Beyond measurable precision

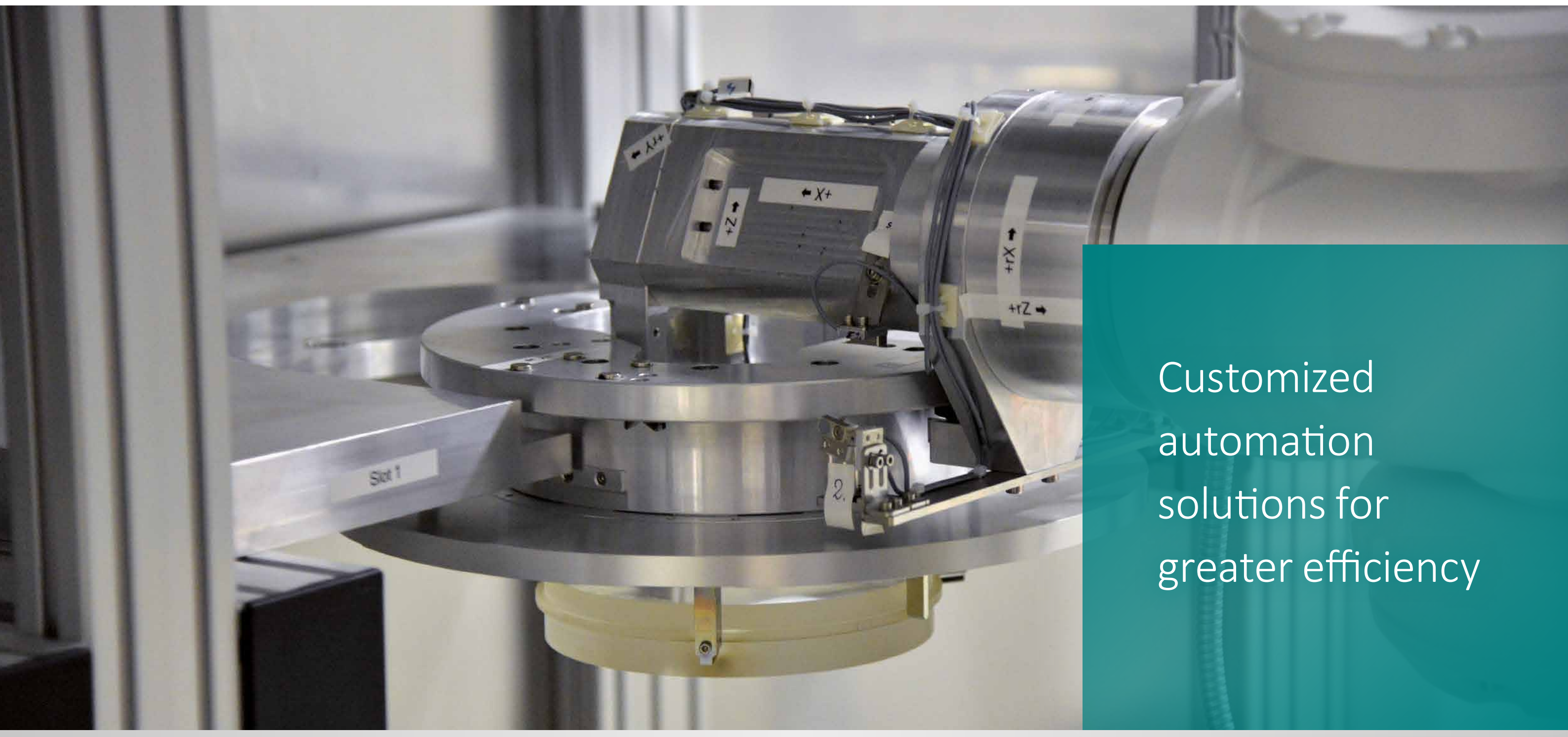
Ion beam figuring

Technology, systems, results

Cutting-edge technology in a vacuum for demanding surface quality requirements

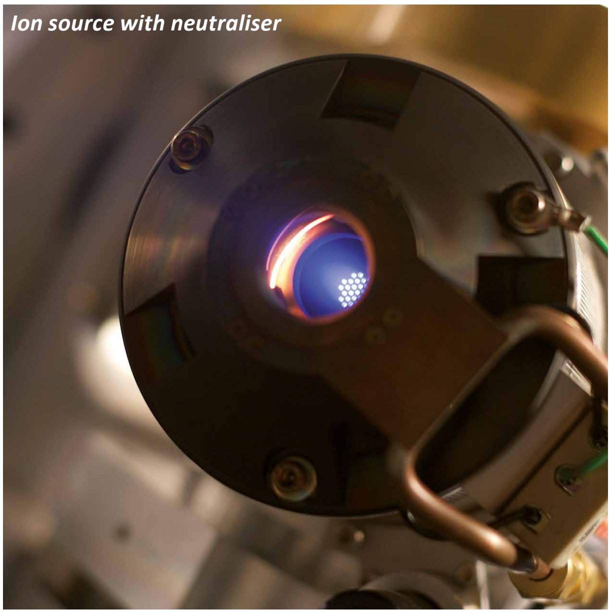
Quelle: Pixabay / Wikiimages

Excellent surface qualities for all kinds of applications – from space, nanotechnology and reflector telescopes to semi-conductors, research and industry



Customized automation solutions for greater efficiency

Precision – Set your own limits



Ion source with neutraliser

Optical systems need to be ever more precise, lasers and high-performance optics ever more powerful, and highly integrated circuits ever more compact. In areas like these, it has long been necessary to achieve geometric deviations and surface roughness levels in the nanometer range. This is difficult enough on flat or curved surfaces, let alone on freeform surfaces such as aspherical objects.

Ion beam figuring (IBF) is the answer to both these challenges and those of the future. The only limits to the precision of this technology are physics and parameters like the diameter of an atom. Neither tools nor a single drop of polish come into contact with the processed surface, just a beam of argon atoms. Accelerated to around 250,000 km/h, this beam hits the workpiece and leads to a microscopic sputtering effect. The process resembles sand blasting with atoms and adjustable intensity, without leaving a single unwanted trace on the surface.

At OPTEG, we have been researching, developing and working with this technology for over 15 years. Our products are the solution of choice for leading players in the optics industry and renowned research institutes. We maintain systems all over the world.

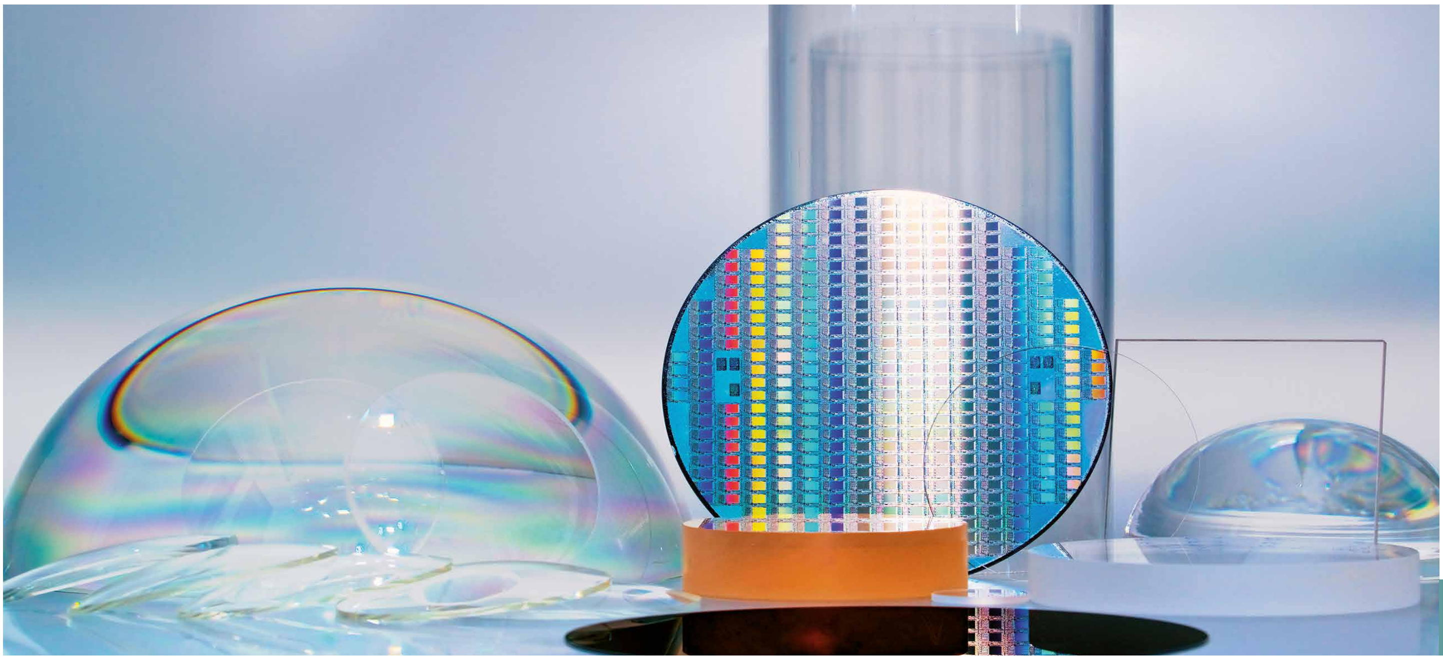
Dive into the world of accelerated ions and experience precision, for which you set the limits. Whether your production comes down to the micrometer or nanometer, we can help you achieve stable and reproducible values.

Our scientists, engineers and technicians look forward to helping you with your challenge. We think beyond limits, both in processes and as a company.

What limits can we help you overcome?

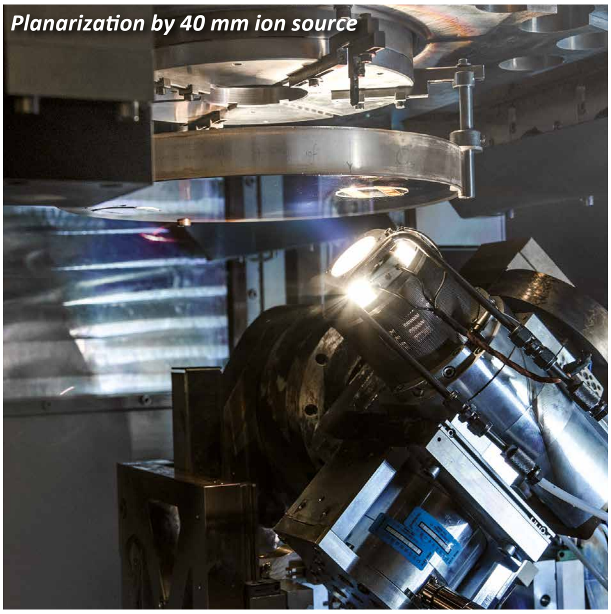
Kind regards,

Dr. Steffen Gürtler
Managing Director

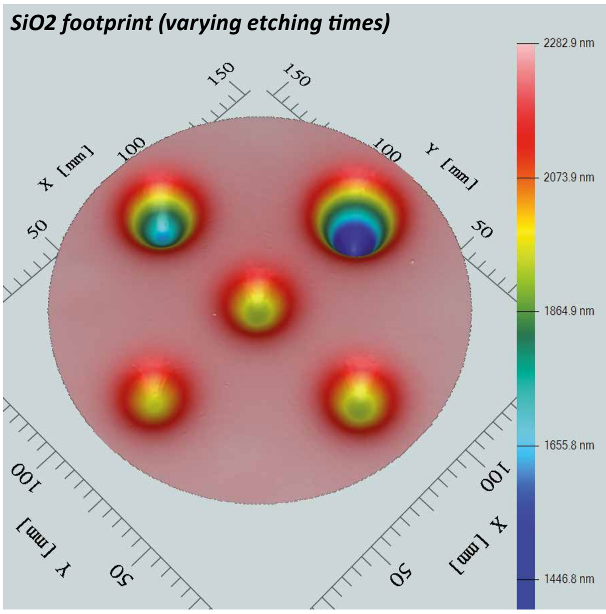


Like sand blasting with atoms – What exactly is ion beam figuring?

OMF 1200



Planarization by 40 mm ion source



SiO2 footprint (varying etching times)

Ion beam figuring makes it possible to correct even the tiniest errors on a surface. It is also known as corrective polishing. Ion beam figuring (IBF) can achieve depth precisions of a few nanometers and local resolutions in the sub-millimeter range. The high level of possible precision makes ion beam figuring an excellent final processing step. Depending on the product and technology, this step may be followed by further coating processes for optical surfaces.

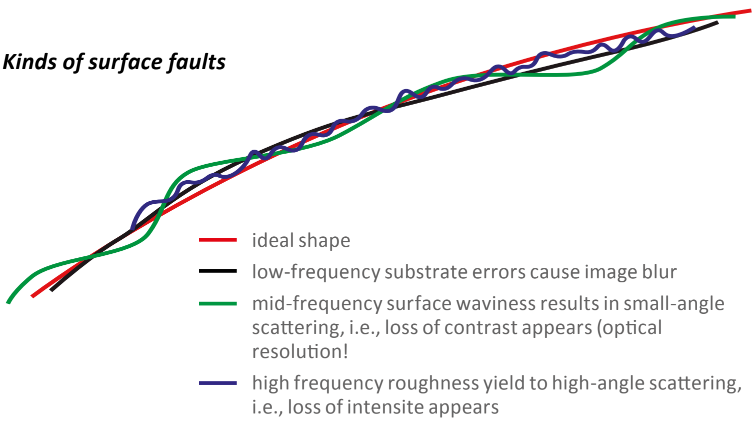
Contactless polishing under vacuum, even beyond the edge

IBF is a contactless process, making it perfect for optical production. Accelerated argon atoms ablate minuscule particles on the surface of the workpiece. The intensity of the ablation is controlled via the dwell time at the affected position on the workpiece (dwell time method). Errors during processing therefore have much less influence on the resulting surface. The roughness value of the surface remains unchanged for most materials. In some cases, such as quartz glass and silicon, it can even be improved. Another advantage of IBF is that it can process workpieces even beyond the edge. This is especially practical when processing optical lenses or mirrors, and increases the clear aperture. Furthermore, the process does not cause any new damage to the surface.

Varying ion beam diameters for perfect results

Ion beam figuring takes place under a vacuum. This means that the processed materials must be vacuum compatible. At the start of the process, the size of the error to be corrected is determined via an interferometric measurement. The correct beam diameter is then chosen, depending on the size of the error and therefore that of the material to be ablated. The diameter of the ion beam source is adjusted using diaphragms set in front of the source, or by using a different beam source diameter. The smaller the error in lateral resolution, the smaller the beam has to be. The process first corrects the low-frequency errors with the larger beam diameter, before gradually working towards the high-frequency errors with the smaller ion beam.

Kinds of surface faults



Step by step to maximum surface quality

Once the program has ended, the sample is removed from the machine and the load lock is opened. This is followed by another interferometric measurement. The iterative process that follows gradually improves the surface quality in every pass until the desired quality requirements are met. The finer the level of figuring required on the surfaces, the smaller the diaphragms in front of the ion source need to be.

Accelerating the process – Changing diaphragms on the ion source within the vacuum chamber

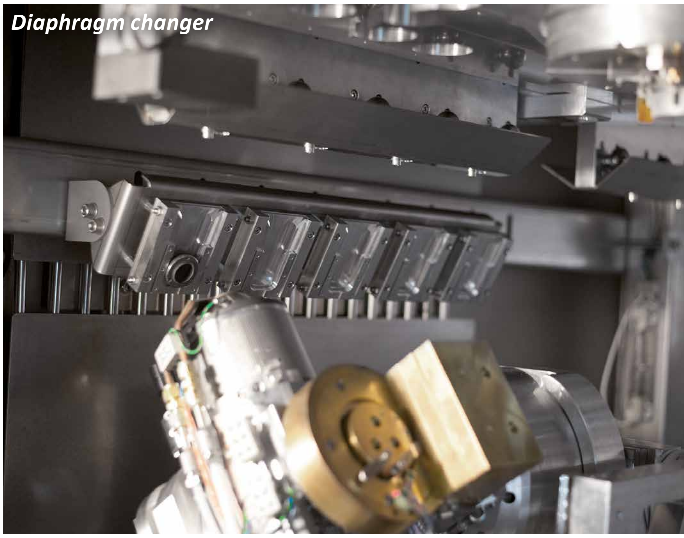
OPTEG developed a system for changing the diaphragms on the ion source within the chamber. This helps further optimize the process and reduces processing time. The system is able to replace an 8-mm diaphragm with a 4-mm diaphragm for the next process, for example, without breaking the vacuum.

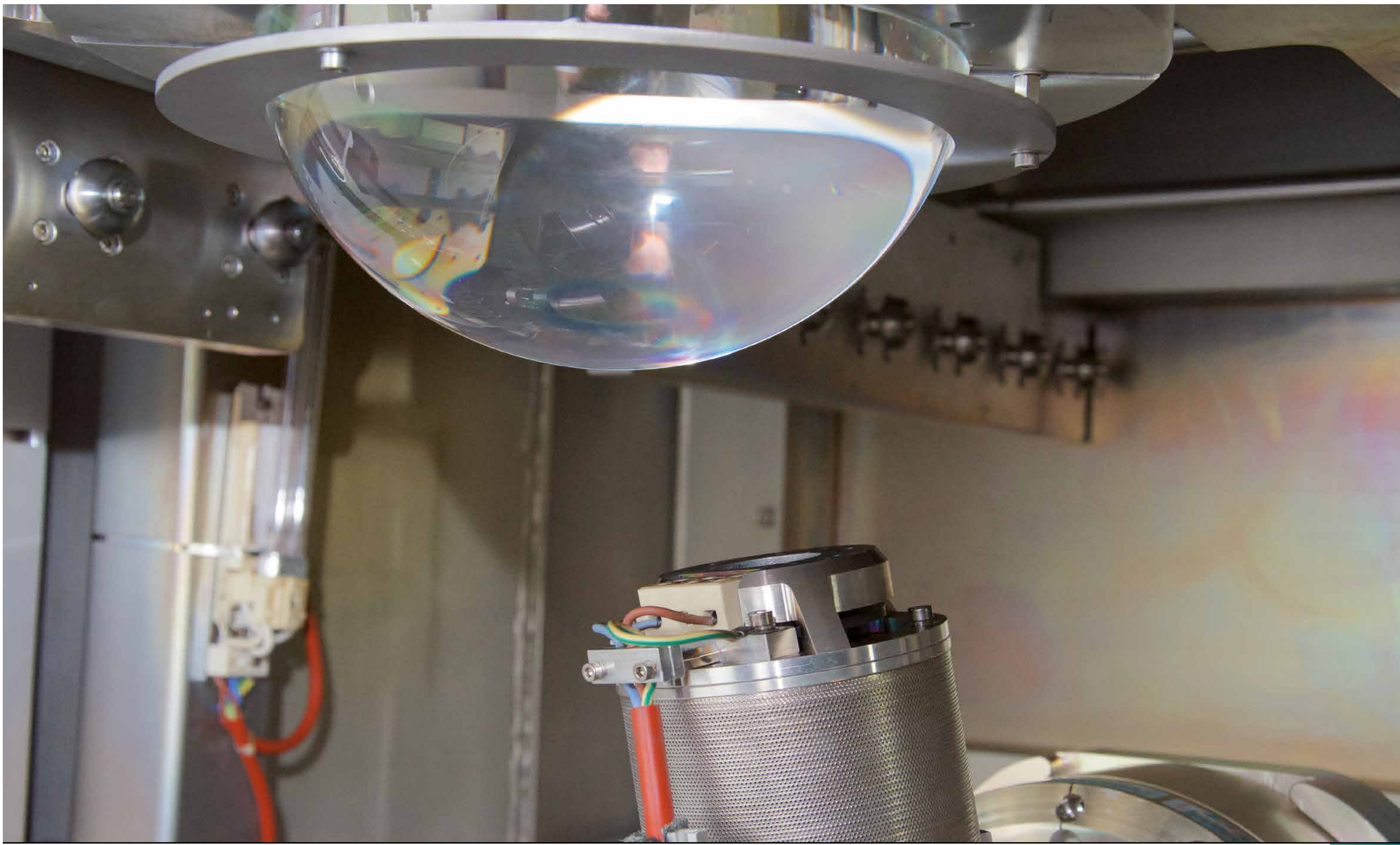
Further innovation – Live etching rate calculation

Our new live etching rate device can be used to determine etching rates without having to process an additional test sample of the same material. This removes the need to insert, process, remove and measure a dummy sample to determine the etching rate. The innovative add-on module can perform this task inside the vacuum chamber, comparable to a Faraday scan. This significantly reduces the preparation time.

Inserting in load lock

Diaphragm changer





Ion beam figuring compared to other technologies

MRF polishing

MRF stands for magneto-rheological finishing. This process uses a magnetic polishing medium on 3 or 4-axis CNC machines to correct tiny errors. Ablation results from the relative movement between the workpiece and a viscous polishing fluid. This fluid consists of deionized water, a polishing medium, and iron powder. This makes it possible to manipulate the fluid using a magnetic field.

This process is also preceded by an interferometric measurement to provide an interferogram. The deviations are calculated as a CNC path before being processed.

This process is technologically unsuitable for water-soluble materials. Each correction also leaves unwanted structures on the workpiece.

Setting up a process to achieve λ/30, for example, is already demanding. But it becomes even more difficult and expensive when processing aspherical surfaces. Both the investment costs for the machine and the running costs for the fluid are very high.

Camera lens

Quelle: Pixabay / tookapic

Computer-controlled polishing (CCP)

In computer-controlled polishing, CNC machines or robots work with small zonal tools. Ablation results from the relative movement between the rotating polishing tool and the workpiece. A polishing slurry is also added. The process is controlled via the dwell time.

In this technology, not only do the fluid and abrasive particles come into contact with the workpiece, but also the polishing tool. This places enormous demands on the motion system.

Despite this, the level of achievable precision is limited. Even λ/20 requires a very high investment.

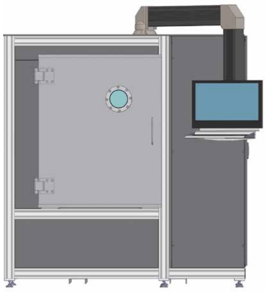
Space telescope mirror

Quelle: Pixabay / skeeze

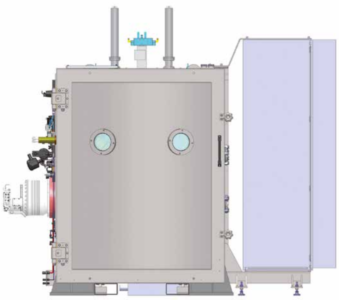
The OMF series – Ultraprecision as standard

Technical data

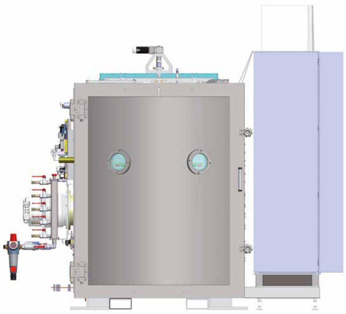
Model	OMF 200	OMF 450	OMF 600	OMF 800	OMF 1200
Directly driven axes	6	6	6	6	6
Max. diameter of flat samples	200 mm	450 mm	600 mm	800 mm	1200 mm
Diameter of other samples	Depends on curvature radius, an additional seventh axis expands the possible workpiece diameter (optionally available)				
Max. thickness	200 mm	200 mm	200 mm	200 mm	200 mm
Max. weight	35 kg	35 kg	100 kg	100 kg	200 kg



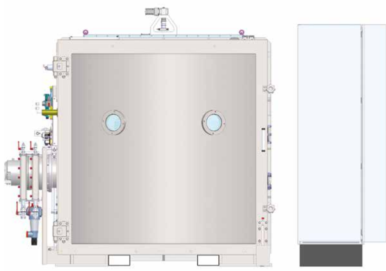
OMF 200



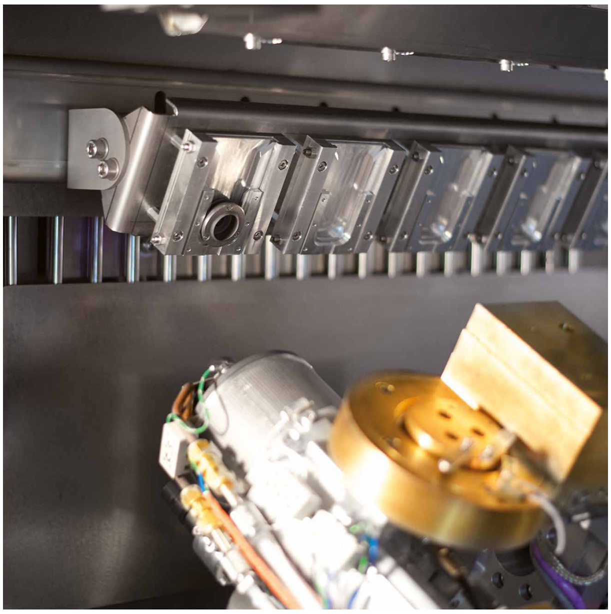
OMF 450

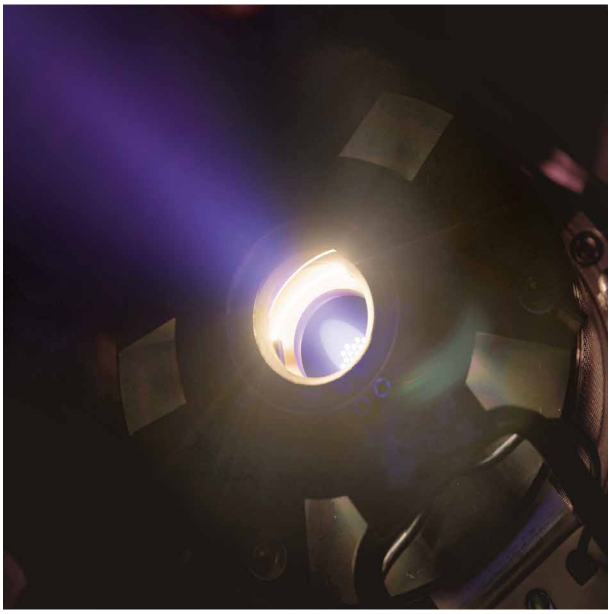


OMF 600



OMF 1200





The OMF series

Outstanding benefits:

- Surface qualities of λ/200 and greater are possible (depending on measurement system)
- Starting precision of one lambda @633 nm is sufficient
- Each machine is fitted with a 6-axis direct drive system, so that the ion source is always at a right angle (orthogonal) to the workpiece surface
- Processable shapes include: flat, spherical, aspherical, freeform, off-axis aspherical, acylinders, prisms, axicons, and others upon request
- Processing across the entire surface up to and beyond the edge
- All processing movements (meandering, spiral shaped, freeform, etc.) are possible, without changing the machine set-up
- All mono-crystalline, amorphous and metallic materials can be processed.
  Examples: all kinds of optical glasses, quartz glass, Zerodur, ULE, KDP, sapphire, Si, SiC, Ge, etc.
- Completely stable processes with high reproducibility
- Each machine has a main chamber and a load lock for faster workpiece changeover
- Automatic integrated diaphragm changer for various ion beam diameters of 0.5 to 20 mm (optionally available)
- Fully automated proces, iterative process workflow, without workpiece measurement between processes with different diaphragm apertures. Process expansion with robots and placing systems for fully automated processing of multiple and different workpieces (optionally available)
- Real-time measurement system for determining the ion beam etching rate within seconds, without the need for a separate workpiece sample (optionally available)
- Low operating costs and maintenance requirements

Options and additional functions

Options

Upgrade option 1 **Load lock system**	Load lock system, consisting of one BUSCH dry vacuum pump and an additional COBRA DP250A pump with 220m³/h of pumping capacity
Upgrade option 2 **Load lock system**	Load lock system, consisting of two BUSCH dry vacuum pumps and an additional COBRA DP250A pump with 220m³/h of pumping capacity separately for the load lock and the main chamber
Additional turbomolecular pump	Additional Pfeiffer vacuum turbomolecular pump with 1,900 l/s of pumping capacity for improved vacuum
Meissner trap	Additional Meissner trap with >0.5 m² surface for significantly quicker vacuum generation in the main chamber for high-efficiency processing
Shut-off valve for turbomolecular pumps	Increases vacuum purity and protects the turbomolecular pumps against contamination when system is vented. Using two turbo molecular pumps and a two-way valve allows one pump to be replaced without breaking the vacuum.

Additional functions

7th axis	Enables processing of larger diameters with pronounced curvature, maximum diameter upon request
Diaphragm changer	Enables the diaphragm for the ion beam source to be changed during operation (in the vacuum chamber), maximum of five diaphragms, all measuring 0.5 to 20 mm in diameter
Real-time etching rate measurement	Measurement system based on low-coherence technology for determining the etching rate of the ion source. Determines the etching rate within seconds to within +/- 0.1 nm/s. Includes an interchangeable sample holder for various materials. Multiple measurements possible with single measuring head
Calibration camera	Enables set-up and calibration of new workpieces without footprint or test etching

Additives for coating processes	Smoothing technology package, consisting of an additional coating unit with a target (e.g. silicone), for coating and etching with different materials
UPS system	Uninterruptible power supply (UPS) for the machine for ion beam figuring, remote control via the power supply network (powerline), with reporting function on a graphic user interface and automatic shut-down.

Control and automation

Manual control and loading system	Manual control system for loading and unloading the machine via a load lock
Robot and workpiece magazine package [1]	Process expansion package with robot and workpiece magazine for fully automated processing of multiple and varying samples, with automatic sample loading and unloading. Enables processing of multiple samples in succession with no human intervention. Range of robot systems available depending on workpiece size and weight

[1] Model OMF 450 requires a larger load lock for robot.

Ion beam figuring on various materials – What you can achieve

Here you can see a series of before-and-after images of materials whose surfaces were processed with one of our OMF machines. What does this tell us?

From a technical perspective, using ion beam figuring can be worthwhile from micrometer-level peak to valley values (PV). Three-digit nanometer values are possible after just one iteration. Precision can be increased as much as the customer or application requires.

The number of necessary iterations depends not on the material, but on the type of surface error. Low-frequency errors can be corrected quickly and easily with a large ion beam. The smaller the error, the smaller the beam needs to be.

Thanks to the highly automated process, the number of iterations is rarely a significant factor. In any case, the variable size of the accelerated ion beam means you can polish more precisely than ever before. This also applies to water-soluble substances. See the results for yourself. Or get in touch and organize a test polishing! We love a challenge.

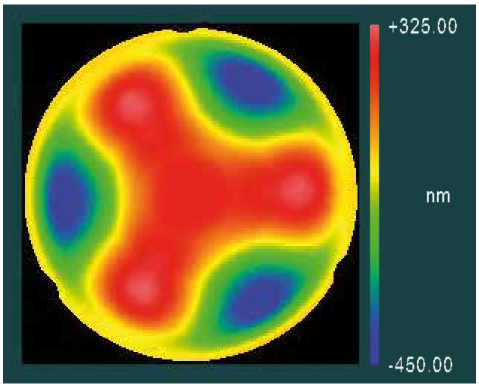
The results behind the numbers and images

The samples presented here were measured interferometrically. The example „Material: BK7" used a flat sample. Notice the striking geometry (Zernike polynomial) of the workpiece surface before polishing. The symmetrical geometries are not coincidental, but were incorporated into the surface on purpose to test the IBF technology. After just two iterations, the PV value was reduced to a seventh of its original level. Quadratic roughness fell by a factor of around 20. The measuring device software had to adjust the scale to the right of the image just to make the remaining surface errors visible. A better correction would require further iterations with a narrower beam diameter.

Material: BK7

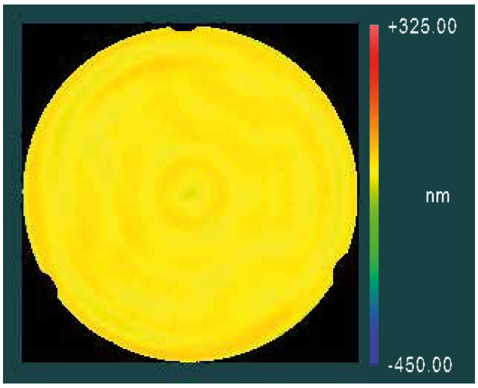
Workpiece properties: flat, ø 70 mm

Before IBF:

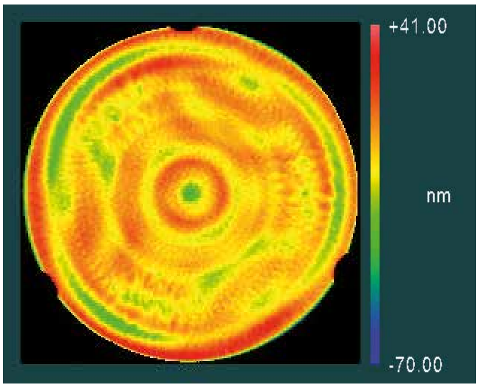


PV	768.261 nm
rms	193.161 nm
Power	-289.192 nm
Re	157.57 nm

Final Figure: 2 Iterations, 7x times better PV, 19,5x times better rms



PV	108.977 nm
rms	9.912 nm
Power	1.555 nm
Ra	7.57 nm

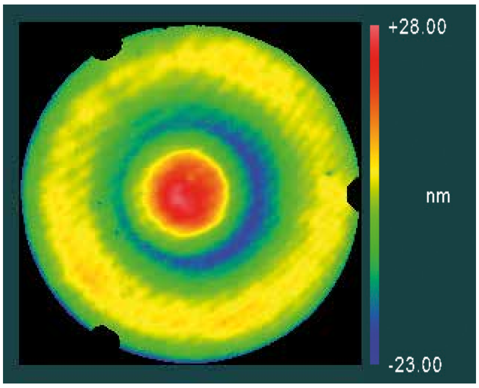


PV	108.977 nm
rms	9.912 nm
Power	1.555 nm
Ra	7.57 nm

Material: SiC

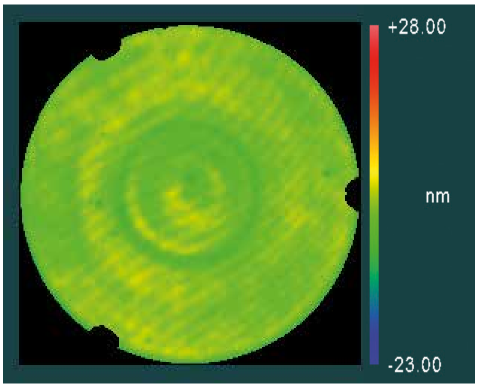
Workpiece properties: flat, ø 100 mm

Before IBF:

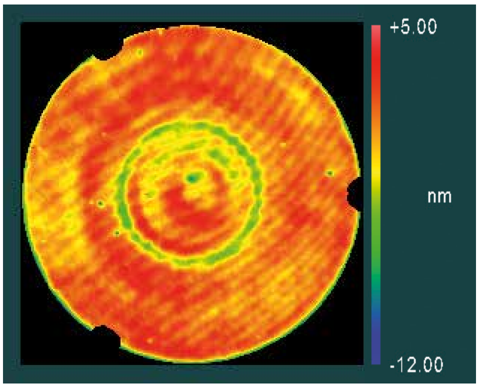


PV	50.601 nm
rms	7.730 nm
Power	1.180 nm
Re	6.10 nm

Final Figure:



PV	16.115 nm
rms	1.765 nm
Power	0.532 nm
Ra	1.34 nm



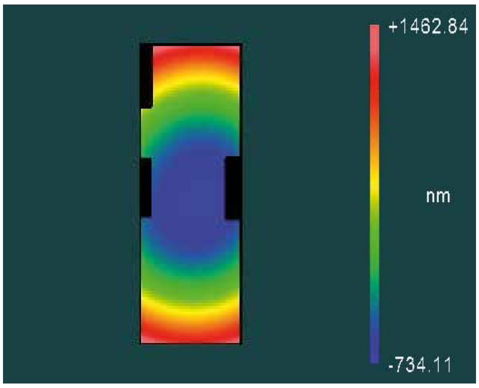
PV	16.115 nm
rms	1.765 nm
Power	0.532 nm
Ra	1.34 nm

Take a look at the sample „Material: Nd:YAG“ (neodymium-doped yttrium aluminum garnet, as used for solid-state lasers). The starting PV value was around 2.2 micrometers. After just one iteration, this fell to 415 nanometers. Using the starting sample scale, it would not be possible to detect any further surface deviation. Only when we „zoom“ in by a factor of 5 (top row, right image), can we still see the tiny deviations.

Material: Nd:YAG

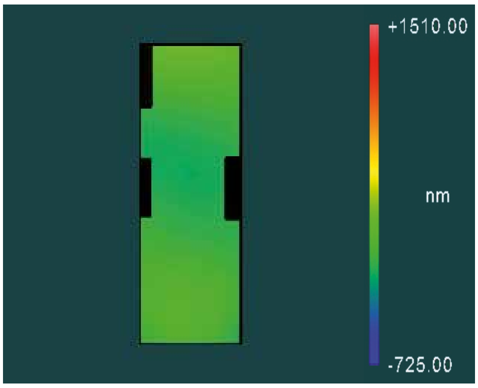
Workpiece properties: flat, 30 x 90 mm

Before IBF:

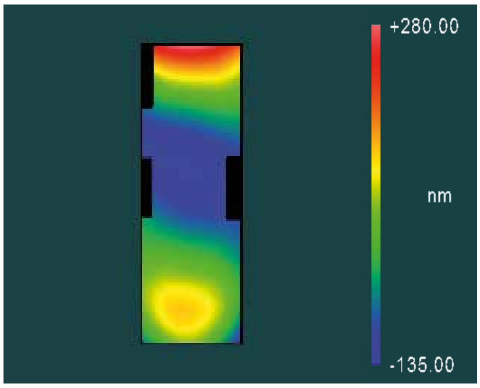


PV 2196.946 nm
rms 569.823 nm
Power 2123.206 nm
Re 485.53 nm

1 Iteration: 5x times better PV, 6x times better rms



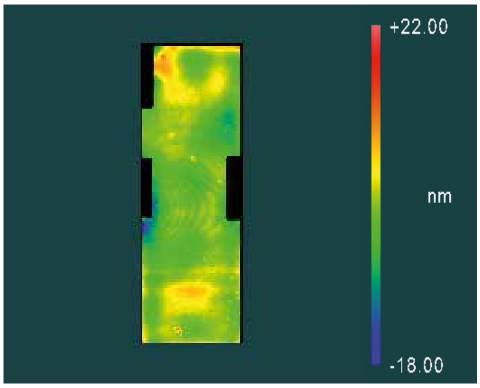
PV 414.582 nm
rms 94.546 nm
Power 285.093 nm
Ra 79.89 nm



PV 414.582 nm
rms 94.546 nm
Power 285.093 nm
Ra 79.89 nm

Final Figure: after 5 Iterations, 55x times better PV, 190x times better rms

PV 39.934 nm
rms 3.251 nm
Power 5.263 nm
Ra 2.43 nm



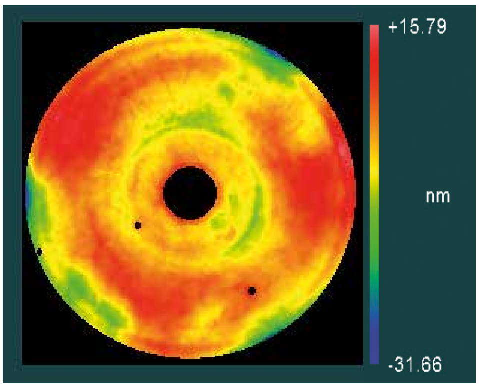
PV 39.934 nm
rms 3.251 nm
Power 5.263 nm
Ra 2.43 nm

The two bottom images show that it is possible to achieve a PV value in the two-digit nanometer range after four more iterations. The image on the left was recorded at the original sensitivity level, while the image on the right was recorded after zooming. This means that with just five iterations, the OMF system improved surface quality by a factor of 55.

Material: SiO_2

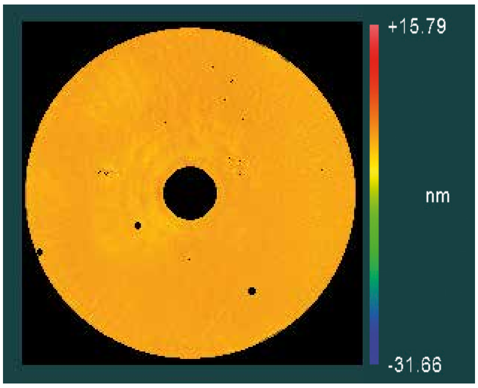
Workpiece properties: concave, ø 200 mm, radius of curvature 339,28 mm

Before IBF:

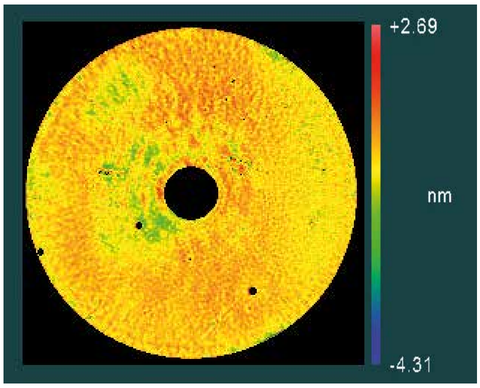


PV	47.448 nm
rms	5.900 nm
Power	-8.914 nm
Re	4.67 nm

Final Figure:



PV	7.003 nm
rms	0.388 nm
Power	-48.274 nm
Ra	0.30 nm

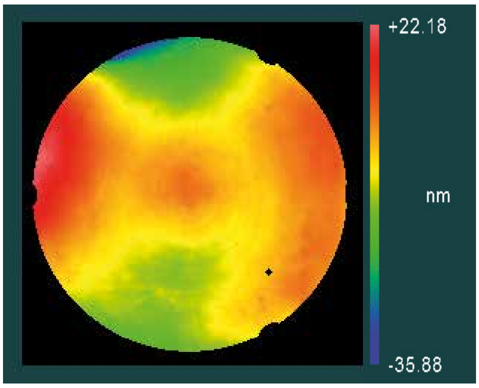


PV	7.003 nm
rms	0.388 nm
Power	-48.274 nm
Ra	0.30 nm

Material: ULE

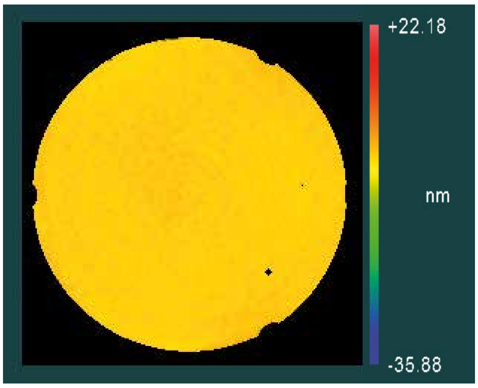
Workpiece properties: flat, ø 100 mm

Before IBF:

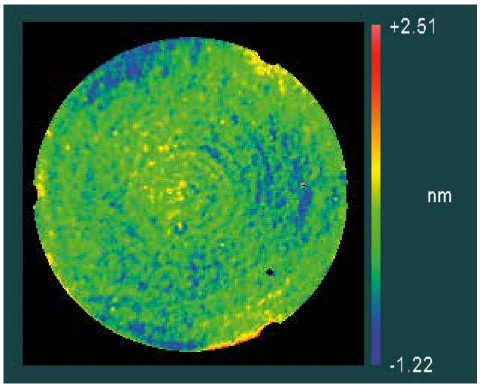


PV	58.063 nm
rms	7.566 nm
Power	-3.518 nm
Re	5.79 nm

Final Figure:



PV	3.730 nm
rms	0.331 nm
Power	-16.875 nm
Ra	0.26 nm

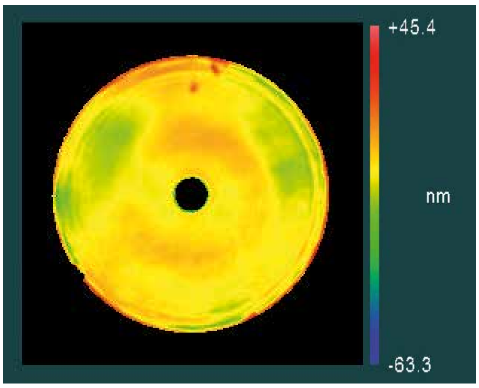


PV	3.730 nm
rms	0.331 nm
Power	-16.875 nm
Ra	0.26 nm

Material: Zerodur

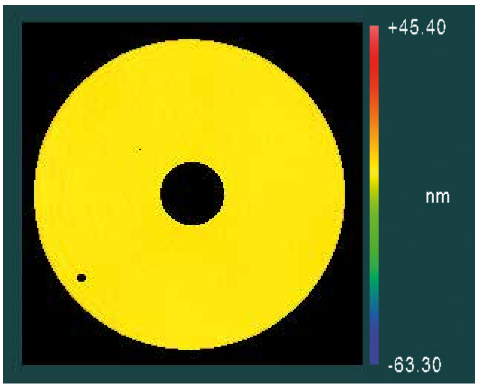
Workpiece properties: concave, ø 200 mm, radius of curvature 339,28 mm

Before IBF:

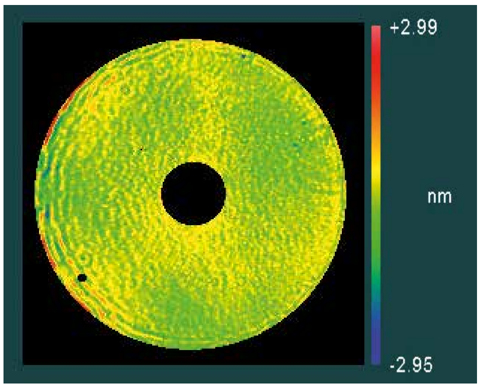


PV	89.914 nm
rms	5.774 nm
Power	-121.690 nm
Re	4.15 nm

Final Figure:



PV	5.946 nm
rms	0.352 nm
Power	0.018 nm
Ra	0.25 nm



PV	5.946 nm
rms	0.352 nm
Power	0.018 nm
Ra	0.25 nm

Ideas and expertise for the products of the future

OPTEG was founded in Leipzig, Germany in 2001 by Dr. Steffen Gürtler, Dr. Reinhard Schwabe, Dr. Axel Schindler and Dr. Volker Gottschalch. They played a major role in both developing ion beam figuring technology and making it ready for market. Today, the company employs 16 people, 14 of whom work in research and development. OPTEG systems are used in Germany, the Czech Republic, the USA, Japan, South Korea and China. This has made OPTEG one of the world's leading providers of ion beam machinery for ultra-precise shaping of optical materials.

Awards for smart solutions and outstanding technology

Our machines for ion beam figuring and plasma-assisted chemical etching of precise optical materials were honored with awards at the INTEC international specialist trade fair in 2008 and 2009. In 2015, OPTEG successfully developed the world's first automatic, robot-controlled loading and unloading system for ion beam correction systems. This made it possible to handle larger-sized workpieces for precision production.

Combined expertise

Our optical measuring technology division develops high-precision devices for measuring surfaces and the thicknesses of films and optical media to within a few nanometers. Our automation division helps customers save costs in production, improves process chains and makes the IBF systems more efficient. Customers value our ability to also fulfill highly individual requirements. Our team includes specialists from several fields. The company's flat hierarchy helps us focus on the challenge at hand and provide the right solution. We help create the future. Maybe we can do the same for you.

OPTEG GmbH

Föpplstraße 9
04347 Leipzig
Germany

phone: +49 341 234 935 19
fax: +49 341 234 935 29
email: info@opteg.de
web: www.opteg.de