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Final Report

Project: PrOpSys

Production Technology of Optical Systems for High Power Diode Lasers (HPDL)

Duration of Project: 01.07.2007 - 31.12.2010

Project Partners:
LIMO Lissotschenko Mikrooptik GmbH, Dortmund
ficonTEC Service GmbH, Achim
Artifex Engineering e.K., Emden
Fraunhofer Institut IZM, Berlin
Fraunhofer Institut ILT, Aachen

1. Summary

With the completion of the pilot system the task has been solved and the goal of the PrOpSys research project has been achieved. The new technology now allows automatic production of high-performance diode lasers whereas micro optics formerly had to be adjusted and assembled by hand before the diode laser bars. After a little more than three years of project time the path towards serial production with constant quality and flexible quantities has thus been leveled.

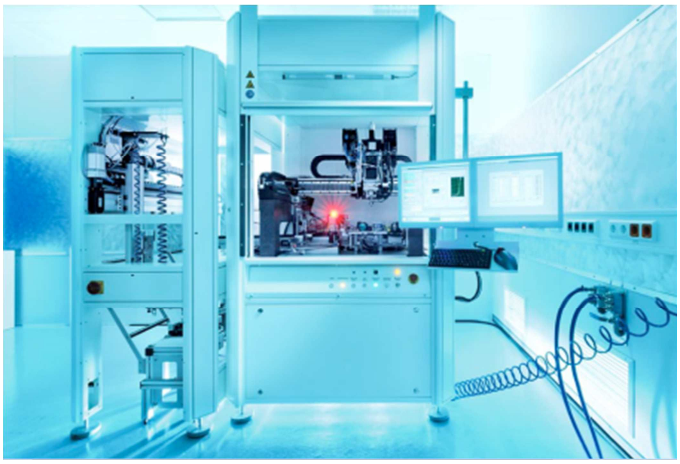


Figure 1: pilot machine for fully automated alignment and mounting of micro optics in high power diode lasers which was designed and set up within the project

The process which calls upon specially developed methods of digital image processing to position the collimating lens in front of the diode laser precisely to the micron range is fundamentally new. Whilst the project dealt specifically with high-performance diode lasers and their components – diode laser bars, collimating and beam shaping optics and fibre coupling – the new technology also opens up completely new opportunities in other areas of micro-optical production.

The research partners included the companies LIMO, ficonTEC, Artifex Engineering and two Fraunhofer institutes (Fraunhofer ILT and Fraunhofer IZM). The main focus for LIMO was on the development of a diode laser design suitable for mass production. ficonTEC primarily dealt with the working points of the automation and Artifex Engineering contributed with opto-electronic components for controlling diode lasers and detecting their statuses. Fraunhofer ILT concentrated in adjustment algorithms and assembly techniques. At Fraunhofer IZM in Berlin a demonstrator system has been installed for photonic packaging process development, reliability testing and error analyses.

The findings of the project are now waiting to be put into practice. LIMO is going to implement automated fabrication steps for the production of high power diode lasers. ficonTEC and Artifex will expand their product portfolio as integrator or for optical components. Fraunhofer IZM can now use the demonstator set-up for ongoing research of assembly and packing technologies. Fraunhofer ILT is going to exploit the results for advanced research on novel laser diode technologies.

2. Objectives

In the frame of this project, the chain of processes for the packing technology of hpdl shall be advanced to fully automatisation by implementing automated alignment and mounting of micro-optics (figure 2). For the process steps up to bonding of laser diode bars as well as for the subsequent steps of characterization and qualification, highly productive, automated machinery is state of the art. However, the intermediate process step of micro optics assembly is dominantly accomplished manually. By closing this gap in the fabrication chain, a significantly higher productivity in an important field of modern production technology is expected.

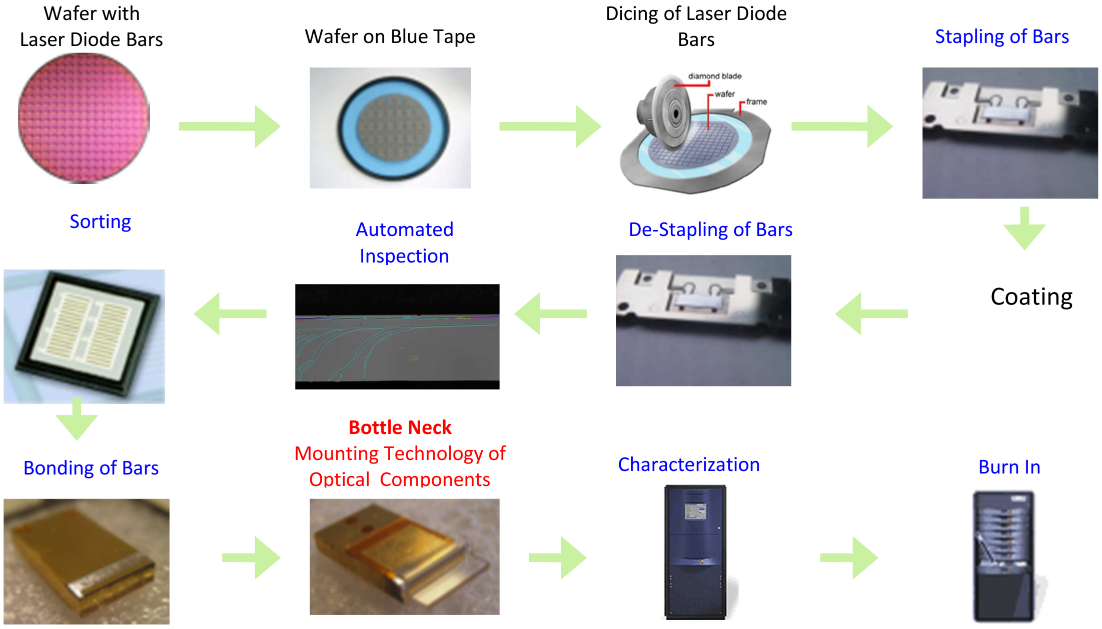


Figure 1: Process chain for the fabrication of high power diode lasers (HPDL)

Target innovations of the project are summarized in table 1. Diode lasers of relatively low power are taken as reference for illustration. This type of laser is already produced in large quantities for telecommunication or data storage applications. Despite the general functions as well as principle process steps of the compared types of lasers are rather similar, there are significant disparities in complexity and requirement profiles of fabrication steps.
The integration of a micro-optical packaging technology in a continuous automated process flow – so called “Design to Mass Production” (D2MP) – is the goal of the project. It is supposed to be demonstrated on the example of a fibre coupled hpdl. In next steps, this technology is going to be adapted to a much wide product range, e.g. diode lasers with specific beam data (not only fibre coupled ones), diode laser systems with multiple bars for power scaling as well as optical systems for beam shaping of other types of lasers. This idea of universal use is essential for an efficient exploitation of the results of the project.
From the fabrication point of view, the goal of the project was to create a process sequence for high efficient optics assembly. Back ground information from automated assembly of laser diode bars on heat sinks is a good starting point to integrate the optics assembly in the overall process chain. Specific modular approaches of the micro-optic systems are supposed to create opportunities for the design of machinery and processes which are flexible and easy to adapt to product modifications. Integrated system concepts, development of novel technical equipment, e.g. universal gripper, integrated measurement and data acquisition, extensive data handling for process control are subject of this project. A data based logistic approach is investigated as the key element for the fabrication of product modifications even on distributed production sites.

Table 1: Comparison of innovation targets for automated alignment and mounting of micro optics for hpdl with the original state of the art for the fabrication of diode lasers

Innovation Targets	Original State of the Art
mounting technology for reliable sub-micron positioning of components in high power systems (>20 W)	mounting technology with tolerances of dominantly >1 µm for power range <<1 W
optimization (alignment) of multi-dimensional target parameter sets (laser beam parameter) with multiple degrees of freedoms (five or more)	optimization (alignment) of scalar target parameters (typically optical power) with mainly maximum of three degrees of freedoms
consideration of individual properties of single components (especially laser diodes) for the mounting process	processing of mainly identical componenets, individual characteristics have no impact on alignment algorithms
flexible systems for the handling of miniaturized components, especially for lenses and lens arrays	handling of a single optical element for one beam source(emitter) at a time
integration of options for modified versions in an automated fabrication process	automated production lines for series >>10.000 pieces

The targets for the work packages were concluded for the matter of manual production of micro-optical systems in hpdl.

- **System Concepts**: The specific requirements of the packing technology for optical systems in hpdl were not analyzed deep enough to be integrated in automated processes. Such system concepts needed to be acquired within the project.
- **Alignment Algorithms:** An active aligment is required for the assembly of optical systems for hpdl which takes into consideration characteristics of the laser beam which passes through the optical system, e.g. divergence angles, beam symmetry, beam displacements etc. The set values of 3-5 degrees of freedoms of parameters have to be detected to place the optical elements properly. Algorithms suitable for automatization needed to be created for such extremely complex alignment procedures. These algorithms may vary depending on the specific type of micro optic.
- **Technical Machine Elements:** Handling systems needed to be developed for the automated packaging technology of micro optical systems, especially universal gripping tools for miniaturized optical components. Furthermore, the high demand on mounting accuracy down to the sub-micron range requires mechanically robust machine constructions which have to be equipped with high precision actuators. Special considerations have to be taken for electrical and thermal aspects since micro optics in hpdl are typically aligned at maximum laser power and mounted under this condition respectively.
- **Status recognition and evaluation:** Sensor systems have to be integrated for the flexible control of active alignment processes. Data of the sensor systems on the one hand will be directly used for the control of the procedures or on the other hand have to be processed in conjunction with input data, e.g. individual properties of optical components. Process data have to be transferred into data base system.
- **Demonstrator and pilot machine for automated assembly.** The proof of concept has to be shown for principle functionalities in a demonstrator and a pilot machine. Production relevant requirement profiles have to be used as reference for the automated assembly of an optical system consisting of diode laser bars and micro optics.

2. Results of Project Partners in the Sub-Projects

3.1 Course of Actions for the Collaborative Project

LIMO as primary user of the addressed technologies was coordinator of the project and provided know-how about production of optics and diode lasers to the project. ficonTEC and Artifex investigated in cooperation all issues of process automatization. ficonTEC also worked on logistic processe. ILT and IZM concentrated on process development, the ILT with emphasis on alignment and mounting, the IZM with emphasis packaging technology and reliability investigations. Artifex gave support in metrology tasks. Feedback steps from evaluation/qualification and modification/optimizations were organized in narrow cooperation of the project partners.

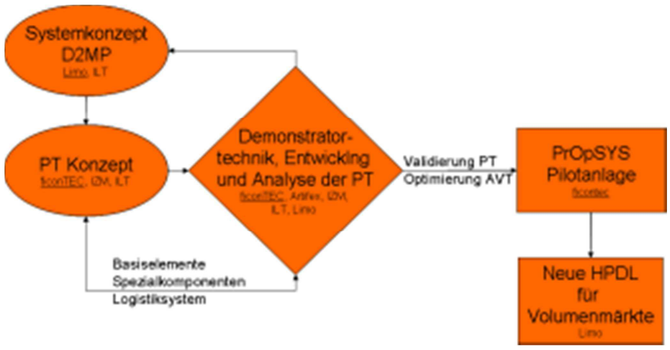


Figure 3: Course of actions for the collaborative project PrOpSys
D2MP: design to mass production, PT: production technology,
HPDL: high power diode laser

3.2 Work and Results of Project Partners

3.2.1 High Power Diode Lasers - design and assembling steps feasible for automated fabrication
LIMO Lissotschenko Mikrooptik GmbH (LIMO)

Design of high power diode lasers and its components feasible for automatization

The opto-mechanical layout of the laser diode heat sink was modified to the needs of automation requirements and improved performance (figure 3). Several suppliers for laser diode were consulted for the evaluation of concepts. Finally, one specific design was agreed on. Several units of hpdl were set up during the project with this novel heat sink.

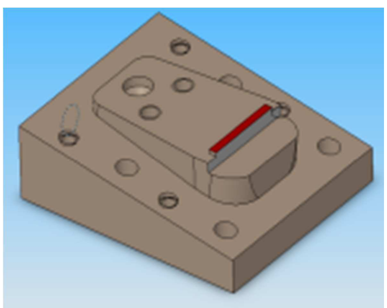
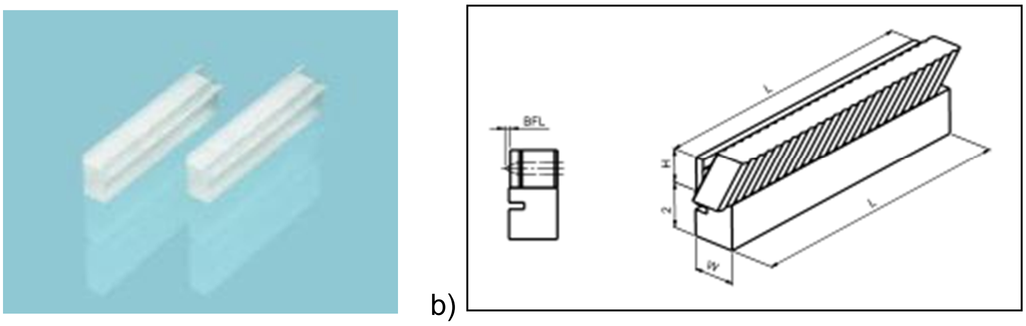
a)  b) 

Figure 4: Laser diode with novel LIMO heat sink (a) and a corresponding newly designed laser housing (b)

The BTS module is the key element for beam shaping by micro optics in LIMO hpdl. The design was revised to the obligations of fabrications in high quantities. Hence, the size of the

BTS was minimized (figure 5). A wavelength specific design of the BTS was additionally generated which took to into consideration tight tolerance of lens thickness and coating concerns.



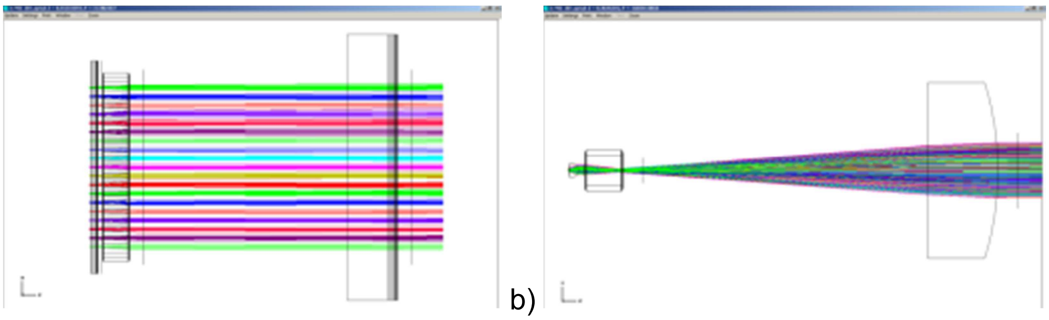
a) b)

Figure 5: BTS module which was modified for producing large quantities and for improved wavelength-specific performancel
(BTS: Beam Transformation System)

Design investigations and tolerance analysis (optics, mechanics)

Initial investigations were carried out in parallel with a micro-optics positioning system with 6-axise in the laboratory and with simulations by means of the optics software Zemax. The detailed tolerance analysis gave essential input for the accuracy and layout of the stages of the alignment system for the demonstrator and pilot set plants.

Ray traycing models are presented in figure 6showing beam lets from 19 emitters passing the BTS lens system (FAC and transformator) and a SAC lens.



a) b)

Figure 6: Ray traycing from Zemax simulations for the novel BTS lens system in a) top view and b) side view

This analysis proved that the BTS needs to be positioned with an accuracy of better than 1 µm to assure an efficient coupling into 100 µm fibre cores. All other optics like SAC lens, redirection elements or focussing lenses require positioning accuracies of better than 10 µm. Tolerances concluded from simulations were verified in laboratory experiments.
Figure 7 shows a typical near field and far field of beam lets directly behind the BTS. Divergences as small as 6,2 mrad (FW1/e^2) were systematically reached. Additionally, beamlets of the individual 19 emitters from one bar are distinctively visible in near field.

a) b)

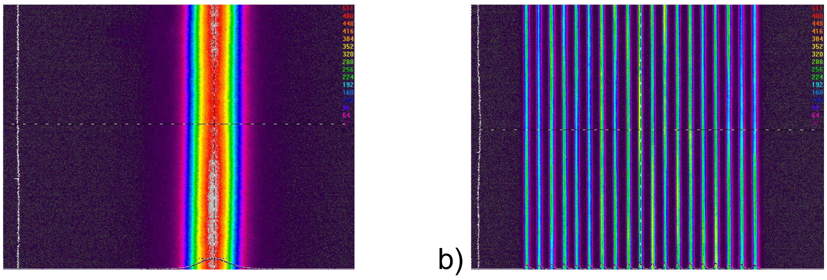


Figure 7: Typical laboratory results of BTS alignment
a) far field (divergence distribution) and b) near field (intensity distribution)
divergence = 6,2mrad (FW 1/e²) for 19 individual emitters of one bar

LIMO laser cover an extensive portfolio of housings variants. All these variants were screened. The most relevant ones were used as reference to be assembled at the pilot plant. Lasers containing one laser diode bars were within the main focus of this evaluation.
Recent progress on laser diode bars to increase output power and consequently larger emitter structures were the motivation to fit the focal length of FAC lens within the BTS module to the emitter structures. The functionality of this optics was demonstrated by setting up test units. The demonstrator as well as the pilot plant are able to process these laser diodes and optics.

Procedures, algorithms and software for the alignment and mounting of micro optics

An alignment algorithm was created in cooperation with ILT. It was verified and optimized by LIMO after programming at ILT. It was necessary to figure out feasible increments and directions for each algorithm step in a way to get it directly implemented to the demonstrator machine. In the demonstrator machine, a 4-quadrant-diode and a power meter were integrated for initializing the alignment process. This was consequently transferred to the machine design. For the first time, an automated alignment and mounting was demonstrated on the demonstrator machine. The software code was modified before its implementation to the pilot plant.

3.2.2 Automation concepts and systemic process optimization ficonTEC Service GmbH (ficonTEC)

In the context of PrOpSys ficonTEC had the responsibility in particular for the development of new innovative concepts for the automation of the handling and assembly process to reach a very large-scale integration of optical systems. In connection with this ficonTEC also had to realize the structure of an experimental basis (demonstrator).
In the first two phases procedures and components were compiled and tested and developed and a demonstrator unit was created. The demonstrator was used for process development, in order to realize a pilot plant in the last phase of the project.

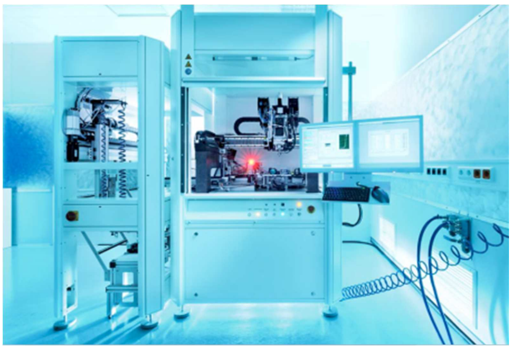


Figure 8: Pilot plant in the clean room; on the left hand site you can see the feeding system and right adjoining there is the actual assembling system.

The assembling system consists of a XYZ axle system, with two goniometric axles and a rotation axle. Further components are the measuring system (measuring platform), the mobile gel pack carrying station, and a UV curing unit, a stroke unit for the work piece carriers and the automated delivery units for the supply of the work piece carriers. Additionally a spectrometer and a process observation camera are inserted.
To the XYZ axle system a Z-head is installed. Here two top side cameras for the component fixing unit as well as two dispensers are installed onto pneumatic axles.
For hardening the adhesive an UV source with two fibres is used. The fibres are located on a holder, which can be tilted over a pneumatic rotation cylinder. The final positions are queried by end position sensors. Additionally the entire unit is installed onto an XY axle system.
The mobile gel pack carrying station can take up 16 x 2 " or 4 x 4 " gel packs. Into the gel pack different components are made available, which cannot to be supplied by way of the supply system or be supposed. The components can be optical elements, but small holders or cover sheet metals can be supplied in such a way.
The supply system is its own module, which ensures the automated supply of different components on work piece carriers. The supply system can be equipped with two carriages, one of it is empty, and the other can be loaded with up to 20 work piece carriers.

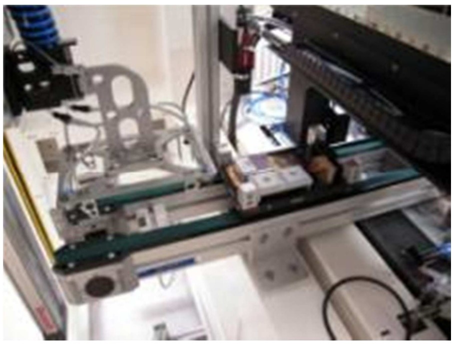


Figure 9: Gripper of the supply system

The equipment with one fully automate supply system as well as extended measuring and operations technology was necessary, in order to be able to validate the suitability for high level processing, which was a global requirement of the project.
For the pilot plant as a goal it was set that 50 to 100 submoduls, consisting of heat sink, laser bar and cover sheet metal, should be assembled fully automated with lenses and/or lens systems.
After the start-up of the pilot plant with the cooperation partner LIMO it could be proven in the test runs that the plant can mount different optical modules and/or submodules fully automatically. Further fully automatic characterisations of optical components were accomplished. The plant fulfils set expectations and represents a milestone, in order to increase automation in the optical industry - special within the range of the micro optics - and lower its costs and to keep thus the production location Germany further competitive.

3.2.3 Automation-supporting optical measurement techniques
Artifex Engineering e.K. (Artifex)

Artifex was responsible for the part of the automation-supporting optical measuring technique in the project PrOpSys. Within the assembling process two tasks are to be fulfilled by the optical measuring technique: on the one hand the feedback of control parameters into the adjustment process, like e.g. the achievement in a defined spot size, on the other hand the examination of optical characteristics before the assembly and in intermediate steps of the total process, e.g. after assembly of the FAC lens. The basic idea is that anyway required

automated assembly (one of the basic conditions for volume markets) also increases the quality of the individual systems.
In the first project phase a detailed instrumentation concept and the basis measuring methodology were compiled.

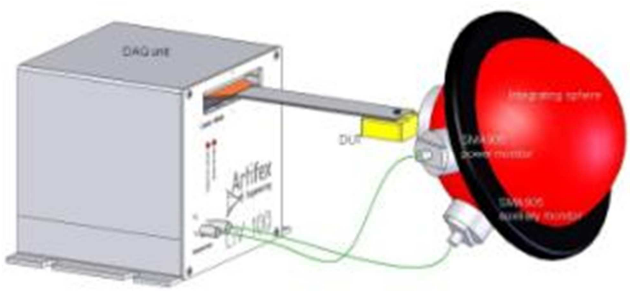


Figure 10: Schematic measuring structure for the characterization of hpdl

During the work for assembling of construction units with similar characteristic (tolerance-optimized assembly) it was noticed that the exit beam can deviate quite far from the target direction directly after the positioning of the elements before the laser. In this case it is difficult to derive from the camera pictures in which way the optics is to be first adjusted. For this reason by Artifex suggested introducing an additional rough adjustment. A concept was provided, which plans the integration of a 4-quadrant-detector into the beam splitting optic. In this manner, the range of the beam position can be restricted clearly in a first rough analysis. An opto-electronic layout was compiled (incl. drivers, application program, Labview libraries for the 4QD-detector).
Furthermore a laser diode driver was developed and converted into a sample structure (incl. system and firm ware). With this system in tests practice-suited driver data were reached:

- Diode current: 0 – 100 A
- Rise time: 30 ns
- Fall time: 40 ns

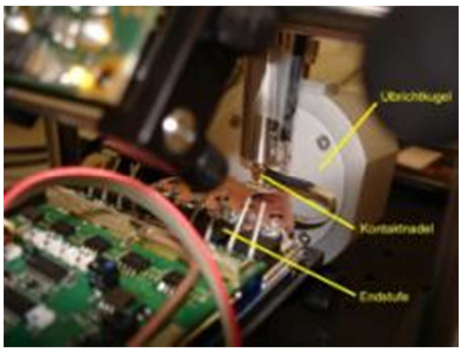


Figure 11: 100A – laser driver

The data link to the process is realized by a 14-Bit analog/digital converter. The system contains differential input stages as well as a FIFO storage. Beyond that a galvanically insulating USB bus was integrated.
A further focal point was the physical integration into the process environment. Thereby above all the determination of suitable contacting procedures for the laser diodes was important. It was compared:

- Direct contacting (pin card)
- Contacting by cables
- Contacting using flat cable

Altogether thereby it was found out that generally flat cables reach the best results, however with too large material thickness there are limitations because of too large inductances. This must be considered within the dimensioning. A layer thickness of 200 µm was proves to be useful. Hereby an optimal contact is reached with justifiable inductance and a contacting by plug contacts is possible.
The planned functionalities were reached. As a result of the sub-project a demonstrator of a system is present for the characterisation and tolerance-referred classification, which was merged into the total demonstrator by the partner ficonTEC and in the test runs operated satisfactorily.

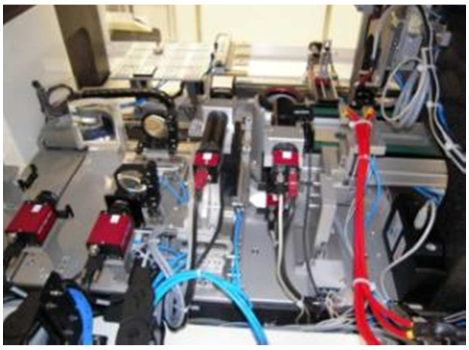


Figure 11: Measurement unit from Artifex within the demonstrator set up

3.2.4 Assembly and packaging technology and demonstrator system for hpdl Fraunhofer Institute for Reliability and Microintegration (IZM)

The Fraunhofer IZM has developed a flexible machine for fully automated assembly, alignment and gluing, of micro-optical components, i.e. fast axis collimators (FAC).
It consists of a five axis base unit, two cameras and the analysis for actively align the components. A prism splits the beam from the diode to four sensors (one camera for observing the near field, one for far field, a power detector and a four quadrant diode).
The project also includes the development and fabrication of a pick-up tool and the coolable assembly stage.

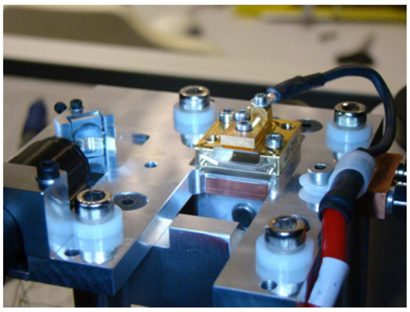
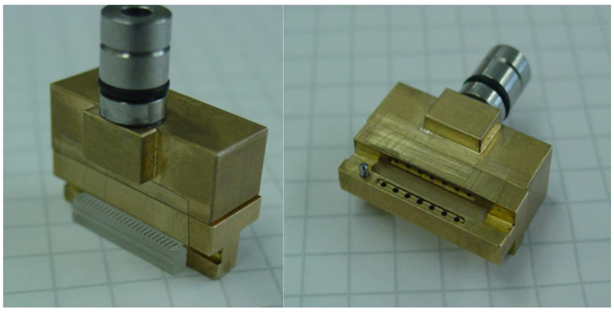
a)  b) 

Figure 12: a) coolable assembly stage; b) pick-up tool for FAC lenses

The two cameras observing the upper and the lower side are able to measure the position of the pick-up tool, the optical components and the laser, especially the emitting ridges. Based on these measurements the laser and the optic could be passively positioned to only a few microns. Now the software analyses the images from the two cameras to optimally align both components. This position is stored. After applying the glue the components are moved back to the stored position and the adhesive is cured.
The resulting displacements needed additional research.

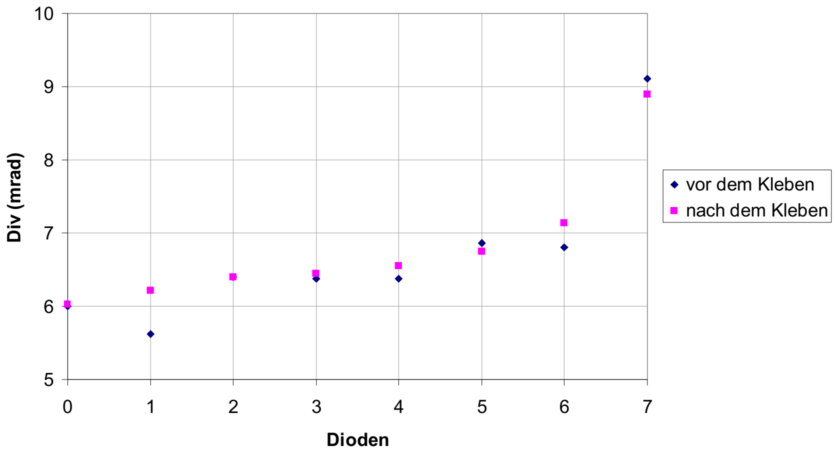


Figure 13: divergence of collimated light from laser diode bars before and after the gluing of 8 laser diodes

As it can be seen from figure 13 the packaging process taking the shrinking behavior of the glue into consideration causes only very good divergence angle stability. These results could be verified by measurements of project partners.
As another part of the project a CO_2 laser based station with a galvo scanner was set up. First tests of fusing optical components were done successfully.

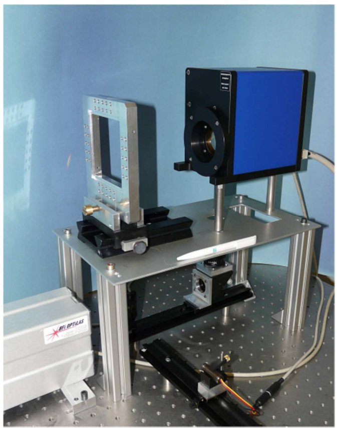


Figure 14: CO_2-Laser assembly station

Fusing of glass with a CO_2-Laser is a relatively new technology, so knowledge from the process of glass bonding is used. Glass bonding describes the fusion of wafers (i.e. silicon) or components on substrates by adding solder and heat.
First tests show that the CO_2-Laser could found the solder glass resulting in small balls of solder that are partly bonded to the substrate. Also stress is induced.
While bonding two thin glasses the soldering glasses only found at the spots where the laser is focused.

3.2.5 Algorithms for automated alignment of micro-optical components Fraunhofer Institute for Laser Technology (ILT)

The goal of the FHG-ILT sub-project in the PrOpSys was the development and test of alignment algorithms for micro optical components for high power diode lasers.
The assembly of diode laser modules is a complex task due to the high number of degrees of freedom of various micro optical components and undetermined target criteria the alignment of micro optical components is done by operators with high experience. In order to increase the production throughput at constant quality the demand for fully automated production grows.
The main task of the sub project was the fully automated alignment of the beam transformation-micro-optic (BTS). The BTS was actively aligned with respect to five degrees of freedom directly in front of a diode laser bar. The BTS alignment requires sub-micron accuracy.
The alignment was realized by splitting the alignment in pre alignment using near field analysis and fine adjustment using far field analysis. The splitting was necessary because the precision of the passive BTS alignment was not sufficient for generating adequate far field signals. Possible reasons are manufacturing tolerances of the used components and parts.
The pre alignment was done by analyzing the near field intensity distribution at approx. 40 mm behind the BTS optic. The adequate alignment position of the BTS was characterized by homogenous and clearly separated signals from the single emitters of the laser bar. For real time analysis of the near field intensity distribution image processing algorithms were developed. The principle of the image processing is given in figure 15. Due to negligible vertical changes the intensity distribution is integrated column by column. From the following column sum distribution the minima and maxima were derived. For every maximum a local contrast ratio was calculated from the values of the maximum and the surrounding minima. In the adequate alignment state the contrast ratio for every found maximum was approximately one and therefore the contrast ratio distribution was homogenous.

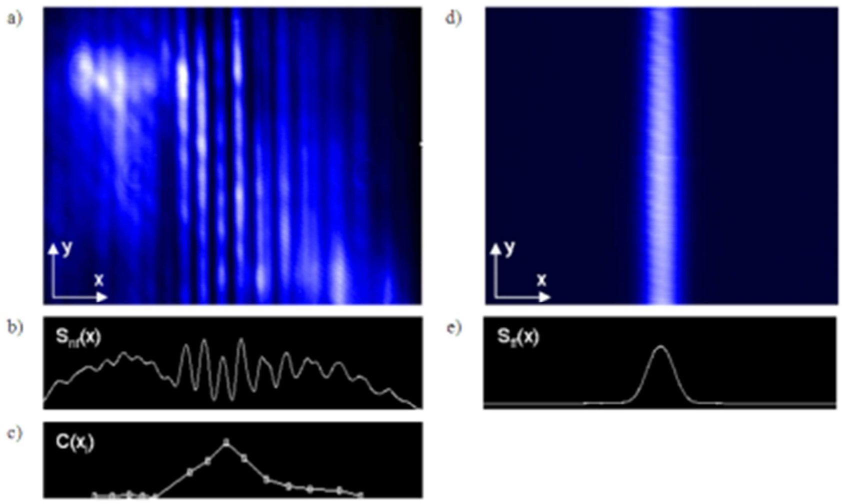


Figure 15: Different steps of image acquisition and processing behind BTS optic.

a) near field intensity distribution at misaligned BTS optic b) Column sum distribution c) local contrst ratio distribution d) far field intensity distribution a aligned BTS e) far field column sum distribution

Experiments at ILT showed that symmetry homogeneity and integral of local contrast ratio distribution and column sum can be related to specific misalignments of the BTS. Therefore reliable characteristics for evaluation and optimization of the alignment state in the near field were found.

After this a sequence of alignment steps was developed. During an alignment step one or two axes were automatically moved as long as one of the mentioned characteristics take extreme or limit values. At the end of the near field alignment process the BTS optic was adequately aligned for generating a detectable far field signal.
From the two dimensional far field intensity distribution the one dimensional column sum distribution was calculated. The column sum distribution width was used to characterize the far field signal. In the adequate alignment state the column sum distribution showed a Gaussian shape with minimum width. Misalignment of critical axes lead to broadening the distribution. The critical axes were automatically moved to the position where the column sum distribution width was minimized. The resulting divergence angle was calculated from the final width. The value of the divergence angle was used to qualify the component pair (diode laser – micro optic) and decides if the micro optic was glued.

4. Outlook

The findings of the project are now waiting to be put into practice. LIMO is going to implement automated fabrication steps for the production of high power diode lasers. Cost effective micro optics and hpdl are preconditions to introduced hpdl to new application, e.g. in medical instruments, for material processing or in printing industry. Furthermore, the principle availabilty of hpdl in large quantities, in attractive cost structure and in uniform quality may also make it realistic to establish hpdl for consumer markets.
ficonTEC is going to adapt the results of the project for new automated packing machine for the assembling of optical systems. ficonTEC will strengthen and expand their product portfolio as integrator.
Artifex Engineering opened up additionally opportunities for new, self-developed opto-electronic components and its commercialization.
Fraunhofer IZM can now use the demonstator set-up for ongoing research of assembly and packing technologies.
Fraunhofer ILT is going to exploit the results for advanced research on novel laser diode technologies.

5. References and Publications

Press Release, Juli 2007
„Project „PrOpSys“ has started“

Paper and Oral Conference Presentation, January 2009
“Automated Assembly of Fast Axis Collimation (FAC) Lenses for Diode Laser Bar Modules”
J. Miesner, A. Timmermann, J. Meinschien, B. Neumann, S. Wright, T. Tekin, H. Schröder, T. Westphalen, F. Frischkorn
Presentation: Photonics West 2009, San Jose, 26th January 2009, PW09L-LA107-7198-15
Paper: Proc. SPIE 7198, 71980G (2009); doi:10.1117/12.809190

Press Release, August 2009
„PrOpSys – Automated assembly high power diode lasers was implemented for the first time“

Press Release, March 2011
„Pilot system for automated production of high performance diode lasers now in place“

Conference Presentation, May 2011
„Fully Automated Assembly of Micro Lenses for High Power Diode Lasers”
H. Schröder, S. Marx, J. Meinschien, A. Timmermann, D. Goldberg, T. Vahrenkamp, A. Weber, B. Neumann, S. Wright, T. Wetsphalen
EOSMOC 2011, Munich, 24th May 2011, Presentation 4400