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F-Theta at Jenoptik – a holistic approach

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Abstract

The continuing development in laser technology and laser applications drives the development of suitable optical systems and components. E.g. both trends to higher laser power as well as shorter laser pulses pose different new challenges for the design, manufacturing, and testing of F-Theta lenses. This contribution will present how Jenoptik Optical Systems GmbH addresses these challenges, employing experiences as a manufacturer for customized optical systems for both laser as well as high-NA UV applications.

system technology, physical simulations, optical system design, high power laser applications

1. Introduction

Both trends to higher laser power as well as ultra-short laser pulses (USP) increase the demands on the optical systems to fulfill industries requirements on lifetime and optical performance.
Jenoptik Optical Systems GmbH, as a manufacturer of both optical components for laser applications in manufacturing as well as high-NA UV systems for the semiconductor market, possesses the required experiences, facilities and technologies to meet the increasing need for efficient and robust high performance optics. Table 1 provides an overview of these key capabilities.

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Key capability	Driving technology
Manufacturing according to highest cleanliness standards	UV semiconductor technology
Mechanical design and adjustment techniques for increased accuracy	High numerical aperture optics
Versatile and elaborate measurement techniques	UV, VIS, IR optics, laser developments, optical components manufacturing, micro-optics
Understanding of system design	Laser development, laser and material processing, micro-optics

Table 1. Required key capabilities for the production of next generation laser material processing systems.

Since these crucial technologies are kept in-house at Jenoptik it is possible to establish a "holistic" development process which allows an efficient development of high quality optical systems (e.g. JENar™ and Silverline™ F-Theta lenses).

In the following, the critical requirements stemming from the high laser power and USP applications will be discussed.

2. Requirements for the development of optical systems for high laser power applications

2.1. Lifetime

The increased intensities lead to a reduced lifetime when surpassing the laser induced damage threshold (LIDT). There are two major issues to be addressed to counteract this problem. On the one hand, the LIDT has to be increased by design and on the other hand a degradation of the LIDT over time and usage has to be prevented. In order to achieve this, the complete product production and usage cycle has to be adjusted. The major issue in this process will be cleanliness. Due to its long experience as supplier for UV optics for the semiconductor market, Jenoptik possesses the required experiences and facilities (see figure 1). A short overview over the affected items of the product production process is given in table 2.

Fig. 1. a) Ultrasound cleaning, b) Preparations to enter the ISO 5 cleanroom

Product phase	Requirements and synergies
Glasses	Materials have different LIDTs. To withstand both high power and ultra-short pulses one is left with a limited choice of materials, mainly fused silica and CaF2. Both are the standard materials used in semiconductor products.
Coatings	Since the coatings play a crucial role for the durability of optical components, their design and manufacturing techniques have to be adjusted to the needs of high intensity and USP. Besides minimizing overall absorption, the design of coatings also has to take into account the electrical field distribution created in the coating layer structure. Therefore, it is very important that the design of the coatings is performed where the optical system is manufactured. It is a routine task to tailor coatings to the exact system requirements and long-time lifetime.
Optical design	Each optical surface in an optical system creates a reflex. Some of these reflexes create real foci which, if located in optical components, might lead to destruction of the system. The optical design therefore has to control the location of the reflexes.
Mechanical design	The mechanical elements of the system, i.e. the housing, have to be low-outgassing. The mechanical design has to take these considerations into account and furthermore prevent external contaminants to reach the optical path in the optical system. As this is a standard requirement for UV systems a deep knowledge in materials and proven design rules exist.
Procurement	Since cleanliness is of outmost importance, suppliers have to be qualified on a regular basis. Furthermore, the incoming inspection has to be able to test for the increased requirements.
Manufacturing	Not only the coatings increase absorption but also manufacturing techniques. I.e. different polishing and finishing techniques for lenses induces considerable absorption on the optical surfaces. These contributions have to be investigated and controlled.
Assembly	The assembly of optical systems for high power and USP systems has to be performed in a clean environment. A standard process for semiconductor optics combined with frequently controlled environments.
Testing	Besides the incoming inspection, also the outgoing inspection has to be able to test for the usability of an optical system for high power and USP applications. This mainly requires a test for transmission/ absorption of the system.
Storage	Once a clean system is assembled this state has to be preserved. Therefore packaging and storage on suppliers side have to be optimized. The choice of materials is strongly influenced from the experience with UV systems where the correct choice of the packaging material is important for the system performance and life-time after production.
Transport	The supplier of the optical system also has to review the transport process and, if necessary, adjust its packaging technique.
Use/ Maintenance	Once the system is at the customers side, it is going to be used and therefore becomes "vulnerable" to contamination. It therefore might become necessary to include purging or cleaning capabilities in the system design.

Table 2. Lifetime requirements from high-intensity and USP laser applications

2.2. Optical performance – thermal focus shift

Due to the heating of the optical system by a high power laser, the optical performance changes over time. The resulting temperature distribution will not be homogeneous but will exhibit a more complicated shape. The two main effects on the optical performance are a shift of the position of focus of the laser and a degradation of beam quality. An exemplary simulation is shown in figure 2. The degradation of beam quality will change the focus shape, e.g. a welding seam might change its width and stability. The focus shift poses a problem for the control of a process since an active refocusing of either the lens or the work piece is required. It would now be in principle possible for the supplier of this optical system to reduce these thermal

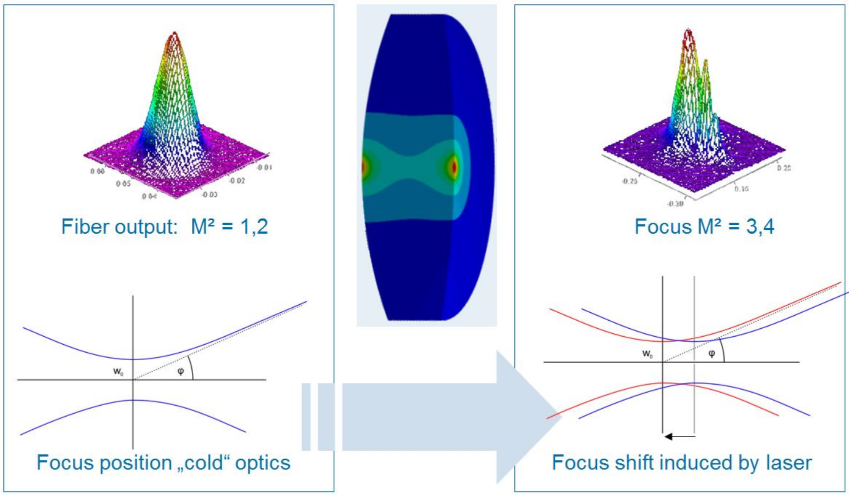

Fig. 2. Simulation of laser induced beam degradation and focus shift

effects if the formation of the temperature distribution was known. This requires an accurate simulation of the process including an iterative solution of the heat equation using appropriate boundary conditions and information about the materials used and the intended laser usage.

In the context of the Research project "BriPro" (funded partially by the BMBF, Nummer 13N11111) Jenoptik Optical Systems investigated and optimized its complete production process with regard to the requirements of high power laser systems. This included the development of a process to accurately describe the thermal behaviour of an optical system and then minimizing its effects on optical performance.

As a result, it was possible to design and manufacture a fused silica objective (λ = 1064nm, f = 160mm) which showed a focus shift of < 0.05 times the Rayleigh range up to a cw-usage of 4kW. The temporal behavior is shown in figure 3.

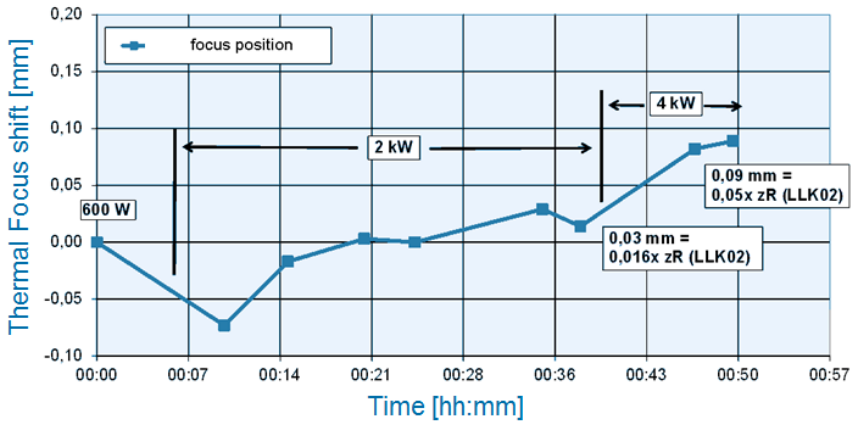

Fig. 3. Thermal focus shift of a thermally optimized F-Theta lens (λ = 1064nm, f = 160mm) designed and manufactured by Jenoptik Optical Systems (zR = Rayleigh range)

2.3. Optical performance – chromatic aberrations

For refractive USP applications, due to the time-bandwidth product, the reduced pulse duration leads to an increased spectral bandwidth of the pulse. This then affects both temporal as well as spatial behavior of the laser beam.

The optical medium will exhibit dispersion, i.e. different velocities of light for different frequencies. If the USP then passes through the optical medium it acquires a frequency dependent phase shift. The quadratic term of this shift, the group delay dispersion, broadens the pulse in time. When designing a system for a particular application this has to be taken into account by either optimizing the system for minimal dispersion or by pre-emptive phase compensation of the optics.

In addition to this temporal effect, the dispersion also leads to a spatial broadening of the pulse. I.e. even if a monochromatic laser would lead to a high quality spot, the usage of a USP laser with the same central wavelength might lead to a very increased spot size. Both effects, i.e. the temporal as well as the spatial broadening of the pulse can be reduced by well-known techniques from the development of USP laser systems by Jenoptik Laser GmbH as well as from the experiences in the design and manufacturing of broadband inspection systems for the semiconductor industry.

2.4. Optical performance – novel applications

The key measure for laser material processing is productivity. Nowadays laser systems are already so powerful that it is the optical system that limits the speed of the process. Therefore novel system designs are developed. One promising example is laser beam multiplexing which multiplies the incoming laser beam (see figure 4) and then uses this new grid of laser beams to process a work piece. I.e. instead of one particular shape written on the work piece at a time the laser writes a grid of NxN shapes. Possible applications include e.g. structuring of solar panels or the drilling of micro-filters.

A schematic drawing of such a setup is given in figure 5.

This parallel processing of a grid of beams poses several difficult tasks on the complete optical system. This starts at the beam multiplier which has to create an accurate angular grid. The scan head than has to add the scanning angle without changing the internal dimensions of the angular laser grid. The following scan head then has to image the angular laser grid onto the work piece without distorting the image.

Therefore, one important novel requirement for optical systems working with multiplexed laser beams is to minimize distortion introduced by the optical system.

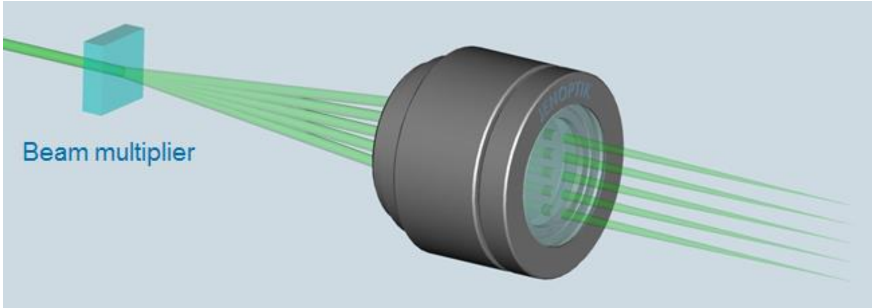

Fig. 4. Concept of beam multiplying for parallel processing

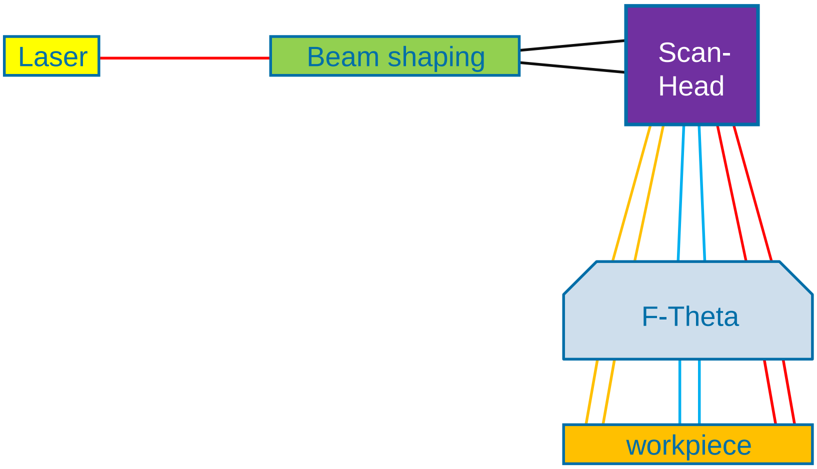

Fig. 5. Schematic setup for a beam-multiplying application

3. Conclusions

In this paper we have demonstrated that Jenoptik Optical Systems GmbH is very well equipped and prepared for designing and manufacturing of the next generation of high-quality optical systems for laser material processing by using a holistic development approach, keeping key capabilities in-house and continuously improving simulation and manufacturing technologies. The challenges that arise from more powerful laser sources and a decrease in the pulse length of USP sources and its solution are:

1. The increasing requirements on cleanliness are solved by transferring design and process know-how from semiconductor lenses to “simple” laser material systems.
2. A thermal focus shift and beam degradation resulting from the high laser power can be almost avoided for up to 4kW with combination of material choice and an optimized opto-mechanical design supported by thermo-optical simulations.
3. Even if chromatic aberrations in the context of laser sources sound unfamiliar at first glance the introduction of ultra-short(er) pulses will require this problem to be addressed by an optimized design.
4. The luxury problem of translating the already available high laser power to productivity can be addressed by a multiplexing approach. The multiplexing will lead to a demand of new lenses with minimal distortion. The capability of designing and measuring extremely small distortions are already available at Jenoptik from high-end UV systems.

Combining these solutions the “holistic” development process is realized allowing an efficient development of high quality optical systems for laser material processing (e.g. JENar™ and Silverline™ F-Theta lenses).

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