Fabrication of highly precise fiber optical array products by use of laser based micro alignment

M. Zimmermann, L. Schaefer, M. Rank, M. Schmidt, S. Roth

Bayerisches Laserzentrum gGmbH, Konrad-Zuse-Str. 2-6, 91052 Erlangen, Germany

Abstract

The proceeding integration and miniaturization of mechanical and optical functions in systems for optical communication, for sensor and environmental technologies or for life sciences require an improvement and a customization of the manufacturing technologies. For fiber optical systems and components, especially for singlemode applications, adequate methods for a precise adjustment are necessary which allow a fast and cost-efficient alignment of fibers and other optical components like microlenses or laser diodes. The demands on the adjustment process rise additionally for array applications. Laser based micro alignment is a promising technology for such critical adjustment tasks. We investigated the use of this technology for the alignment of fibers within fiber arrays. They are used for the assembly of fiber collimator arrays. We developed and analysed suitable actuator geometries for this application. In this paper we show some important results of the FEM based analyses to demonstrate the influence of the laser irradiation regime. First experimental results confirm the actuator behaviour calculated in the FEM analysis. Based on the simulations and experimental results, we are developing a compact alignment module which is adapted to the demands on the assembly process of fiber optical components. This alignment tool is one module within a complete miniaturised, scaleable and modular assembly line for the production of fiber collimator arrays.

Keywords: laser based micro alignment, fiber collimator array, assembly platform

1. Introduction

Many micro system devices such as computer hard disk drives or micro-optical systems are crucially depending on the precise alignment of specific lenses, sensors or other functional devices. The problem of meeting the tight positioning tolerances represents an up-to-date key assignment in micro-manufacturing. Instead of manufacturing each individual component extremely accurate, it has turned out to be much cheaper and easier to perform to adjust them after assembly. The produced components and most of the steps in assembly may have loose tolerances because of the fine laser adjustment of critical components in a second step.

Unlike other alternatives, laser based processes represent a very elegant and convenient way to manipulate mounted components in a micron range. As miniaturized devices are typically difficult to access and highly sensitive to mechanical forces and impacts, especially applications in micro technology benefit from the main advantage of laser adjustment processes to allow a completely non-contact interaction. Moreover, the laser offers unmatched flexibility and controllability as well as ideal adaptability to the process and the application.

2. Basics of laser based thermal adjustment

Coming from macro-procedures like laser-forming or laser-bending for automotive applications, the laser based micro-alignment is a technology with a great capability for aligning micro-optical, fiber-optical or electro-optical systems. The first approach in creating a laser micro-adjustment technique was to adapt the macro process of thermal laser forming into the domain of micro systems. The process is typically based on laser induced temperature gradients: the so called “Temperature Gradient Mechanism (TGM)” which is shown in Fig. 1.
3. Laser micro adjustment of fiber collimator arrays

In many optical systems for data communication the information is transmitted in a parallel way to fulfill the permanent and rising demand on bandwidth. Especially in interfaces like switches or optical rotary devices free-space coupling of light is often realised with the help of fiber collimator arrays (FCAs), which consist of an array of either multimode or singlemode fibers and microlenses. The performance of these systems strongly depends on the quality of the optical coupling. Particularly singlemode systems require a high precision assembly in the sub-µm range to reduce attenuation of the transmitted light.

For the alignment of fibers to a microlens within fiber collimator arrays a new actuator system has to be designed which can be integrated into an array with a pitch of 2 mm or smaller. The actuator should allow a total movement of 10 µm in each direction in a plane perpendicular to the fiber axis and the precision of adjustment should be better than 0.1 µm. The setup of the FCA is shown in Fig. 2. The array containing the actuators and the fibers is fixed to the micro lens array (MLA) still allowing a movement of the fibers relative to the lenses in the plane of the array. After the final laser alignment the gap between fiber and MLA can be filled with index matching adhesive to reduce the reflection at the fiber end and to stabilize the complete system. The material of the actuator is invar, an iron nickel alloy. The advantage of this material is the low thermal expansion of $\alpha_T = 0.6 \cdot 10^{-6} \, 1/K$. It has nearly the same value as fused silica ($\alpha_T = 0.51 \cdot 10^{-6} \, 1/K$) which is used as material for the micro lens arrays.

![Fig. 2. Layout of FCAs for laser micro alignment](image)

3.1 Design of an actuator for fiber alignment

It has been shown that besides other possible actuator setups a three bridge actuator as illustrated in Fig. 3 is the best geometry for the fiber alignment with the laser based upsetting mechanism [4]. The fiber (9/125 µm single mode fiber) is fixed inside a mounting hole by a temperature hardening adhesive. This adhesive can withstand a maximum temperature of 350 degrees Celsius. The laser irradiation zone is on the top side of the bridges, leading to a heating of the bridge and the boundary zones due to thermal conduction. According to the basic process of thermal adjustment, the actuator contracts during cooling down and therefore the fiber is moved within the direction of this shrinking.

![Fig. 3. Single bridge actuator (upsetting mechanism)](image)

As it was shown in [4] the performance of the actuator depends on its thickness and the length of the bridges. A decreasing of the actuator thickness leads to a larger displacement on the one hand but also to a strong heating of the adhesive fixed fiber because of the smaller volume of the actuator material. With increasing actuator thickness, the gradient of the temperature from top to bottom side increases and leads to the TGM and therefore to a dumping of the actuator and the fiber. The best compromise between temperature, displacement and dumping is an actuator-thickness of 100 µm with an actuator-width of 0.15 mm but this still leads to high temperatures at the adhesive if a larger displacement is required. A solution to this problem can be found by a defined laser irradiation regime and irradiation planning. FE-simulations are useful for understanding the behavior of the actuators with different laser irradiation timings and to optimise the lateral adjustment paths.

3.2 FE-simulation of the system

With the aid of FE-simulation, realized with the software suit SYSWELD, the effect of pre-heating with a secondary applied laser pulse at an actuator on the opposite site of the mainly irradiated actuator is investigated. It has been shown that the pre-heating has a positive effect on reducing the maximum temperature at the fiber-adhesive and increasing the displacement up to 50 % compared with usual irradiation of one actuator. The diagram in Fig. 4 shows the displacement depending on the pulse regime and the power of the laser beam. In this simulation the power of the main-pulse is kept constant while the power and the impact time to point of the secondary laser relative to the main pulse is varied. In pulse regime 1 and 3 both pulses are applied with a pulse-width of 10 ms one after the other respectively starting with a secondary or primary pulse. In regime 2 both pulses impact at the same time. By reason of elastic stretch and therefore the buildup of stress strains both actuators influence each other. The displacement of the fiber can be either depressed or amplified by adeptly choosing laser impact timing and power parameters. The largest displacement of the fiber can be realized with the first pulse regime and the lower laser power of 5 W.
A power of 6 W induces plastic deformation to the secondary illuminated actuator, hence the total displacement of the mainly irradiated actuator is constrained. Further optimisation of the pulse width and laser power results in a significant improvement of the fiber displacement of approx. 50% in comparison to the starting value without pre-heating technology. With these optimised parameters the temperature at the adhesive of the fiber falls below a value of 250 degrees Celsius and a maximum displacement of approx. 0.8 µm can be realised.

Fig. 4. Dependence of the displacement on the pulse regime of the applied pulses and the laser beam power

In order to increase the adjustment distance of the fiber, multiple pulses are applied to the actuator. The logical consequence is a rising temperature. In this case the pre-heating of the secondary actuators eminently increases the temperature at the drilling but also the displacement of the fiber. With a total number of 5 laser pulses and a laser power of 12 W the displacement amounts 3 µm in comparison to less than 1 µm without the pre-heating process. Further investigations shall show the influence of a geometric modification of the actuator to constrain heat conduction and therefore high temperatures at the adhesive (Fig. 5, left).

If two laser shots with a defined laser power are applied to two of the actuators, the fiber can be moved arbitrarily in lateral direction. The displacement after the irradiation of two actuators is shown with a magnification of factor 25 in Fig. 5, right figure.

The FE-simulation demonstrates the strong influence of laser-parameters like pulse-regime and power of primary and secondary laser pulses. For the transfer of this technology to a production process a flexible laser source and beam delivery system is required. Firstly an experimental evaluation of the FE-simulation results shows the elementary functionality of the laser based micro adjustment.

3.3 Results of the laser micro adjustment

The actuator-array is manufactured by laser-micro-cutting and drilling with a Nd:YAG laser (Fig. 6, left). Before the laser adjustment process is applied, the fiber has to be assembled into the drilling of the actuator-array. For this task a mechanical stage combined with a CCD-camera and image processing unit is used. After hardening the adhesive with a heat source (Fig. 6, right) and treating the array with the common fiber-packaging steps like polishing, the fiber-actuator array is provided to the laser alignment unit.

Fig. 6. Left: Actuator-array with 10 single bridge actuators, right: fiber and actuator

The first investigations were accomplished with an experimental setup which allows an irradiation of single points of the actuator with a Nd:YAG laser. The results show the dependence of the generated displacement on the number of applied pulses and on the laser frequency. Up to now only a few tests have been carried out and so each result shown here is based only on a single experiment. Nevertheless, they can give good information about the principle behavior of the actuators. The laser frequencies used for the tests are 0.033 Hz and 50 Hz. The pulse energy (23 mJ) is chosen in such a way that 10 pulses applied with a frequency of 50 Hz will heat the bridge to a temperature slightly below the melting point. The pulse length is 3 ms. For the test series with 0.033 Hz the same bridge of one actuator is always used. In contrast to this, different actuators are irradiated with multiple pulses and a frequency of 50 Hz. The corresponding results are shown in Fig. 7. For a pulse frequency of 0.033 Hz the increase in displacement becomes smaller with an increasing number of pulses corresponding to the result of previous FE-analyses. The maximum displacement for 10 pulses is 9 µm.

Fig. 7. Dependence of the displacement on the number of applied pulses and the laser frequency

The generated displacement for 5 pulses with a frequency of 50 Hz is above 14 µm and therefore nearly twice the value of the same pulse number for 0.033 Hz.
The reasons for this are the higher maximum temperature in the irradiated bridge and moreover a heating of the complete actuator for a frequency of 50 Hz. The relatively low displacement for 10 pulses can possibly be due to the heating of the complete actuator as a quite similar behavior is shown by FE-simulations. The displacement caused by a single pulse is investigated in dependence on the temperature of the complete actuator.

The first experiments above show the functionality of the laser based process for fiber adjustment. For detailed investigation of the behavior of the actuator systems and in the face of transportation of the laser alignment process to an industrial manufacturing of fiber collimator arrays an adequate irradiation and measurement system is required.

3.4 Laser alignment and measurement setup for industrial manufacturing of FCAs

Before the laser process finishes the high accurate adjustment process other steps of assembling and pre-alignment of the fiber actuator array to the micro lens array are necessary. For this task we use an image processing unit in combination with a 4-axis alignment system. The pointing accuracy of each single channel is measured with a precise sensor (Fig. 8) which allows the reliable determination of a pointing accuracy of less than 20 µrad or expressed in fiber to micro lens movement approx. $\Delta x = 25$ nm.

Fig. 8. Determination of the fiber displacement with the help of a converging lens and quadrant diode

Light with a wavelength of 1310 nm is coupled into one of the fibers. The light divergently leaving the fiber end is collimated by the corresponding micro lens. A small displacement $\Delta x$ of the fiber causes a tilt $\sigma$ of the collimated beam. With a converging lens the angle can be transformed into a displacement after the focal length of this lens. With the help of a quadrant detector the displacement can be measured and the fiber displacement is determined.

4. Manufacturing facility for fabrication of high precision fiber optical components

As shown above the production of fiber collimator arrays requires many different processes. The individual process steps like fiber cleaving, splicing, packaging, laser alignment and quality assurance are implemented in separate modules (Fig 9). A transportation system handles the movement between the modules. The advantage of this modularity is the scalability for different requirements of micro-optical components. By implementation of clean room techniques local dust free environments are created. The benefit is the local restriction of the clean area that has a favourable effect on the total costs of production. Combining the modules, an automated or partly automated manufacturing line for high quality micro-optical and fiber optical components can be realized. Fig. 14 schematically shows an example of a production line for a fiber collimator array.

Fig. 9. Example of a platform module for manufacturing fiber optical components like FCAs

5. Conclusion

As described herein, laser induced micro adjustment is a method for precisely aligning components in the micro-optical or fiber optical domain. A great capability of the technique can be seen in the future for other areas of application as well. The industrially employed techniques for laser macro bending have been adapted by downscaling to micro dimensions in the past. The thermal adjustment has found its industrial application for example in assembling fiber optical systems. Because of the flexibility and different degrees of automation the process will see rising shares in assembly.

References


