Fabrication of Si Photonics Waveguides by Thick Resist-Mask Electron Beam Lithography Proximity Effect Correction

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1. Introduction

Silicon photonics has been an active research field in the last decade due to the potential of optoelectronics integration [1]. Silicon photonics devices can be integrated within a CMOS compatible process to yield high performance Si chips that offer optical functionalities with reduced cost. Hence, it can be a promising candidate to exceed the speed bottleneck for data interconnects.

Electron beam lithography is a convenient patterning process for R&D applications, including Si photonics [2]. However, long exposure time and pattern proximity effects are the main drawbacks that are discussed in this work.

2. Experiment Results

In this process, 700 nm thick ZEP resist is used as a soft mask for ICP-RIE of 220 nm top Si to fabricate 500 nm width SOI waveguides. Since forward and backward scattering of the e-beam causes beam broadening and proximity effects respectively, proximity effect correction (PEC) is used to control pattern width and to allow for narrow side-cladding trench to reduce the exposure time.

Firstly, the beam shape is deduced experimentally by the line-spread function (LSF) method [3], as shown in Fig. 1. Single isolated lines with various dosage are exposed with 50 kV system, developed in ZED-N50 for 30 secs, and measured. Since the resist is relatively thick compared to the conventional thickness around 200 nm [4,5], measurements are performed for the bottom width as the critical dimension needed to control. The main difference in this work is that development is performed after cleavage to allow the resist to interact directly with the cross-section without development loading effects taking place in narrow line grooves. Hence, extracted widths and beam shape are more accurate, especially for small widths corresponding to short- and mid- range scattering.

Higher-order Gaussian functions have been used in literature for more accurate fitting of the radial beam intensity function [4,5]. Thus, the extracted LSF is fitted to a 4-Gaussian function and used in BEAMER software [6] to expose a dose modulation calibration pattern that consists of 500 nm waveguides with various pattern densities at various base dosage. As shown in Fig. 2, the base dose is at 190 $\mu C/cm^2$ where the resist bottom width is least affected by the pattern density.

Finally, the 500 nm × 220 nm waveguide is fabricated with 5 µm and 1 µm side-cladding trench without and with PEC, respectively. As implied in Fig. 3, PEC allows for more sharp resist sidewalls that improves the pattern shape. Therefore, various passive optical devices can be fabricated with a relatively thick resist mask without a SiO_2 hard mask. Hence, possible under-etching of the buried-oxide can be avoided during hard mask removal.

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References

[1] R. Soref., *IEEE* **12(6)**, 1678 - 1687 (2006).
[2] Y. Atsumi, *et al.*, *JJAP* **53**, 06JB04 (2014).
[3] S. Aya, *et al.*, *JJAP* **35**, 1929-1936 (1996).
[4] S. J. Wind, *et al.*, *JVST* **7(6)**, 1507 (1989).
[5] H. Kobinata, *et al.*, *JJAP* **42**, 3816-3821 (2003).
[6] https://www.genisys-gmbh.com

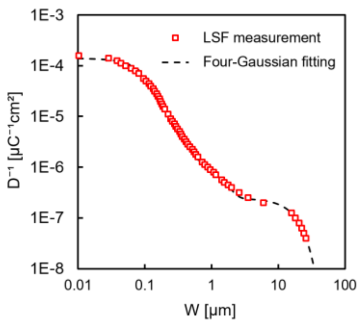

Fig.1 Line-spread function fitted to 4-Gaussian model

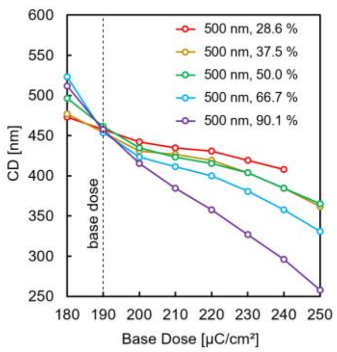

Fig. 2 Waveguide pattern bottom width at various pattern densities vs. the base dose

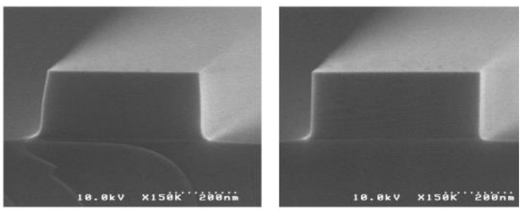

Fig. 3 500 nm width waveguide (a) without PEC, and (b) with PEC.