Patterning of Periodic Structures Using Continuously Moving Stage

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ABSTRACT

There are numerous photonic, plasmonic and biological/chemical applications that require high-fidelity nano-scale features patterned in repetitive periodic arrays that extend across large macro-scale regions. Examples include distributed feedback (DFB) lasers, fiber Bragg gratings, optically variable devices (OVD), holograms, UV / x-ray optics, photonic crystals, nanosieves and the like. Traditional vector scanning EBL technology can offer higher resolution and more flexibility for writing these periodic structures over large areas, as compared to direct write laser lithography or interference lithography, but vector scanning EBL systems are subject to field-to-field stage movement (i.e., stitching) errors and overall throughput constraints. We report on an EBL writing methodology which patterns periodic structures while continuously moving the sample stage, thereby reducing stitch errors and also increasing throughput.

Keywords: lithography, nanofabrication, photonic crystal, grating, stitching

1 INTRODUCTION

As previously mentioned, there are many photonic, plasmonic, biological, etc., devices which require periodic structuring at the micro and nano scale. Gaussian-beam, vector scan, electron beam lithography (EBL) systems are capable of patterning to the 10 nm regime and below, and thus are widely used for fabrication of such devices, but, they are also subject to stitching errors of roughly the same magnitude, or even greater.

Existing vector scan EBL systems employ a classic write-and-step patterning strategy, also known as stitching. If the overall design cannot fit into a single patterning field, the design has to be written field-by-field with subsequent stage step between each write. Such systems are subject to stitching errors at the field boarders due to factors like stage accuracy, field distortion, etc. Stitching accuracies of the order 10 nm and better can be obtained with state-of-the-art EBL systems, and that is satisfactory for many applications.

Nevertheless, even within this small error range, small positional errors such as shifts at stitch field borders within periodic structures can significantly degrade the device functionality and performance, causing side modes in DFB lasers [1] and dips in the transmission spectra of photonic crystals [2].

Techniques to minimize stitch errors commonly involve the use of overlapping writing fields, or exposing the pattern several times but with just a partial clearing dose, and changing the location of the field boarders between each exposure. These techniques (sometimes called shot-shift or voting) essentially smear out and reduce the effect of the stitching errors, but cannot remove the errors completely.

We report on a very unique modulated-beam-moving-stage (MBMS) exposure method which does not rely on ordinary field-to-field stage stepping and is therefore idealy suited for patterning periodic structures requiring high placment accuracy over large lateral distances.

2 METHODOLOGY

MBMS patterning is based upon, but different from, FBMS patterning which was previously reported [3]. This new MBMS exposure method relies upon very precise speed control of the sample stage in direct synchronization with the pattern generator beam deflection. Distinct structures (shapes) are written while the stage is in continuous motion.

In the classic write-and-step process , the entire pattern is decomposed into individual writing fields. (Figure 1 illustrates the case of writing a grating.) The stage remains stationary in the center of each field while the pattern generator deflects the beam about the field to pattern all of the individual structures. When the writing of one field is complete the stage moves to the next field, and so on.

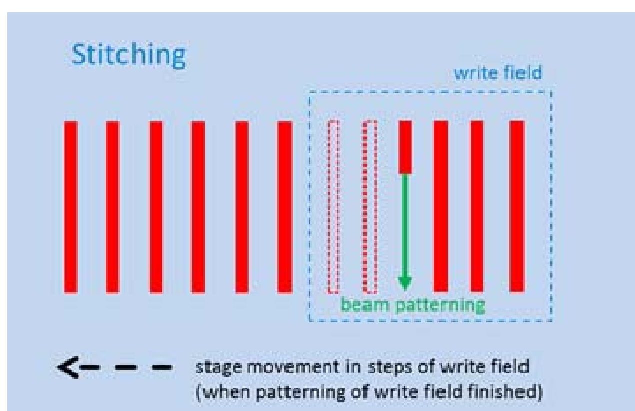


Figure 1: Conventional write-and-step stitching method.

To write the same grating in MBMS method, the sample stage would travel at a predefined velocity and the pattern generator would write only a single line structure, matching the beam (pixel/position) placement to the travel velocity of the sample (see Fig. 2). The pattern generator repetatively cycles through the same shape while the stage continues to travel. The pattern generator is effectively writing an entire grating but it is doing so by repetatively cycling through just one line structure.

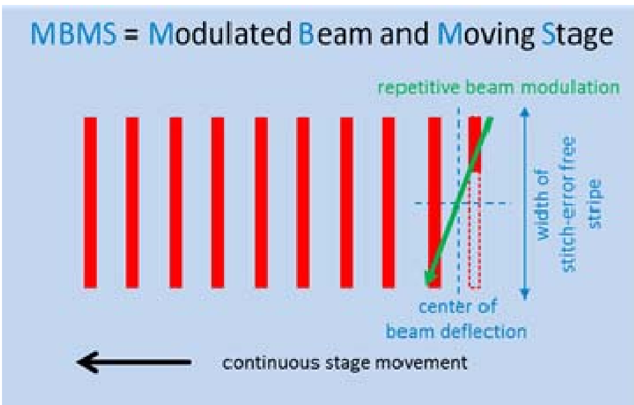


Figure 2: MBMS continuous movement patterning.

The scheme depends upon the repetitive nature of the pattern, for it must be able to be broken down into a “unit cell” which can be repeated again-and-again, while the stage is in motion, in order to create the entire pattern.

The “effective” writing field size can be from tens to hundreds of micron in width, but the length of the field is dictated only by the size of the sample. Thus, patterning is accomplished stitch-error-free due to continuous movement of the stage.

Additional passes of the stage allow the creation of patterns which are otherwise too large to fit within a single field width. Writing of patterns over large areas is therefore accomplished in a strip-wise fashion (see Fig. 3).

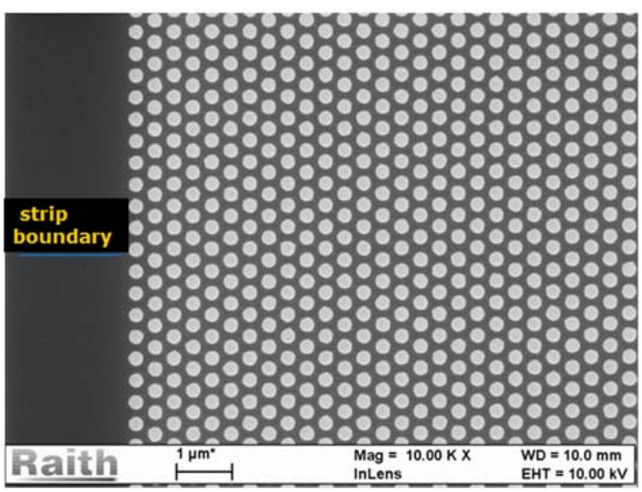


Figure 3: MBMS patterning strip boundary within a large area photonic crystal device.

MBMS patterning can lead to substantial throughput increase when writing over large areas. In conventional EBL systems, pattern file size, subsequent data transfer, and stage stepping can bottleneck or otherwise limit the overall exposure time (*i.e.*, the oveall exposure time depends on various “overheads” in addtion to just the “beam on” time.) MBMS patterning involves much less overhead because a relatively small data set is sent only once to the pattern generator (which then repetatively and rapidly cycles through the data.)

In theory, MBMS patterning can also improve overall pattern fidelity by effectively decreasing field distortion errors. In conventional vector scanning lithography, the field distortions in a 2D writing field causes stitching errors, but also size and placement distribution among the written structures of periodic patterns. In MBMS, the beam is deflected primarily in a 1-dimensional (1D) manner, thus making it easier to correct for field distortions in the 1D direction and eliminating field distortions in the orthogonal direction.

3 RESULTS

A typical application that would benefit from MBMS would be Bragg gratings on waveguides. As an example, Bragg grating patterns were created by MBMS using PMMA on Silicon substrate. Four sepate gratings, 50 µm wide by 1 mm long were written with target periods of 185 nm, 185.4 nm, 185.8 nm, and 186.2 nm (see Fig. 4).

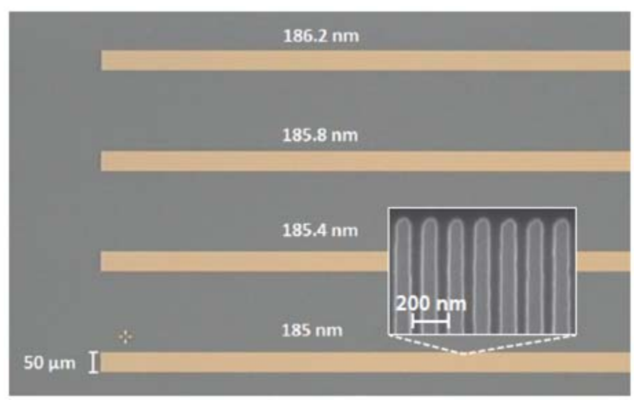


Figure 4: SEM image of Bragg gratings; target pitch was 185 nm, 185.4 nm, 185.8 nm, and 186.2 nm.

The resulting pitch of each grating structure was subsequently measured by scanning electron microscope-based metrology. The pitch was determined by measuring the distance between a set of 100 lines, along the 1 mm length of each grating. The measurement results are depicted in Figure 5. The statistics show pitch control of +/- 0.1 nm (3 sigma).

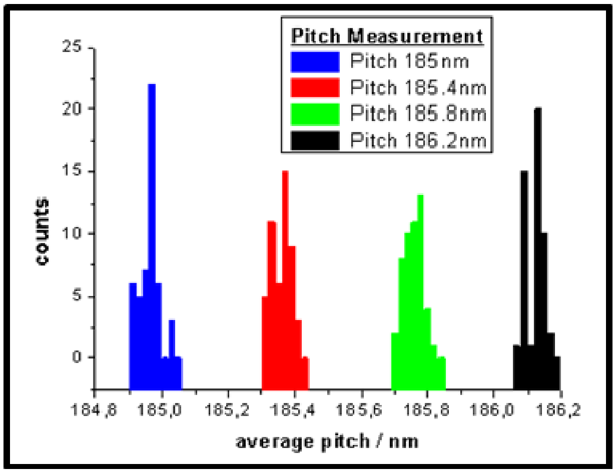


Figure 5: Pitch measurements of Bragg gratings.

Qualitatively, the exposures also exhibit low line edge roughness. The gratings are 1 mm long, but a realatively small writing field and small beam step size can be used. Other EBL systems may attempt to use ever-larger exposure fields in order to write critical devices without the need for stitching, but an unwanted effect can be loss of fidelity and resolution due to increasing field size.

MBMS patterning is stitch-error-free in the direction of stage travel (1D writing.) Large lateral 2D designs will require writing in strips, which introduces a potential strip error (or strip-stitch-error.) The magnitude and occurance of this effect is currently under investigation, but early qualitative results are promising.

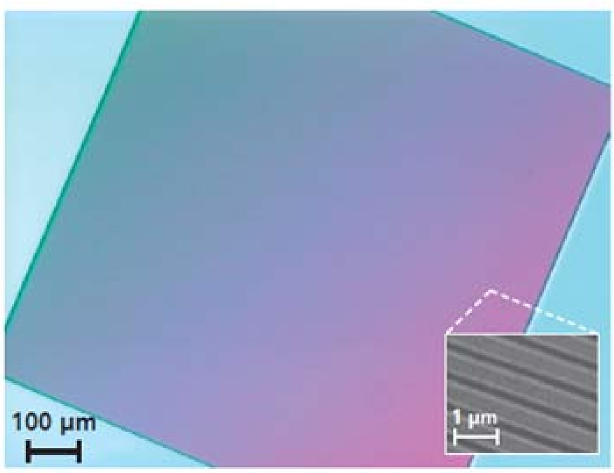


Figure 6: Light microscope image of 1x1 mm^2 grating.

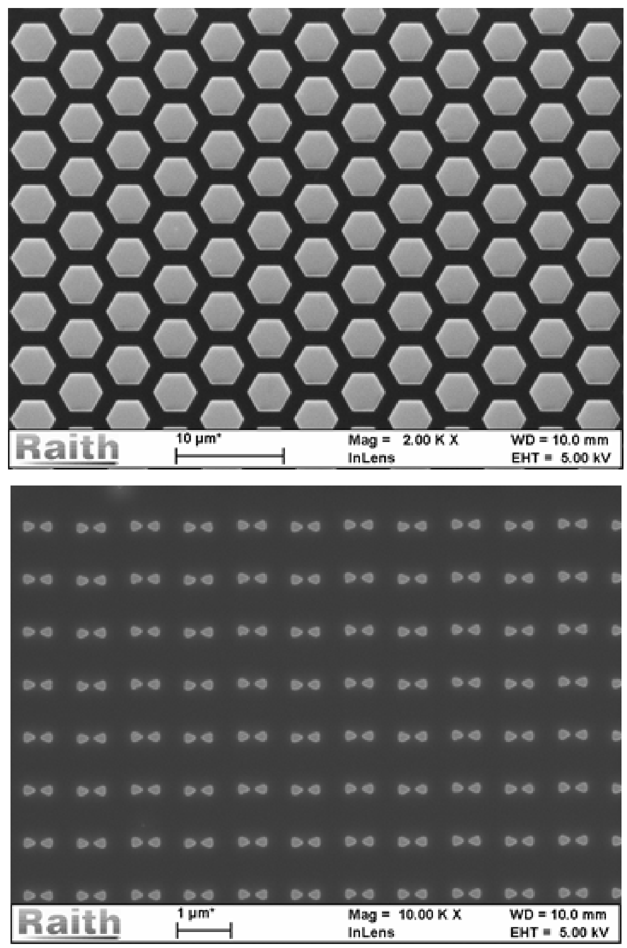
Figure 6 shows an image of a 1x1 mm^2 grating written by MBMS. Optical images of large area gratings are classicaly very sensitive to stitching errors and field distortion imperfections down well below the 100 nm regime. The image show no visible patterning strip-error or blemishes. Likewise, qualitative SEM inspection of the photonic crystal pattern of Figure 3 also exhibits no obviously noticeable strip-error.

The inset of Figure 6 is a SEM image showing low line edge roughness. This is noteworthy because the grating was also exposed at rather high speed. The 1x1 mm^2 area was written in approximately 30 minutes.

4 CONCLUSIONS

The MBMS patterning method proves to be a viable way to create high fidelity micro/nano scale structures of a periodic nature, with truly stitch-error-free performance in 1D. Large-area 2D patterning also shows exceptional performance, and with higher throughput than conventional write-and-step strategies.

The MBMS exposure method is capable of patterning a wide range of applications, ranging from simple line gratings, to otherwise seemingly complicated patterns (see Fig. 7).



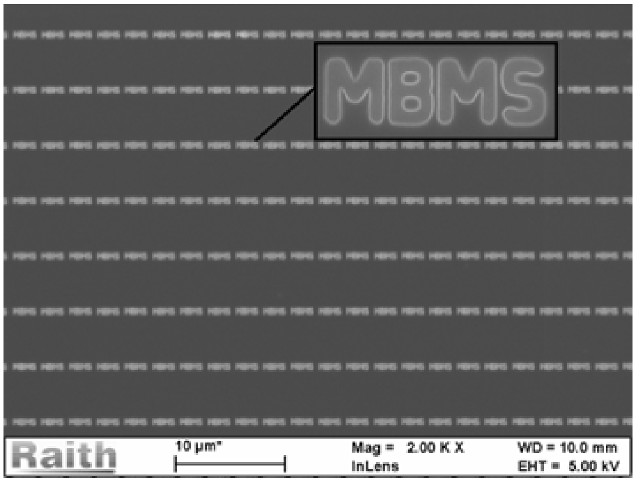


Figure 7: Examples of various periodic patterns written using MBMS.

REFERENCES

[1] D. J. Dougherty, R. E. Muller, P. D. Maker, S. Forouhar, J. of Lightwave Technol., 19, 1527-1531, 2001.

[2] G. Pagnotta, L. O'Faolain, D. O'Brien, T. F. Krauss, Microelectron. Eng. 84, 1463–1466, 2007.

[3] J. Sanabia, J. Klingfus and M. Aktary, oral presentation, Nanotech 2010.