Patterning of non-planar surfaces via electron beam lithography and its challenges

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There is growing interest in patterning non-planar surfaces using electron beam lithography for applications such as spectrometers and for meta-material anti-reflective coatings. Many challenges need to be overcome compared to patterning a conventional planar surface. The correct pattern placement on planar surfaces is ensured by knowing the correct distance between the substrate and final lens, this distance is measured in-situ during exposure using a laser height meter. Unfortunately, the height meter gives incorrect readings on non-planar substrates. Thus, to be able to accurately pattern a non-planar surface one needs to have an accurate height map in advance referenced to the coordinate system of the electron beam writer. The method used to obtain the height map depends on the substrate type, here we classify two types:

- **Type 1 - Non-planar substrates with surfaces that are defined with an analytical mathematical function.**
- **Type 2 - Non-planar substrates with surfaces that have an unknown shape.**

Once height map data is obtained, the pattern data must be fractured into height zones that are treated as separated pattern layers in the pattern preparation. The size of the zones is optimized such that the focus variation across the height zone is minimal. The flat projection of the pattern onto a non-planar surface results in placement errors during exposure. These errors can cause non-continuous lines, line width variation and field stitching errors. Figure 1 shows that if a planar image is projected onto a sloped surface, the misplacement is dependent on the distance between the deflected beam position and where the substrate height is the same as the planar image surface.

In this paper we show how we obtain accurate height maps for both types of substrates combined with exposure results on the surface of a spherical lens. Our techniques to obtain height information differ depending on the type of substrate. For type 1 we use pre-patterned in-situ markers on the substrate to obtain the height at enough points on the non-planar substrate to solve the mathematical function for the height map. For type 2 we measure a complete height map with the use of an advanced external height mapping system integrated into the external alignment microscope of the Raith EBPG5200 e-beam writer.

We will present and discuss the results of our exposures over a lens like the one shown in Figure 2. This lens is coated with 100nm aluminum and 500nm thick spray-coated ZEP520A. During exposure, the Z drive in the EBPG5200 e-beam writer allows the sample to be accurately moved along the Z axis during exposure, making e-beam lithography over a 10mm height range possible. The Z drive is fast enough that the lens can be patterned efficiently without the need for additional calibrations during the exposure. It is difficult to measure the stitching errors across the field with the concentric ring pattern. In this paper we will elaborate on our strategies for measuring these placement errors and for minimizing them on non-planar substrates.

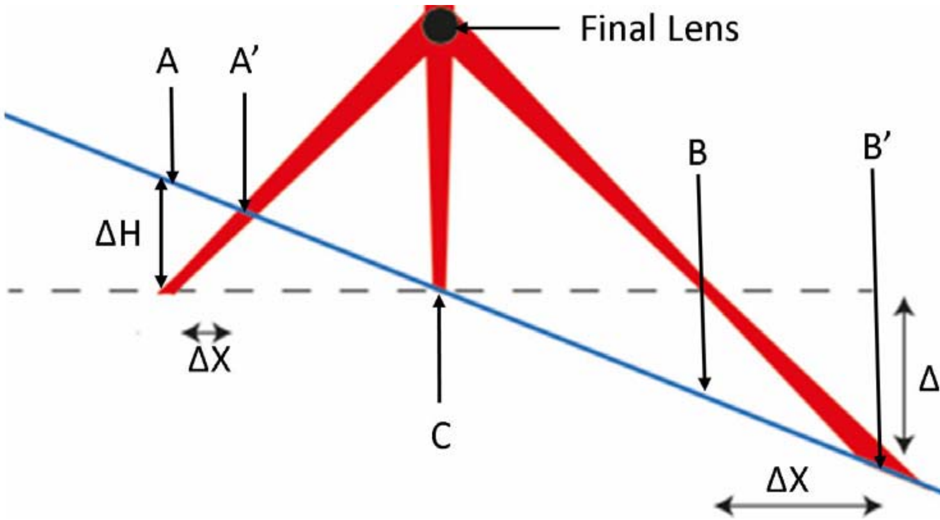

Figure 1: The blue line represents a non-planar substrate that is being patterned via electron beam lithography. The dashed line represents the planar image. The red lines represent the electron beam as it is deflected across the field. As the electron beam is deflected across the exposure field, there is a difference between the substrate height and the planar image height that is represented in the pattern data. At point C, where the height of the substrate and the flat pattern intersect, there are no placement errors and the beam focus is ideal. At Point A, the substrate is higher than point C and the pattern is placed at A'. Similarly point B is below point C and the pattern is placed at B'. There is a placement error of ΔX and a height error of ΔH. If the field is appropriately sized for the slope of the substrate, this height error will be within the depth of focus of the electron beam and will not impact the lithography.

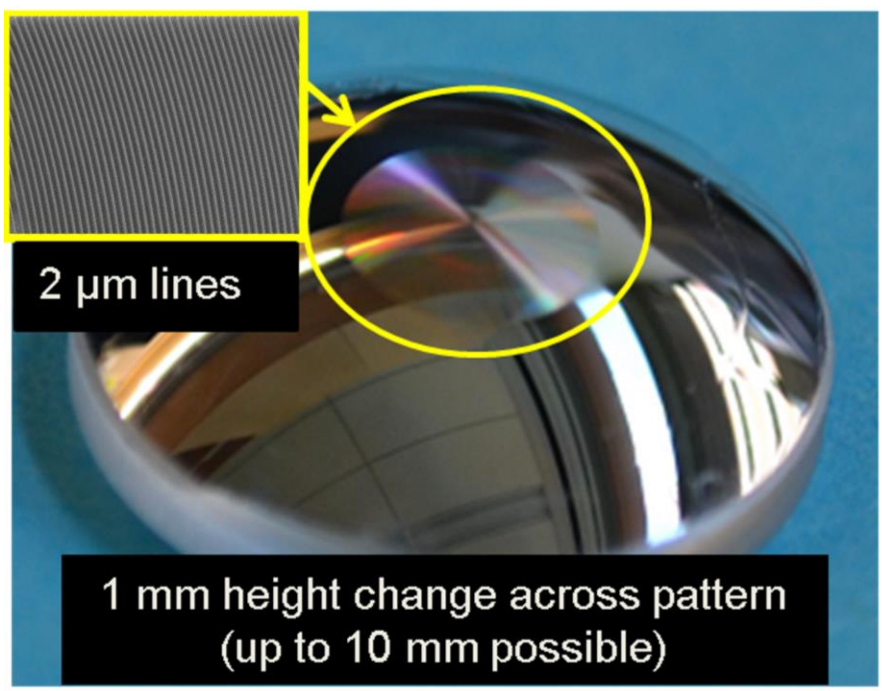

Figure 2: Spherical lens patterned with a 2 µm concentric ring pattern with 1 mm of height change. Inset shows a FESEM micrograph of the 2 µm lines.