STSM REPORT

STSM Reference number: COST-STSM-BM1205-32069

STSM Application number: STSM-BM1205-010316-070829

STSM Grantee: Ugis GERTNERS

STSM title: Planar Optical Elements for Biomedical Application

Home Institution: University of Latvia, Institute of Solid State Physics, Riga, Latvia

Host Institution: National Institute of Material Physics, Magurele, Romania

STSM period: 2016-03-01 to 2016-03-31

STSM purpose:

The purpose of this short term scientific mission was to exchange ideas and perform scientific experiments in the foreign country regarding the possibility to produce various planar optical elements for biomedical application.

Description of the work carried out during the STSM:

The main topic for this STSF was related to investigate the possibilities to produce various planar optical elements. During this STSM a linear-to-radial/azimuthal polarization converter and diffraction gratings for measuring equipment were investigated in detail. The investigation process also included research and development of new materials and innovative techniques for this particular work. My research field is related to investigation of processes related to light-and-matter interaction, therefore direct recording techniques also were used during this work. Direct patterning is the key technique for fabricating one- and more dimensional surface structures on a wide variety of components. This is new and innovative technique – in order to obtain usable optical element it is possible to replace all or most of the chemical processing parts with the direct patterning. The principles of this technique are similar to those for non-invasive laser surgery or non-contact optical tweezers where a light intensity gradient controls how the exposed object or matter will react. Two different approaches were investigated and compared: the holographic recording setup with visible light source (405 nm) and focused electron-beam processing. Pros and cons for each of the setups were examined.

Description of the main results obtained:

A part of the work was related to get familiar with the facilities and equipment available at the Host institution. I was particularly interested into various types of lasers and related optics. Direct holographic recording experiments were performed by the available equipment and the obtained results are discussed in this section. Electron-beam lithography and a possibility to modify this equipment to use it for direct patterning experiments was another important topic in this joint work.

To properly use the focused electron-beam lithography and achieve the best results on the thin layer of amorphous chalcogenide it is necessarily to test its ability and to find the best experimental parameters. A computer model of the performed tests and the outcome of this test imaged by an optical microscope are shown in Figure 1. This experiment was divided into several sections which are denoted with a red rectangle and associated with a letter. For example, the outcome of two-dimensional shapes was tested on the C section and the exposure dose – on the B section. It is shown that this technique is capable to pattern sub-micron structures on

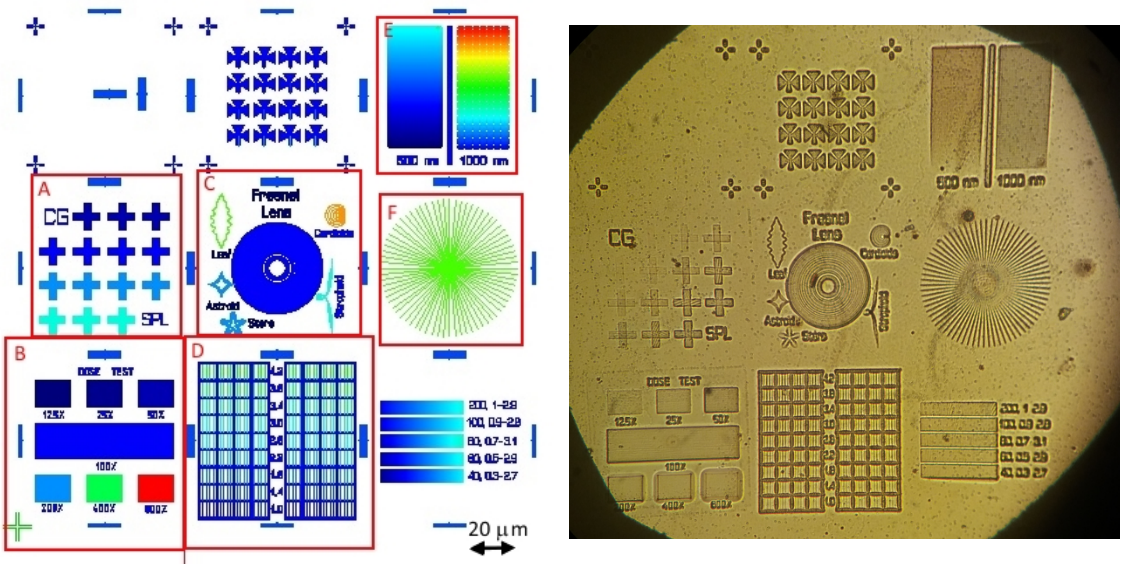

Fig. 1. Direct recording test of the focused electron-beam setup
Various kinds of tests have been put together: A- crossed gratings, B- exposure dose, C- 2D shapes, D- gratings into gratings, E- dots of various sizes, F- lines and angles, etc. Obtained results are shown on optical microscope

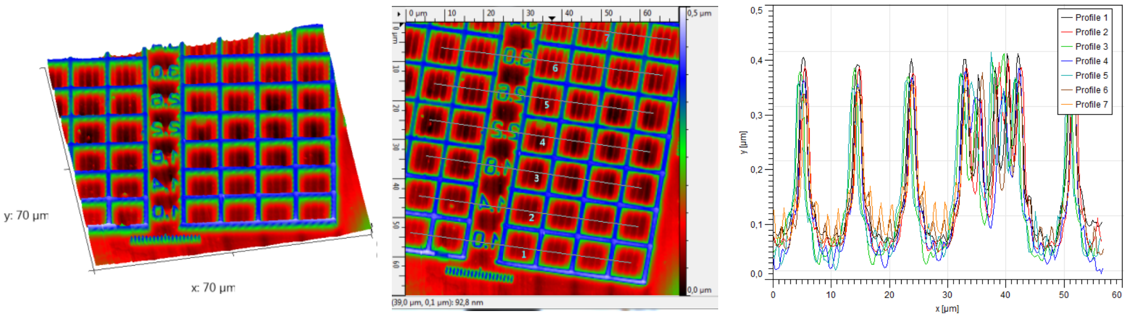

Fig. 2. AFM morphology pictures and its profiles of the D section

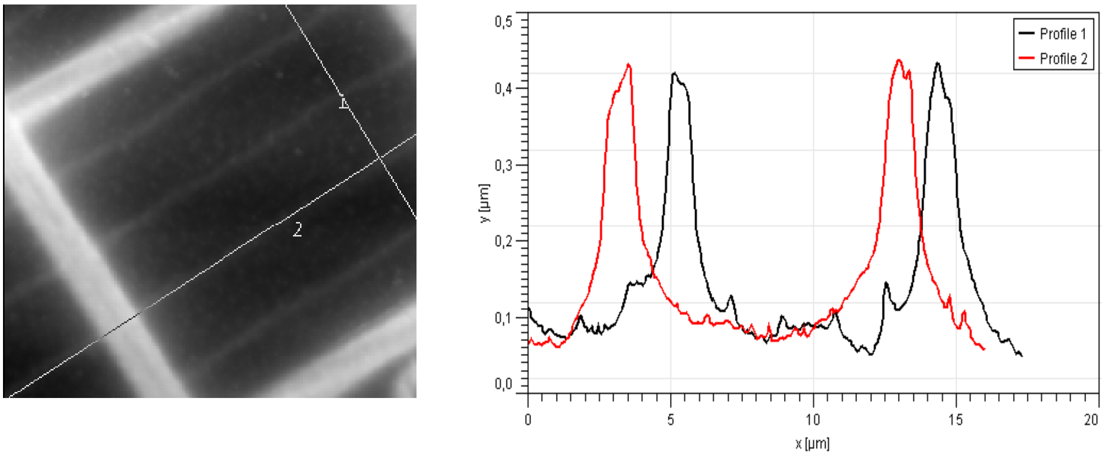

Fig. 3. Closer look of AFM morphology picture and its profiles of the D section
The *Profile 1* has been obtained across the sub-gratings of two micron period

amorphous chalcogenide thin films. This resolution is sufficient for our application to produce diffractive gratings and polarization-sensitive elements. Closer look of the D section is shown in Figure 2. Is is shown that very high precision and repeatability regarding the obtained amplitude have been achieved. In this case the height of the obtained lattice is 410 nm. In this ten-by-ten micron lattice a sub-gratings of two micron period were implemented. As a result of physical dimensions of the AFM tip and specific software-related data processing artifacts it is almost impossible to measure this sub-structure on AFM.

Next part of the work was related to obtain diffractive optical element or diffraction gratings by focused electron-beam and to compare it with the gratings made by direct holographic recording. Scheme of the latter case is shown in Figure 4a. The obtained high quality diffractive gratings and its profile are shown in Figure 4b. Diffractive gratings and top-view photo of the sample obtained by focused electron-beam are shown in Figure 5. Both direct patterning techniques have some

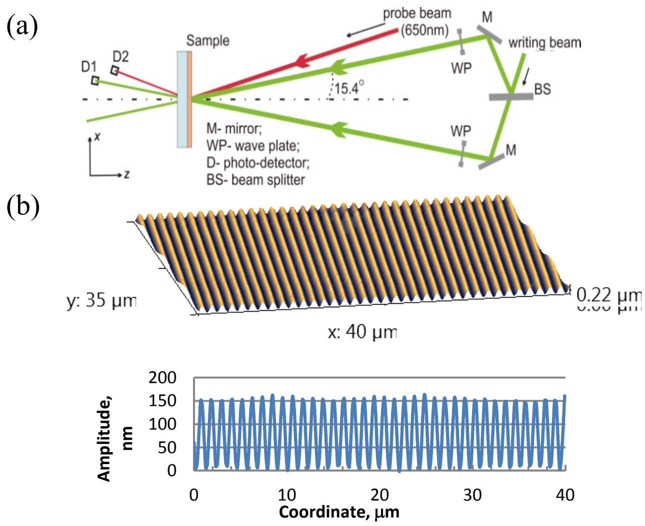

Fig. 4. Direct holographic recording setup and obtained gratings on amorphous chalcogenide thin films

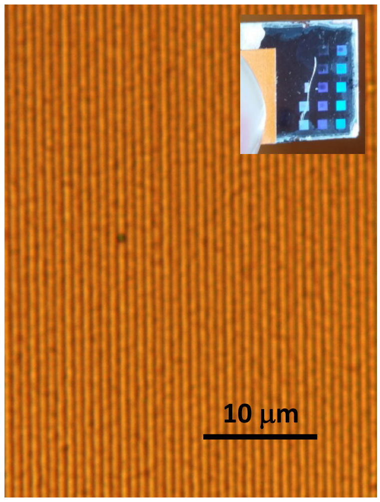

Fig. 5. Optical microscope picture of the obtained diffraction gratings by focused electron-beam, the inset contains a top-view photo of the test sample

advantages and disadvantages. For example, holographic recording is a one-step process and therefore obtained structures are with very high precision and can be obtained relatively fast. Focused electron-beam technique is a one-point-at-a-time process and therefore it is more time consuming and with less predictable outcome. However in the latter case it is possible to obtain more complex structures with much higher resolution.

From the application point of view, the patterned samples can be accurately replicated as a nickel shim followed by mass production through embossing into thermoplastic polymers or other materials. Afterwards, it could be used for the production of a variety of optical and electro-optical devices, including *resonant waveguide grating (RWG) biosensors*. RWG biosensors are capable of monitoring the binding of small molecules to proteins and most notably have been used to monitor mass redistribution of proteins and organelles of live cells upon treatment with test agents.

The last part of this work was related to investigate possible options to obtain polarization sensitive planar optical elements by direct recording technique. Radial and azimuthal polarization is interesting for various applications, ranging from fundamental research to practical use in industrial fabrication. Illustration for each polarization distribution is shown in Figure 6. Introducing an innovative direct patterning technique in this field can definitely improve the overall research and production process. One of the methods to achieve transformation of linear to radial or azimuthal polarization is by a sub-wavelength grating. In practice, the radial/azimuthal polarization element consists of typical diffractive gratings like discussed before, but in this case those gratings are "bended" around one point on the sample surface. Precise 2D morphological structure for each wavelength can be calculated by computer software. Such gratings act as a uniaxial birefringent crystal. The obtained optical element affects the beam's polarization differently in different regions of the beam, thus producing a beam with inhomogeneous polarization.

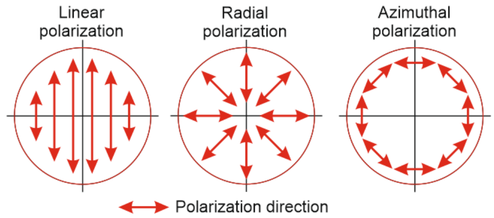

Fig. 6. Various polarization distributions at cross section of the beam

A few test samples by using direct electron-beam lithography were obtained at the Host's institution. The polarization distribution measurements for newly obtained elements showed that the transformed polarization is neither perfectly radial nor azimuthal. This could be related to refractive index of the substrate or the material, improperly patterned gratings or insufficient transparency of the obtained element. Either way, the cooperation between institutions has not ended and this technological process will be further investigated during our future work.

From the application point of view, linear-to-radial transformer elements can be used in various clinical and surgical equipments. Radially polarized light can be focused much more tightly than conventionally polarized light, thus enabling many potential applications in microscopy and nanoparticle manipulation.

During my work we came across to a new idea on how to use a focused light beam with this polarization distribution. By focusing this beam into the problematic tissue it is possible to crates a light intensity gradient which is perpendicular to the skin surface. Polarization for this light intensity gradient is homogeneous- the electromagnetic vibrations oscillate inward and outward from the center of the beam. From my previous research it is known that light-induced mass transfer is possible due to intensity gradient of the polarized light, therefore these conditions may improve the process of dosing the medicine into the problematic tissue. This is something completely new and it is necessary to perform further experiments to make some conclusions.

Mutual benefits for the Home and Host institutions:

This project is a foundation for a mutual support between *National Institute of Material Physics* group (Magurele, Romania) and *Institute of Solid State Physics* group at University of Latvia (Riga, Latvia). Both institutions benefit from this visit. This cooperation has provided the opportunity to use our high quality samples and expertise in light and matter interaction processes and to perform experiments on equipment not available at my institution.

Future collaboration with the Host institution (if applicable):

This STSM has started a new and progressive cooperation between two scientific groups. We will definitely continue to exchange of ideas regarding the investigation and production process of planar optical elements. In this year there will be a joint conference presentation where we will meet in person again and discuss further cooperation.

Foreseen journal publications or conference presentation expected to result from the STSM (if applicable):

Based on the obtained results a joint journal paper will be submitted to a scientific peer-reviewed journal. At least one joint presentation will be prepared and presented at a major scientific conference in 2016.

STSM outcome form

STSM application number	Home institution & country	Host institution & country	BM1205 WG	Objective of the collaboration	Results of the collaboration
COST-STSM-BM1205-32069	University of Latvia, Institute of Solid State Physics, Riga, Latvia	National Institute of Material Physics, Magurele, Romania	WG4	Investigation and development of direct patterning techniques focusing on production of planar optical elements	Planar optical elements with two different direct patterning techniques have been obtained and corresponding recording efficiency and its performance have been investigated and compared

Confirmation of the STSM

I confirm the successful competition of the STSM entitled "Planar Optical Elements for Biomedical Application" carried out by Dr. Ugis Gertners at the National Institute of Material Physics (Magurele, Romania) from 01.03.2016 to 31.03.2016. The entire work plan was completed successfully and important results regarding the STSM were obtained. This project has strengthened the cooperation between the applicant's group and my institution. We will definitely continue to exchange new ideas and results which will lead to new scientific breakthroughs. A joint publication regarding this STSM will be prepared and submitted to a peer-reviewed journal.

Dr. Adam Lőrinczi

Signature: Lőrinczi Ádám

1st April 2016