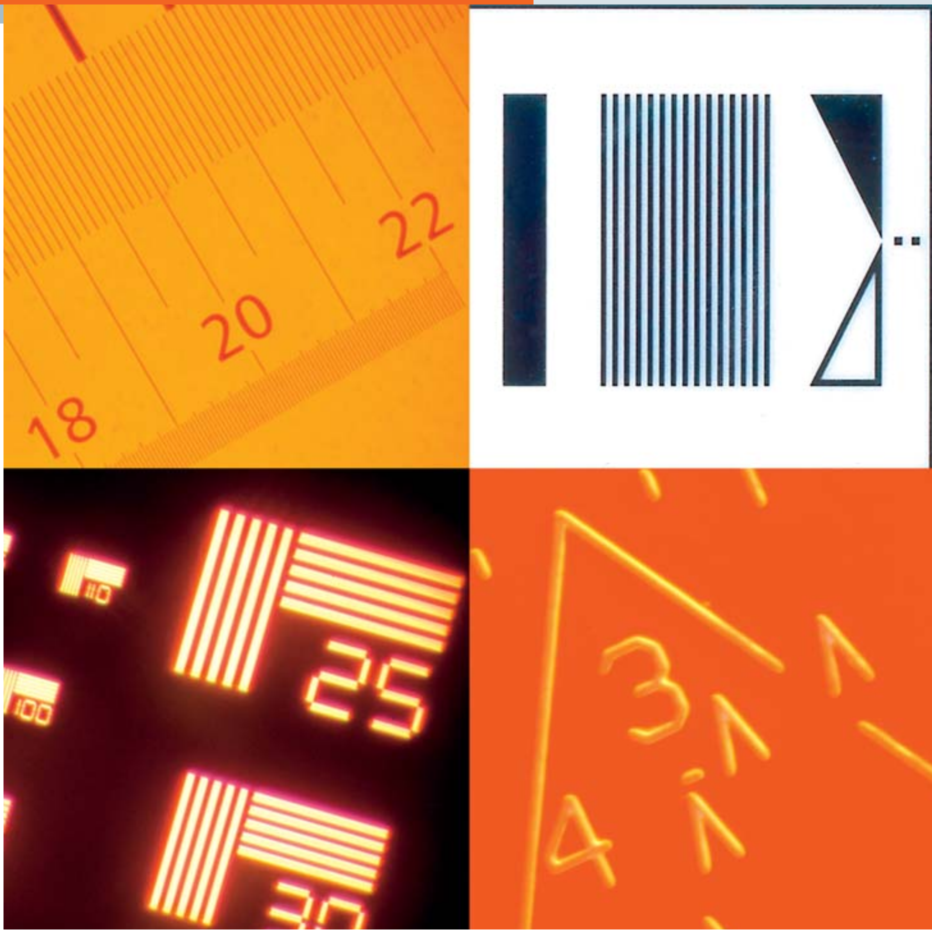


Resist-chrome structure made by lift-off (top left), low reflective chrome structure on ceramics (top right), a structure etched in a chrome layer (bottom left) and structure etched in glass (top right)

Microstructured optical elements

FUNDAMENTALS – METHODS – APPLICATIONS

Reticules, calibration structures or incremental scales give precision instruments optical refinery. The manufacturing methods are elaborate and – like in the semiconductor industry – cleanness in the production process is a critical factor.

THOMAS STEGLICH
JAN SCHUBACH

The terms ›microstructures‹ or ›microstructured optical elements‹, in practice, refer to different applications which require clear definition. In the wide field of microsystems technology, which comprises micromechanics, microoptics, microfluidics and microelectronics, the production of microstructured optical components based on photo lithography or electron beam lithograph represents only a small part. Products here include, in particular, reticules, calibration and test structures, reference circle diameters, incremental scales or apertures used in different precision mechanical and optical instruments, such as in measuring equipment, including industrial image processing and microscopy, or in sport and military optics. Not included in this field are diffractive optical systems, spherical and aspherical lens structures, Fresnel lenses and lens arrays or prismatic structures.

CONTACT

POG Präzisionsoptik Gera GmbH,
D-07549 Gera/Germany,
Tel. +49 /3 65 /7 73 93 -0,
Fax +49 /3 65 /7 73 93 -29,
www.precisionoptic.com

Applied methods of microstructuring

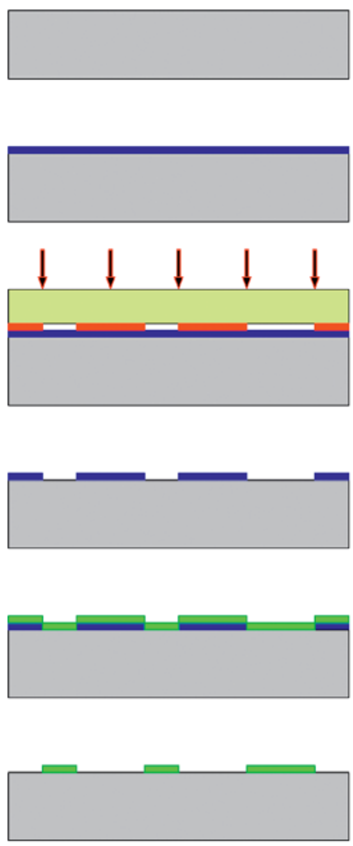
Basically, a difference is made between structures in metal layers applied to a substrate and structures etched in glass. The lift-off method (**Figure 1**) exposes substrate exclusively coated with UV-sensitive photoresist. After development, the substrate with the developed resist mask is coated with chromium, for example. When the resist mask is removed, the so-called lift-off, the actual metal structure remains.

Chromium-etching (Figure 2) is applied on substrates provided with photoresist and metallic coatings in earlier processes. After exposure and development, the exposed chrome layers are etched and the metal structure remains on the substrate.

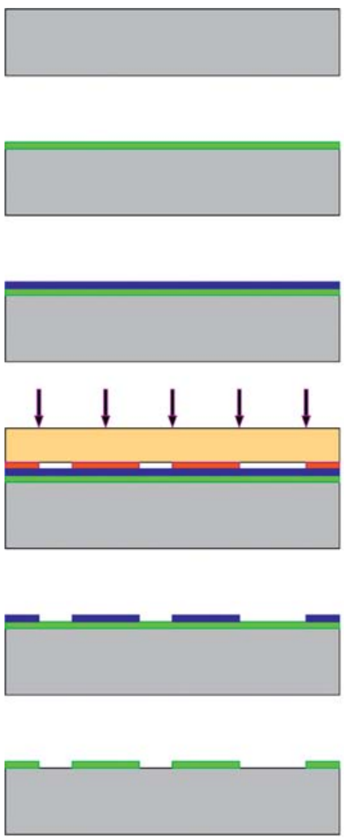
Another method of making optical structures is to etch the structure in the material by using a hydrofluoric acid-resistant mask (Figure 3). These ditches with depths of up to a few micrometers can be filled with color pigment to which suitable binder is added.

Substrate materials and dimensions

Possible substrate materials include different types of optical glass and also ceramics or glass-ceramics. Dimensions from a few millimeters to several meters, such as, e.g., for glass scales, are possible. However, standard materials of the types



2 Substrates for etching already have a photoresist and metallic coats



1 Sequence of processing by lift-off

commonly used in the semiconductor industry are preferred for cost reasons: for example, flat substrates of 0.5 to 3 mm thickness and 4“ or 5“ edge length of B270, soda lime glass or quartz.

Spherical surfaces can also be structured even if at much higher cost.

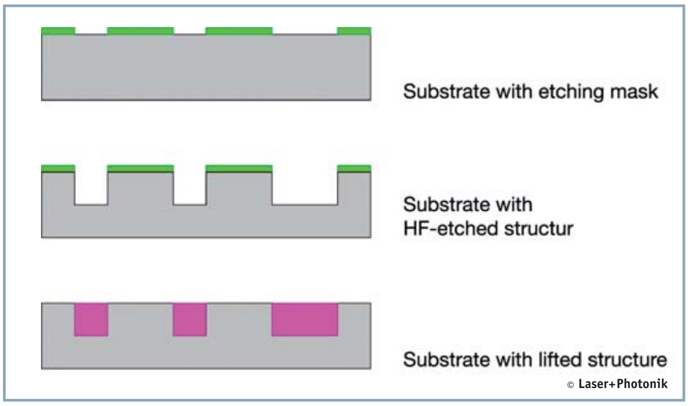
Project steps for microstructuring

The application of photolithographic methods requires availability of a mask for production. Normally, this mask is produced by electron beam lithography or direct laser writing using specially conditioned CAD data. If no standardized substrate with photoresist coat can be used, the substrates are made individually. The (negative) structure on the mask is then transferred on the substrate by the above photolithographic method. More complex structures requiring superimposition of several coatings may require repetition of these processes. If necessary, structures can be etched in material with hydrofluoric acid. Depending on the requirements, the surfaces can then be treated with anti-reflection coatings or the sub- ▶

strate finish-machined by cutting or rounding and protection chamfering. After comprehensive quality tests, certain products (calibration targets, scales) can require additional DKD calibration.

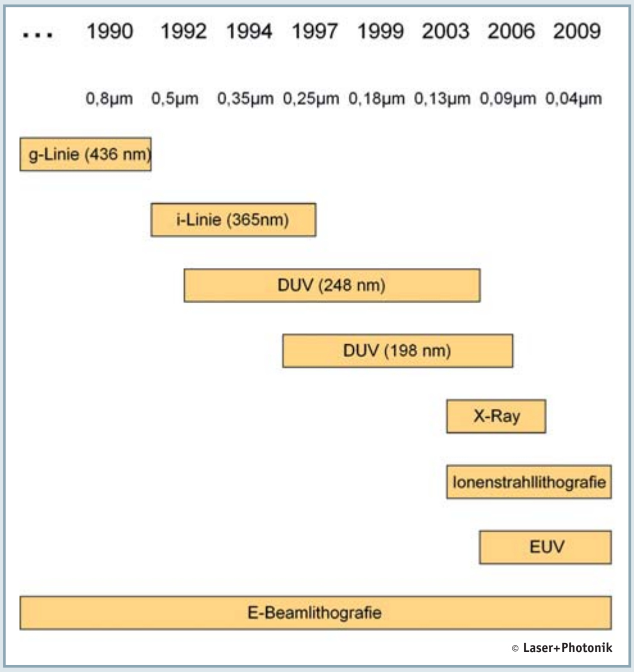
General parameters and achievable accuracy

Reproducible structural dimensions. Currently the smallest attainable and repro-



3 **Structures etched in glass can have ditches several micrometers deep**

INFO: The development of microlithography



Modern lithographic methods in semiconductor manufacturing today approach structural resolutions around 0.06 µm

In the 19th century and right until the 1980s of the 20th century, optical microstructures (optical divisions) were produced mainly by mechanical methods. Today, photo- and electron beam lithography developed for printing and semi-conductor applications have by and large replaced mechanical methods. The development of lithographic methods and the discovery and production of photosensitive materials can be traced back to the end of the 19th / beginning of the 20th century. The first light-sensitive resist for the printing industry was marketed in 1921 by the firm Freundorfer. This is worth a mention because much later (in 1955) the firm Carl Zeiss was able to produce line grids of 1-µm wide structures on this basis. (The requirements for semiconductor applications at that time were resolutions of 5 µm.) The development of the ›Novolack‹ systems, which are used to this day, was also spurred by the needs of the printing industry. One patent was issued in 1944 to the firm Kalle in Wiesbaden (IG Farben, Hoechst), whose US subsidiary was Shipley. There, the systems were improved to today's AZ resists. Another precondition was the development of high-vacuum coating since 1936, a process to vapor-deposit thin metal coatings (chromium, silver, aluminum, and other metals) on glass substrates. The 1950s saw the virtually concurrent development of the ›C‹ method by Carl Zeiss Jena and the ›Diadur‹ method by Heidenhain: two almost identical methods of making chrome partitions. To meet the growing needs of the semiconductor industry, the speed of the development of the lithographic core methods for the transfer of ever more minute structures on semiconductor wafers had increased dramatically since the 1980s. Whereas structures of the order of 1 µm were still common for these applications at the beginning of the 1990s, the development of manufacturing methods now has arrived at about 0.06 µm (Figure). In the same way in which methods from the printing industry were transferred to other industries (electronics, optical divisions) during the 1950s, equipment and methods of the semiconductor industry are today employed throughout the field of microsystems engineering. The microstructured optical elements discussed here cannot be made with the current standard reached with semiconductor manufacturing equipment; the costs of advancing to a new level of technology have increased exponentially in comparison with the rising demands. The output level, which remains low (compared with chip manufacturing) despite the versatile applications of these products and the less strict requirements on the dimensions of structures do not justify the enormous investments. The current methods and dimensions of structures are discussed in the article overleaf. The transformation from the traditional to microlithographic structuring and the related higher investment in new production equipment have caused the number of suppliers to shrink during the last 15 years and only a few big full-range suppliers have survived.

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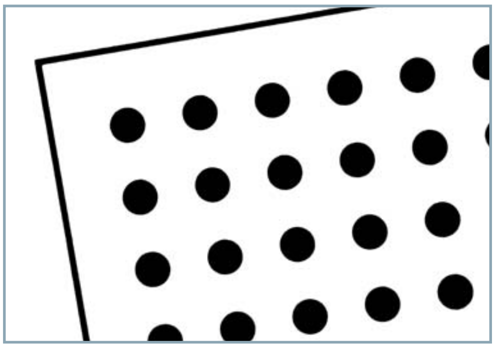
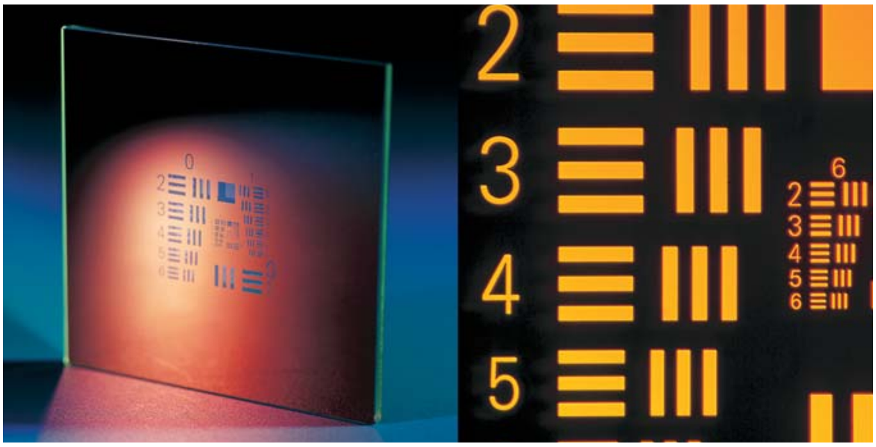


4 Low reflective chrome structures are often used s calibration structures



5 USAF targets are used for testing optical systems

ducible structural sizes depend according to the method on which they are based:

- Contact lithography / mask aligner: resolution 1.0 µm,
- Projection lithography / stepper (g line): resolution: 0.6 to 0.8 µm,
- Direct Laser Writing: resolution > 0.6 µm,
- Electron beam exposure: resolution: 0.4 to 0.6 µm.

Metal coatings. Most structures produced today are chrome. Experts make a difference between low reflective chrome (LRC) and high reflective chrome (HRC). Other metal coatings include aluminum, silver and gold.

Surface defects. Depending on the product and the applicable norm (Mil or DIN ISO 10110-7), specific defect sizes and numbers of permitted defects are defined. As in most applications the structured optical element is on the image plane, the requirements on surface defects are extremely strict - therefore production in clean room environment is essential.

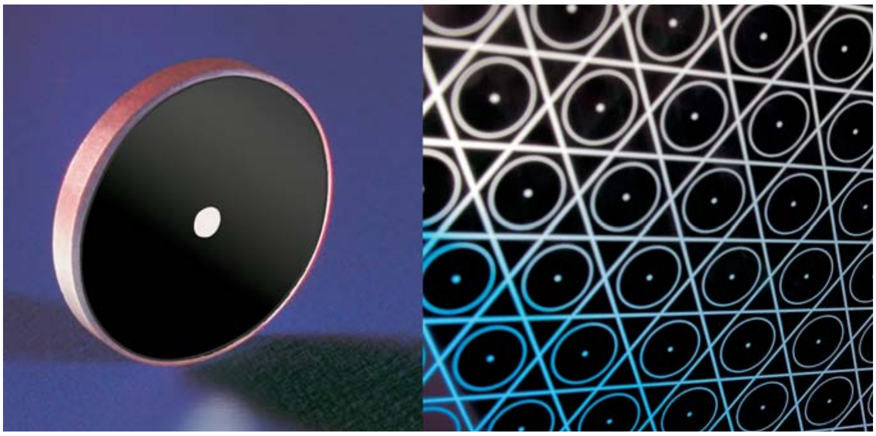
Optical density. The standard of optical density (OD) for chrome, for example, is 4 @ 550 nm. Special coating designs for specific requirements, e.g., for the IR range, are also possible.

AR coatings. Both, standard broadband anti-reflection coatings with R < 0.5 @ (420 to 675 nm) or special coats for UV and IR are available.

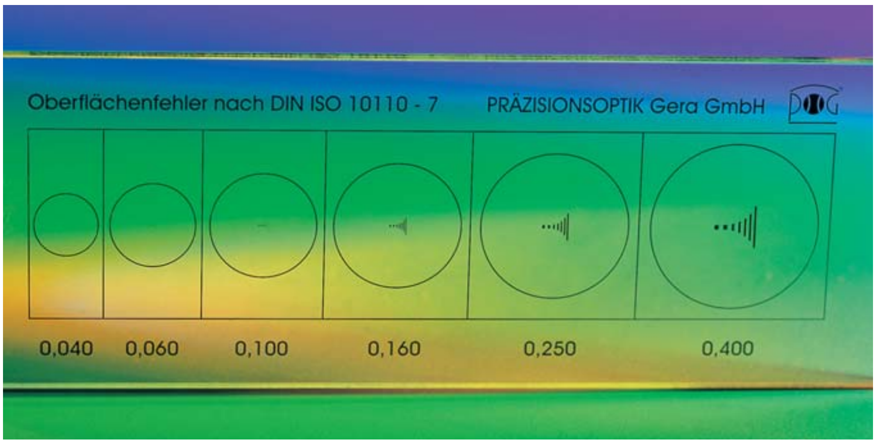
Centering accuracy / edge alignment of sawn parts. The standard centering accuracy of centered parts is 50 µm, up to 10 µm is possible. Accuracies of this order are also obtained with square parts cut, for example, with a wafer dicing saw.

Examples of products and applications

In addition to the common structures on glass, calibration structures on ceramics, opal glass or flashed opal glass are suited very well for the reflected-light applications in the calibration of optical systems (Figure 4). As a rule, to improve contrast, LRC structures are applied to the white background. Several standard resolution tests are available for testing the resolution potential of optical systems. One of the best known examples is the USAF test target (Figure 5). Different types of apertures and microapertures (Figure 6) are made for applications in medicine (endoscopic devices). Surface



6 Mikroapertures are used e.g., in endoscopic devices in medicine



7 Surface defect patterns ease the quality check in optics manufacture

defect pattern according to DIN ISO 10110-7 with defect structures of the step numbers defined there are often used or quality control in optical manufacturing and minimizing subjective factors (Figure 7). ■

Resume: Master the methods of chip making

Microstructured optical elements have proved their worth for measuring engineering, for example, in industrial image processing or microscopy, and in sport and military optics. The production of structures ever more critically depends on methods from the semiconductor industry. The article provides an overview of products, methods and attainable parameters.

AUTHORS

Dipl.-Ing. THOMAS STEGLICH (thomas.steglich@precisionoptic.com) is technologist in the microstructures field at POG in Gera.

JAN SCHUBACH M.A. (jan.schubach@precisionoptic.com) does marketing for POG in Gera.