Nanofabrication of Photonic Crystal-Based Devices Using Electron Beam ***Spot*** Lithography Technique

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Abstract: Photonic crystal-based devices are fabricated via the ***Spot*** Lithography technique using electron beam lithography and reactive ion etching. This technique produces uniform, submicron and nanometre scale periodic holes over large areas in the millimetre range and the write time is a factor of 200 less than the conventional technique.

Key words: electron-beam nanolithography, photonic crystals, nano-devices, high-throughput nano-patterning

Introduction: Photonic crystal-based devices have a wide range of technological applications in sectors such as telecommunication, medical and sensing. Since these devices involve features on the sub-micron and nanometre scale, electron beam lithography is the most suitable fabrication technique. However, this technique has a very low throughput, particularly when periodic arrays of holes with very high resolution over large areas in the millimetre range [1] have to be defined. The Electron Beam Spot Lithography (EBSL) technique has been used to write periodic holes with dimensions as small as 30 nm over a 10x10 mm area. For an equivalent pattern design, size and feature dimension, the E-Beam write time takes approximately 90 mins compared to 19200 mins using the conventional meander direct-write strategy, used in most E-Beam tools, representing a write time reduction factor of more than 200. This write strategy exploits the Gaussian beam which is inherently circular in shape to define the photonic crystal holes. The 'spot-by-spot' lithography concept [2] reported earlier reduces the write time by only an order of magnitude. This work aims at developing the '*spot lithography'* technique to reduce the write time drastically and also, to implement novel methods to write periodic holes in several other geometrical arrangements. Moreover, this technique can reduce resist and substrate heating [3], particularly on non-conducting substrates. Photonic crystal devices such as a photonic crystal microcavity filters are fabricated and the pattern fidelity and device performance are compared with equivalent devices [4] manufactured with the conventional technique.

Fabrication: The material chosen was a Silicon-on-Insulator chip coated with a 150 nm ZEP520A resist. A 10x10 mm array of periodic holes with a 200 nm pitch was defined using the ***spot*** lithography technique on a Vistec EBPG5000+ system. The electron beam voltage and current were 100 kV and 5 nA, respectively. The sample development was carried out in ZED-MAC for 60 secs and rinsed in a solution of MIBK: IPA (9:1) for 30 secs. Fig. 1 shows the impact of increasing beam dose on the hole diameter. Fig. 2 shows a section of a 10x10 mm array of periodic holes with a nominal diameter of 50 nm, at a beam dose of 50 µC/cm^2, with the insets showing uniform holes and their cross-section with vertical side walls.

Conclusion:

The patterning of large areas of sub-micron holes in photonic crystal-based devices using the conventional electron beam tool is quite slow. The EBSL technique can reduce the write time by at least a factor of 200 and produces uniform holes with high reproducibility. This technique could be a potential candidate for the mass fabrication of photonic-crystal based devices and other devices requiring sub-micron or nano-scale pattern definition over large areas. Also, this technique can substantially reduce substrate and resist heating.

References:

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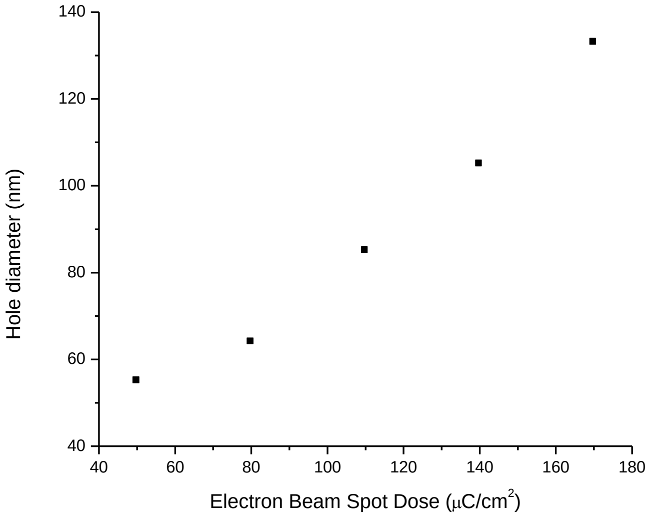
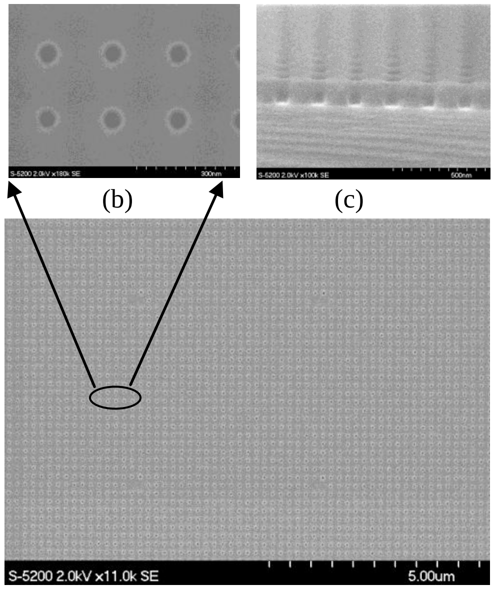


Fig. 1: Variation of hole size diameter with increasing electron beam spot dose, using a 5 nA beam current.



(b) (c)

(a)

Fig. 2: (a) Photonic crystal holes of 55 nm diameter with a periodicity of 200 nm fabricated using Electron Beam ***Spot*** Lithography, with insets (b) close-up view of the 55 nm holes, (c) cross-section profile of the holes.