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Focused Ion Beam milling of Diamond Waveguides

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I. Introduction

Diamond is unmatched in its optical, mechanical, thermal and electrical properties. Its high thermal conductivity, extensive chemical inertness, biocompatibility, high density, large Young modulus and ability to produce single photons are also of great benifit for various applications. It is transparent from the deep ultraviolet to the far infrared and in addition, it has a high refractive index of 2.4 [1]. This allows for small waveguides with sharp bends, crucial for nanophotonic integration. In this work, diamond waveguides are etched by focused ion beam (FIB) using an automatic alignment procedure for stitching.

II. Diamond Waveguides

A. Thin layers of diamond

In recent years, it has become possible to grow thin layers of synthetic diamond on a wide range of substrate materials using chemical vapor deposition (CVD) [2]. This is a key step in developing diamond integrated optical circuits, because vertical light confinement is now automatically achieved by growing the diamond layer on a low index material.

For this work, diamond was grown by CVD at the Institute for Material Research of Hasselt University. Layers of various thicknesses (100 to 475 nm) were grown on a micron thick SiO_2-layer on top of a Si-substrate. The grain size and consequently surface roughness increase with layer thickness. In figure 1 the surface of the 475 nm thick sample can be seen.

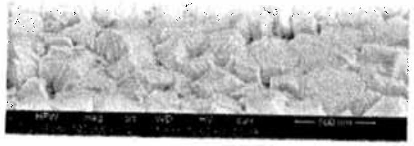

Figure 1. SEM image of the diamond surface.

B. Focused Ion Beam

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. In addition, images can be made by scanning the entire field of view and recording the secondary electrons for each pixel.

At any given magnification, the number of points that can be addressed individually is the same. Reducing the magnification (i.e. increasing the field width) will thus lead to less accurate structures. When large or long structures, such as waveguides, are required, 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.

C. Automatic alignment procedure

Using the runScript application from FEI company, an automatic alignment procedure was programmed. The horizontal field width was chosen to be 100 μm and the waveguide is built up out of pieces of 80 μm. Figure 2a shows the two trenches and alignment markers that are etched in black. After etching, areas A and B are imaged and stored as reference images. The next step is to move the stage over 80 μm and take images of areas A' and B'. 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 is etched.

Figure 2b shows result of this stitching procedure. It can be repeated as often as required.

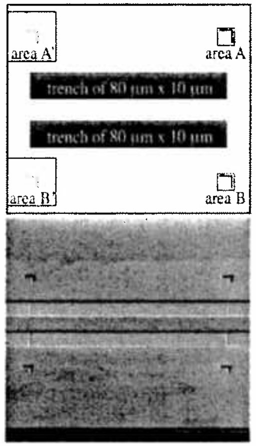

Figure 2. Automatic alignment procedure for stitching: a. scheme and b. SEM image of result.

D. Light coupling

There are various approaches to couple light in and out of a waveguide. One way is to etch the waveguide from side to side of a thin sample and focus light onto one of the facets. The outcoupled light is collected by an objective lens and measured with a power meter. It is however difficult to obtain clean facets and there is a very low alignment tolerance.

In silicon photonics, grating couplers are often used to couple light between optical fibres and waveguides in a vertical way [3]. The coupling efficiency is wavelength dependent and can be simulated. Grating couplers were etched with FIB using a lower current (1nA), see figure 3. Both facet coupling and grating coupling measurements were attempted, but so far, no unambiguous results could be obtained.

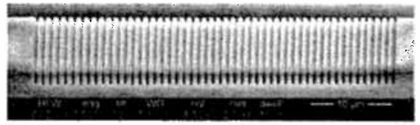

Figure 3. SEM image of grating coupler.

III. Conclusions

An automatic alignment procedure was used to stitch waveguides. FIB etching allows for a very short development cycle. Attempts to couple light by facet coupling (horizontally) or grating coupler (vertically) so far didn't result in loss figures. Further efforts will be made to improve waveguide stitching and optimize the grating design and fabrication. Furthermore, it wil be crucial to reduce surface roughness, since this is expected to cause large losses.

Acknowledgments

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