Direct-write lithography for holograms

Holograms-based security technology is constantly developing new methods of protection. For this reason, the companies in this field have to keep their research and development in search for new solutions. At some point, the development process is defined by the tools at hand.

Heidelberg Instruments provides advanced direct-write lithography solutions for more than 35 years. It is an expert in laser lithography and produces tools from relatively simple table-top R&D systems to industrial-scale wafer writers. Depending on an application, throughput from low- to medium-volume production is available. Each tool can be equipped with different write-heads to match the resolution and speed requirements of the customer. Moreover, after a recent expansion, Heidelberg Instruments tools also cover the nanoscale range.

Direct-write laser lithography uses the laser beam to expose the resist without a mask, patterning a structure line-by-line or in a vector mode (for example, drawing a circle as a continuous line). The exposure and the further fabrication steps are very well established both in research and industrial production environment.

The benefit of direct-write laser lithography is that it completely eliminates the need for masks. For this reason, it is also referred to as maskless lithography. This approach enables rapid prototyping (a few days instead of months) and helps to save costs and time (no masks need to be ordered and maintained). It is also very well suited for grayscale exposures to create quasi-3D relief in the resist. In addition to that, maskless lithography eliminates the security risks associated with outsourcing the mask production.

The capabilities of the direct-write lithography are well-suited for holographic applications of any complexity. Most hologram types require grayscale lithography (DOE's, Fresnell lenses, blazed gratings), since they incorporate 2,5D structures. DWL series from Heidelberg Instruments is extremely well suited for this task (Fig. 1-2) and can be used to produce high-quality master molds for replication. The master molds for the so-called binary structures (e.g. lines and spaces as in Fig. 3-4) can be patterned using Heidelberg instruments' MA150 or written directly on the substrates by MLA300, which is suitable for low-to-mid-volume production. The latter approach would not require a replication step, which would significantly simplify the production process.

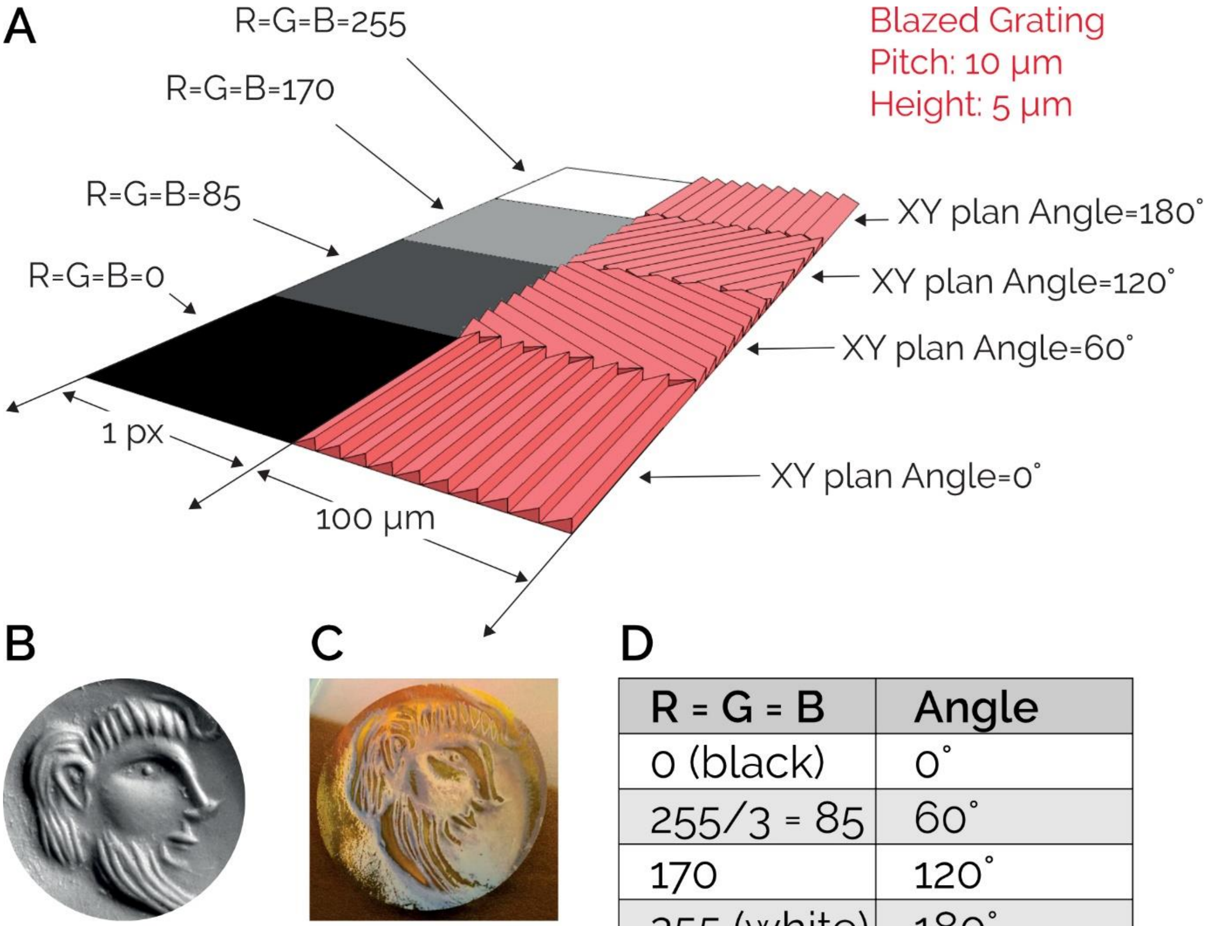
Heidelberg Instruments has recently grown to accommodate a Nano division (formerly known as SwissLitho) that makes thermal scanning probe lithography systems called NanoFrazor. The working principle of these tools is similar to atomic force microscopy. It uses an ultra-sharp heatable cantilever to remove thermal resist and to simultaneously read-out the resulting pattern. This approach can reliably produce binary and grayscale patterns down to a few nm in lateral dimensions (Fig. 5, A-B).

The unique technology called Closed-Loop Lithography compares the produced profile with the target and implements in-situ corrections. As a result, sub-nm accuracy in vertical dimension is achieved. This approach can also be applied for stitching correction, yielding sub-10 nm stitching accuracy.

As compared to electron beam lithography, NanoFrazor technology doesn't suffer from charging effects and doesn't require vacuum. It offers a straightforward and economical way to pattern high-resolution binary and grayscale structures with quality and resolution hardly achievable by other nanofabrication methods. Structures patterned directly in resist can reach 150 nm in depth and can be amplified up to 4 um. This is particularly useful for creating high-precision master

molds for nanoimprint lithography, soft imprint lithography, and other similar processes (Fig. 5D).

The solutions offered by Heidelberg Instruments constantly advance together with increasing complexity of the applications. From a wide range of available systems, customers can choose the tool best suited for their applications. Heidelberg Instruments can also customize the tools in order to optimize the performance for specific needs.



R = G = B	Angle
0 (black)	0°
255/3 = 85	60°
170	120°
255 (white)	180°

Fig. 1 Gray value – Blazed Grating Holograms. A: The hologram is created by blazed grating pattern (saw-tooth-like profile) with different angles in the horizontal plane. With grating height of 5 µm, the resulting image gives an impression to be 200x thicker: ca. 1 mm in depth. B: Source 8-bit .bmp image. C: The resulting hologram. Each pixel is replaced by a 100 x 100 µm² square filled with a blazed grating pattern. D: The orientation of the pattern in the x-y plane is defined by the gray value of the pixel. Resist: AZ4562. Image courtesy: Heidelberg Instruments.

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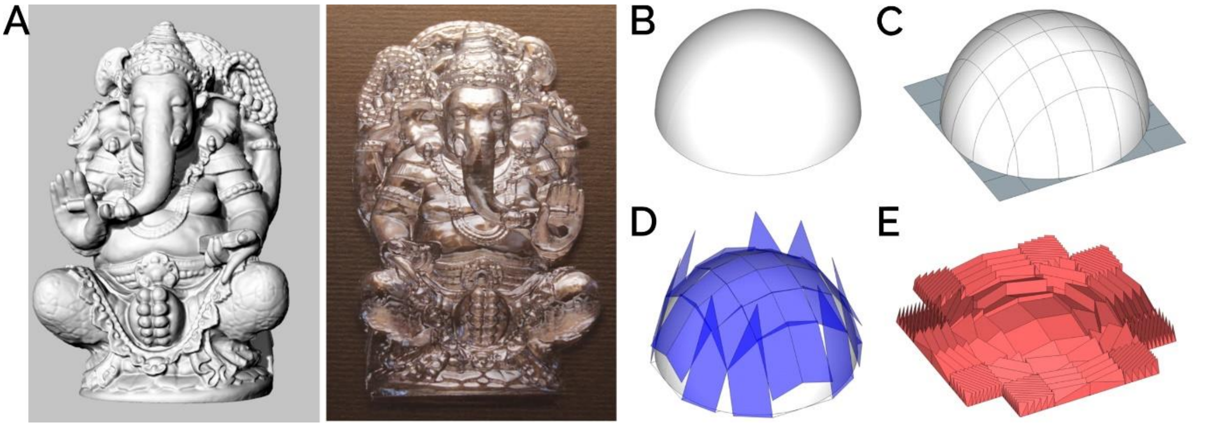

Fig. 2 Fresnel Holograms. A: Source .stl fine of a 3D structure and the resulting hologram with apparently deep relief in a very thin layer of resist (~10µm). **Example of Fresnel approach. B-C:** A half-sphere with a 90 µm radius is cut with a 30µm-pitch grid. **D:** Within each square of the grid, the plane tangent to the 3D structure is calculated. **E:** Resulting planes are vertically sliced, similar to a Fresnel lens. Image courtesy: Heidelberg Instruments.

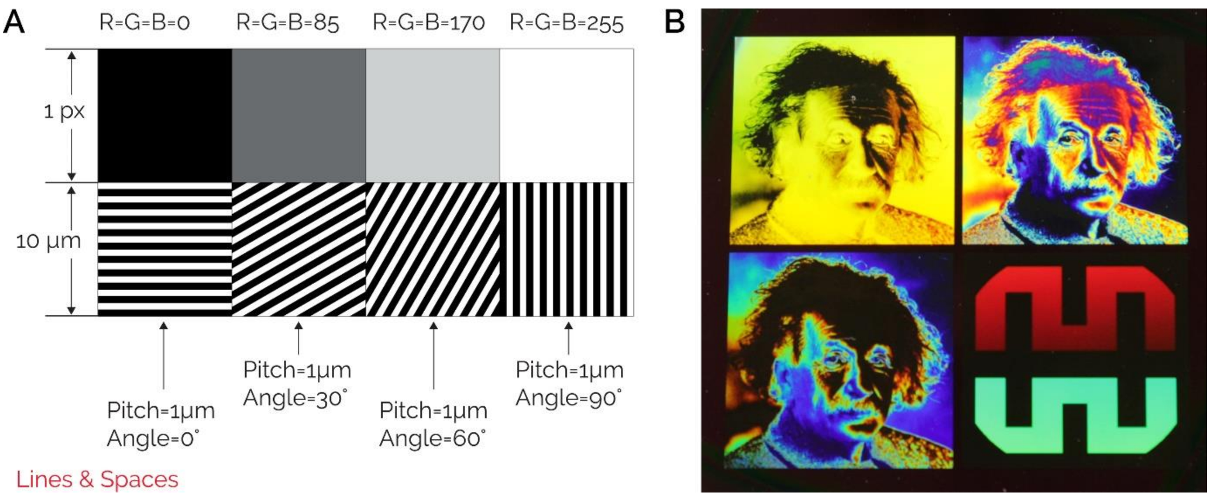

Fig. 3 "Bright" holograms. Similar to the Blazed Grating Hologram, lines and spaces can produce the effect of high color contrast and brightness in a grayscale image. **A:** Lines and spaces gratings with different orientations in the XY plane diffract the light differently. As a result, different gray values (from the input image) create different colors. Each pixel is replaced by a 10 x 10 µm² square composed of lines and spaces (1 µm pitch). Angle of "lines & spaces" pattern in the XY plane is determined by BMP gray value. **B:** A bright image, where colors change with the viewing angle. Top left: only the pitch varies with the gray value of the input image. Top right: only the XY angle of a fixed pitch grating varies with the gray value of the input image. Bottom left and right: the pitch and the XY angle of the grating vary with the gray value of the input image. Image courtesy: Heidelberg Instruments.

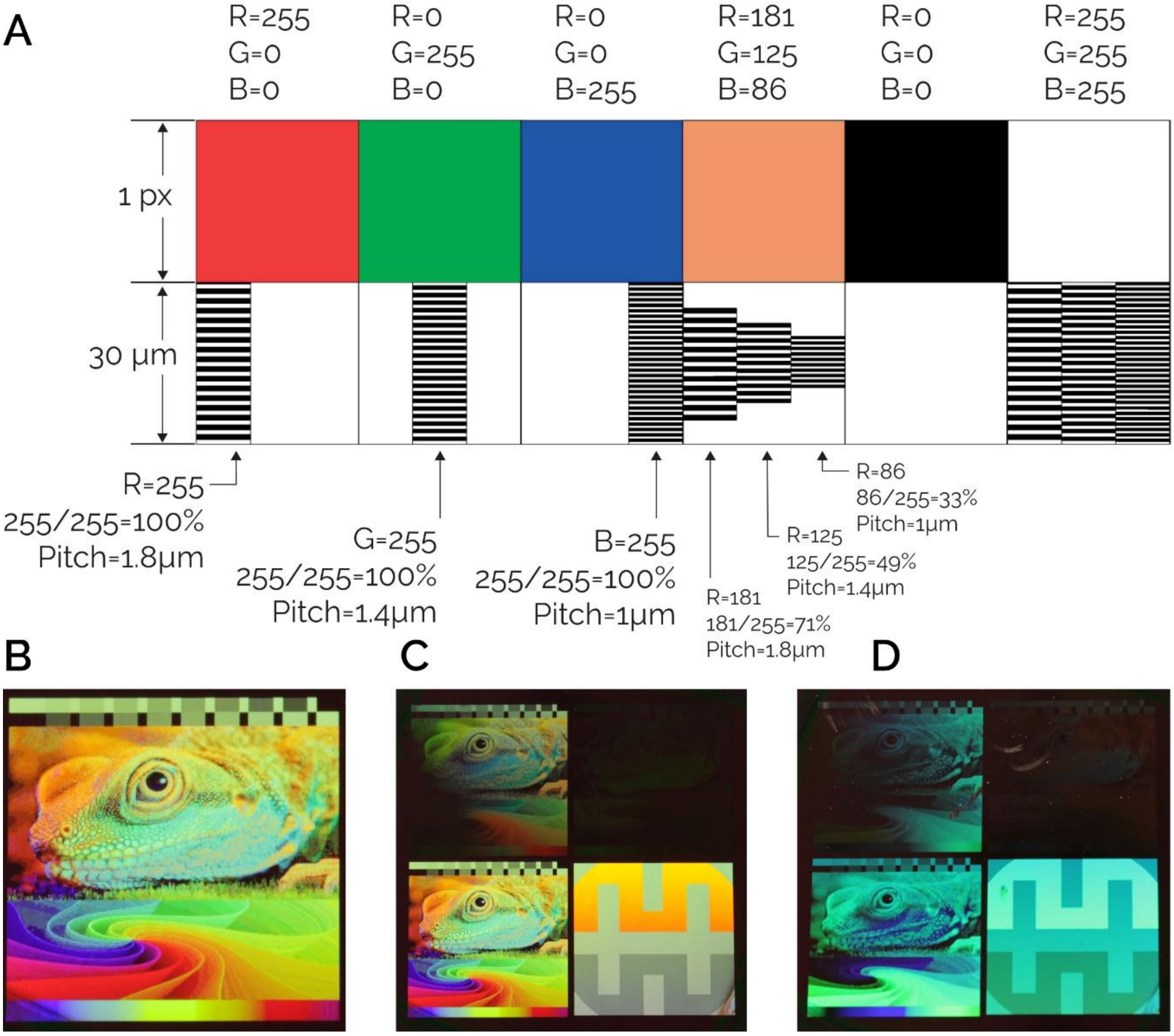

Fig. 4 Realistic color holograms. Gratings in a thin layer of resist (here 500 nm) can recreate a color image without pigments. **A:** Schematic of grating structures for different colors. Each pixel is transformed into a 30 x 30 µm² area. Each square is divided into 3 rectangles of 30 x 10 µm² with varying pitch corresponding to the RGB values. **B:** Depending on the incoming angle of the illumination (white light) and on the viewing angle of the observer, a certain pitch gives a certain color effect. **C-D:** The same structure at different viewing angles. Pixels in images shown here have the same pitch/RGB correspondence but the XY angle is different: Top left: XY angle=45°, the colors are not clearly reproduced. Top right: XY angle= 90°, with the illumination angle and viewing angle almost nothing is visible. Bottom left and right: XY angle=0° (horizontal), with the illumination angle and viewing angle, the original colors are reproduced. Images courtesy: Heidelberg Instruments.

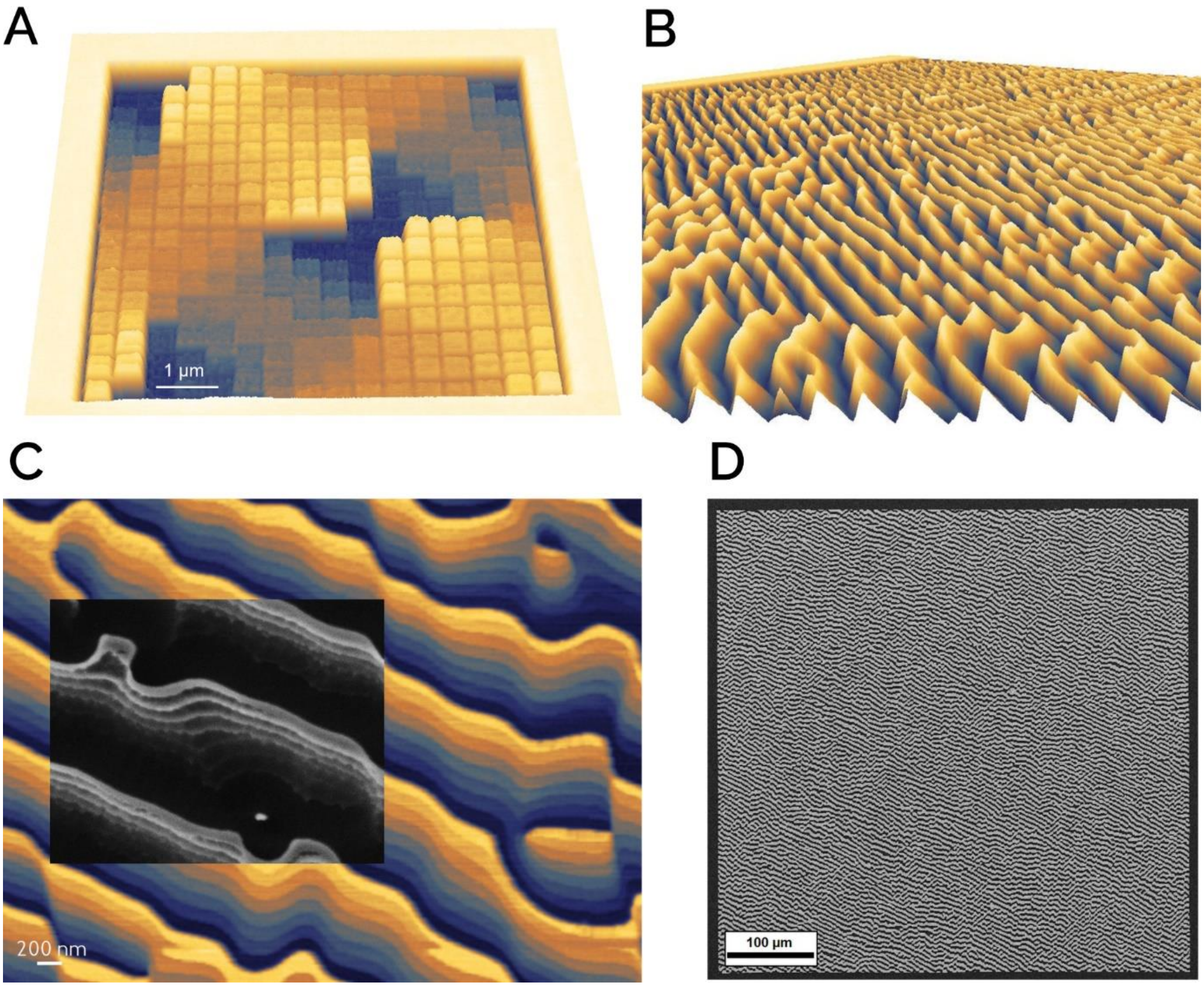

Fig. 5 Nanoscale master molds patterned using NanoFrazor technology. A: Computer-generated multilevel hologram in PPA resist. **B:** An atomic force microscopy image of a 3D hologram pattern in PPA resist. **C:** 3D computer-generated hologram patterned in PPA resist (64 nm deep) by t-SPL, and its amplification in Si (700 nm deep). The column is ca. 70 nm in diameter. **D:** A scanning electron micrograph shows a 2D hologram produced by a simple lift-off. The hologram shows no stitching errors due to the patterning active stitching correction based on closed-loop lithography algorithms. A: Image courtesy of Heidelberg Instruments Nano & Dr. Margit Ferstl, Heinrich Hertz Institute, Germany; B & D Image courtesy Heidelberg Instruments Nano, Hologram design: Prof. J. Dong, Sun Yat-Sen University, China.