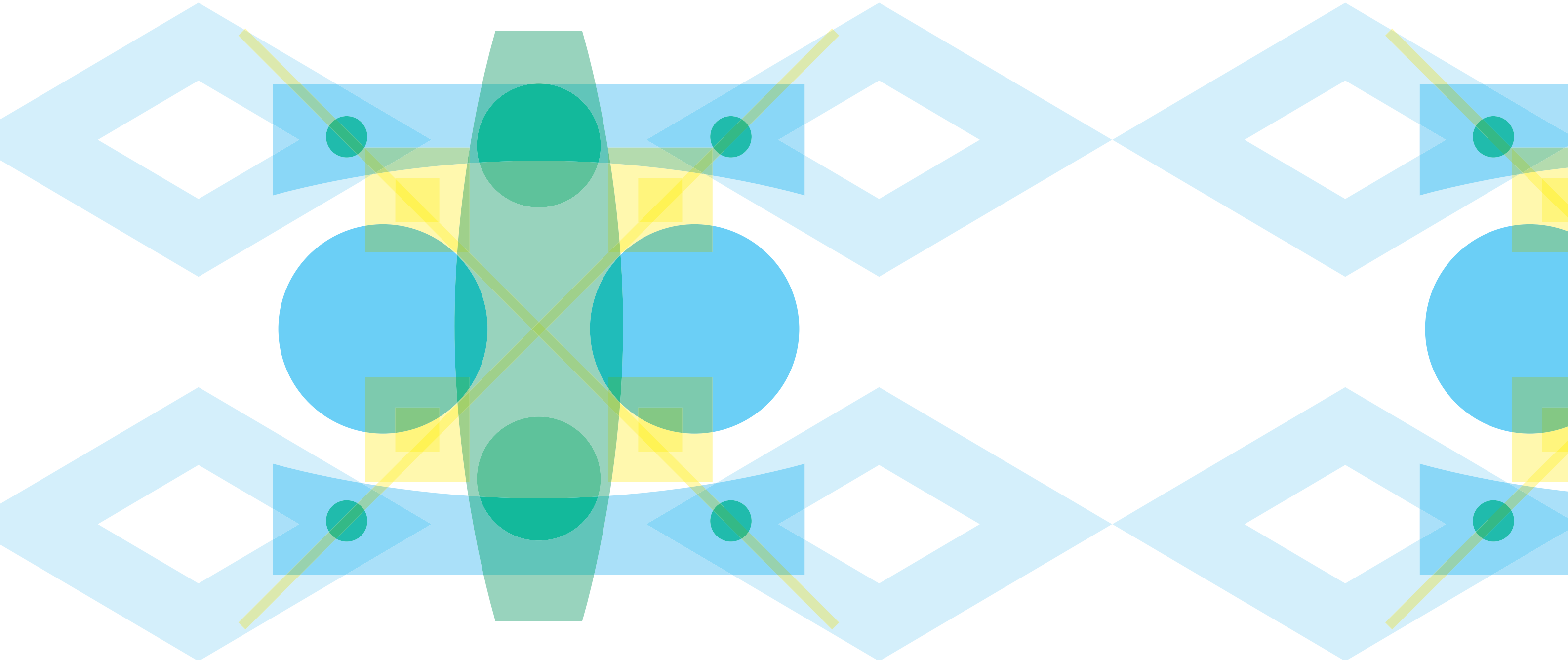
FISBA Innovators in Photonics



Economical, High Performance Fast Axis Collimators for High Power Blue Laser Diodes

One of the most important developments in laser diode technology over the past few years has been the introduction of relatively high power (up to 5 W from a single emitter) products with output in the blue. These short wavelength sources offer advantages over their more common near-infrared counterparts, particularly in applications such as displays and cutting and welding of metals which strongly absorb blue light (such as copper and gold). Unfortunately, the collimating lenses traditionally used for near infrared laser diodes cannot provide optimum performance for these high power blue laser diodes. This limits the potential applications that could otherwise benefit from these unique light sources.

In terms of wavelength, in particular, it is difficult to collimate the output of high power, blue laser diodes because even small levels of absorption in the lens material produce heating, which, in turn, adversely affects the performance of the optic. This document reviews this problem and explains how FISBA overcame it by combining a careful material evaluation program with a proprietary lens fabrication method. The resulting new generation of fast axis collimators (FACs) delivers superior performance when used with high power laser diode sources emitting in the blue. And, most importantly, these new FACs are produced using a scalable process at market enabling prices.

Laser Diode Collimation

Laser diodes typically have output characteristics which are substantially different from most other laser types. Specifically, they produce highly divergent output rather than a collimated beam. Furthermore, this divergence is asymmetrical; the divergence is much larger in the plane perpendicular to the active layers in the diode chip, compared to the plane parallel to these layers. The more highly divergent plane is referred to as the «fast axis», while the lower divergence direction is called the «slow axis».

Effectively utilizing laser diode output almost always requires collimation or other reshaping of this divergent, asymmetric beam. And, this is typically done using separate optics for the fast and slow axes because of their differing properties. Accomplishing this in practice therefore requires the use of optics which have power in only one dimension (e.g. cylindrical or acircular cylindric lenses).

One key optical definition to understand about collimators is that of Numerical Aperture (NA), which is a measure of light collection efficiency. Specifically, NA is the sine of angle between the beam edge and the optical axis (actually, it's the index of refraction × sin(θ), but we're assuming that the system is in air which has a refractive index of 1.0). This is illustrated in the drawing (see Figure 1).

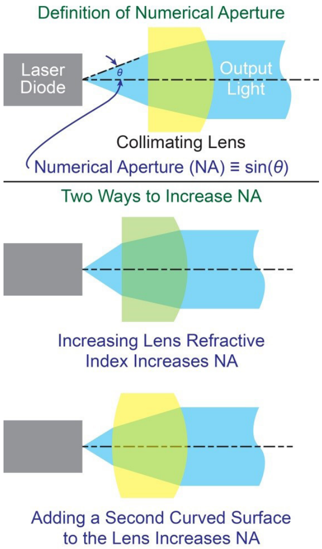


Fig 1. For a lens of a given shape, a higher index material will produce a shorter focal length and higher NA. Alternately, without changing material index, using steeper curve(s) on the lens surface(s) will reduce focal length and increase NA.

The high divergence of the fast axis of most laser diodes means that a high NA lens is required in order to collect all the output light. Plus, a very short focal length is often desirable because it reduces beam height. However, as focal length decreases, residual divergence increases. The optimum value depends on the specific optical design, but in many applications, effective focal lengths significantly below 1 mm turn out to be the best solution.

There are two primary ways in which to achieve high NA in a single element FAC microlens. For a lens of a given shape (radii of curvature), increasing the refractive index of the lens material reduces the focal length, which, in turn, increases NA. Alternately, using steeper surface curvature, and/or adding curvature to the second surface of the lens (which is shown as flat, or plano, in the first two parts of the drawing (see Figure 1)), will also reduce lens focal length and therefore increase NA.

Blue FAC Challenges

Producing high NA, short focal length FACs for high power, blue laser diodes presents some unique challenges. Specifically, many optical materials have higher absorption in the blue than at longer wavelengths. And, this is particularly true of the higher index of refraction optical materials which are traditionally used for FACs because they facilitate the production of optics with very high NAs.

Even small levels of absorption cause heating within the lens when exposed to high power blue light. This leads to bulk changes in FAC shape due to thermal expansion. Plus, the index of refraction of the material also varies with temperature. These two mechanisms cause so-called «thermal lensing», which is a spatially dependent change in the refractive properties of the bulk material. The net result of thermal lensing is a displacement of the back focal plane of the FAC lens, resulting in an increase in its divergence. These can dramatically affect the properties of the focused beam into the downstream application, therefore degrading the system performance.

Heating of the FAC due to applied laser energy also creates a secondary problem. Specifically, bulk heating of the lens also raises the temperature of the adhesive used to bond the FAC to its support substrate. Heating of the glued interface can produce additional mechanical displacement, and therefore, misalignment. A more robust mechanical design can counteract this, but usually with a negative cost and size impact.

Blue FAC Material Testing

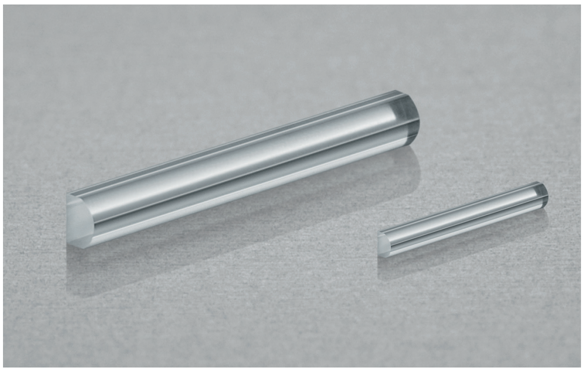
In order to meet the challenge of producing next generation FACs which provide both the optical and thermal performance characteristics necessary for successful use with high power, blue laser diodes, FISBA started by conducting a testing program to explore thermal lensing in three of the most promising lens materials [1]. The key properties of these materials are listed in the table (see Table 1).

	S-TIH53	FISBA «Blue»	Fused Silica
Transmission @ 450nm	Poor	Good	Excellent
Coefficient of thermal expansion	Large	Moderate	Low
Refractive index	High	High	Low

Table 1. Comparison FAC material properties for applications with blue diode laser

The material S-TIH53 is a high index glass produced by OHARA Corp. which is widely employed in FACs for high power infrared laser diodes because of its high index of refraction (which simplifies the production of a high NA lens for the most commonly used fabrication methods). FISBA «Blue» is a specially selected optical glass which offers a good balance of characteristics, specifically for use at blue wavelengths. Fused silica is a widely employed optical material, particularly for use in the blue and ultraviolet, and also as a mirror substrate (due to its low thermal expansion coefficient).

In the experimental setup for this research, the output from a 200 W blue laser diode module was focused to a 200 µm spot diameter at the front focal point of FACs made from each of the materials just described. Each of these FACs had an effective focal length (EFL) of 600 µm. The subsequent increase in lens temperature as a function of applied laser power was measured with an infrared camera. The measured results were then compared against values computed using finite element analysis (FEA).



Two examples of FACs made from FISBA «Blue»

Not surprisingly, the three FAC materials exhibited orders of magnitude differences in thermal behavior which correlated directly with their blue transmission characteristics, and which matched the FEA modeled predictions closely. Specifically, optical performance of the S-TIH53 FAC degraded significantly when exposed to more than just a few Watts of laser power. The FISBA «Blue» FAC demonstrated intermediate performance, and was able to handle on the order of 50 W of laser power before its optical properties changed appreciably. The fused silica FAC demonstrated essentially no thermal lensing or change in EFL even when exposed to the full 200 W output of the test source.

Blue FAC Solutions

This research proves that, for collimating blue laser diodes of up to 50 W (a power level much higher than currently available single emitter sources), FACs produced from FISBA «Blue» represent an optimum choice. Besides demonstrating good thermal characteristics, this material also has a sufficiently high index to enable use of plano-convex designs. This shape is less sensitive to misalignment in the fast axis direction than lenses which have a convex surface facing the emitter. Thus, they are easier to integrate into the system, and less likely to become misaligned over time. FISBA «Blue» FACs are also a cost competitive option.

For the even higher power blue laser diodes, such as multi-emitter arrays that are in development, fused silica FACs represent a possible solution. However, most lens manufacturers using traditional FAC fabrication methods are not able to readily produce these components – at least not at the unit volumes and price points required by most commercial customers.

Specifically, this is because FACs are typically microlenses which employ at least one acircular cylindric surface. The two most common commercial methods for fabricating these microlenses are precision glass molding and other wafer-based processing methods. But, the low refractive index of fused silica necessitates the use of a biconvex shape in order to achieve high NA. Unfortunately, with any wafer-based manufacturing process, it's difficult to maintain the highly precise alignment between the cylindrical axes of the front and back surfaces. Also, there isn't currently a suitable mold material that can withstand this high molding temperature required for fused silica, and which can be microstructured with the necessary accuracy.

FISBA is instead developing an alternative, proprietary fabrication method which overcomes all these drawbacks. Specifically, this approach enables fabrication of high precision, biconvex, acircular cylindric FAC microlenses from fused silica or other materials. Furthermore, this process is readily scalable in volume with excellent unit to unit consistency. And, most important, FISBA has acquired enough process knowledge and process control technology to be able to yield the required quality level for high power, blue laser FACs at market enabling prices.

Summary

To summarize, laser diodes virtually always require FACs. For near IR laser diodes these lenses are usually made from high index optical glasses in order to reduce size, complexity and costs. But FACs for high power blue laser diodes cannot be made from these glasses because they experience excessive thermal lensing due to absorbed laser light. Research at FISBA has now identified a high index material which does support use with all currently available blue laser diode single emitters. At this power, FACs made from this FISBA «Blue» offer an unmatched combination of cost and performance. For the even lower absorption levels required at the higher power levels that may become available from diode arrays, FISBA is developing a new process that enables the volume production of fused silica FACs. Specifically, it allows the production of highly curved, biconvex, acircular cylindric optical forms that cannot be cost-effectively manufactured in volume using existing methods. These will deliver the combination of performance and economy needed to take full advantage of these exciting new high power, short wavelength light sources.

References:

[1] Fused silica fast axis collimator lens for blue high-power laser diodes, P. Wuest, F. Saupe, H. Forrer, FISBA AG (Switzerland); M. Huber, FISBA LLC (United States); H. Moser, M. Forrer, FISBA AG (Switzerland), SPIE Photonics West Proceedings Volume 10899: Components and Packaging for Laser Systems V, March, 2019