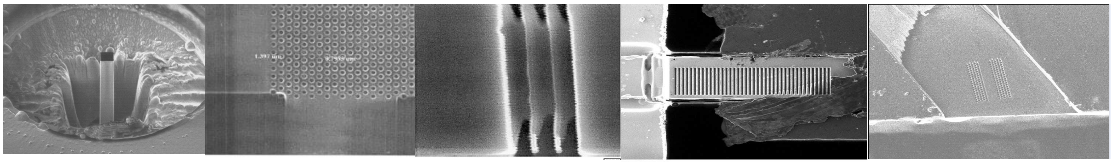

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Automated Alignment Procedure for Stitching using a Focused Ion Beam

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Abstract—**With a focused ion beam, large structures need to be etched in parts to maintain a good scan resolution. The required stage moves are too inaccurate to ensure a good alignment of these parts. We present an automated alignment procedure for photonic waveguides based on image recognition of marker structures.**

Focused ion beam; stiching; automated alignment; image recognition

I. Introduction

A focused ion beam tool (FIB) offers a wide range of possibilities thanks to the combination of milling and imaging [1]. However, when large structures are required, they cannot be etched at once without compromising the scan resolution. Instead, it is necessary to etch part of the structure and move the stage to continue with the next part. This is called stitching. Since stage movements cannot be made with sub-micron accuracy, an alignment procedure is necessary.

This paper presents an alignment procedure for stitching, based on image recognition of alignment markers. Both scan rotation and beam shift are adjusted to correct for inaccurate stage moves. We use this procedure the stitch long waveguides, but its applications are not limited to this type of structure.

II. FIB milling and imaging

A beam of gallium ions is focused to a nanometer sized spot to remove the target material. By moving the beam according to a certain pattern, sub-micrometer sized structures can be produced with a precision of tens of nanometers. This precision is limited by the beam size, which is smaller when lower currents are used. During the etch process, gallium ions are implanted in the target material, causing additional losses through absorption.

In addition to milling, a high resolution image can be made by scanning the entire field of view (FOV) or part of it. Apart from atoms, secondary electrons are released from the material. These can be detected and form an image of the scanned structure, in a very similar was as in a SEM (scanning electron microscope). One should note that taking an image with ions is exactly the same as etching a large rectangle. This means atoms are removed and gallium ions are implanted. When using the imaging feature for alignment purposes, it is thus important to avoid imaging the structure itself, in order to avoid additional losses.

At any given magnification, the number of pixels that the beam can address individually is the same. Increasing the FOV (i.e. reducing the magnification) will thus lead to less accurate structures. The number of bits available for the digital patterning board determines the maximal FOV that can be used without compromising the scan resolution. This means that - for a certain desired scan resolution - the size of the structures that can be etched at once is limited. Structures that are larger than the maximal FOV - e.g. long waveguides - have to be split up in several parts. These parts are etched sequentially. After etching a part, the sample stage is moved to continue with the next part. Unfortunatly, the accuracy of the stage moves is too low to ensure a good alignment between the different parts. Therefore, an alignment procedure is needed.

III. Automated Alignment Procedure

Using the runScript application from FEI company, an automatic alignment procedure was programmed to create a long ridge waveguide. Because these are large structures, a relatively high current is used (7 nA). The acceleration voltage is 30 keV.

We set the horizontal field width to 100 µm. Our FIB has a 12-bit patterning board, so the locations that are addressed individually with this setting are about 24 nm apart. The waveguide will be built up out of 80 µm long parts.

A. Setting the scan rotation

Before starting the actual stitching procedure, the scan rotation of the system has to be adjusted. Each FIB tool has been aligned in order to match the axes of the sample stage with the scan axes of the beam. In general however, a slight mismatch remains. This can be corrected by adjusting the scan rotation of the beam.

To determine the correct scan rotation, four markers are etched in the corners of a square. Each marker is etched in the center of the FOV and the stage is moved to go from one corner to the next. After etching these four markers, the stage is moved to the middle of the square and an image is taken. Through image recognition, the location of the four markers is determined. In case of a misalignment between the stage and scan axes, the square will be slightly rotated in the ion image.

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This rotation can be calculated and corresponds with the scan rotation that is needed to correct for the misalignment.

From the same data, the magnification can be adjusted for calibration purposes. Both scan rotation and magnification are adjusted once before starting the actual stitching procedure. Their values are maintained throughout the entire procedure.

B. Setting the beam shift

To obtain a waveguide, two long trenches have to be etched at certain distance - the waveguide width - from each other. Since imaging causes material damage and ion implantation, we will rely on alignment markers to determine the stage error. The markers are etched above and below the waveguide and only these areas of the FOV will be imaged. This way, we avoid unnecessary losses in the waveguide itself.

Fig. 1 shows the two trenches and alignment markers that have to be etched in black. After etching, areas A and B are imaged and stored as reference images. In the next step, the stage is moved over 80 µm and areas A' and B' are imaged. In case of a perfect stage move, the two markers are exactly in the middle of these areas. In reality, there will be a small deviation. A matching procedure will now look for the best match with the reference images, thus determining the actual stage move. According to these results, a beam shift is introduced to correct for the stage inaccuracy and the next part can be etched.

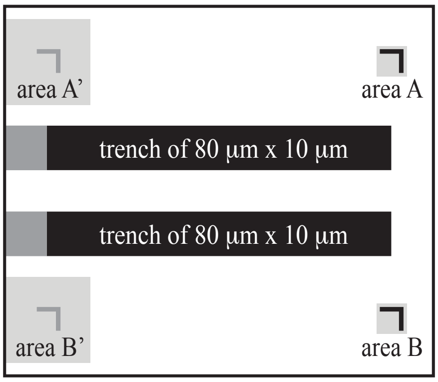

Figure 1. Scheme for stitching, indicating structures to etch (black), areas to image (light grey) and previously etched structures (dark grey).

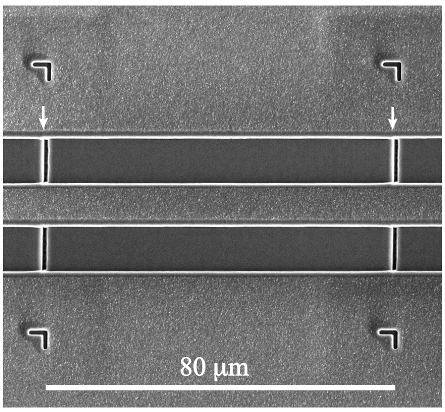

Figure 2. The apparent overlap after stitiching is found almost entirely to the right of the stitch line (white arrows), indicating that the edge rate is faster near the edge of the previous rectangle.

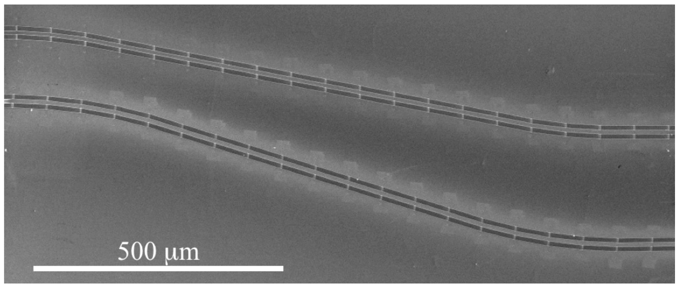

Figure 3. The stitching procedure was used to create smooth bends.

IV. Results

Fig. 2 shows a SEM image of the result of the stitching procedure. There is no notable difference with the situation of two rectangles etched next to each other without moving the stage. The apparent overlap between two parts can be attributed to two effects that are typical for ion beam etching. First of all, a small overlap can be expected because the sidewalls of an etched structure are never perfectly vertical [2]. More importantly though, etch rates are higher when etching near an edge [3]. The deeper etched region is located almost entirely to the right of the stitch line (indicated with small arrows in Fig. 2). This confirms that the left side of each rectangle is etched faster. In our case however, the waveguide doesn’t suffer from this effect.

The stitching procedure can be repeated automatically as often as required. We have used it to etch millimeter-long straight waveguides, as well as waveguides with a smooth bend (Fig. 3). To obtain the bend, parallellograms with different shapes were used instead of rectangles.

V. Conclusion

We have successfully developed an automated alignment procedure that allows us to stitch long waveguides with a high scanning resolution. The inaccuracy of the stage moves is corrected by introducing the appropriate scan rotation and beam shift. During the procedure, only the alignment markers are imaged to avoid unwanted damage to the structure itself. This is in particular important for photonic structures, since the ion implantation will cause additional absorption losses.

Acknowledgements

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References

[1] A. A. Tseng, “Recent developments in micromilling using focused ion beam technology,” J. of Micromech. and Microeng., vol 14(4), pp. R15–R34, 2004.

[2] D. Kunder et al., “Simulation of focused ion beam etching by coupling a topography simulator and a Monte-Carlo sputtering yield simulator,” Microelectronic engineering, article in press

[3] M. J. Vasile et al., “Depth control of focused ion-beam milling from a numerical model of the sputter process,” J. Vac. Sci. Technol. B, vol 17(6), 1999