Diamond turned holograms for multiple wavelengths

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Abstract

Diamond machining has proven to be a suitable technology to effectively fabricate high performance optics with microstructured surfaces. For machining of diamond turned holograms (DTH), a nano Fast Tool Servo (nFTS) supported diamond turning process has been developed. The latest investigations in this field are concerned with DTH for multiple wavelengths, which generate different intensity distributions when illuminated with specific wavelengths using the same microstructured surface.

1. Introduction

Freeform and microstructured optics are an inherent part of many optical systems used for imaging, light concentration or illumination applications, due to their enhanced functionality [1]. Diffractive microstructures are commonly fabricated by lithographic processes, requiring a demanding manufacturing environment. However, with the advent of fast tool servos, diffractive and holographic microstructures can be machined by diamond turning. Various approaches were undertaken to mechanically inscribe information into a workpiece surface in terms of a microstructure [2, 3]. Li et al. used a slow tool servo for diamond machining of a multi-leveled diffractive optical element with an area of $2 \times 2\ \text{mm}^2$, which was applied for shaping a laser spot into a ring pattern [3]. But also more complex intensity distributions can be generated using diamond turned holograms (DTH), which for instance are applicable as masks for UV lithography [4]. For machining of such holographic structures, a nano Fast Tool Servo (nFTS) supported diamond turning process has been developed. The spectrum of applicable wavelengths ranges from ultraviolet to near infrared. Also, DTH for multiple wavelengths are possible, e.g. as security features against forgery, displaying different images for each wavelength. The fabrication of a multi-coloured DTH for two wavelengths is presented in this paper.

2. Diamond turning of holograms

The machining of the DTH is based on a face turning process using an ultra-precision lathe. As additional accessory, the nFTS is integrated in the machine tool and supplies the interface for the diamond tool. The piezo driven nFTS actuates the diamond tool perpendicular to the workpiece surface, and thus, allows for a modulation of the depth of cut. The stroke depends on the application and usually measures half the wavelength of the applied radiation. In the given application, two wavelengths are used, which requires structuring over a larger vertical range.

Therefore, an advanced nFTS model is introduced, featuring a stroke of 1 µm and a maximum operating frequency of 5 kHz. With this setup it is possible to cut a defined structure into the workpiece consisting of 2 000 separate segments per workpiece revolution, each exhibiting a defined height level. A specifically developed algorithm calculates the height levels for each segment [5]. To realize a precise positioning of the segments in lateral and angular direction, the nFTS modulation is triggered by the encoder signal of the main spindle. In advance of machining DTH, a performance test of the new nFTS was carried out. A measurement of the machined test structure is depicted in Figure 1. In total, twenty segments with alternating height levels (0 nm, 100 nm, 0 nm, 200 nm, etc.) were machined in order to verify the correlation between control voltage and displacement of the nFTS.

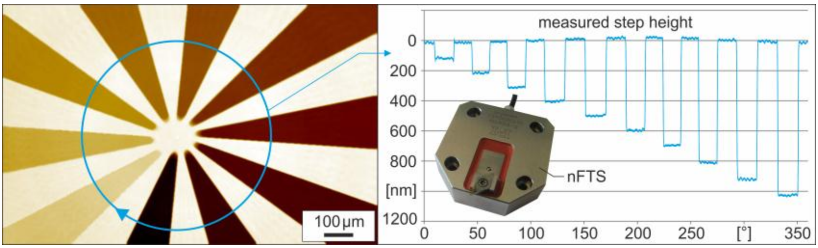

Figure 1: Performance test of nFTS with a maximum stroke of 1 µm. White light interferometer measurement of structured surface (left) and profile (right).

The workpiece center was measured by white light interferometry to obtain the step heights between adjacent segments. The average deviation of the nominal stroke measures 3 nm with a maximum deviation of 10 nm. Due to the excellent linearity, the system can be operated open-loop.

DTH for the visible spectrum are predominantly machined in nickel silver (copper-nickel-zinc alloy), for which an optical surface finish (Sa < 10 nm) and an excellent structure accuracy can be achieved. Figure 2 shows the structured nickel silver workpiece and a magnification of the microstructure obtained by a white light interferometer. The full structured surface of the workpiece has a diameter of 20 mm and consists of approximately 1 000 000 segments. It represents a relief hologram, which modulates phase values of coherent radiation incident to the surface. Every segment of the surface contributes to the final interference pattern, and thus, a defined intensity distribution can be generated in the far field.

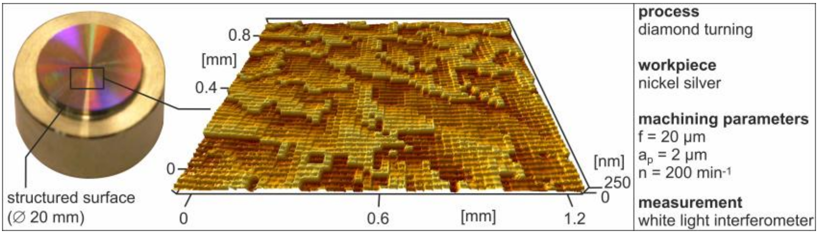

Figure 2: Machined DTH and magnification of the microstructured surface

3. Multi-coloured holograms

In order to enhance the functionality for application as security features, DTH for multiple wavelengths are desirable. For this purpose, a new design algorithm was developed, which allows the formation of multiple independent intensity distributions with different wavelengths using only one DTH [4].

The machining of this DTH required two modifications of the diamond turning process. Firstly, compared to previous experiments, a new nFTS with a stroke of 1 µm was applied to enable structuring over a larger vertical range. Secondly, the structure geometry had to be modified slightly using a flatter structure angle. This increases the diffraction efficiency while decreasing the signal-to-noise-ratio at the same time, which improves the quality of the optical reconstruction.

Figure 3 depicts the setup for testing the multi-coloured hologram and shows the intensity distributions obtained by the same DTH measured with a CCD camera. The images show the LFM and BIAS logo for $\lambda_1 = 633$ nm and $\lambda_2 = 532$ nm, respectively. Both images could be reconstructed in good quality without crosstalk between each other, despite the low difference of the wavelengths of only 100 nm.

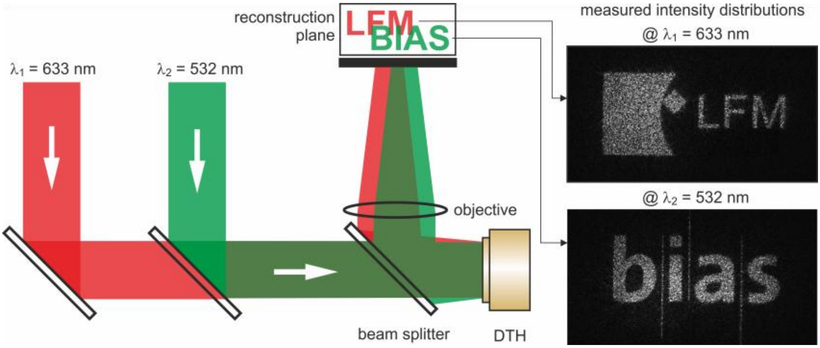

Figure 3: Experimental setup and measured intensity distributions for a multi-coloured hologram designed for two wavelengths

4. Summary and Conclusion

A nano Fast Tool Servo (nFTS) assisted diamond turning process is introduced to machine holographic microstructures, which are able to project different images for specific wavelengths using the same diffractive surface. For this purpose, an advanced nFTS was required providing a stroke of 1 µm. The positioning accuracy of the new actuator was assessed and subsequently a diamond turned hologram (DTH) was machined. The functionality of the DTH was verified in an optical setup and two intensity distributions for different wavelengths were reconstructed in good quality.

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