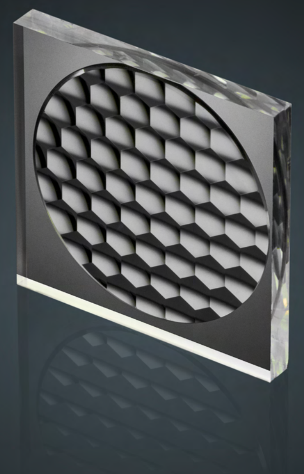


Efficient and precise production of microlens arrays using precision glass molding

Microlens arrays combine a large number of individual lenses in a well-defined arrangement on a substrate.

Depending on the application,
the lenses can have very different shapes and sizes. Spherical, aspheric, or cylindrical surfaces are often used. The shape of the microlenses can be round, rectangular, or hexagonal, among others. Microlens arrays can be used in many ways. Important examples of applications are the beam shaping of LED and laser sources, in measurement technology or for coupling light into fibers, e.g. in the datacom sector.

1. Applications

Microlens arrays will play a key role in fibre-optic data transmission in the future

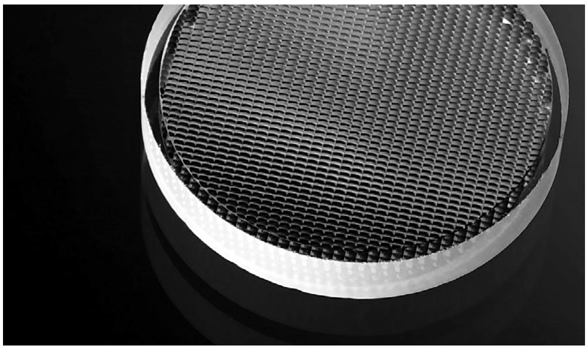
The number of possible applications is large, corresponding to the variety of design options that can be manufactured. The most important of these are highlighted here.

An arrangement of rectangular or hexagonal microlenses arranged on both sides, which fill the entire surface of a lens array with the smallest possible gaps, can be used for the homogeneous illumination of surfaces. In addition to the lens array, a collimating lens is required, which is arranged behind it in the beam path. The incoming light can have any intensity distribution and is divided into different channels by the lens array, which are superimposed by the collimating lens. This allows an area whose shape corresponds to that of the individual lenses to be illuminated homogeneously.

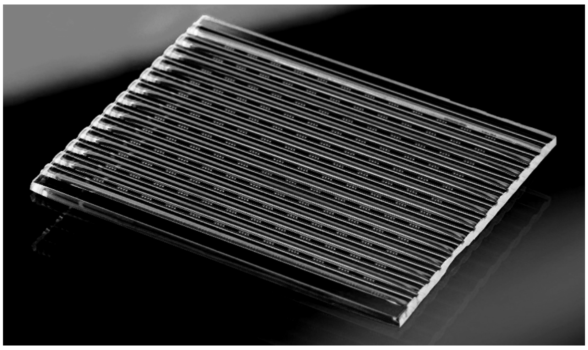
Microlens arrays play an important role in fiber optic data transmission, especially in the coupling of light from fibers into photonic integrated circuits. With their help, the efficiency of transmission can be significantly increased. Microlens arrays are an interesting alternative to the use of individual lenses, as they considerably reduce the effort required for alignment. To further simplify assembly, alignment elements can be integrated together with the lenses.

The focal length of the lenses is usually small and is in the range of a few 100 µm, which corresponds to a radius of curvature in the range between 150 and 250 µm, depending on the glass selected.

Another important area of application for microlens arrays is Shack-Hartmann sensors. These are used to measure the wavefront to determine the quality of optical components. The incident wavefront hits a microlens array and is split according to the arrangement of the individual lenses and focused into a grid of points on a CCD chip. The wavefront can be calculated from the position of the individual points. An important application of acylindrical lens arrays is the collimation of diode laser arrays. Diode lasers emit light with a strongly elliptical profile. The so-called fast axis is collimated with a highly apertured acylindrical collimating lens (FAC). Behind this, a slow-axis collimator array (SAC) can be used to collimate the individual lasers in the direction perpendicular to the fast axis.



Double-sided lens array for homogeneous illumination of a rectangle using an LED



Lens array for datacom applications. The array consists of 576 individual lenses with a radius of curvature of 180 µm.

2. Precision glass molding of microlens arrays

Microlens arrays with a positioning accuracy of < 1 µm

Precision glass molding is a manufacturing process for the production of high-precision optical components and is used for a long time for the production of aspherical lenses.

Compared to other manufacturing processes, it offers considerable cost advantages, especially for mass production. Further developments in the area of molding processes and tool manufacture in recent years have significantly expanded the possible applications.

This allows GD Optics to produce microlens arrays with a positioning accuracy of 1 < µm. Polished glass blanks are used as the starting material for precision glass molding, which are formed into the desired shape while hot. In the case of lens arrays, polished glass wafers are used. The glass blanks are inserted into the molding tools in a cold state and heated together with them. The glass is brought to a temperature above the glass transition temperature and is then in a soft but not yet liquid state with a viscosity in the range of 10^7 to 10^8 Pa·s. For the different types of glass that can be used, the temperatures required for this are generally in the range between 450°C and 700°C.

Depending on the application, the process time is between 10 and 30 minutes. Due to the comparatively high cooling rates required, the refractive index of the glass components produced is in the range $\sim 3 \cdot 10^{-6}$ below the value specified by the glass manufacturers in their catalogs.

Precision molding is carried out in a controlled atmosphere in a vacuum chamber. This prevents gas inclusions and extends tool life. Precise control of the force curve during molding and good control of the glass temperature are crucial for the quality of the microlens arrays produced. Quality characteristics that are largely determined by the molding process are the flatness, the center thickness and the distance between the individual lenses of the array.

A wide range of materials from different glass manufacturers is available for precision molding. The glasses have a low transition temperature compared to many other optical glasses, which is advantageous for the accuracy and efficiency of the process. With the available materials, a wide range of refractive index and dispersion as well as transmission properties for different wavelengths can be covered.

Maximum quality and cost-effectiveness

Precision glass molding offers a high degree of reproducibility and enables significant cost advantages over lithographic production. Once the molds are ready, it enables short reaction times regardless of the quantity required.

3. Mold Manufacturing

Our high-quality material selection is crucial for maximum quality

In order to withstand contact with hot glass, the molds for precision molding must have high chemical resistance and temperature stability. The choice of suitable materials is therefore very important.

The materials should have high mechanical stability and wear resistance as well as a suitable coefficient of thermal expansion. Suitable materials such as carbides are hard and brittle and can generally only be machined by grinding. The requirements for the surface quality of the molds correspond to those of the lens arrays, as the process does not result in any smoothing.

Machining is carried out using specially developed grinding processes on so-called ultra-precision machines using diamond grinding tools. These machines are extremely rigid and have straightness and perpendicularity of the axes in the nanometer range.

In conventional grinding processes, the material is removed by breaking off small fragments. The resulting cracks propagate in the remaining material as subsurface damage. If each individual diamond grain of the grinding tool only removes a very small amount of material, even otherwise brittle materials behave in a ductile manner. The range of ductile grinding can only be achieved with very low-vibration processes and very precise machines.

Surfaces ground in this way achieve the quality required for optical applications. In some cases, polishing can further improve the surface quality. However, this only needs to remove a few nanometers due to the lack of subsurface damage.

After grinding and cleaning, the tools are coated with an anti-adhesive film to prevent the glass from sticking to the mold during the molding process.

4. Optical Properties and Manufacturing Possibilities

We fulfil the requirements for precise process control

Microlens arrays can be manufactured with very different properties depending on the application. The focal length of lens arrays can vary over a very wide range.

For fiber coupling and diode laser collimation, focal lengths in the range of a few hundred micrometers are sometimes required. Depending on the refractive index of the material used, the required radii of curvature of the lenses can be less than 150 µm.

For many applications, it is very important that the individual lenses are as evenly spaced as possible. As shaping in precision molding takes place at temperatures of several hundred degrees and the expansion coefficients of the lenses and the tool material are different, meeting this requirement is a particular challenge. Precise process control makes it possible to achieve positional deviations of the individual lenses of less than one micrometer over a length of 10 mm.

The table below lists further parameters for the description of microlens arrays as well as values and tolerances currently achievable with precision molding.

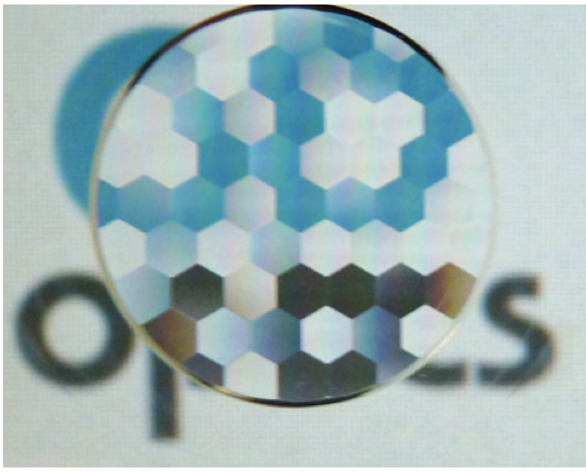
	Lowest Value	Highest Value	Tolerance
Size in mm	1	45	0.02
Radius of curvature in mm	0.15	30	< 1 %
Effective focal lenght in mm	0.22	20	< 1 %
Lenslet size in mm	0.05	10	
Pitch in mm	0,05	10	< 1 µm über 10
Number of lenses	4	3,000	
Precision in nm	150		
Size of „dead“ zones in µm	< 10		
Offset front to back	+/-0.01		

Low material waste compared to conventional manufacturing processes

Precision glass molding for microlens arrays offers high reproducibility, enabling mass production with consistent optical performance.

The process allows for the creation of complex and customized lens shapes with micron-level precision, leading to improved optical functionality.

Additionally, it is a cost-effective method, as it minimizes the need for post-processing steps and reduces material waste compared to traditional manufacturing techniques.



Hexagonal lens array with high fill factor

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