Fachhochschule Nordwestschweiz
Hochschule für Technik

VII International School and Conference on Photonics
26 August - 30 August 2019, Belgrade, Serbia
PHOTONICA 2019

Laser micromachining of gratings for X-ray interferometry imaging and sub-micron hole patterns

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Abstract

We compare micromachining with an F-Theta and axicon lenses using an UV picosecond laser system to obtain a tungsten grating for X-ray interferometry medical imaging and sub-micrometer hole patterns.

Introduction

Laser micromachining is an approach providing precise structures down to few µm feature size in metals, dielectrics and other materials. Pico- or femtosecond laser machining minimizes the micro cracks and other unwanted effects, down to 1 µm level. Recently, Bessel beam formation with axicon lenses has demonstrated possibility to form structures with lasers in sub-micron width range and large depth (high aspect ratio) .

We investigated fs green laser and ps UV laser with Gaussian and Bessel beam focusing to achieve a few micrometer pitch gratings with 100-200 µm depth and high quality edges for the X-ray grating interferometry (GI) imaging.

Setup

The laser used for these experiments is a picosecond laser system Duetto from Time-Bandwidth Products AG operating at λ = 355 nm (UV). The laser delivers pulses with ~10 ps duration, an adjustable pulse repetition rate from 50 to 8200 kHz and an average power up to 15 W.

Two configurations have been implemented (see Figure 1): (1) focusing with an axicon lens with an angle of α = 20°, movement of the tungsten foil via a 3-axis system and (2) an F-Theta lens with focal length f = 32 mm, laser beam movements via a scanner (x- and y-axis) and a dynamic focusing unit (z-axis).

The optical grating material is a tungsten foil, with 99.95% purity, and 200 µm ± 25% thickness.

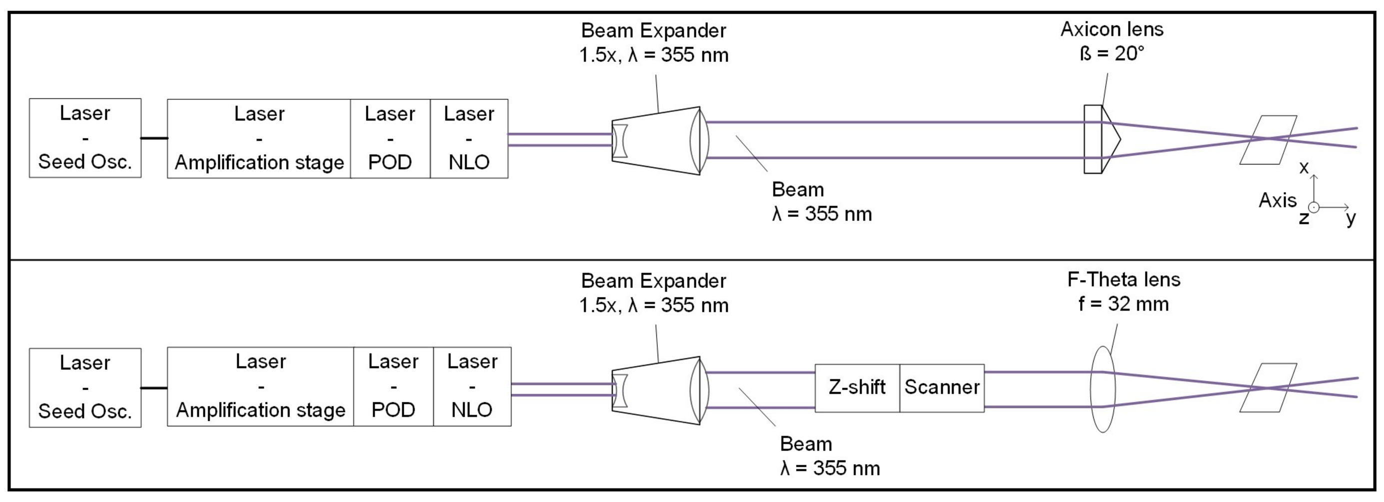

Figure 1: Setup for the laser ablation - above: axicon lens with movements provided by a 3-axis system and below: F-Theta lens, f = 32 mm, with 3D scanning system.

The laser parameters used for micromachining tungsten foils with each lens are listed in Table 1.

Table 1: Parameters used for each lens configuration.

Parameter	F-Theta lens (f = 32 mm)	Axicon lens (α = 20°)
Power in UV (average)	4.6 W	4.2 W
Frequency	120 kHz	10.7 kHz
Pulse energy	0.38 µJ	39.2 µJ
Focused point diameter	4 µm	0.93 µm

Results

First, the intensity profile for the axicon lens was measured to define the depth of focus (see Figure 2). The intensity remains constant over the first centimeter downstream of the axicon lens. It is in this area that the tungsten sheet is placed in order to machine the grating.

The deep machining of the tungsten foil could only be achieved with the F-Theta lens (see Figure 3). The slits made with the axicon lens are blocked in depth by the ablated particle cloud, preventing the laser beam to penetrate and ablate the slits deeper. An Helium gas flow (blow) did not help significantly.

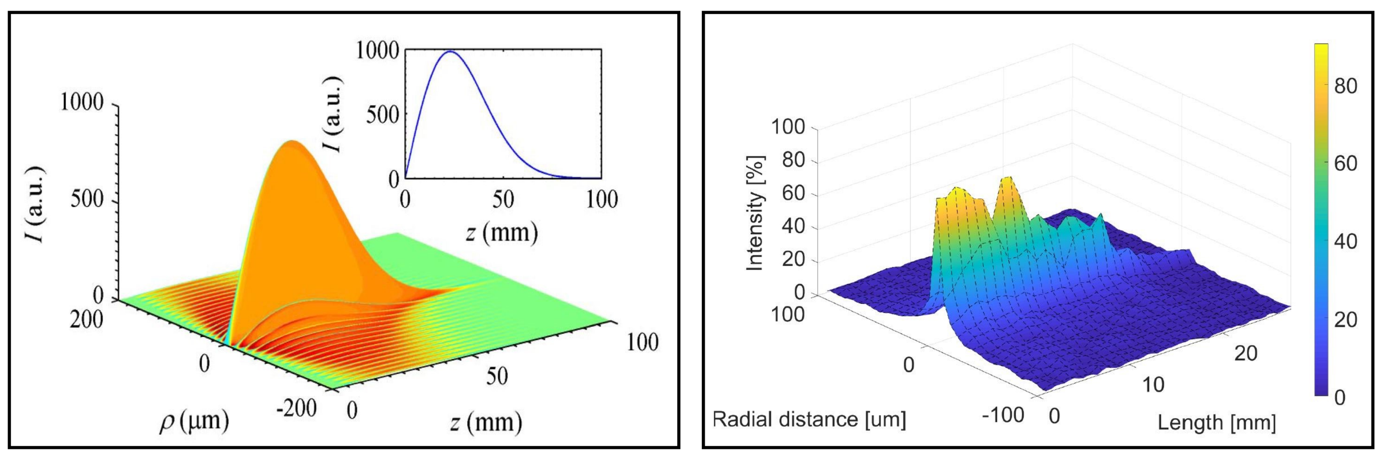

Figure 2: Laser beam intensity profile after the axicon lens as function of the longitudinal propagation - left: theoretical model and right: mesured beam profile.

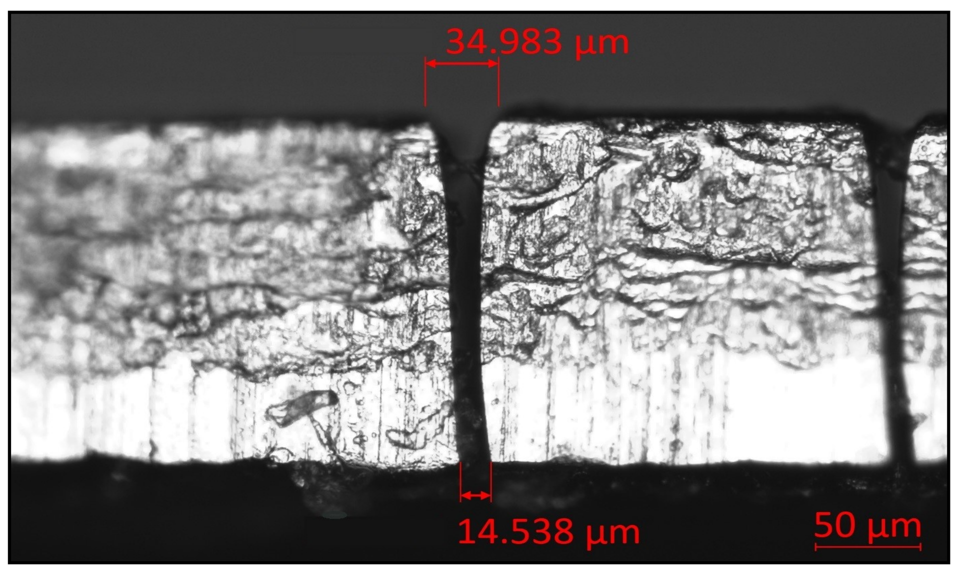

Figure 3: Cross-section view of the tungsten foil, machined with the F-Theta lens.

<u>Disadvantages of the Gaussian beam with F-Theta lens:</u>

1. As sharp rectangular shape is desired, the curved intensity distribution of the Gaussian beam will degrade the edge quality of the slit walls (see Figure 4, left).
2. The relative large spot size of the focused beam (4 µm) compared to the beam focused with the axicon lens (0.9 µm) does not allow structuring the bottom of the slit with micron-level precision.

On the other hand, the axicon lens and its focused spot size below one micrometer allows obtaining sharper-edge walls and a much more homogeneous slit bottom (see Figure 4, right).

<u>Disadvantages of the axicon lens and Bessel beam shape:</u>

1. A larger amount of energy is required to achieve the ablation of material, due to the Bessel beam side-lobes containing significant amount of energy. We measured that approximatively 85-90% of the whole pulse energy is not in the main peak, but is distributed into the side-lobes,
2. The advantage of the small focused spot diameter also means that the machining time is significantly increased (5 to 6 times longer).
3. For each scanned beam pass, ablation depth is less with the axicon lens, i.e. less than one µm ablation depth per pass is obtained with Bessel beam, while it is several µm ablation depth per pass with the F-Theta lens.

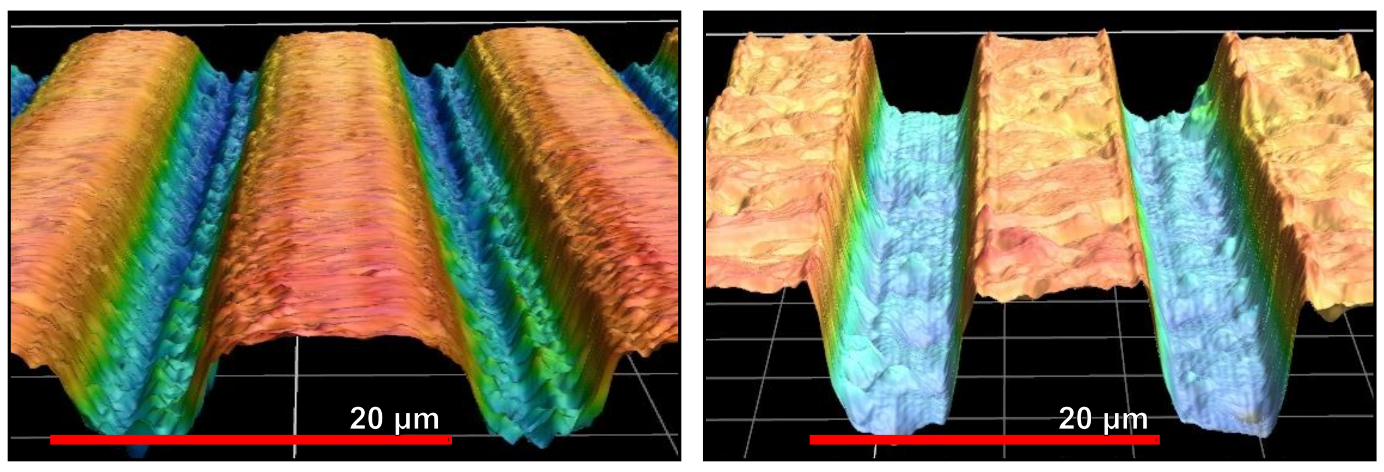

Figure 4: Measurement of the grating profile using a laser-scanning microscope - left: machining with the F-Theta lens, f = 32 mm and right, machining with the 20° axicon lens.

In addition, we investigated the smallest feature that we could obtain with the axicon lens. The result is displayed in Figure 5. The theoretical focal point diameter of 0.82 µm with the axicon lens matches well with the experimentally obtained values of ~0.93 µm.

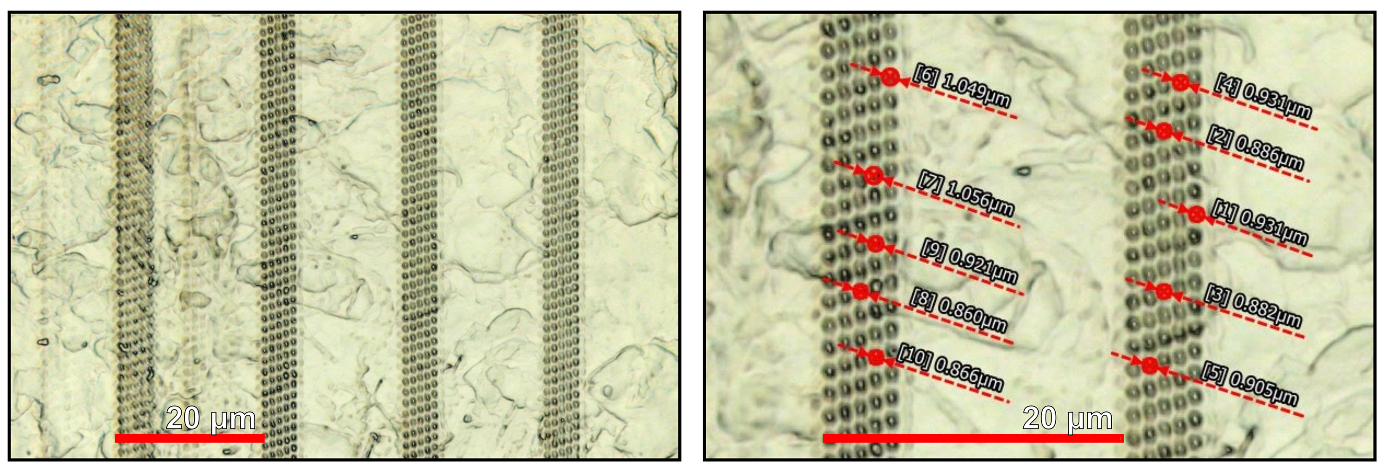

Figure 5: Diameters of the holes made with the axicon lens, with no overlap between the pulses - left: Structure made and right: zoom and diameter of the holes.

Conclusion

The advantages of Bessel beams compared to Gaussian beams are investigated for machining of rectangular profile gratings with sharp edges. The high-aspect ratio grating (10 microns wide and 200 microns deep) from tungsten foil could only be obtained with the Gaussian beam and focusing with an F-Theta type lens.

The significant advantage of the Bessel beam is that the central peak could be formed with a diameter smaller than 1 µm with a depth of focus of several millimeters, enabling sub-micron hole patterning.

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