White Paper

Line Laser Technology and Applications in Advanced Manufacturing

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1 High power lasers applications in advanced manufacturing

High power lasers have witnessed rapid and exciting developments in numerous applications and penetrated diversified industries in the recent past decades. Different types of high power lasers emerge one after another. High power CO_2 lasers and the lamp pumped Nd:YAG lasers have been the main forces in the industry for material processing applications for a long time. Excimer lasers as a gas laser operating in short wavelengths in ultraviolet spectrum have been traditionally very popular and highly applicable in the applications of micro- and nano-processing. Excimer lasers for many years have been applied in photolithography techniques for semiconductors manufacturing process. Excimer lasers are playing an important role as unique tools for micro-structuring by direct photo ablation.

The arising of reliable high power laser diodes has revolutionized the technology development of high power solid state lasers. Diode lasers began to be used as a pump source instead of lamps for solid state lasers, which have already entered the industrial market. Beyond that, disc and fiber lasers have appeared, which do not have a prior lamp pumped counterpart. Diode pumped fiber lasers spanning kW-class CW lasers, pulsed lasers from nanoseconds down to ultrafast, and wavelengths from 1μm to 2μm, which could be rated as one of the most important laser developments in recent years due to their high efficiency, excellent beam quality, high reliability, and robust design. The power increase and anticipated performance improvements leads to a rapid and deep penetration of fiber laser systems into applications formerly dominated by other lasers.

Nowadays, as a new tool, high power lasers' applications in the industry are becoming countless and limitless. In the traditional manufacturing field, the applications include laser cutting, welding, drilling, marking, scribing, surface treatment: hardening, remelting, alloying, cladding, texturing; etc. In the advanced manufacturing area, the applications keep growing and become irreplaceable by traditional methods, which include rapid direct metal deposition manufacturing, micro- & nano-structuring, photomask ablation, thin film structuring, MEMS manufacturing, etc.

Through the overview above, it is not difficult to find out that high power diode lasers are becoming the important cornerstone and workhorses in high power lasers technology and applications for industry. They are the pump sources for fiber laser, disc lasers and other solid-state lasers which dominate the global industrial lasers use.

Furthermore, high power diode laser technology keeps advancing to higher power and better beam quality, that even they can be directly used as a light source of laser system for materials processing in many applications such as laser brazing, soldering, plastic welding, surface hardening, cladding, rapid manufacturing, low-E glass annealing, semiconductor wafer annealing, etc.

The major advantages of diode lasers are their high efficiency, compact, high reliability, low running cost, easy integration. Meanwhile, the most disadvantage is the relatively poor beam quality. Fortunately, parallel to the development of the diode laser technology, new types of micro-optics and comprehensive beam shaping technology were well developed that enable to combine a large number of laser emitters into one beam and shape the light of the diode laser arrays into a beam optimized for processing. The combination of diode lasers, micro-optics, beam shaping technology enables the high power direct diode laser based laser system for industry. Especially, a line shaped beam system can be easily generated by direct diode lasers due to their "poor" beam quality from their inherent asymmetrical beam distribution.

This paper will introduce line laser technology and system. Firstly, an overview of different photon generators as light sources and key photon control optical elements will be briefly introduced. Then, three major beam shaping methodologies and three system scaling concepts are summarized. The characteristics and advantages of high power line laser in applications are discussed too. Thirdly, the typical and latest line laser system applications in advanced manufacturing are introduced and discussed including semiconductor wafer annealing, low-E glass annealing, ACF bonding, plastic welding, mini & micro-LED laser reflow, laser soldering, etc. Ultimately, an outlook of line laser technology and system product is discussed for future product development.

2 Focuslight line laser technology

Just as its name implies a line laser system is to generate a laser beam profile which has length and width attributions. Focuslight line laser system synthesizes comprehensive expertise including photon generation, photon control, beam shaping technology and photonics application solutions. Line beam shaping uses high power lasers and high precision micro-optics.

The line-shaped beam can be called as narrow line, line, rectangle or square beam by different aspect ratios and different homogeneity distribution in length and width directions. The system at least provides a homogenized beam in one direction. Our laser systems can provide a very large rang of aspect ratio from 1:1 up to 50,000:1, maybe even higher if needed. This characteristic offers extremely broad application scenarios.

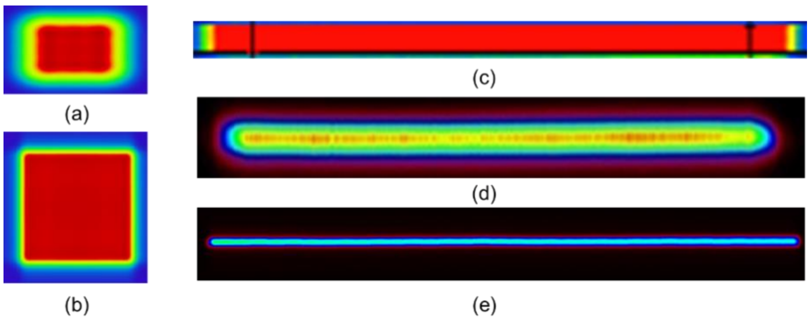


Figure 2.1 False color diagram of different "line" profiles

It should be noted that the final line beam on the work plane may not always be a continuous line in energy distribution according to some applications' requirements and it could be discrete dotted / line / square / rectangle points which finally compose a "dashed" line. Furthermore, the line beam may not always need a totally homogenous distribution and a predefined power density distribution could be achieved for different application demands.

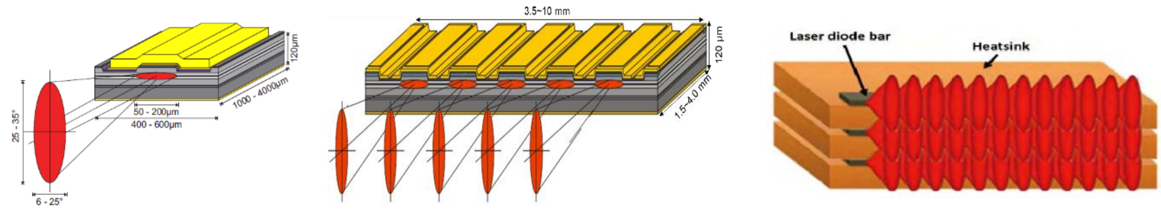
2.1 Photon Generator– light sources

Apparently, laser sources which generate photon are the engine for a line laser system. Basically, there is almost no limitation of the laser types and work conditions to be the laser source of our line laser system. These laser sources could be direct diode lasers, fiber coupled diode laser modules, fiber lasers, solid state lasers, excimer lasers, etc. and their working modes could be in CW, QCW or pulse.

2.1.1 Direct diode lasers

Direct diode lasers include edge emitting lasers (EELs) and vertical cavity surface emitting lasers (VCSEL). In this paper a diode laser (DL) refers to an EEL without beam shaping unless otherwise specified. High power diode lasers (HPDLs) are becoming more and more important light sources both for pumping solid-state lasers/fiber lasers, and for direct applications in advanced manufacturing such as IC wafer annealing, material surface processing, soldering, etc. HPDLs offer a lot of significant advantages of high wall-plug efficiency, high reliability, long lifetime, relatively low total cost and small footprint. The main drawback of open packaged HPDLs, so called “open device”, is its poor beam quality [1]. Many applications, including laser cutting, welding, and drilling etc., require high laser power and small light spots with high beam quality, while HPDLs can hardly meet such requirements directly. This is a traditional and standard idea, but it is not always true for line laser systems.

However, things are changing when the diode laser systems are combined with better homogenization micro -optic components such as FAC, beam transfer unit (BTU), micro-lens arrayed homogenizer (HOM) and better beam shaping technology. The “poor” beam quality di ode laser is not a bottleneck for a homogeneous line laser system. Especially, when a line beam with a large aspect ratio is required, the open device is rather beneficial because the illumination inherent property of the diode laser is already highly asymmetric in beam quality.



(a) (b) (c)

Figure 2.2 (a) The schematic structure of a single emitter diode laser and its far field profile; (b) The schematic structure of a semiconductor laser bar and its far field profile; (c) The schematic structure of a vertical stack diode laser

Table 2.1 BPP comparison of different types of direct diode lasers

Diode laser	BPP_s (mm*mrad)	BPP_f (mm*mrad)
Single emitter	4~10	0.31
Diode laser bar	~400	0.31
Diode laser stack	~400	0.31*Pitch*(n-1)

Pitch: bar to bar distance between neighbor bars in stack; n: diode laser number in stack; BPP: the beam-parameter product. BPP_s / BPP_f refer to BPP in slow and fast axis respectively. BPP of a laser beam is defined as the product of the waist radius and the far-field divergence half-angle. The BPP_f of a laser bar with a SMILE value (s) is about 0.31*(1+s) mm*mrad. With a proper collimation to increase the optical filling factor in the vertical direction to 1, BPP_f of a diode laser stack can be close to 0.31.

Normally, vertical stack diode laser among all kinds of open devices will be chosen to be the preferred light source for high power line laser system due to the flexibility to scaling up power, compact size, and higher power per laser bar with micro-channel cooler (MCC). In addition, Focuslight developed a novel laser device named “DMCC” which is packaged with totally AuSn hard solder with very low SMILE distribution increasing the reliability level and optimizing the optical spatial performance since 2016 [2]. This packaging technology enabled kW+ modular line laser system.

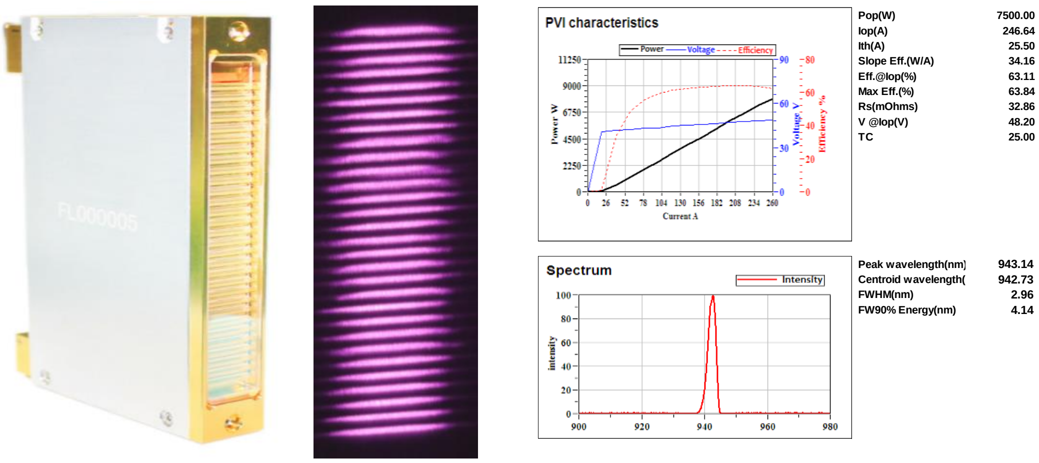


Figure 2.3 Focuslight 30-bar hard solder DMCC-packaged diode laser stack with FAC (left), the beam image from 30mm distance (mid) and LIV curves and spectrum (right)

SMILE effect indicates the degree of curvature among individual emitters of a laser bar. Referring to Figure 2.4 (left). Define SMILE as follows. SMILE = B µm = (C – A) µm.

- A: Emitting width of each emitter along fast axis.
- B: Distance between the center point of the highest and the lowest emitter.
- C: Distance between the edge of the highest and the lowest emitter.

The SMILE value of a laser bar hard soldered on a MCC (HMCC) is rather large in the order of 12 µm. Figure 2.4 (mid) shows the measured SMILE shape and value of a 1 cm wide bar AuSn soldered on a HMCC. Figure 2.4 (right) shows the SMILE distribution of recently produced 1733 pieces of 1 cm wide bar AuSn soldered on DMCCs. DMCC with SMILE ‹ 2µm accounts for 93%, the average SMILE is 0.93µm.

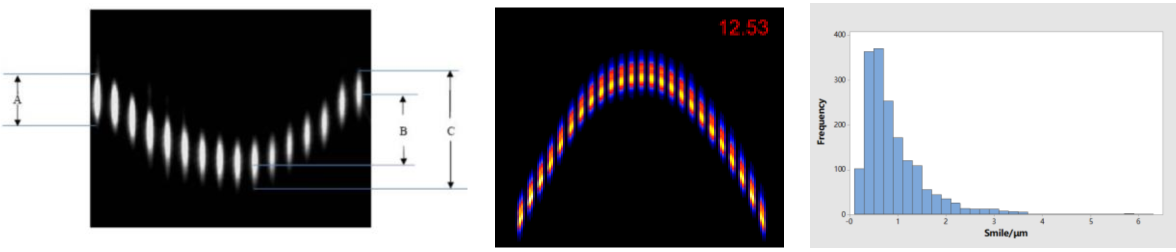


Figure 2.4 SMILE definition (left), typical SMILE of a 1 cm wide bar AuSn soldered on a HMCC (mid) and SMILE distribution of 1733 pieces of 1 cm wide bar AuSn soldered on DMCC (right) .

2.1.2 Fiber coupled diode laser

A fiber coupled module (FCM) can also be clarified as a direct diode laser source but with beam shaping and output through an optical fiber. The FCM can be based on multiple single emitters, multiple mini-bars or multiple full bars. Each scheme has its own advantages depending on the field applications and demand. In general, FCM has several advantages compared to open device due to the following characteristics and features. Firstly, FCM is normally packaged in a sealed housing providing a first level protection to the diodes. And then, due to the flexibility in length and orientation of the output fiber FCM can be placed separately from the laser processing head (LPH) which is susceptible to vibration, shock, contamination, and heating from the manufacturing process. The FCM is easy to be replaced during the maintenance or repairing in the field because the output beam is normally uniform and stable due to the homogenization effect of long fiber. The operation can be an easy plug and play without extra optical re-alignment.

Furthermore, the FCM and LPH can be connected by a standard connector, so it is very convenient to have a modularized design for the whole laser system. For example, the FCM can be upgraded to a higher power without changing the LPH with the same connector.

Table 2.2 BPP comparison of different types of FCM examples

Power (W)	Fiber core diameter (μm)	NA	BPP (mm*mrad)
200	100	0.22	11
300	200	0.22	22
500	400	0.22	44
600	200	0.22	22
1200	300	0.22	33

Depending on different fiber coupling technologies there may be different BPPs at the same output power and fiber core diameter which will not be explained in detailed herein. FCMs are also used as pumping sources for a fiber laser mentioned later playing a significant role in the laser system. Figure 2.5 shows FCM examples produced by Focuslight.

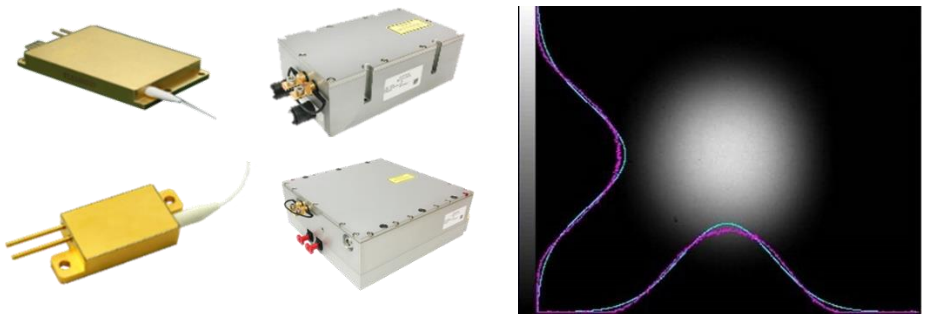


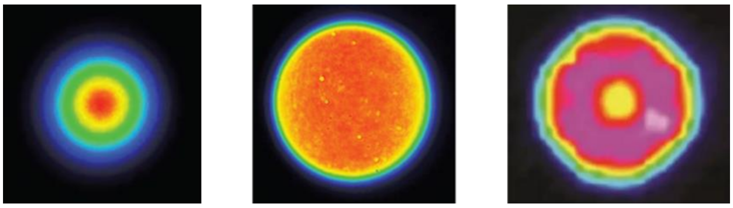
Figure 2.5 Focuslight FCM sources (left) and spot distribution (right)

2.1.3 Fiber laser

High power FCM pumped fiber lasers act as an efficient brightness converter. The relatively low-brightness diode laser pump emission is converted into high-brightness laser output. At the same time the pumping lasing wavelength is converted into the rare-earth-doped glass fiber stimulated emission wavelength. Over the past decades, fiber laser technologies have undergone rapid progresses and tremendous developments in almost all aspects of laser performance such as power, spectrum, beam quality, and reliability. Compared to traditional lasers, fiber lasers possess many attractive advantages including good beam quality, high stability, compactness, easy integration, low operation and maintenance cost, and so forth.

Nowadays, the emission wavelengths of fiber lasers range from near IR to mid-infrared. Continuous wave (CW) fiber laser output power is over 100 kW with a single multimode fiber, and diffraction-limited power output from a single large-mode-area (LMA) fiber reached 10 kW [3].

The fiber lasers are normally directly used as a light source for many applications due to its inherent advantages such as high power with good beam quality. However, in some applications, a laser process head can be equipped to shape the round gaussian beam into a rectangle or squared beam for better processing which extends their applications. The power density distribution of the fiber laser can be round gaussian, round top-hat, and even donut as shown in Figure 2.6 Figure 2.6 [4].



(a) (b)

(c)

Figure 2.6 False color image of fiber laser output beam in Gaussian, Top-hat, Donut shape

2.1.4 Excimer laser and UV DPSSL

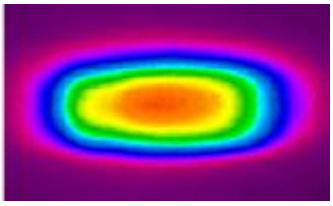
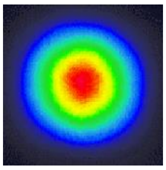
An excimer laser is a traditional and good laser source for many applications which is well developed for several decades. It is basically a gas-based laser that generates high power and short ultraviolet pulses directly without complex and low efficient frequency multiplication technology such as UV DPSSL. The name of excimer is an abbreviation express of “excited dimer”, which means a compound of two identical species that exist only in excited states. The most widely used wavelengths are 193nm(ArF), 248nm(KrF), 308nm(XeCl) and 351nm(XeF).

Excimer lasers are well adapted to applications where the UV range wavelengths and high pulsed energy are required. Excimer lasers provide a wide range of processing power, with average processing powers up to 1000 W, repetition rates up to 4 kHz, energies higher than 1J and pulse width from 10 to 250 ns [5][5]. The intense UV output with extremely high pulse energy, high lateral resolution, and high flexibility in terms of output parameters make the excimer laser attractive for a variety of processes. Excimer lasers are indispensable laser sources in pulsed laser deposition, high-precision marking, low-temperature surface annealing and large area micro-patterning such as material laser lift-off (LLO) process in OLED display industry.

However, excimer lasers also have some drawbacks, such as relatively poor beam quality (higher-mode structure and high divergence), operating costs, and maintenance requirements. The major one is the expensive excimer laser maintenance and associated frequent re-adjustment of the optical beam shaping system [5] [5]. For this reason, an alternative solution of excimer laser emerges in this field named ns UV DPSSL (diode pumped solid state laser).

A UV DPSSL produces UV light at 355nm or 266nm light by frequency tripling or quadrupling 1µm wavelength laser from Yb:YAG or Nd:YAG crystalline pumped by high power diode lasers. In contrast to excimer laser, DPSSL systems have advantages of size compactness, reliability, and durability. It also offers several logistic, regulatory, and environmental advantages such as no noise, simple system installation, longer optics’ lifetime, low operation and service costs. All these benefits make the system more user friendly, lower handling and operation complexity and lower total system running costs through the whole service time. At the same time, the shortage of UV DPSSL is also obvious due to its relatively lower pulse energy. That means several DPSSL light sources are required in one system to match the same pulse energy from one excimer laser, that requires a beam shaping scheme for these multiple beams. Another feature of DPSSL is the better optical quality with a symmetrical M^2 about 20. Focuslight LIMO Display has introduced an optical technique for anisotropic beam quality transformation and developed a UV line system with DPSSLs for industrial lift-off application [6][6].

Table 2.3 Comparisons of excimer laser and UV DPSSL

Power	Wavelength	Beam profile	Output beam quality	Output beam shape
Excimer laser Max. ~3000W	157nm, 193nm, 248nm, 308nm, 351nm;		Multi-mode, asymmetric, unstable	Roughly rectangle 3~20mm x 5~40mm
UV DPSSL Max. ~400W	266nm, 355nm;		Multi-mode, smooth gaussian, symmetric	Round: 1~20μm dia.

All the light sources mentioned above play its own role in different industry area through direct output beam or shaped beam by optical system. Laser systems based on the direct laser diodes are gaining more and more attractiveness and popular due to their advantages in inherent performance, high efficiency, compact size, operation convenience and total cost in advanced manufacturing. In the next chapters, the direct high power diode lasers (HPDLs) based photon control technology, beam shaping scheme, line laser system applications will be focused and illuminated. Hereon, it is to be emphasized that the photon control and beam shaping technology can also be applied to other light sources including fiber laser, DPSSL solid laser, excimer laser, etc.

2.2 Photon control technology

In addition to the efficient generation of laser light with HPDLs it is important to make use of the photons and to bring them with highest efficiency for every application. Micro-optics has enabled the possibility to control and deliver photons emitted by light sources to the right place at the right time.

Focuslight LIMO has over 25 years expertise and experiences in design and manufacture cylindrical free-form micro-optics / arrays / diffusers / DOE splitters to control the photons for versatile laser systems and applications. Based on our unique wafer-level synchronous structured laser optics manufacturing technology to produce 12-inch (300mm x 300mm) glass micro-optics wafers, with nano-level precision refraction microlens array (ROE) technical capabilities, it can meet different application requirements.

2.2.1 Fast Axis Collimation (FAC)

In most HPDLs optical systems, the first and most important optical component attached is normally the FAC lens whether for the bars or single emitters. The use of refractive micro-lenses with a high order acylindrical surface shape can reduce the fast axis divergence with diffraction limited performance.

Focuslight has developed a new lens type, especially optimized for diode laser bars. The FAC lens produces collimated beam leading to high efficiency in pumping solid state lasers and opens new applications in material surface processing, as shown in Figure 2.7 Figure 2.7 Figure 2.7 Figure 2.7 Figure 2.7 Figure 2.7 .

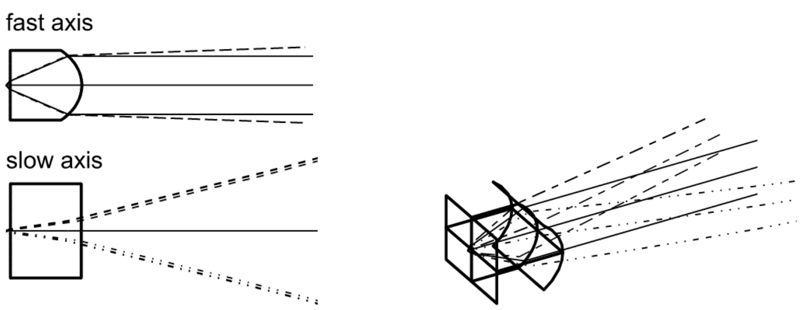


Figure 2.7 Optical scheme of fast axis collimation

The anti-reflective coating ensures extremely low absorption for high-power applications, the large numeric aperture allows the collimation of the entire diode power with best beam quality. Consequently, very high transformation efficiency for diode lasers can be achieved due to high transmission and good collimation properties.

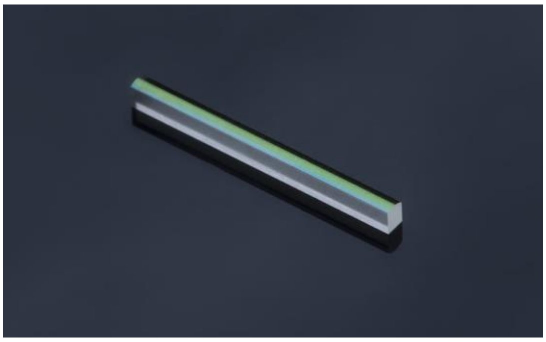


Figure 2.8 Picture of a FAC lens

2.2.2 Beam Transformation System (BTS)

The BTS transforms the asymmetric far field distribution of a diode laser bar into approximately symmetrical beam parameter product. BTS is normally used for a diode laser bar based FCM or laser system.

To scale power of a HPDL based systems it is necessary to combine a couple of emitters into one fiber core. The use of individual emitters and fast and slow axis collimation micro-optics already is a standard in industry. For further simplification it is possible to use emitter arrays in combination with special designed biconvex cylindrical lens arrays that can change the orientation of the emitter 90° and generate a more symmetric far field distribution that can be easily focused into a circulation fiber core with a single asphere, as shown in Figure 2.9

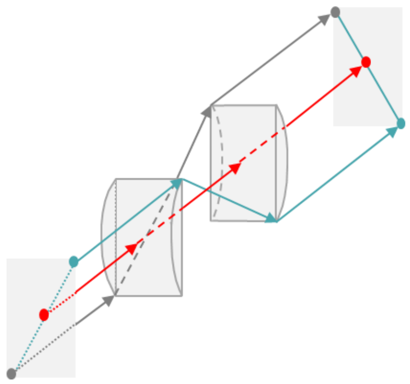


Figure 2.9 Function principle of BTS

BTS consists of a FAC lens and a transformation lens array as shown in Figure 2.10. With only a single alignment and fixing step up to 50 emitters can be coupled into one fiber core. The compact and cubic design can be easily handled with an automatic alignment and assembling system. This optical component is a key element for HPDLs that will consist of small number of laser bars plus BTSs instead of large number of multiple emitters with optics.

Figure 2.10 Picture of BTS lens

2.2.3 Homogenizer

Focuslight homogenizer basically is composed of refractive microlens arrays. Our technology does not involve in etching processes at all. This allows the processing of a large range of materials, such as glasses, semiconductors and crystals, e.g. fused silica and BK7 for near IR applications, CaF2 for UV-NIR applications and Si, Ge and ZnSe for CO_2-lasers in FIR applications. Wafer sizes up to 300x300 mm^2 with surface accuracies on the order of 10-100 nm can be produced. The lens apertures cover a range from about 50 μm to several mm with relative focal length variations well below 1%. And the cylindrical lenses for the horizontal and vertical directions can be designed independently from each other, rectangular light fields or lines with different aspect ratios can be produced. Figure 2.11 shows a picture of homogenizer.

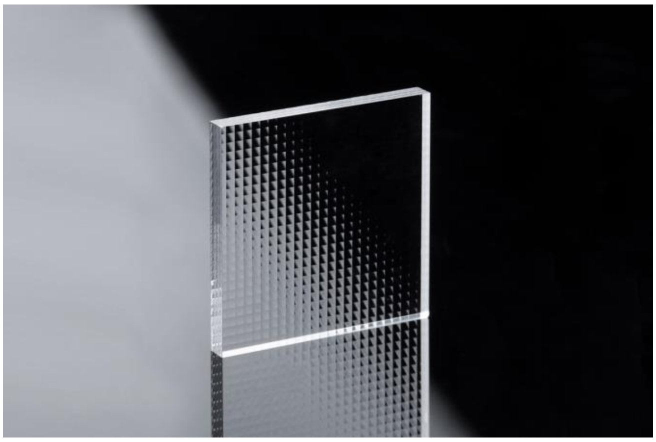


Figure 2.11 Picture of homogenizer consisting of micro-lens arrays

2.3 Beam shaping technology

Light sources and micro-optical lens provide physical materials basis for a laser system. Comprehensive and appropriate beam shaping scheme and technique should be deployed to match the photon generator and photon controller to take full advantages of their high quality.

In general, laser beam shaping is a process changing beam geometry and intensity distribution before and after passing the optical system. The following three methods were used to design and produce the optical beam shaping elements and related beam path:

- Phase shifting (single-mode laser)
- Beam transformation (multi-mode laser)
- Beam mixing (multi-mode laser)

These beam shaping methods can be use separately or together depending on the final output beam performances and manufacturing process requirements in different applications. There are many proven practice examples for each beam shaping design concept, due to the limited space we will not dive deep inside the examples. Please refer to the cited reference documents for details.

2.3.1 Phase shifting

Many laser sources, e.g. several solid-state lasers, fiber lasers and gas lasers, operate in a single transverse mode with a well-defined Gaussian beam profile. In order to obtain a homogeneous top hat profile from such laser sources, phase shifting optical elements can be utilized to transform the Gaussian beam profile into a top hat one.

The principle of beam shaping by a free-form phase shifting optical element is shown in Figure 2.12 for one direction, exemplarily. The collimated Gaussian beam with well-defined beam diameter and divergence is impinging on the refractive acylindrical free-form optical element. Followed by an additional field lens, the angle distribution can be transformed into a spatial distribution on the target plane. The surface is designed as such that a redistribution of the intensity profile from Gaussian to top hat is achieved by spatial phase shifting [7].

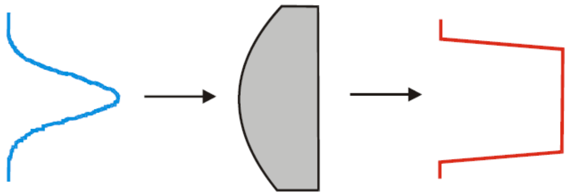


Figure 2.12 Function principle of a free-form phase shifting element to transform the impinging Gaussian beam profile into a top hat beam profile.

2.3.2 Beam Transformation

Especially for the processing of semiconductor material, Focuslight developed a new technology that transforms a symmetrical multi-mode laser beam into a line beam with nearly single mode quality in scanning direction and homogeneous flat top profile along the line.

The optical set-up consists of an anamorphic system which treats the x- and y-directions separately considering the different optical transformations for the long and short axis, as shown in Figure 2.13 Figure 2.13 . At first the symmetrical laser beam is expanded by a telescope to illuminate several lenslets of the beam transformation unit (BTU = symmetrization of the BPP). The BTU divides and transforms the original beam into several beamlets which are re-imaged onto the micro-lens homogenizing unit (HOM) for the long axis. Finally, an anamorphic focusing system generates the long line. The key components of this beam line generator are the beam transformation unit as well as the homogenizing unit. Both components consist of micro-optical beam shaping systems. This concept was applied in Focuslight tunable UV solid-state laser lines for surface processing[6].

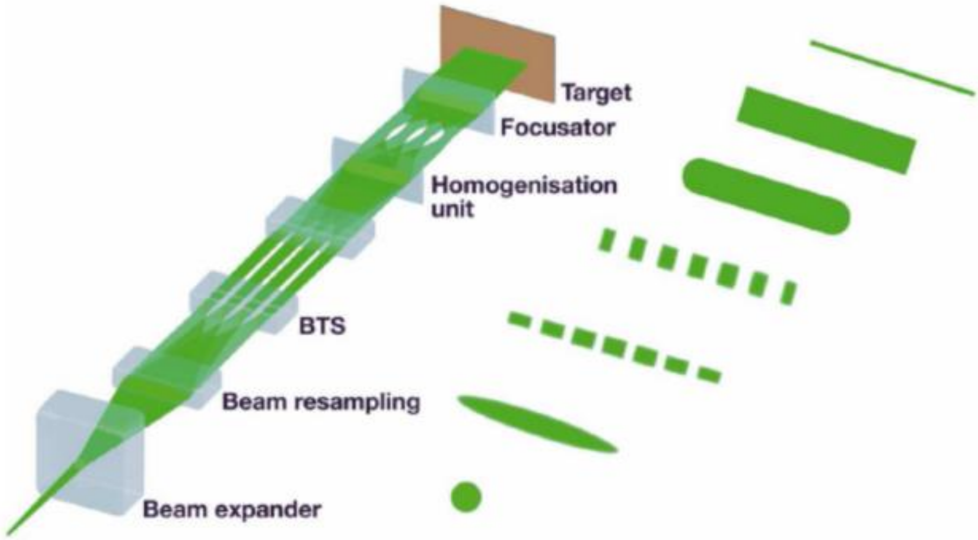


Figure 2.13 Optical scheme of the beam transformer and homogenization system.

Based on this beam transformation technology line beams with an aspect ratio > 10,000 become possible.

2.3.3 Beam mixing

The beam profiles of multi-mode lasers, e.g. high power diode lasers, various solid state lasers and excimer lasers, can be usually homogenized and transformed by the principle of beam mixing[7]. Thus, uniform rectangular light fields or light lines can be produced. Such a setup consists of one or two cylindrical lens arrays and a subsequent field lens. A better uniformity can be achieved with the latter setup which is schematically depicted in Figure 2.14 [8].

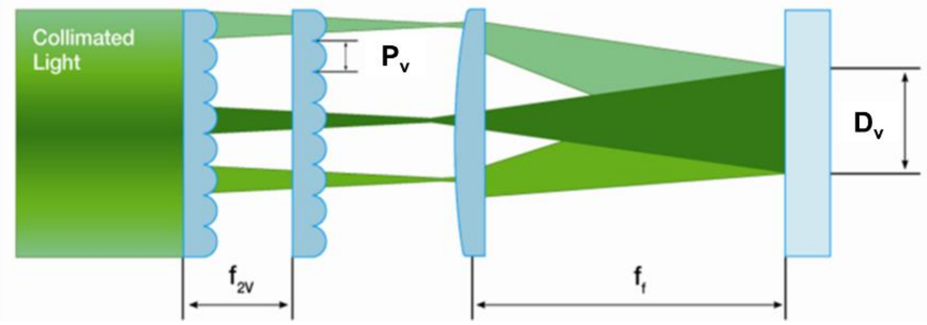


Figure 2.14 Performing principle of a system of two cylindrical lens arrays and a subsequent field lens. P_v, f_{2v}, f_f denote the pitch, the focal length of the second lens array and the field lens, respectively. D_v denotes the vertical dimension of the uniform field.

The performing principle is shown for the vertical direction (index v), exemplarily. Similarly, it holds for the horizontal direction. Both arrays are oriented to each other symmetrically and they have the same pitch P_v. The distance is given by the focal length f_{2v} of the second array. A field lens with focal length f_f is subsequent to the second array. The collimated multi-mode input beam is divided into partial beams by the first lens array. They are directed to the opposite lenslets of the second array and must not outshine them – which is controlled by the focal length of the first array. The second array in combination with the field lens images the single lens apertures on the target plane which is identical to the focal plane of the field lens. Due to the image superposition of all lenslets a uniform profile is generated.

Apart from symmetrical lenslets, arrays with asymmetrical lenslets can also be produced as shown in Figure 2.15. In this case the micro-lenses are of an asymmetrical shape defined by uneven-polynomial terms and/or an asymmetrical cut-off from an even polynomial surface. In the most complex situation, all the lenslets on the wafer can be designed and manufactured independent from each other with respect to the surface profile, aperture and thickness resulting in a large range of novel solutions in optical systems design [9].

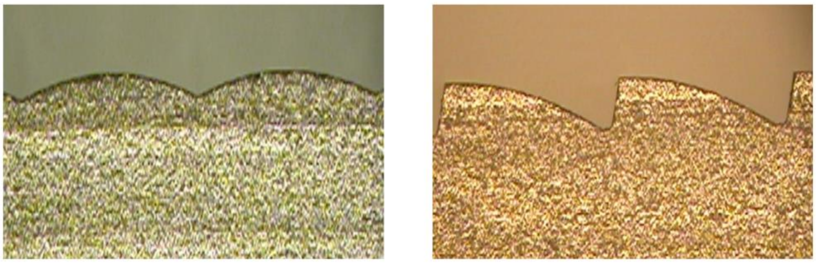


Figure 2.15 Microscope image of the cross-section of a small part of a micro-lens array with symmetrical (left) and asymmetrical lenslets (right).

A new emerging design concept for laser beam homogenization occurred that suppresses interference based micro-modulation and is suitable for pulsed high-power applications. By switching from an imaging homogenizer setup to nonperiodic lens arrays, also non-periodic far field distribution is generated, free of interference based micro modulation [10][10]. Refer to Figure 2.16 for detailed.

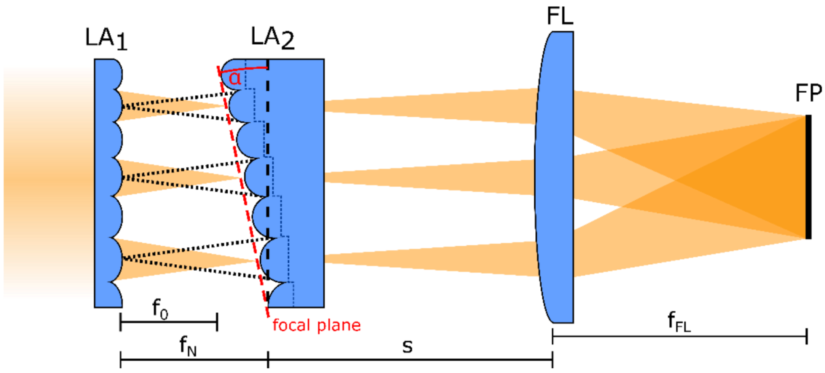


Figure 2.16 Non-periodic lens array in an imaging homogenizer setup with the second lens array exhibiting a step-pyramid shape. $f0$, fN – focal length of the 0th or Nth lens channel. LA1, LA2 – lens array 1, 2 respectively, FL – Fourier lens; FP: target plane; α – wedge angle at the second lens array; d – lens array separation; s – separation of LA2 and FL; f_{FL} – Fourier lens focal length.

2.3.4 Scalable line laser system scheme

A line laser system usually requires a combination of beam shaping techniques including optical transformation, combining, and mixing. Due to the diversity and complexity of different process requirements in advanced manufacturing area, higher power density, scalable power, and flexible line length are desired for a line laser system. For example, several laser sources instead of one are necessary to form one entire beam to achieve higher power or longer line length. This is sometimes because the power limitation of one light source or considering the cost effectiveness or flexibility to upgrading at field.

Three typical scalable line laser system schemes are introduced herein to integrate multiple individual laser sources or modules into one homogenous line beam as shown in Figure 2.17.

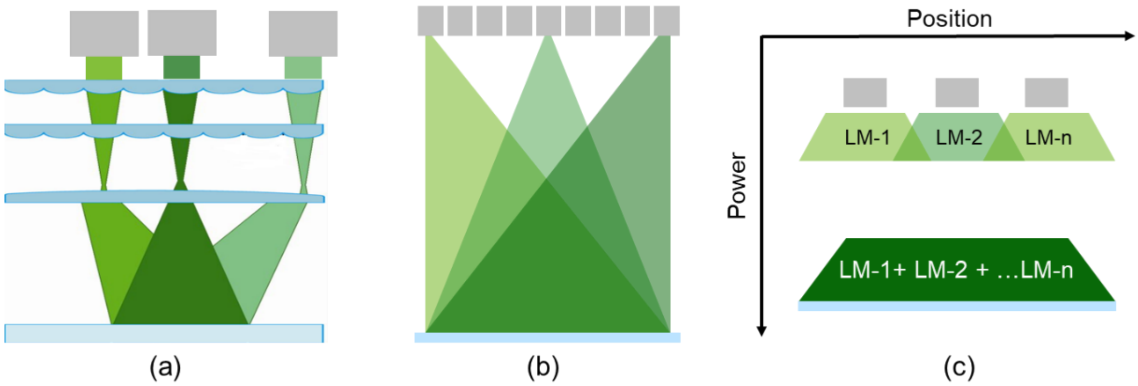


Figure 2.17 Three typical scalable line laser system schemes

(a) Beam mixing concept of all laser sources by using symmetric homogenizer.
(b) Beam mixing concept of all laser sources by using asymmetric homogenizer.
(c) Beam stitching concept for the generation of long uniform lines.

A first advantage of the concepts is the source independency. Free-beam sources for example vertical stack (VS) as well as fiber coupled modules can be used. The fiber coupled module source needs to be collimated with a spherical lens. The free-beam source is collimated by means of a fast axis collimator and a slow axis collimation array.

One line laser system layout example using beam mixing concept of Figure 2.17 (a) shown in Figure 2.18 consists of ten high power fiber coupled diode lasers (1). Each source is collimated with a spherical lens (2). There is a focusing lens (4) used to reach the line width. To reach the high homogeneities, the concept uses two different homogenizers. With the pre-homogenizer (3) ten homogenous sources are created. The second homogenizer (5) flattens the overlapping beams from the sources and generates in this case a long highly homogeneous line. With this beam shaping concept it's even possible to generate longer lines by extending the system [11].

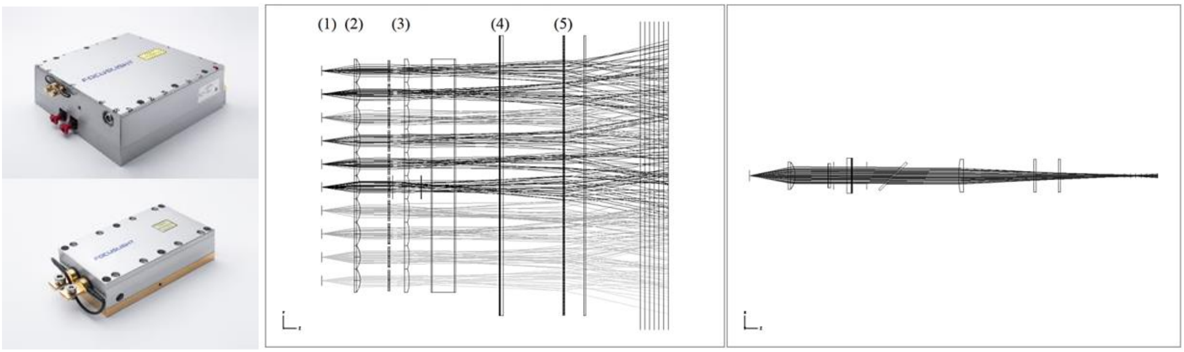
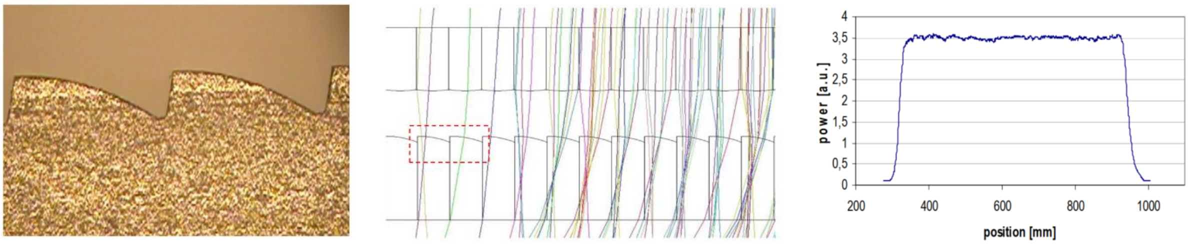


Figure 2.18 Top view and side view of the beam shaping scheme of FCM based line laser system

The beam mixing concept of Figure 2.17 (b) can be enabled by an asymmetric cut off of lens segments. The sketch shows one laser line, asymmetric but homogeneous illuminated from different source points. The beam shaping concept is based on free form micro optic homogenizers like the pictured in Figure 2.19 (b). The resulting intensity distribution of a laser system build up based on this beam shaping concept is shown in Figure 2.19 (c).



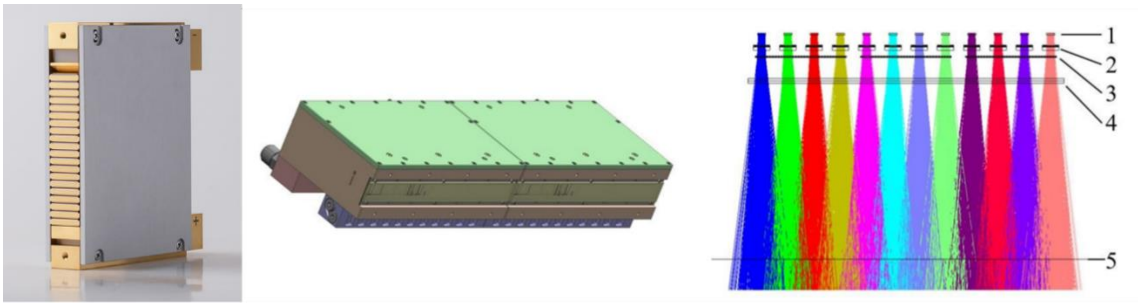
(a)

(b) (c)

Figure 2.19 (a) asymmetric cut off detailed image; (b) homogenizer with cut off; (c) "off axis" intensity distribution.

As an application example of this concept, a line laser system for vision applications was presented for an automated optical inspection system of overhead contact line systems for railways [12].

The beam mixing concept of Figure 2.17 (c) can be illuminated by a line laser system based on vertical stacks. The light sources (1) are several vertical stacks with multiple laser bars. The vertical stack itself is a modular design composed of single bars which can scale up the source power by changing the number of bars with small variation of size. The first optical elements are the FAC lenses mounted directly at the laser bars. The lens array (2) generates the beam width profile. Just one homogenizer (3) mixes the beams in line direction. A second homogenizer can be used to improve homogeneity of the line beam and lower the sensitivity to the slow axis divergence changes by the diode laser driving current. The distance from the double exit windows (4) to the working plane (5) is defined as the work distance [13].



(a) (b) (c)

Figure 2.20 (a) Laser source of DMCC based vertical stack; (b) 2x Laser modules side by side 3D model; (c) Optical scheme.

This "stitching" concept is quite simple due to no polarization or wavelength combination involved in order to scale up the source power. The beam length scalability is easy to be achieved by changing the laser modules numbers side by side. By shaping and stitching of several line beam modules can enable almost "infinite" long line beams for certain applications.

3 Line laser characteristics and advantages in applications

Focuslight line laser system can manipulate and shape almost all kinds of known laser sources. From diode laser to fiber laser, from edge emitting diode laser to Vertical-Cavity Surface-Emitting Laser (VCSEL), from excimer laser to solid state laser, all of them can be used as the light source to form a line-shaped beam with high uniformity level both in length and width directions. The major advantages are high aspect ratio, high process efficiency, high beam homogeneity and combined performance, etc.

Given a fixed output power, the line system can reach a comparatively higher power density with larger aspect ratio visually much narrower line. For instant, most of the material treatment processes need to reach a certain optimal energy density (OED) threshold to motivate the processing, it is beneficial to design narrow short-axis profiles with a top-hat shape to maximize energy utilization based on a relatively low power [14][14].

From the laser process point of view, the line-shaped beam provides a set of benefits. In contrast to a point-shaped laser spot, the line need not to be scanned in two directions, but just in one, which increases the speed of processing [15][15]. Figure 3.1 shows the differences between a 2D scanning based processing with a round spot and the linear scanning of a CW laser with a line beam profile for a material processing.

2D scanning with punctiform laser source Linear scanning with line beam laser

Figure 3.1 Line beam scanning vs. 2D scanning punctiform beam.

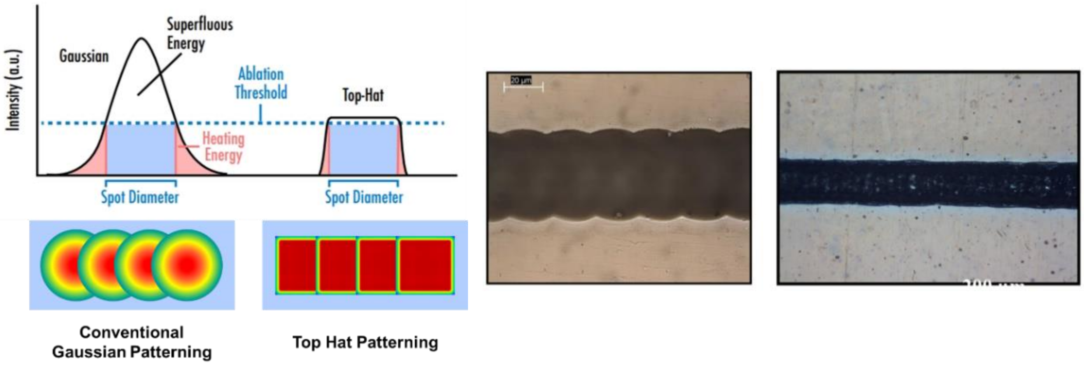
In comparison to the multidirectional diffusion of energy using a punctiform beam with a 2D scanner, the linear scanning with a shaped line beam has only a linear diffusion of energy during processing and therefore a much higher energy efficiency and accuracy with homogeneous and continuously processed target material [16][16].

During the same scanning process with pulsed energy, the homogenized line-shape beam with top-hat patterning laser system also exhibits prominent advantages compared to conventional Gaussian patterning beam in round shape, which is normally directly generated from fiber laser, solid state laser for examples. Figure 3.2 illuminates a comparison between conventional structuring with Gaussian beams and top hat profiles.

Obviously, the active area of a Top hat profile compared to a regular Gaussian profile increases and at the same time the wasted energy decreases resulting a smaller heat affected zone (HAZ). A sawtooth pattern is observed at the border of the trenches produced by the Gaussian beam. This is due to the round shape small spatial overlap < 70% between the pulses. The edges of the sawtooth profile may lead to increased mechanical stress and brittleness of multi-layer micro-structures.

In contrast with square top hat profiles of our homogenous line laser system smooth grooves are generated.

Additionally, a higher throughput can be achieved in production since only a smaller spatial overlap between pulses is needed. It has to be noted that with Gaussian beams the sawtooth profile can also be eliminated. However, then the spatial overlap between pulses has to be > 90%. This strongly reduces the throughput of the system, especially for single pulse thin film ablation. As well it may introduce thermal stress to the substrate [17].



(a)

(b)

Figure 3.2 Scheme for the generation of trenches with a Gaussian beam profile compared to a top hat one; (b) The respective ablation results in polyimide (Laser source: Nd:VYO4 laser, THG @ 355 nm, 3.5 W, 30 kHz and 15 ns pulses)

Some applications for example laser lift-off (LLO) process require highly homogeneous and very narrow line. In addition, a large depth of focus and working distance ≥ 100 mm are necessary for the applications. Combination of these requirements is highly challenging and in some respects contradictory. Focuslight anisotropic laser beam quality transformation provides an effective way to solve this contradiction [18].

4 Line Laser Applications in Advanced Manufacturing

4.1 Semiconductor wafer annealing

Laser annealing (LA) is one of the key technologies in the fabrication of 28nm and below logic chips. The process uses a near-infrared band diode laser source, through well-designed beam shaping and homogenization optical system, to achieve 12mm x 75μm extremely narrow line laser beam in the working distance and ensures the energy uniformity › 95% in line length direction. In the laser non-contact heating mode, the atoms on the wafer surface are heated to more than 1000 °C in less than one millisecond from the preheating temperature of around 100°C, and then rapidly cooled down to form ultra-shallow junctions and highly activated junctions on wafer surface so as to improve the yield of wafer production.

The Focuslight Dlight-S series line laser systems are dedicated to address semiconductor integrated circuit wafer annealing process. It combined different core technologies within one system including photon generation, photon control and beam shaping. The totally indium-free hard solder eutectic bonding and thermal management technique applied to the DMCC based vertical stacks guarantee the compactness, high power and reliability of light source. The thermal stress control methodology ensures low Smile of the laser bars be easy to be shaped by micro-optics. The key optics lenses such as FAC and homogenizers are all designed and manufactured inhouse. The laser beam shaping scheme and light field homogenization technology produce an extremely narrow line beam in the near infrared band with an aspect ratio of 160:1. The energy uniformity and energy stability in the direction of line length are more than 95% and 98% respectively.

The key performance specifications include the following parameters:

- Beam length: 12 mm
- Beam width: 75 μm

- Maximum output power: 1500 W
- Rated output power: 1050W
- Wavelength: 808 nm
- Beam uniformity › 95% along line length

The line laser system is now used to complete dynamic surface annealing (DSA) process in the front end process of semiconductor manufacturing FAB.

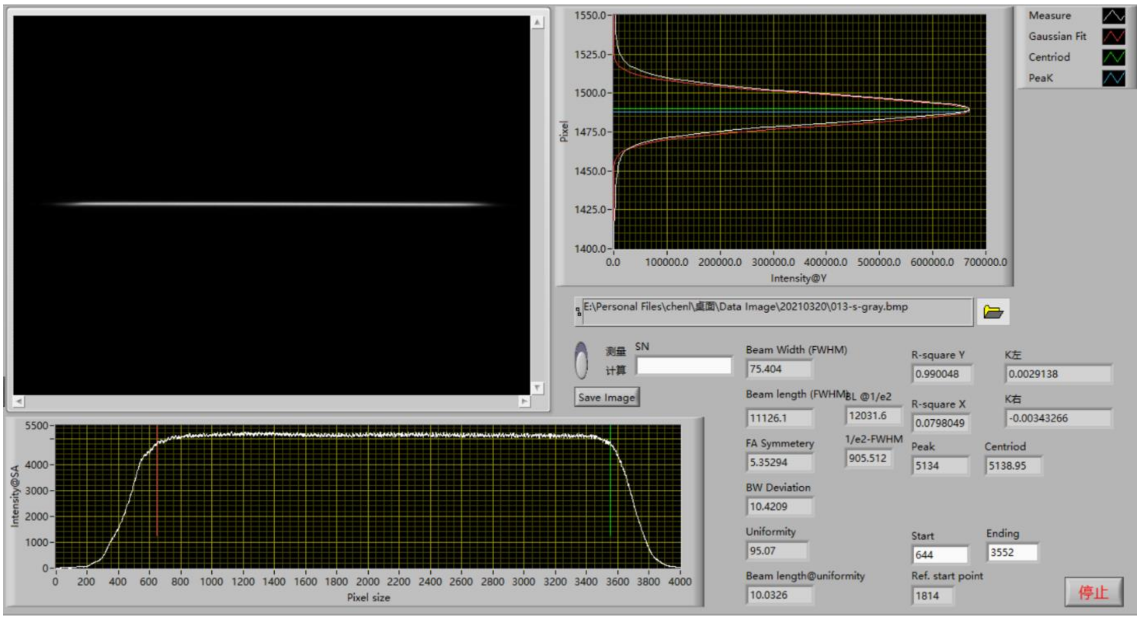


Figure 4.1 Actual beam size test results 75.4μm x 12.03mm, beam energy uniformity 95.07% @ top-hat

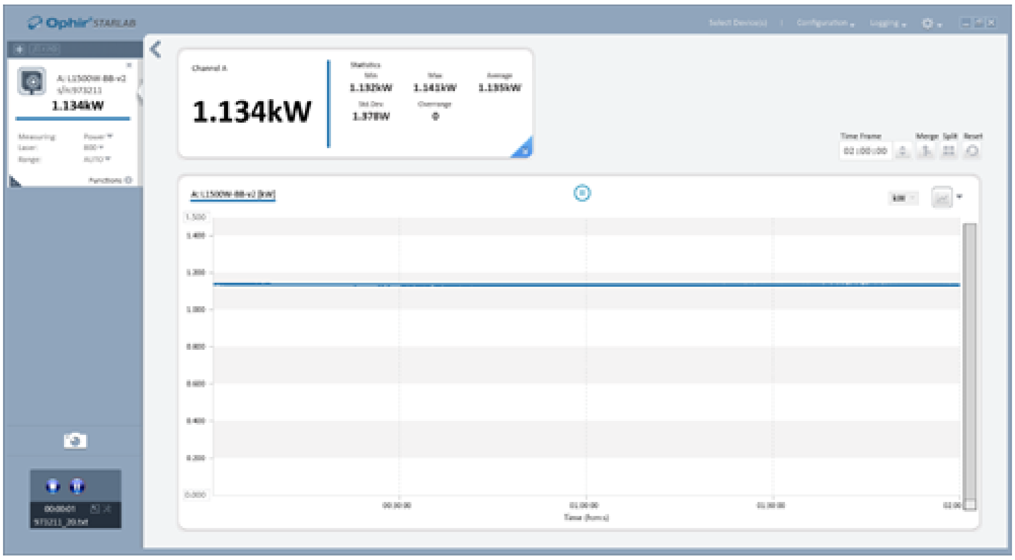


Figure 4.2 Actual output energy stability 99.2% @ 1134W.

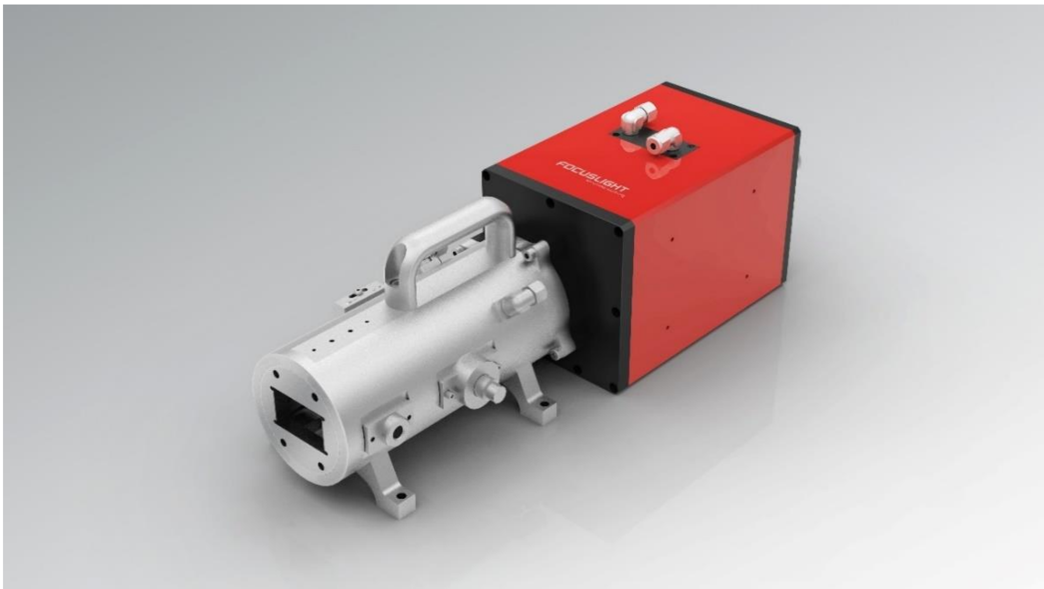


Figure 4.3 Picture of the line laser system (laser process head shown only)

4.2 Low-E Glass annealing

Low-E glass, also known as low radiation glass, is a kind of film product composed of multilayer metal or other compounds on the surface of glass. Compared with common glass and traditional architectural coated glass, the coating has excellent heat insulation effect and good light transmittance. Low-E glass annealing is an advanced manufacturing process that uses a high power line spot semiconductor laser system to transform amorphous Ag layer coated on Low-E glass into crystalline Ag layer by heat treatment, so as to reduce the emissivity of glass, improve the insulation performance and enhance the performance of Low-E glass itself.

The Activation IR series high-power line laser system launched by Focuslight technology can provide high-energy line laser with single laser power of 18kW, line length of 350mm and line width of 400μm. At the same time, it can expand infinitely in the spot length direction to meet the needs of different processing formats. In addition, Activation IR series high-power line laser system has broad application prospects at the application end, including:

- Annealing: electron mobility & concentration, dopant activation, reduced resistivity, transmission spectrum, stress reduction
- Cross-linking: stochastic or directed photon induced cross-linking for imprint or lithography
- Sintering: higher conductivity, mechanical and thermal stability
- Oxidation: under stochiometric reactive interfaces, selective oxidation, bandgap engineering

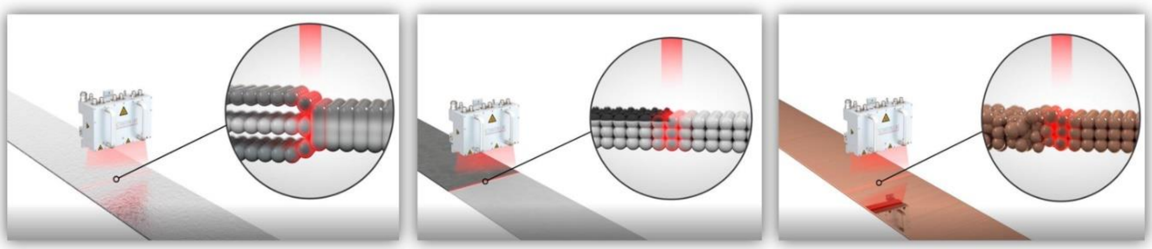


Figure 4.4 Typical product application: laser hardening/sintering (left), laser cleaning (middle), laser crystallization / annealing (right)

Figure 4.5 Picture of the line laser system with 3x laser modules (laser processing head shown only)

4.3 ACF bonding in display industry

Anisotropic conductive film (ACF) has been used for components packaging in the display industry for decades. ACF bonding is an interconnection technique mostly used for connecting displays to PCB's using anisotropic conductive adhesive and flex foils. Characteristics of ACF bonding make electrical and mechanical bonding possible at the same time. By aligning the parts precisely and applying the right heat and compression for the right duration of time, ACF bonding technology ensures a strong and reliable electrical-mechanical interconnection.

New developments in display technologies require the ACF bonding process to happen in a much smaller area, such as the extremely narrow frame of a flexible display. The bulky size of a traditional thermal head makes ACF bonding in such a small area infeasible. Non-contact laser heating, with customized beam size, energy density, and process curve, is suitable for such applications. The bonding area can be heated rapidly to achieve the bonding process.

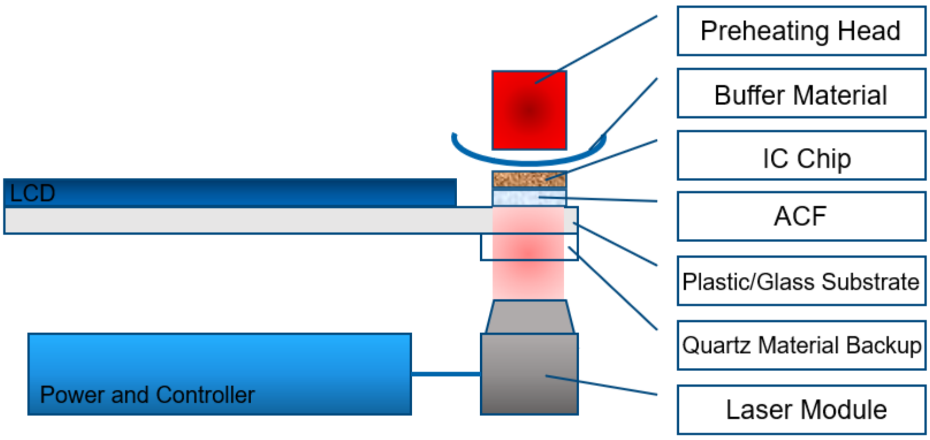


Figure 4.6 Concept diagram of ACF bonding process

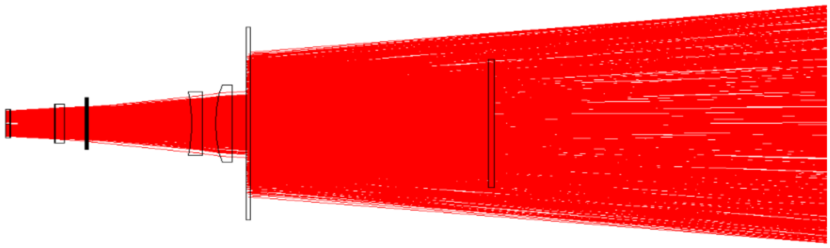


Figure 4.7 Optical design scheme of laser system

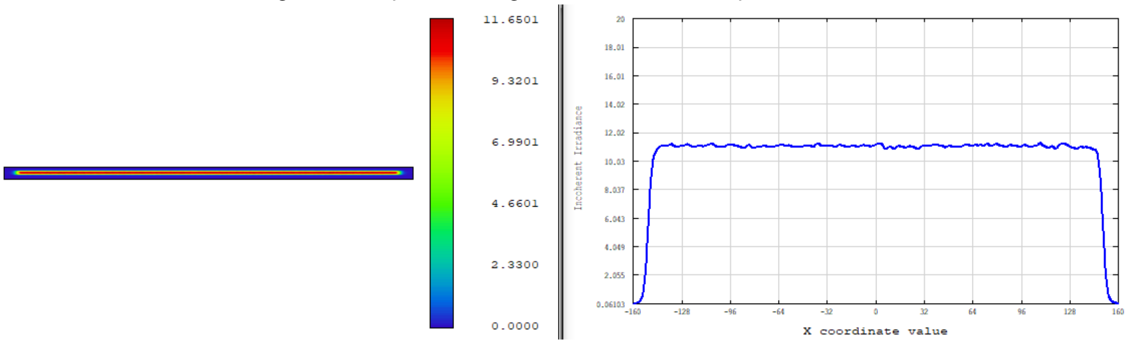


Figure 4.8 Optical simulation result

For ACF bonding application, we designed a uniform line beam. Infrared diode laser vertical stack with output power of up to 1 kW is selected as the light source, and the diode laser stack is AuSn soldered with low Smile. The emitting light is first collimated with fast axis and slow axis collimator lens, and then it is shaped further with collimators to reach desired spot size, finally Focuslight proprietary ROE (Refraction Optical Element) technology based homogenizer that could stand high power density is used to further homogenize the light beam. A uniform laser line beam (e.g. 300mm long, 3mm wide) is formed eventually at the working distance, and the uniformity of the rectangular beam is more than 95% in both directions. Different masks can be applied to the line beam to meet bonding requirements of areas with different sizes.

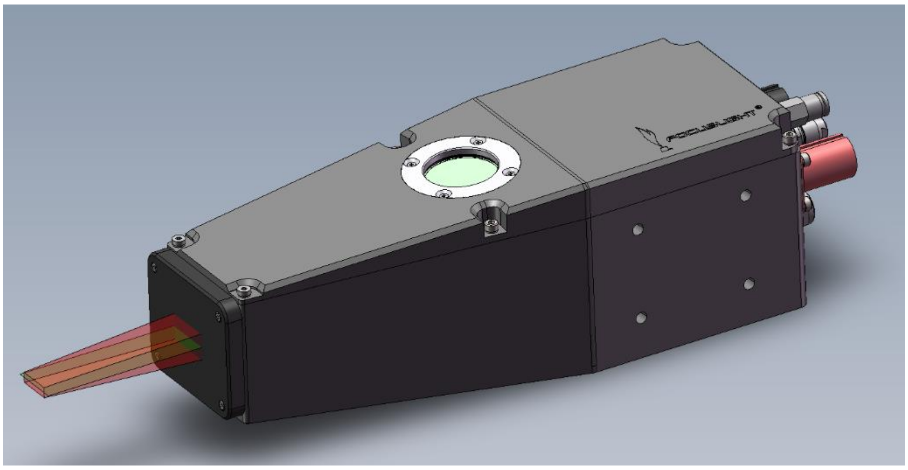


Figure 4.9 Laser module for ACF bonding application

4.4 Plastic welding

What is the laser plastic welding? It is a welding method using a high energy density laser beam as a heat source, which passes through the upper transparent part and is absorbed by the lower part. The lower part will be heated, and the surface will be melted, then through the heat conduction two materials of two parts are melted and jointed together. The process of the laser plastic welding is illuminated in Figure 4.10Figure 4.10 .

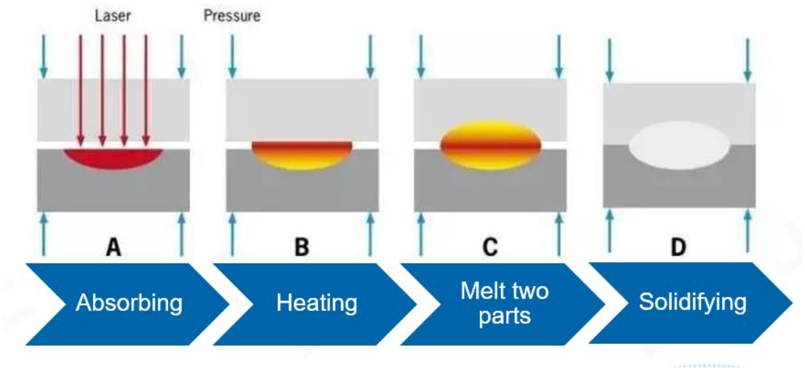


Figure 4.10 The process of the laser plastic welding

Since the beginning of the 21st century, the development of laser technology has made laser plastic welding a better process choice for many applications. Although the plastic laser welding just accounts for the total market share of less than 20% of plastic welding processing, due to 2 ~ 3 times higher efficiency of laser plastic welding than traditional welding process, that will increase plastic laser welding market share especially in some high welding efficiency and stringent appearance requirements occasions. Table 4.1 summarized commonly used four welding methods comparison. The advantages of the laser plastic welding compared with the traditional welding methods are obvious.

Table 4.1 Comparison of four plastic welding methods

	Hotplate welding	**Vibratory friction welding**	**Ultrasonic welding**	**Laser plastic welding**
Advantages	• Low machine cost • Can operate manually	• Suitable for multiple and big components • Short welding period • Low maintenance cost	• Short welding period • Can do non-planar welding • Low maintenance cost	• Artistic welding joint • Clean process – no particle generated • Can do complex, big size components • No contact welding • Low thermal and mechanical stress • Can monitor the welding process • High welding quality • Short welding period • Low maintenance cost
Disadvantages	• Only fit for simple product • Easily over melted of base materials	• Having particles during process • High mechanical stress • Only fit for planar contour • Wide welding joint	• Having particles during process • High mechanical stress • Process limited by product size	• High setup cost initially • Special requirements for base materials

Thus, the laser plastic welding technology is applied for more and more industry fields, for example, most majority automotive car plastic components utilize the laser plastic welding technology. The components are from external parts to internal parts such as head light, trail light, camera, car key, the internal filter, ABS, gear cover, gas liquid separator and so on. Figure 4.11 has exhibited some components used laser plastic welding in an automotive car.

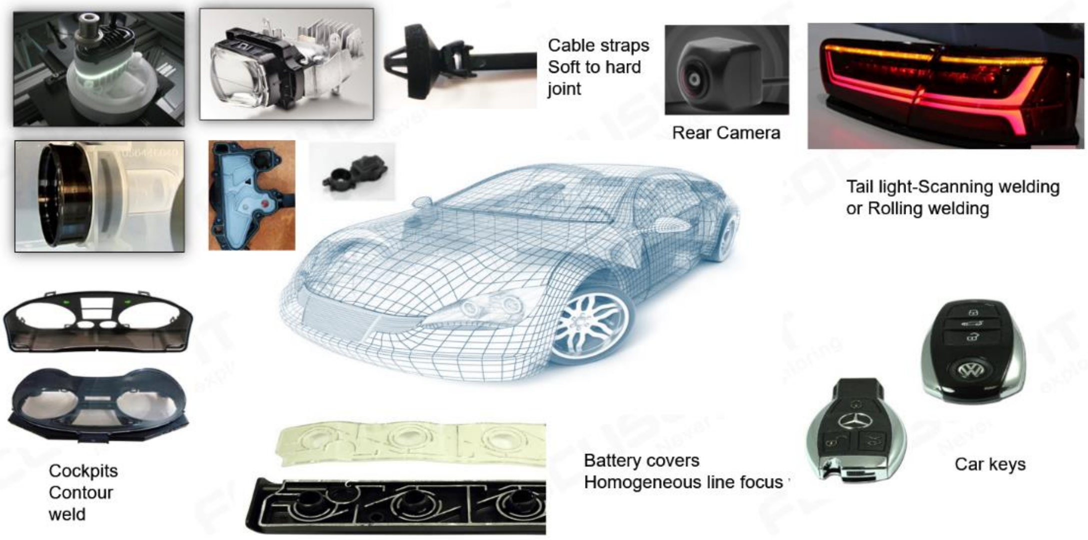


Figure 4.11 The laser plastic welding used in automotive car

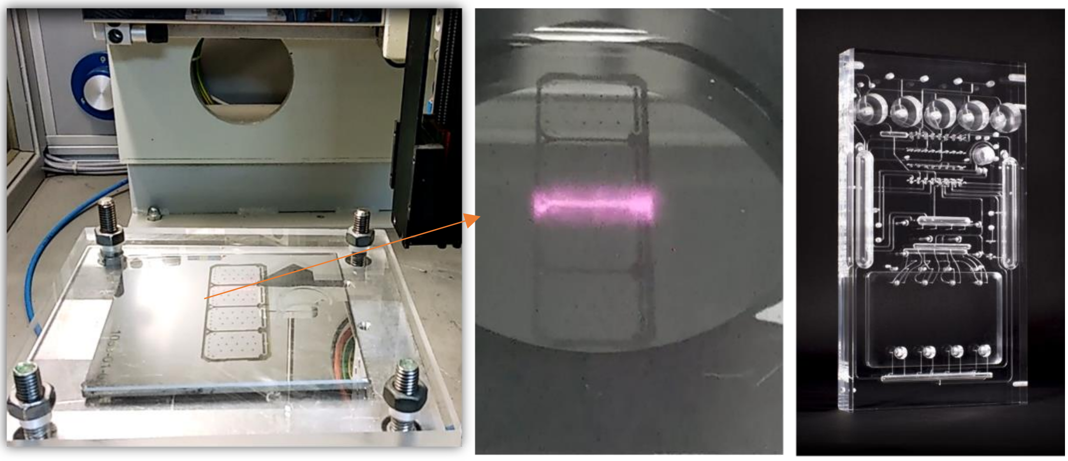
Also, more and more medical components apply the laser plastic welding. For example, microfluidic components, medical aid, blood analyzer, dosing pump and so on.

Figure 4.12 The laser plastic welding on medical components

Line beam laser demonstrated a lot of advantages in plastic welding process. For some components, the welding contour width is wider than normal, multiple times welding is needed by point laser beam to achieve the welding quality. With the line laser beam, just one time scanning is enough to attain better quality. Line laser improves the welding efficiency and reduces the overlap or gap resulting in better welding quality. One example is given in Figure 4.13 on welding two auto car components. The width of welding contour is about 10mm. The spot beam diameter less than 1mm generally which takes >3 times welding to ensure the welding quality and intensity. The implement of a 10mm line beam laser can meet requirement and dramatically decrease the cycle time. Therefore, line beam laser is a perfect solution for such kind of wide width welding contour components.

Figure 4.13 The example for auto components of width welding contour

Additionally, line beam has advantages on welding components with complex structures. For the medical components of microfluidic welding, it has very complex structure. Using the line beam that showing in Figure 4.14 to scan the welding area can greatly shorten the welding cycle time and ensure the quality.



(a) (b) (c)

Figure 4.14 Line beam soldering plastic microfluidics demo at Focuslight application lab, Xi'an (a) tooling set up (b) line beam scanning on the plastics (c) a typical plastic microfluidic sample

Focuslight provides a completed line laser system including fiber coupled module (FCM) as light source, laser processing head (LPH), laser power supply, cooling system, and control unit. This product is based on modular design concept in a defined range. The output power and wavelength can vary by simply changing the FCM laser source setup. The beam shaping and mixing functions are integrated into the LPH which can adapt different FCM setup and adjust the output laser beam to different shapes so as to be suitable for different application scenarios. Meanwhile, it also has temperature close loop control function to implement processing control in order to assist customer improving process efficiency. The system can provide perfect solution for the laser plastic welding. Figure 4.15 shows the line laser system product served for laser plastic welding.

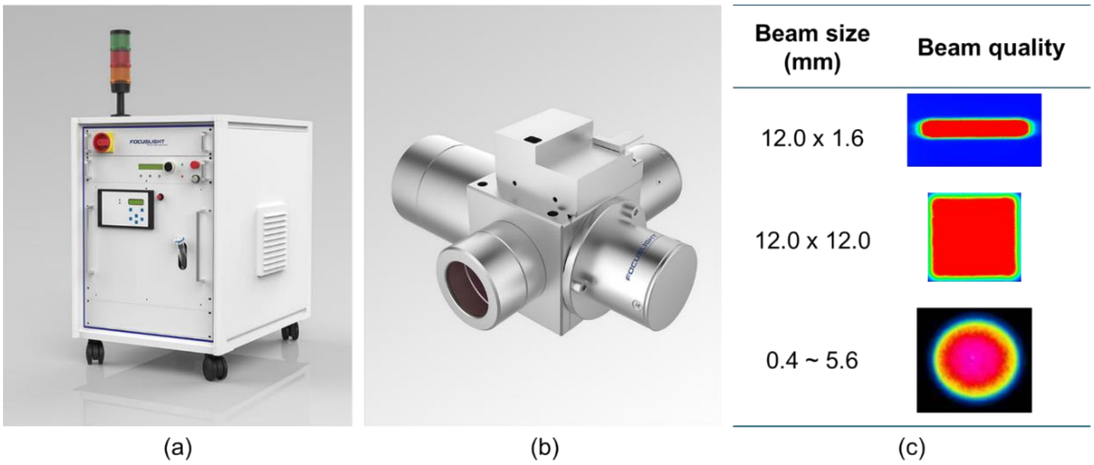


Figure 4.15 (a) Integrated FCM, laser power supply, cooling system, and control unit (b) Laser processing head (c) output beam key parameters and false color image of beams

The output power of the line laser system can be selected from 50W to 500W. The wavelength covers from 800nm to 1000nm.

4.5 Mini & micro-LED laser reflow

Mini & Micro LED (also called μLED) refers to the size of the chip less than 100μm. Same as ordinary LED, it is also self-luminous, and each pixel can be displayed by RGB LED chip with three kinds of luminous colors. Mini & Micro LED display is using the Mini& Micro LED chip to achieve full color display of a general term of technology. Long-term development logic of LED industry conforms to "Haitz's Law" which is the LED industry's equivalent of Moore's Law for semiconductors. It means the output of LEDs increases 20-folds every decade, while the cost falls to a tenth of what it was. From the development of LED industry in the past 30 years, high power, miniaturization and full color become the key words to promote LED application in display, backlight and lighting.

It is expected in the next decade, with the size of LED chips/beads and the cost further reduced, Mini/Micro LED will bring a revolution in backlighting and display technology, pushing the number of LED shipments to more than 10 trillion. According to Yole's forecast, the mini-Micro LED display market is expected to reach 330 million units' shipments by 2025, with a potential market size of $3 billion. On the other side, mini &micro-LED inherits the characteristics of LED, the power consumption of Mini & Micro LED is about 10% of LCD and 50% of OLED, it has 30 times brighter than OLED, with a resolution of up to 1500PPI. Otherwise, it has lot of advantages, such as energy saving, high reliability and fast speed, very long lifetime, superfast response, spontaneous light, ultrahigh resolution. In a word, the mini & micro-LED has obvious strengths on display [19].

Figure 4.16 depicts the procedure of producing the mini &micro-LED display. There is one procedure named reflow. The traditional reflow used the high temperature reflow furnace. The chip of mini & micro-LED was too small and was apt to shift in the process of the solder solid crystallization. Also, the whole cycle time was very long, and the entire substrate will be heated so that the substrate is easy to deform in reflow process. So, the laser reflow becomes the unique choice and alternative technology for traditional furnace reflow.

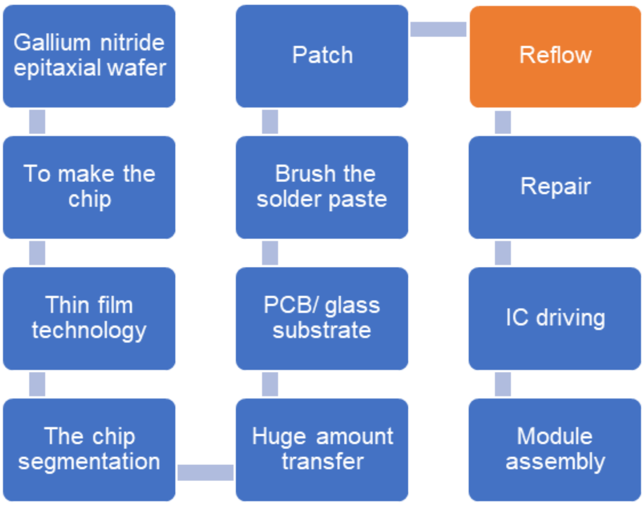


Figure 4.16 Mini & micro-LED manufacturing procedure

The laser reflow has obvious advantages such as local heating, high welding quality, and no chip shifting in welding process. Meanwhile, the traditional laser reflow uses the spot laser beam also facing big challenge. For example, on July 25th in 2021, Austrian TV brand C-SEED announced the release of the world's first 165-inch foldable Micro-LED luxury TV, M1-4K TV. This 4K TV has 24 million LED chips, if it is soldered by the spot laser beam, the processing efficiency is unimaginable. However, the long uniformity line or rectangular beam can realize a huge amount of welding simultaneously. The welding efficiency will be greatly improved.

Focuslight tailor-made mini & micro-LED massive welding solution, the line laser system can provide 1000W ~ 4000W output power, and the uniformity in both directions is above 95%. The output line beam is bidirectional homogenized, the shape of the output light spot can be rectangular, linear and square, and the size can be customized according to customer's requirements. At the same time, the system also includes coaxial temperature detection and closed-loop control function, which can simulate the solid crystallization process of solder in the reflow furnace, and perfectly replace the traditional reflow furnace process.

The whole line laser system solution is shown in Figure 4.17 . Component #1 is the fiber coupled module light source cabinet integrated with the laser power driver, cooling system and control unit. The desired laser with high power and consistent optical performance is transferred to component #2 named laser processing head through a flexible fiber with an industry standard interface. The laser beam exits from LPH window and forms a highly homogenous line on the target surface of mini & micro-LED panels i.e. component #3. The component #4 is the temperature monitor which can acquire the real-time soldering temperature data. Then the data will be processed in the program (item #5) and feedback the result to the laser controller to adjust the laser output. Thus, a close loop control is achieved for better process performance.

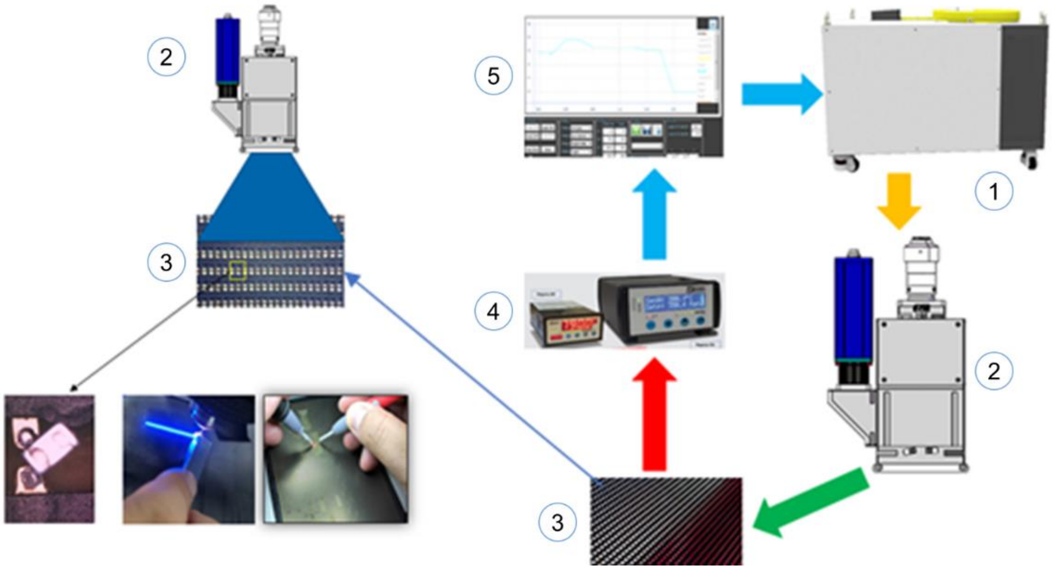


Figure 4.17 A huge amount of welding for mini & micro-LED

The main parameters of the line laser system are listed in Table 4.1 Table 4.2.

Table 4.2 The main parameters of the huge amount laser reflow system

Item	Parameter
Laser power	≤4000W
Fiber connector	QBH
Wavelength	900nm ~1000nm
Uniformity	≥95%
Focal depth	>±1mm
NA	≤0.22
Cooling	Water cooling (non-DIW needed)
Structure	Modular construction
Temp. control	Infrared measuring temperature, Coaxial detecting temperature closed loop control

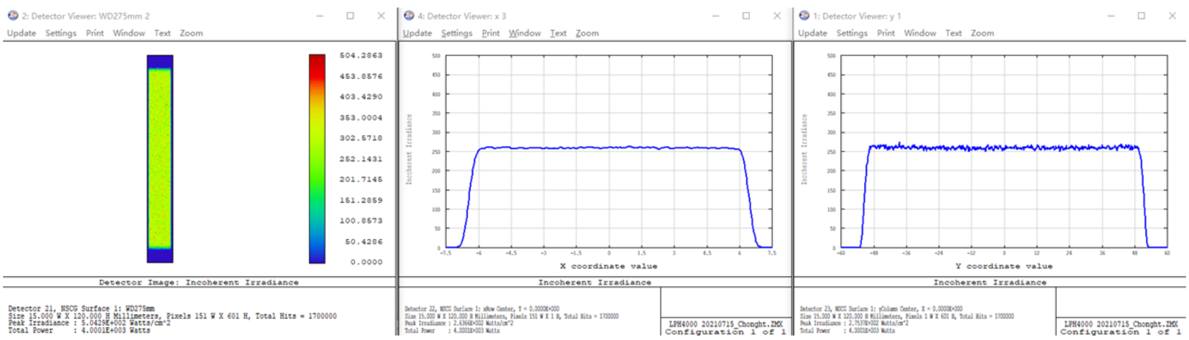


Figure 4.18 Simulation result of the laser beam profile for the huge amount laser reflow

4.6 Laser Soldering

Laser soldering is using the laser beam as the heat source to directly irradiate at the welding position, heat the solder zone, cause the solder to melt, resulting in a good solder joint.

Figure 4.19 The process of the laser soldering

With the development of precision, thin, short, small and differentiated electronic components, the traditional process has been increasingly unable to meet the requirements of ultra-fine electronic substrate, and multi-layer spot parts welding. Laser tin soldering with "non-contact welding, no static electricity, real-time quality control" and other technical advantages have gradually become a new technology to make up for the shortage of traditional welding process and has been widely used in the industry. With the growing demand of the market, laser tin soldering technology also brings more development space for the electronic industry.

For example, laser solder ball welding is a new technology of laser soldering. The main advantage of this process is the ability to interconnect at very small sizes, with solder ball sizes as small as tens of microns. Because the solder ball does not contain flux, laser heating and melting will not cause splash and contamination. After solidification is full and smooth, there is no follow-up cleaning or surface treatment of the solder pad additional procedures. With high precision, laser ball soldering is especially suitable for mobile phone camera module, precision sound control devices, data wire solder joint assembly and other small solder pads solder welding.

With the advent of 5G era, it is pushing the smartphones upgrading. In the first half of 2021, 653 million smartphones were shipped worldwide. Take example for the laser soldered camera module of the smart phone. Figure 4.20 shows one camera flash module of typical smart phone. There are 8 solder balls need to be soldered for each product, the welding time of each solder at least need 2 seconds because the solid – liquid - solid transition should be achieved for each solder, totally need 16 seconds. If it uses one square and multiple spot beam to cover all the solder points, it just needs 2 seconds totally, the efficiency increases by 8 times.

Table 4.3 shows the comparison between three kinds of laser beams for camera flash module. In principle, multiple spots beam shape is perfect solution for a specified product. But there are two disadvantages. Firstly, it is hard to locate the welding position because the solder ball just around 0.5mm, it is very difficult to locate several spots simultaneously, and the accuracy requirement for each spot alignment is also very stringent. Secondly, the pattern of multiple spots should be re-designed if the product's solder points upgrade to next generation. The smart phone releases new version every year, the camera module size will be not change frequently, but the welding positions tend to change. Although the utilization ratio of a single uniformity spot is lower than other two ways, but it can be reused for different products as long as the whole solder area does not change. So, the single large uniformity beam is the first choice to decrease the cost and improve the efficiency.

Table 4.3 The comparison of the three kinds of beams for laser soldering

Beam type	Cycle time	Welding area	Power utilization area ratio	Adaptable for different product ?
Single spot beam	16s	0.8 mm²	~100%	Yes
Multiple spots beam	2s	8×0.8 mm²	~100%	No
Square beam	2s	25 mm²	~30%	Yes

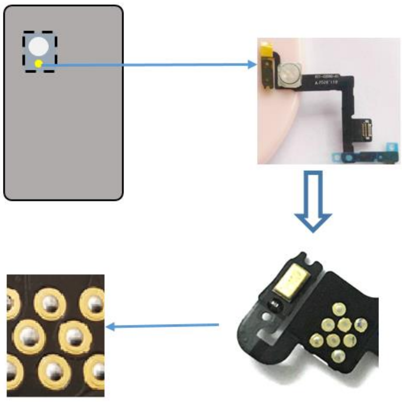


Figure 4.20 The laser ball soldering on cameral flash module of smart phone

There are two key factors to be noticed. One is the temperature close loop control to perfectly meet the melting temperature profile of solder ball. The ideal temperature should be set in advance, then through the temperature close loop control the laser system can adjust the laser power real time. Another factor is the laser beam high uniformity. All the solder balls must be melted and formed at the same time to obtain the same soldering quality. Focuslight AE120W serials laser system can solve these two factors perfectly. It has high uniformity laser beam quality with the temperature close loop control system.

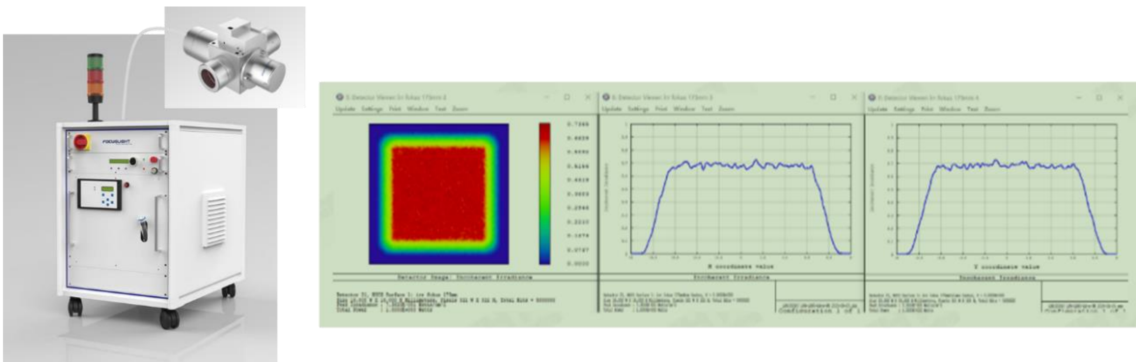


Figure 4.21 The square beam system for laser soldering

The laser system is equipped with a 120W 980nm fiber coupled module diode laser and a standard laser processing head.The beam size is tunable from 5mm to 12mm depending on the process requirements.

A summary is provided in Table 4.4 to illuminate some different applications above mentioned, the key parameters and technologies used in the laser system.

Table 4.4 Summary of different applications and technologies

Application	Wavelength (nm)	Line geometry (mm)	Max. power (W)	Laser source	Beam uniformity	Max. power density (W/mm²)	Working distance (mm)	Beam shaping technology	Incumbent approaches
Semiconductor wafer annealing	808	12 x 0.075	1500	VS hard soldered	＞95% @line length; Gaussian @line width	1700	45	Beam mixing using symmetric homogenizer	Laser annealing or annealing furnace
ACF bonding	940	330 x 3	2400	VS hard soldered	＞95% @line length and width	2	200 ~300	Beam mixing using symmetric homogenizer	Contact heating
Laser cladding	900 ~1000	20~28 x 3	10000	VS hard soldered	＞90% @line length	150	300	Beam mixing using symmetric homogenizer	Traditional electroplating
Low-E Glass annealing	940	350 x 0.4	18000	VS hard soldered	＞95% @line length; Gaussian @line width	125	180	Beam stitching	Annealing furnace
Plastic welding	800 ~1000	12 x 1.6 ~12 Round Dia.: 0.4 ~5.6	500	FCM hard soldered	＞95% @line length and width	20	100 ~200	Beam mixing using symmetric homogenizer	Ultrasonic welding
Laser soldering	980	5~12 x 5~12	500	FCM hard soldered	＞95% @line length and width	2 ~ 20	100 ~ 200	Beam mixing using symmetric homogenizer	Traditional soldering
Mini & micro-LED laser reflow	900 ~ 1000	100 x 2 ~ 15	4000	FCM / VS hard soldered	＞95% @line length and width	20	300	Beam mixing using symmetric homogenizer	Reflow furnace

5 Summary and Outlook

High power line laser system synergizing laser sources, micro-optics and beam shaping techniques are systematically reviewed and discussed. The line laser involved technologies were demonstrated by our laser systems delivered to the fields for industrial applications. The applications included not limited to semiconductor wafer annealing, low-E glass annealing, ACF bonding, plastic welding, mini & micro-LED laser reflow, laser soldering, cladding, etc. High power diode lasers have significant advantages in efficiency, reliability, total cost, compact size, etc., HPDLs have been proven to be one of most promising lasers and found the fastest increasing in many fields compared with other type lasers in recent years. However, the poor beam quality is the main disadvantage limiting their direct applications. Focuslight line laser technology can take full advantages of diode lasers' asymmetrical distribution attribution to make the beam quality in one direction better with the sacrifice of the other direction. Successful examples of diode laser light sources and beam shaping techniques are presented. Two points are necessary to be emphasized herein. Firstly, besides direct diode laser and FCM, almost all types of different laser sources including fiber laser, DPSSL, excimer laser, etc. can be well controlled and shaped by utilizing our line laser technology. Secondly, the line laser system can conveniently expand their applications in to medical, automotive LiDAR, 3D sensing, illumination, scientific research etc. by changing the laser wavelength, power and beam shape.

Based on accumulated rich experiences on the line laser technology and applications for years, the line laser system demand as a series of product should be growing. Over a broad range of customers and applications, different processing power varies from dozens of Watts to several kW, and beam profile size and shape requirements vary in broad range from sub-mm up to several hundred mm. That is a big challenge for laser system designer and manufacturer to catch up the growing market. A modular designed line laser system with scalable power and tunable beam is an urgent demand. Standard and reliable laser sources, micro-optics, structure, cooling concept should be well defined and unified. The ultimate objective is to reduce both the delivery time and customer acceptance time, improve the system's reliability level and increase the conveniency of operation and maintenance.

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About Focuslight

Founded in 2007 and headquartered in Xi'an, China, Focuslight Technologies Inc. is a fast-growing company that develops and manufactures high power diode lasers (photon generation), laser optics (photon control), and photonic modules and systems (application solutions) used in advanced manufacturing, health, research, automotive, and information technology applications. In 2017, Focuslight acquired LIMO, one of the leading manufacturers of micro optics and beam shaping solutions, and a pioneer in groundbreaking photonics production technologies. Focuslight has over 400 patents worldwide and is ISO 14001, ISO 45001, ISO 9001:2015, and IATF 16949 certified. Additional information can be found at www.focuslight.com.