Lasers in Manufacturing Conference 2017

Novel optical concept for large area rapid thermal processing

C. Tillkorn[a,*], L. Canova[b,†], S. Dorer[a], M. Lang[c], M. Huonker[a]

[a]*TRUMPF Laser GmbH, Aichhalder Straße 39, 78713 Schramberg, Germany*
[b]*Saint-Gobain Glass Deutschland, Poststrasse 103, 51143 Köln-Porz, Germany*
[c]*TRUMPF Laser- und Systemtechnik GmbH, Johann-Maus-Str.2, 71254 Ditzingen, Germany*

Abstract

With the availability of high-power infrared laser sources, laser-based rapid thermal processing of large area substrates becomes more and more attractive. Aside from the laser source, one of the core components is the beam shaping optics for generation of a line-shaped intensity profile with extreme aspect ratio. We report on a novel optical concept for laser-based large area rapid thermal processing which relies on the established thin disk laser platform providing an output power of 12 kW per unit. One of the unique features of this modular concept is the capability to precisely combine optical units to realize a processing width of larger than 3 m. To fulfill the high demands on homogeneity and depth of focus we make use of advanced beam-shaping and measurement techniques. Together with the proven robustness of fiber-coupled laser sources this modular approach has demonstrated the ability of 24/7 operation with industrial standards in terms of process quality, treatment speed and efficiency at our strategic partner. For the first time in history rapid thermal annealing was applied to thin films deposited on jumbo-size architectural glass without affecting the glass substrate. Due to the highly improved crystallization, the resistivity of e.g. thin Ag-based stacks could be decreased up to 30%. This led to a breakthrough in the development of high energy efficiency functional coatings on glass.
This technology opens a large field to new cost-effective glass products with improved energetic balance, simultaneous high transparency and improved electronic transport properties and many others. Perspectively applications for sheet-metal refinement can also be considered.

Keywords: Rapid thermal processing; laser annealing; functional coatings; disk laser; high power optics; robustness; scalability, stitching.

* Corresponding author. Tel.: +49-7422-515-219.
E-mail address: christoph.tillkorn@de.trumpf.com.
† Coauthor. Tel.: +49-220-3859373.
E-mail address: lorenzo.canova@saint-gobain.com.

1. Introduction

With the availability of robust high-power infrared laser sources laser-based rapid thermal processing (RTP) of large area substrates becomes more and more attractive. However, up to today e.g. annealing and tempering of multi-functional coatings on architectural glass are dominated by IR-lamps or furnace-based processes. Due to the non-selective heating of the entire substrate, these processes bear several disadvantages such as poor efficiency and low treatment speed. Moreover thermal distortion and microstructural changes can affect the substrate. To overcome these shortcomings laser-based RTP is a promising alternative utilizing the full potential of the RTP-technology due to the selective application of heat to a specific area or layer. The standard setup for laser-based RTP for highest throughput consists of a high-power laser source and an anamorphotic beam-shaping optics providing a line-shaped beam profile and a feed axis for a linear scanning process (Fig. 1). Such systems have been widely applied at small sizes in the semiconductor industry but their productivity is limited by a maximum processing width of approx. 1.5 m due to the availability of optical components, which need to feature the same large dimensions. Thus laser-based RTP has not been applied to large area substrates, yet.

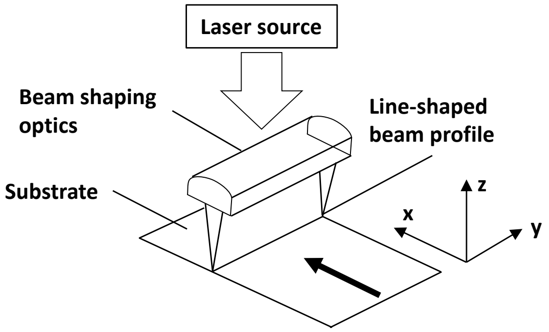

Fig. 1. Laser-based RTP with linear scanning and line-shaped beam profile.

In this paper we report on novel optical concept providing full scalability of processing width, robustness and power input per unit length in excess of 40 W/mm for the RTP of functional coatings on architectural glass featuring dimensions of 6 m x 3.2 m.

Chapter 2 presents the optics for the generation of a line-beam with extreme aspect ratio featuring an optical modularity to combine several of these optics while maintaining homogeneity in y-direction.

Chapter 3 describes how this technology was applied for the first time to an industrial process to develop and launch on the market new products with breakthrough performance for the building market

2. Modular Line Beam Optics

In order to realize a processing width of 3.2 m we have chosen a modular approach, which is based on an optical sub-module featuring a line length of 415 mm combined with multiple laser devices of the established thin disk laser platform providing an output power of 12 kW per unit. The optical design of the line beam in the long axis direction (y) is such that the beam profiles can be stitched together providing constant power per unit length (Fig. 2). The advantage of this concept is a reduced complexity, since the total number of modules is low compared to free-beam approaches. Moreover this concepts provides exceptional robustness, since it combines the advantages of high-power fiber coupled infrared lasers with a very efficient optical design. However, the line optics module must be able to handle a maximum of 18 kW of laser-power at close to diffraction limited beam quality, which can be derived from basic specifications of the significant beam parameters (Table 1).

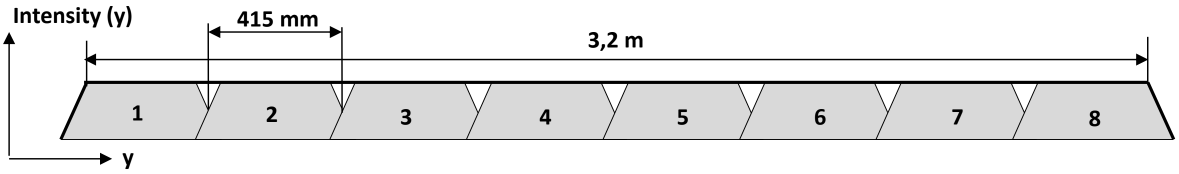

Fig. 2. Stitching of individual line optics modules

According to Table 1 each module is fed by 2 TruDisk 12002 disk lasers with an M^2-value of 28 per fiber.

Table 1. Specification of beam parameters of line optics module

Parameter	Value	Unit
Maximum power per unit length	40	W/mm
Maximum power per optics sub-module	18	kW
M^2 per fiber port	28	
Total line length, y-axis	3200	mm
FWHM Line length line opitcs sub-module, y-axis	415	mm
Number of line optics sub-modules	8	
FWHM Line width, x-axis	65	µm
Depth of focus, x-axis	1.3	mm
Homogenity (Imax-Imin)/(Imax+Imin), y-axis	10	%
Optical efficiency (output/input)	90	%

2.1. Optical Concept

The optical concept of this line beam optics is unique with respect to its

- beam transformation and beam shaping technique,
- operational power-level,
- efficiency and
- compactness.

In Fig. 3 a schematic of the optical concept for a single fiber port is given. Each fiber exit is collimated with an anamorphotic optical system to an aspect ratio x/y of approx. 10. Afterwards the elliptical intensity distribution is transformed by a 2 mirror beam transformer (*Clarkson, Hanna, 1996*) resulting in an M^2-value in the x-direction of approx. 3. In the y-direction the transformed beam is propagated through an imaging fly´s eyes homogenizer. Finally the beam is focussed in both directions onto the working plane such, that the beam profile can be stitched to scale the line length.

The entire optical system features dimensions of 1000x400x300 mm³ (z / y / x) at a weight of approx. 110 kg so that it still can be manipulated by state-of-the art actuators. The alignment accuracy needed for the stitching procedure is directly related to the focal dimension in the short axis and corresponds to several microns.

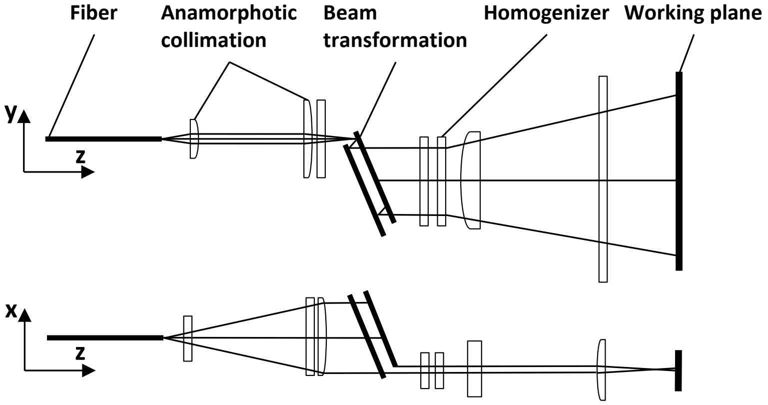

Fig. 3. Optical concept of the line optics module for a single fiber port

2.2. Measured Beam Profiles

One of the most critical aspects is the precise measurement of line-shaped intensity distribution. In order to precisely predict the beam properties we developed a CCD-based linear scanning measurement system, which is capable to measure the line beam at full power. In Fig. 4 the characteristic measurements at 18 kW comprising integrated long axis scan and short axis FWHM-width plotted over line length are shown.

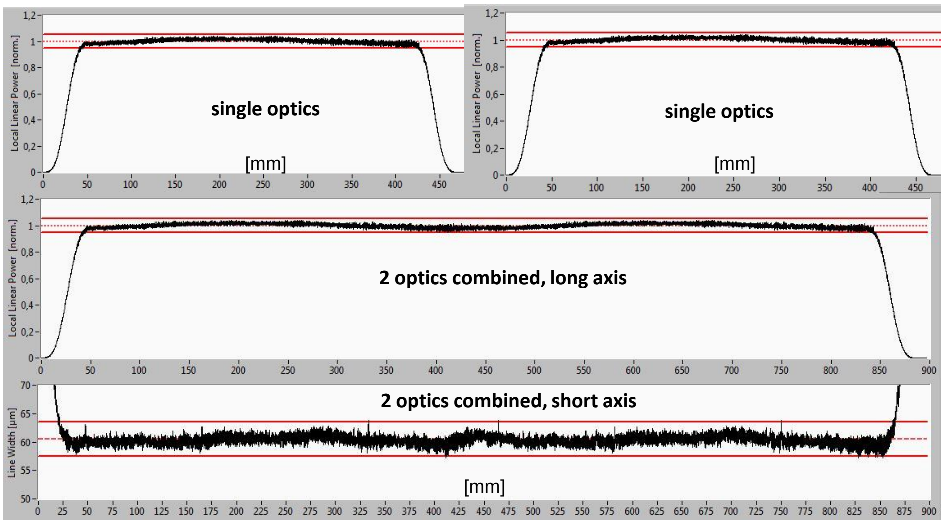

Fig. 4. Integrated long axis beam profile at 18 kW: Single optics (top), two modules stitched (middle), red lines indicating maximum and minimum intensity. FWHM-line width plotted over line length (bottom), red lines indicating maximum and minimum line width.

It can be seen that both individual and combined profile meet the specification of 10 % homogeneity so that stitchability of the beam profiles is given. It may be noted that the combined profile is evaluated by theoretical stitching, i.e. that the measured profiles are virtually stitched.

With respect to the short axis we can state that beam transformation and focusing optics are well suited to fulfill the high demands on beam quality, since the FWHM-width is well below the 65 µm border.

2.3. Opto-mechanical Design

The opto-mechanical design of the line-optics module is based on a rigid aluminum plate construction. The key aspects include robustness for 24/7 operation, tightness, thermal stability and a control interface which allows for online-monitoring of the critical parameters. In Fig. 5 the CAD-rendering including the exit beam is presented.

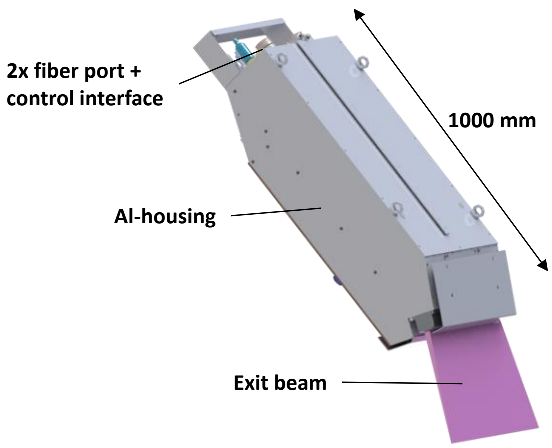

Fig. 5. CAD-rendering of the line-optics module including exit beam

For the precise combination of several units each line-optics module must be positioned on a precision alignment stage. Due to the compact design, a small foot print compared to furnaces can be realized facilitating integration into conveyor belts.

3. Application-New Highly Efficient Functional Coatings on Architectural Glass

Thin coating glass for building applications is a highly competitive market where all the suppliers use similar technologies for coating deposition.

Starting from early eighties, the glass industry introduced magnetron cathodic sputtering as a key-technology to functionalize large area glass (thermal insulation, solar reflection etc.). Contrarily to float CVD, magnetron sputtering provokes a limited thermal energy transfer to the film, leading to amorphous or poorly-crystallized material.

Later, new sputtered stack designs allowed the coated glass to be tempered. The heat treatment applied by the tempering process allows to improve the crystallization of metallic and some dielectric films significantly, but remains limited to glazings for which safety is required.

The novel modular optical concept developed by TRUMPF combined with multiple laser devices of the established thin disk laser platform providing output power of 12 kW per unit was applied for laser rapid thermal annealing of thin films deposited on jumbo-size architectural glass (3.2 m x 6 m) for the first time ever.

This technology permits to selectively heat the coating without affecting the glass substrate. The achieved intensity homogeneity along the entire laser line permits to process the coating homogenously, fulfilling the strict optical requirements of for coated glass. In addition, the large depth of focus proved to be a key to tolerate glass vertical movement during conveying under the fixed laser line.

Furthermore the technology has demonstrated its robustness and ability of 24/7 operation with industrial standards. In particular this implies a stable and reproducible processing speed in accordance with an inline process (> 10 m/min) fulfilling efficiency requirements of the glass industry.

Due to the highly improved crystallization after laser processing, the resistivity of e.g. thin Ag-based stacks could be decreased homogeneously up to 30%. This led to the development and launch on the market of new products with breakthrough performance.

This technology opens a large field to new cost-effective glass products with improved energetic balance, simultaneous high transparency and improved electronic transport properties and many others.

4. Conclusion and Outlook

In this paper we have demonstrated the successful implementation of a novel line-beam optics for rapid thermal processing of large area substrates providing power per unit length of more than 40 W/mm. By application of a modular approach several line-beam optics can be combined to scale the line length to more than 3 m. The key features of the line-optics module comprise high reproducibility of the beam profile, large depth of focus and good homogeneity. Due to its robust, compact design and its control interface it is predestinated for industrial 24/7 operation.

Perspectively we want to raise the power level per optics to 32 kW targeting new fields of application such as sheet metal refinement.

References

Clarkson, W.A., Hanna, D., 1996. Two-mirror beam-shaping technique for high-power diode bars, Opt. Lett. 21, pp. 375-377

Dickey, F.M., 2014: Laser Beam Shaping. Theory and Techniques, Second Edition. Boca Raton, Fla (CRC Press).

Skorupa, W., Schmidt, H., 2013. Subsecond Annealing of Advanced Materials: Annealing by Lasers, Flash Lamps and Swift Heavy Ions. Berlin Heidelberg: Springer Science & Business Media.

Tsang, W.M. et al., 2008. Transparent conducting aluminum-doped zinc oxide thin film prepared by sol-gel process followed by laser irradiation treatment. Thin Solid Films 517, (2008), pp. 891-895.

Völkel, R., Zimmermann, M., 2006. Homogenisierung von Laserstrahlen. Photonic 3/2006, pp. 76-79.

Wang, X., Bellouard, Y., Vlassak,J.,J., 2005: Laser annealing of amorphous NiTi shape memory alloy thin films to locally induce shape memory properties. Acta Materialia 53 (2005), pp. 4955-4961.