The development of a diffraction grating for an element of directional output of radiation from microlasers

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Introduction

Axisymmetric microlasers

Axisymmetric microlasers (Fig. 1) have lots of advantages. They can be used in many scientific and industrial areas. For example, in microchips for wireless data transfer in order to make electrical circuits smaller. But there is a drawback, which doesn't allow to use them nowadays: microlasers radiate in all directions. To direct the radiation we place a waveguide near the microlaser and apply a diffraction grating to it (Fig. 2).

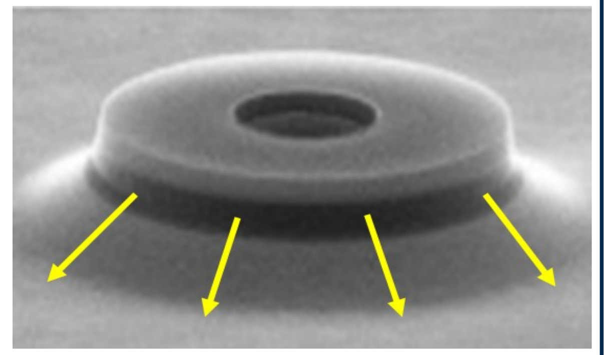


Fig. 1. Microring

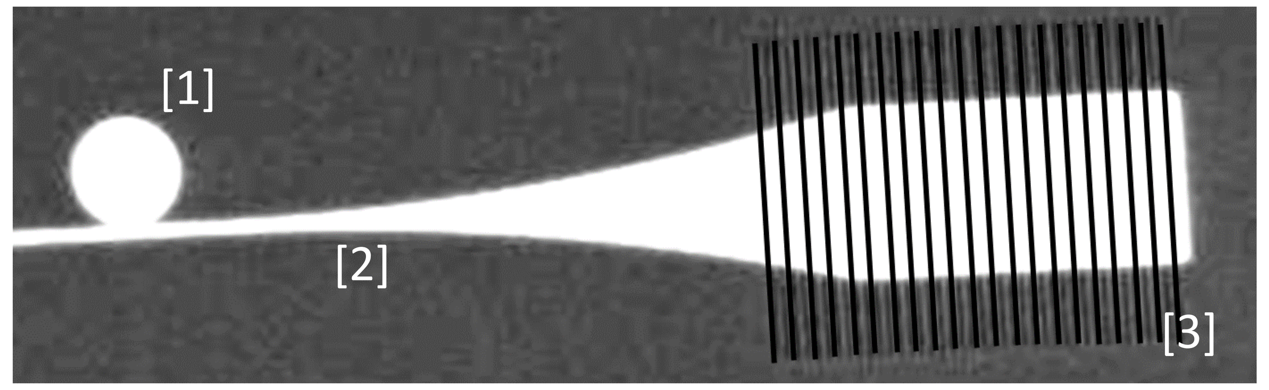


Fig. 2. Potential prototype
[1] Microlaser
[2] Waveguide
[3] Applied diffraction grating

Method: atomic force microscopy lithography

This type of lithography is performed on an atomic force microscope (Fig. 3). This device investigates the relief of nanostructures with a small needle (a probe).

If we increase the probe-surface force, we can scratch on a soft sample the required relief. This is called lithography.

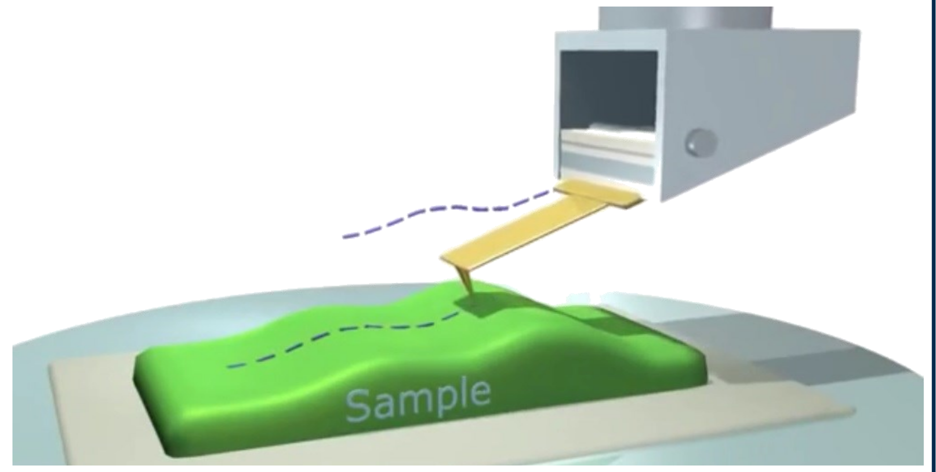


Fig. 3. AFM work principle
Source: NanoEducator LE® YouTube channel

Our goal

To produce a prototype of a diffraction grating using a relatively cheap technique: **atomic force microscopy lithography**.

Tasks of the project

1.Prepare an atomic force microscope.
3.Select the depth of lithography considering the hardness of our material.
4.Investigate the range of allowed periods of the grating.
5.Perform nanolithography of the necessary diffraction grating.

Preparing experimental installation

Making a probe

After several lithographs, the probe bends. To make a new one we formed a workpiece of tungsten wire. Next, we placed the workpiece in a drop of alkali and formed the tip of the probe by electrochemical etching (Fig. 4).

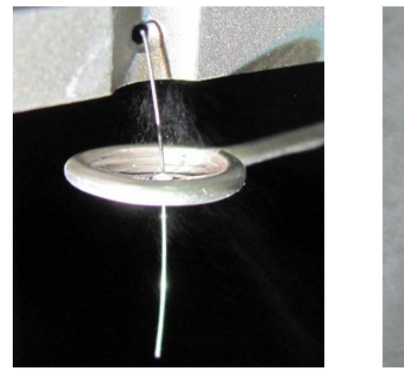
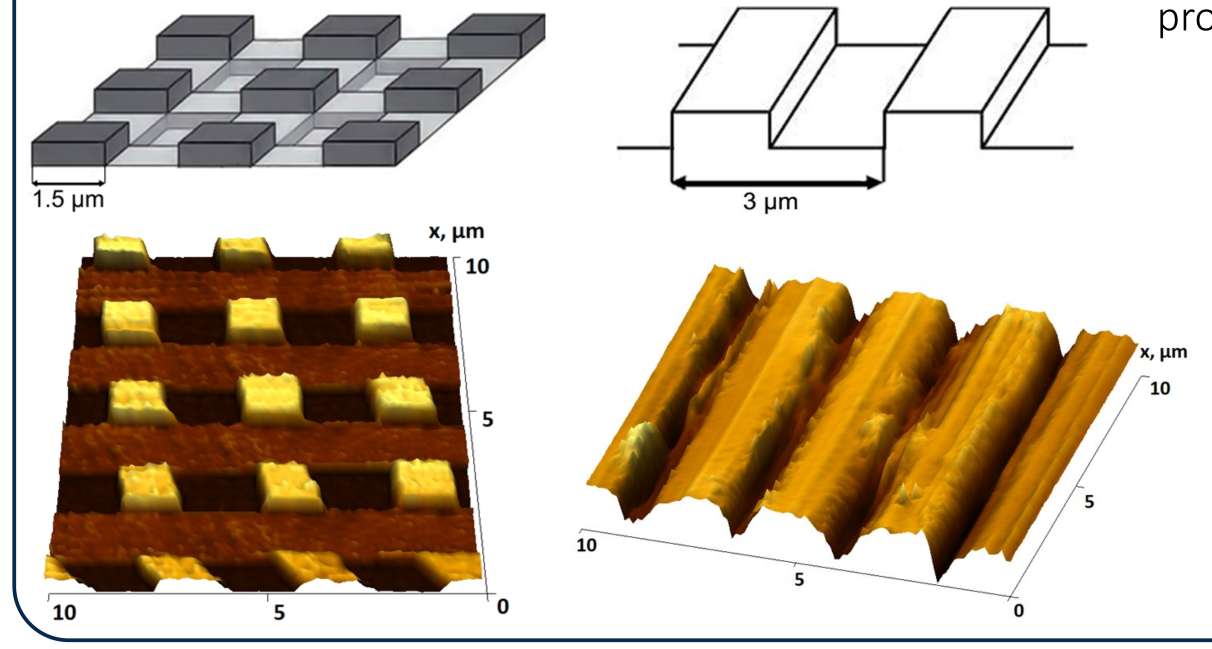


Fig. 4. Semi-finished probe in a drop of alkali

Fig. 5. Probe under a microscope



Testing the installation

To verify that the device is working correctly, we have scanned several nanostructures with a known relief. The relief obtained experimentally is the same as declared by the manufacturer.

Depth of the grating

For our prototype we cut a sample out of a CD. It's own relief consists of regular grooves with the height ~ 30 – 40 nm (Fig. 6). To be able to analyze gratings, we need to make them deeper than the grooves.

The depth of lithography is implicitly defined by the parameters of interaction between the probe and the surface. This is why we had to perform lithography in several stages, gradually increasing the depth.

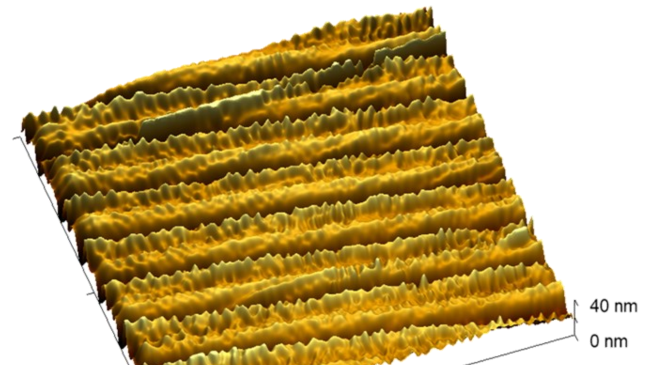
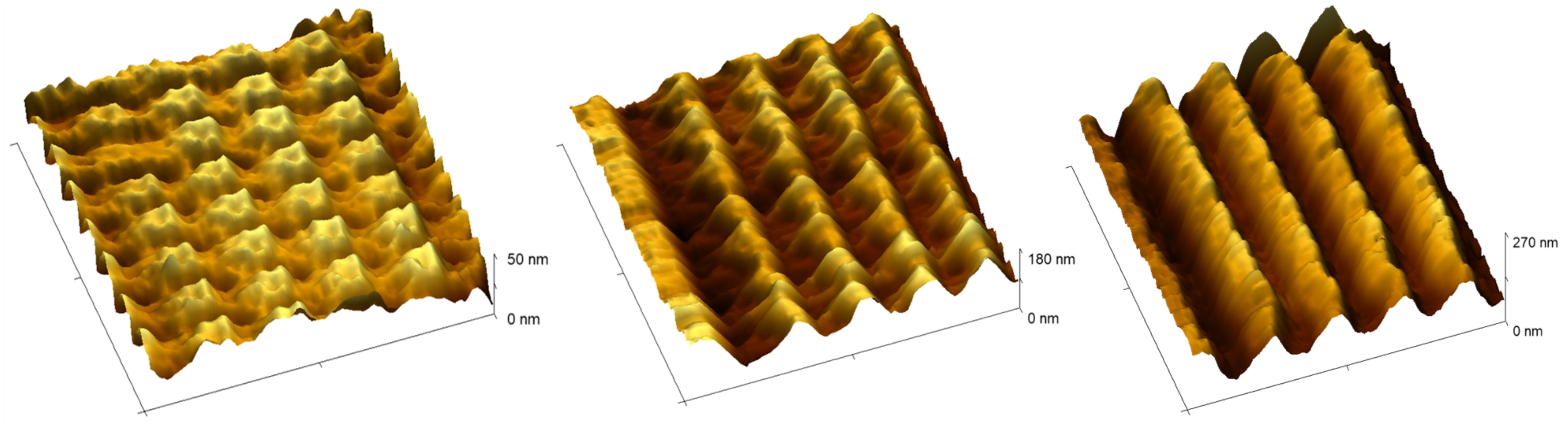


Fig. 6. Own relief of the CD



Insufficient depth → Sufficient depth

Period of the grating

Period of the grating d determines **radiation output angle θ**. To know, which angle we can set, we investigated the range of allowed periods. Grating with a period of 2 μm has good profile. Grating with a period of 1 μm has noticeable irregularities associated with limiting resolution of the scanner.

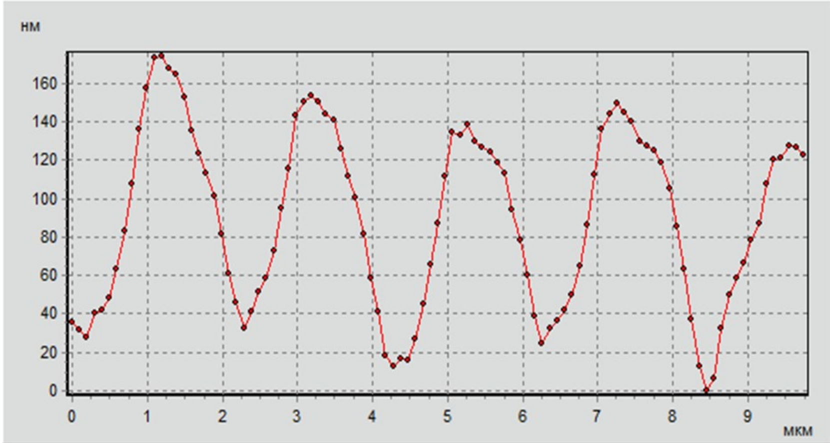


Fig. 7. Period of 2 microns

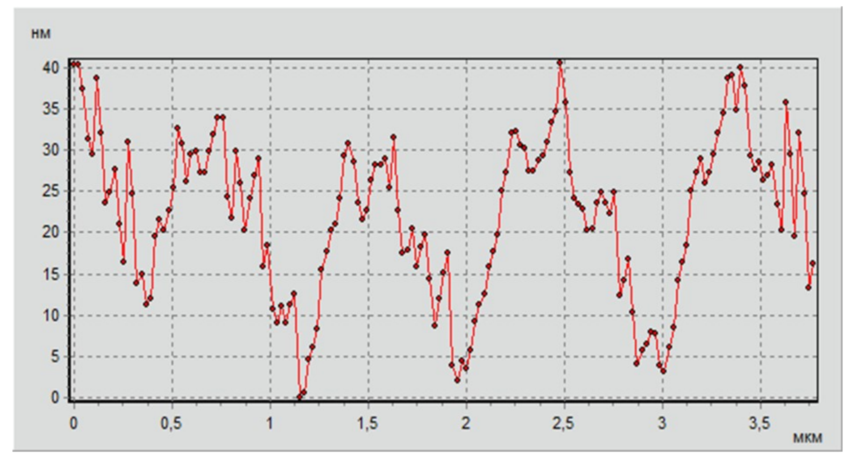


Fig. 8. Period of 1 micron

$$\sin\theta = n - \frac{\lambda}{d}$$

Parameters of our laser:
- Laser wavelength λ = 1300 nm
- Refractive index n = 1.5

Domain:
$\sin\theta \in (0;1) \Rightarrow d \in (0{,}9\ \mu m; 2{,}6\ \mu m)$

We can obtain suitable $d \approx 2$ μm.

Then the angle $\theta \approx 60°$

Conclusion

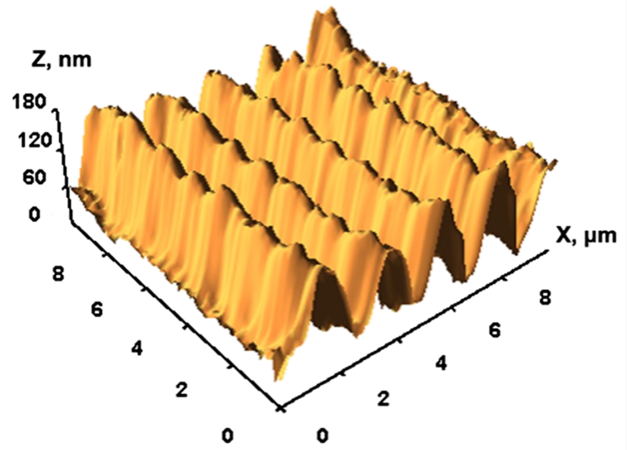


Fig. 9. Final grating

Summary

1. Information about atomic force microscopy was learned.
2. Atomic force microscope was prepared.
3. The depth of lithography was selected.
4. The range of allowed periods was investigated.
5. **The prototype of a diffraction grating with necessary period and depth was manufactured (Fig. 9).**

As a result, it was shown that atomic force microscopy lithography can be used to create diffraction gratings for elements of directional output of radiation from microlasers.

Directions for further research

1. Improve limiting resolution of the technique.
2. Apply our method of selecting the depth of lithography to the waveguide material.

Bibliography

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