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# Alignment procedures for micro-optics

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**Abstract.** The alignment procedure is an important step in the process chain of the assembly of micro-optical components and has a direct impact on the system performance of the micro-optical system, the necessary assembly time and the manufacturing costs. For these reasons, only alignment procedures that are adapted to the special requirements of each assembly task will be able to save costs and attain the best optical system performance. The paper describes the alignment methods and illustrates the assembly procedures based on selected micro-optical examples.

**Keywords:** alignment, assembly, micro-optics, adhesive bonding, laser beam soldering

## Alignment requirements of micro-optics assembly

The requirements of micro-optical alignment tasks are defined by the optical system design. The calculated tolerance budget describes the number of Degrees of Freedom (DOF) and the alignment accuracy. When a lens is placed into a mount, the rotational DOFs around the Rx- and Ry- Axis are defined by the mechanical stops of the mount, the z-DOF (along the optical axis) is also defined by the mount. The lens has to be centred into the mount with an accuracy of 10  $\mu\text{m}$  to 50  $\mu\text{m}$  to allow for manufacturing tolerances and the necessity of fixation with minimal mechanical stress applied to the optical parts, or to create an athermal mounting.

In comparison with a lens fixation, the DOF for the alignment of micro lens arrays often require a 6 axis alignment as a result of the mounting accuracy of the CCD chip. Using the CCD socket as the fixation base, the CCD chip can be misaligned with respect to the socket by up to 100  $\mu\text{m}$  in x- and y-direction and rotated in Rx and Ry direction by up to 200 mrad. Depending on the pixel size and the design of the micro lens array, the assembly requirements in x - and y-directions (overlay accuracy) are in a range of 0.1  $\mu\text{m}$  to 1  $\mu\text{m}$ . The micro lens array has to be rotated (Rz) against the CCD pixel lines with an accuracy of 5  $\mu\text{rad}$  to 50  $\mu\text{rad}$ . The alignment accuracy of

the fibre to fibre coupling depends on the fibre core diameter and is in the range of 1  $\mu\text{m}$  to 5  $\mu\text{m}$  using multimode fibres and 0.05 to 0.1  $\mu\text{m}$  using single mode fibres. If the fibres are also used for polarized application, the rotation around the optical axis also has to be aligned.

The alignment of the collimating lens is the most important assembly task during the manufacturing of laser diode modules. Most of the applications require a 6 DOF alignment of the lens to reach optimal focusing of the emitted beam profile with an alignment accuracy of 1  $\mu\text{m}$  to 5  $\mu\text{m}$ . Using moulded aspherical lenses, the alignment accuracy requirements can be relaxed up to 50  $\mu\text{m}$ .

The special characteristics of using micro-optical components often require adapted handling and alignment devices due to the small part geometries, the low mass and the brittle material properties.

## Alignment methods

Two basic principles for the alignment of optical- and micro-optical systems can be used, active and passive alignment. Active alignment means that the optical system properties in function are used as a feedback for closed loop control.

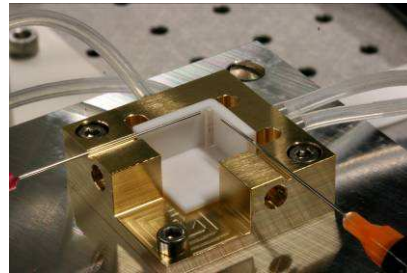
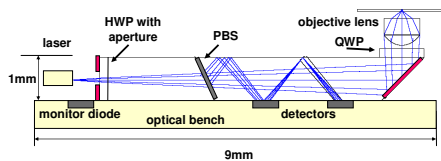
During the alignment of a focusing lens with respect to a laser diode module, the beam profile in the far field and the detected intensity of the system are the criteria for the alignment status. During fibre coupling, the factor of optical damping is used for alignment. In special cases, wave front properties are measured by wave front sensors and used as alignment criteria. The detected intensity on the pixels of a CCD sensor is used for the alignment of micro lens arrays. By a calculation of the row and line intensity, the alignment can be precisely controlled. If every pixel of the CCD sensor detects the same intensity, the alignment can be finalized.

In contrast to active alignment, a passive alignment procedure is based on the detection of geometrical properties of the components or alignment structures without any closed loop control by the optical system output. The passive alignment is done by using mechanical stops of the mount to orientate the optical components. Furthermore, the detection of outside diameter or edges of prisms is used for the alignment of micro optical parts with respect to each other. This kind of alignment is often supported by image processing for detection and calculation of the distances of the parts to each other and to the optical system. The technique of mark detection is also a passive alignment procedure. By using lithographic structured alignment marks on MEMS or MOEMS, accuracies of less than 1  $\mu\text{m}$  can be attained.

## Alignment examples

### Assembly of a blue ray DVD pickup system

The hybrid optical system (fig. 1) works at a wavelength of 407 nm. The laser source of the pickup is a blue laser diode, which is soldered on a base made of thermal conductive material for reasons of thermal management. The generated laser beam is coupled into a prism assembly, reflected by a  $90^\circ$  prism to an objective lens and focused into the optical disc. A half wave plate (HWP) with a structured aperture for stray light reduction on it rotates the polarisation at  $90^\circ$ . The reflected light is focused into an arrangement of two detectors using a polarising beam splitter (PBS) layer which is deposited onto one prism. The polarisation vector of the laser beam is rotated in a range of  $45^\circ$  two times passing the quarter wave plate (QWP). A segmented photodiode detects the high frequency data signal and can also be used for controlling the track and focus determination.



**Fig. 1.** : optical design of the DVD pickup

**Fig. 2.** : HWP/QWP assembly device

At first, the laser diode is soldered to the substrate, whereby the direction of the laser beam is given by the orientation of the gap of the laser diode. After that, the prisms are fixed by adhesive bonding at the prisms' surface on which a polarising beam splitter layer is deposited. This alignment task is done using a precise assembly device. The prisms are fixed by the assembly device; the orientation of the prisms to each other is given by mechanical stops. The prisms are fixed to each other by adhesive bonding.

An aperture is structured onto the surface of the half wave plate (HWP), which is assembled to the surface of the first prism, to define a special diameter of the optical beam. The aperture has to be aligned with an accuracy of  $\pm 25 \mu\text{m}$  perpendicular to the optical axis (x-and y-direction). The assembly step is done using a device that has mechanical stops for alignment of the HWP to the prism assembly (fig. 2). Before curing the adhesive, the alignment status is checked by image processing which calculates the distance of the aperture to the centre of the prism assembly.

The prism assembly is aligned and fixed by adhesive bonding to the optical bench in the next assembly step. The alignment of the prism assembly takes place with respect

to the optical axis (beam) given by the assembled laser diode. The prism assembly is gripped by a vacuum gripper and placed onto the optical bench. After placing onto the optical bench, the distance of the laser diode to the edge of the first prism is measured using image processing. If the calculated distance is in a range of  $20\ \mu\text{m}$  and the orientation of the prism assembly to the optical axis is in a range of  $1^\circ$ , the prism assembly can be fixed by adhesive bonding.

The next alignment step is the mounting of the lens on the prism assembly. The lens is fixed in a precisely manufactured mount prior to that and requires DOF for the x and y directions (fig. 3), using a wave front measurement as the alignment criteria. The lens is moved in x and y directions on the prism surface with a step size of  $0.1\ \mu\text{m}$ . After scanning, the lens is fixed to the prism assembly in the position of the lowest amount of wave front error. By aligning the objective lens to the laser beam, the correction of further assembly steps is possible. Finally, the assembly task for the alignment of the detector for focusing control and data analysis is very important and sophisticated as a result of the small detector geometry and the necessary contacting of the detector pads for signal analysis. The DVD pickup system is switched on during the detector alignment; the focus of the system is reflected by a moveable disc (fig. 4). Because of sinusoidal moving of the focus in the optical axis (z-direction) with an elongation of around  $50\ \mu\text{m}$ , the detected focus signal can be used for the active alignment of the detector. If the variable signals are symmetrical to the outer two detector segments, the detector is aligned.

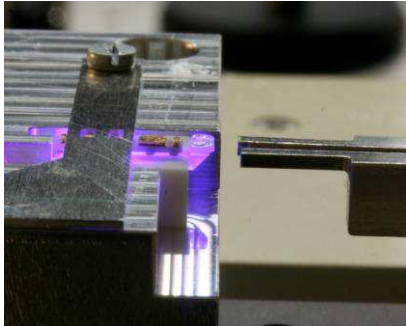


Fig. 3. Lens alignment

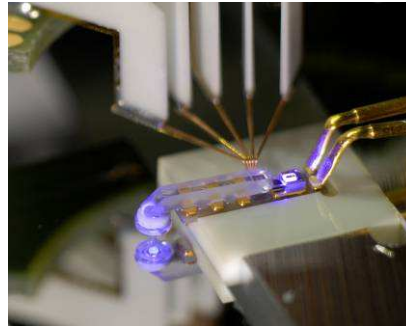


Fig. 4. Detector alignment

#### Assembly of a Micro Lens Array on a CCD sensor

The assembly and alignment of micro lens arrays (MLAs) is a necessary process step to increase the fill factor of special CCD sensors, e.g. in astronomical applications. To increase the intensity per pixel, the light of neighbored pixels is collected by a micro lens and focused onto one pixel. Linear arrangements of cylindrical lenses often collect the light of 3 or 4 pixel lines into one pixel line. Depending on the pixel size, the required alignment accuracy is less than  $1\ \mu\text{m}$  after alignment and fixation. To reach the best performance of CCD sensors and to eliminate the position tolerances of

the CCD chip mounted into a ceramic socket in this application a 6 DOF alignment is necessary to align the spots of the micro lenses to the CCD sensor pixels.

The assembly concept requires a mounted MLA that is aligned to a frame. The frame is a structured holder made of ceramic or steel with a CTE that is adapted to the CCD socket material or to the silicon substrate of the CCD. The MLA is fixed to the frame by adhesive bonding using a two component epoxy adhesive. The mechanical stops integrated into the frame guarantee a pre pre-alignment of the MLA to the frame.

The first assembly step is gripping the MLA at the frame and positioning it with respect to the CCD. By detection of the pixel intensity, the alignment in z-direction (optical axis) is the first alignment step. After that, the rotation around the x- and y-axes is aligned by detecting the homogeneity of the intensity over the whole CCD pixel array.

The alignment of the rotation of the z-axis is the next important assembly step. The summarized lines and rows intensities are calculated and used for alignment of rotation around the z-axis for the MLA against the CCD sensor. The intensities of all pixels should be in the same value along every pixel line. The final assembly step is the alignment in x- and y-direction, meaning the alignment of the focus spots into the centre of the CCD sensor pixels. By comparison of neighbouring lines, the alignment information of the overlap accuracy of focusing the micro lenses onto the sensor pixels can be derived. Alignment steps of  $0.5\ \mu\text{m}$  can be detected by the camera control software. The positioning device used for alignment is a 6 DOF hexapod. The gripper holding the MLA frame is mounted onto the moveable platform of the positioning device. The user interface allows for defining a pivot point in the centre of the MLA, so the alignment can easily be controlled.

If the alignment is done, the gap between the CCD socket and the MLA holder is filled with a two component epoxy adhesive and the MLA is fixed to the CCD socket. By using an adhesive curing for 24 h at room temperature, minimal misalignments between the MLA and the CCD frame of less than  $1\ \mu\text{m}$  was measured.



**Fig. 5.** Assembly of an MLA on a CCD sensor

### **Alignment of a Fast Axis Collimator Lens to a laser diode**

A further example for the active alignment can be given by cylindrical aspheric Fast Axis Collimator (FAC) lenses that need to be assembled in front of diode laser bars or

single laser emitters. The usage of Bottom Tabs enables for all necessary six degrees of freedom for alignment while simultaneously creating virtually zero joining gaps between FAC and Bottom tab as well as Bottom Tab and heat sink of the diode or bar, which is the assembly reference in this case. Alignment and joining of this assembly is a complex process in which four solder bumps are applied overall, inter alia at the outer geometry of the FAC lens (fig. 6). It is evident that dealignment not only occurs due to application of the solder, but also due to overall handling, alignment and joining and the mechanical and thermomechanical stress introduced in the process. After basic optimisation of the process, the results indicate that it is possible to reach a dealignment of the FAC lens in the range of  $\pm 0,5 \mu\text{m}$ .

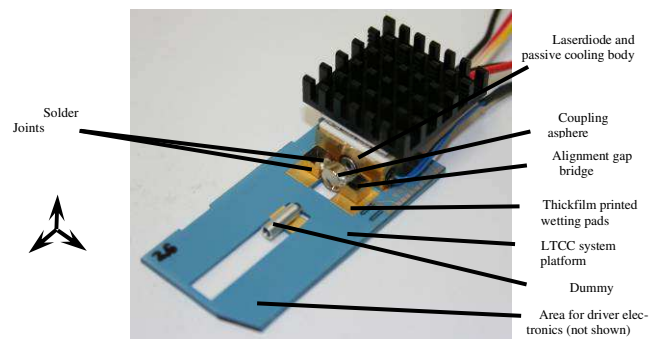


Fig. 6. : Laser diode module with fixes FAC lens

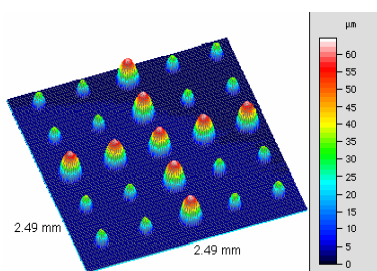
## Fixation of the alignment status

After the alignment process, the fixation of the aligned micro-optical components has to secure the alignment status over the lifetime of the optical system. The fixation can not be done by mechanical clamping, known from macro-optics, for reasons of the small geometry. The mechanical fixation elements are one or more dimensions larger than the micro-optical system. Consequently, the fixation of micro optics is done by adhesive bonding or laser soldering.

## Adhesive bonding

Joining by adhesive bonding is the most common technology for the fixation of micro-optical components. The most important properties of optical adhesives are a high transmission in the spectral region of interest and the possibility of refractive index matching to the interfacing optical materials. To reach a minimal misalignment during curing, adhesives with minimal shrinkage (about 1-2 %) and well defined drop volumes as well as a symmetric placement of the drops with respect to the optics are necessary. Adhesives based on curing by UV-radiation mechanism were used for

alignment tasks which require lengthy alignment procedures and also allow for very short process times during an automated assembly. Two component epoxy adhesives curing several hours at room temperature were used for joining components with very low mechanical and thermal stress generation during curing. These adhesives reach tensile strength up to 35 MPa and were successfully used in space applications. Due to an increasing miniaturisation of optical systems, the application of very small drops of adhesive, the realisation of well defined gaps filled with adhesive, and uniform adhesive layers between the optical elements are becoming important. The application of adhesive volumes down to the picolitre range can be realised using a micro-drop dosage system (figure 7).



Volumes: 6pl and 120 pl  
**Fig. 7.** Array of adhesive drops



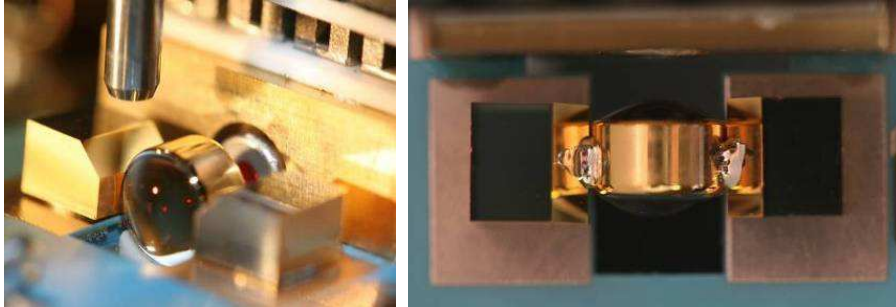
**Fig. 8.** : Adhesive gap of <math>< 3 \mu\text{m}</math>

The application of spherical spacer elements to the adhesive layer (micro pearls) can be used to obtain well defined gap geometries in the  $\mu\text{m}$ -range (figure 8). The well-known limitations of adhesives are operating temperatures lower than  $120^\circ\text{C}$ , long term stability, yellowing and poor environmental humidity resistance.

### Laser beam soldering

To reach higher thermal and mechanical stabilities and to eliminate aging effects of the polymer adhesives, a soldering technology alternative has been adapted to micro-optical assembly. To use the soldering technology in optics, a metallisation of the optical components is necessary. A coating technology for the metallisation of optics and for depositing AuSn solder layers directly onto the optical components was developed and investigated /2/.





**Fig. 9.** : Lens soldered by solder ball bumping (front and top view)

The solder ball bumping technology known from micro-electronics was successfully integrated into the micro-optical assembly process chain.

A misalignment during and after fixation by solder ball bumping in a range of less than  $0.2\ \mu\text{m}$  was attained /3, 4/.

## Conclusion

The aspects of alignment and assembly of micro-optics were illustrated by examples using the active and passive alignment procedures. Using different fixation technologies, the alignment status can be secured with an accuracy of less than  $1\ \mu\text{m}$ . The handling devices and the environment condition have to be adapted to the special requirements of micro-optic alignment.

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