Si photonic device uniformity improvement using wafer-scale location specific processing

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***Abstract*—We report two-fold improvement in Si photonic device uniformity over a 200mm SOI wafer through location specific processing. A within wafer thickness non-uniformity of 0.8nm yielding a grating fiber-coupler peak-wavelength non-uniformity of 1.8nm is achieved.**

I. Introduction

Over the years silicon photonics has matured from being a research interest to a commercial reality. Being a high-index contrast material, Si PIC allows compact circuits reducing foot by many orders of magnitude compared to traditional silica-on-Silicon based circuits. The drawback of high confinement when using 220 nm Silicon on top of 2000 nm BOX is the high dependence of device response to dimensional variations (thickness, line width and etch depth). For example, a simple device such as a grating fiber coupler will see its peak coupling wavelength shift by 2nm for only 1nm of silicon thickness variation. This illustrates the important of dimensional control for commercial viability of highly confined Si PICs. Hailing from semiconductor industry, these wafers have within wafer thickness non-uniformity(NU) of ± 10% nm, which is too large to make matched devices. Hence identifying schemes to address the NU issue for wafer-scale manufacturing process has become more important.

In this paper, we present within wafer grating fiber-chip coupler uniformity improvement through location specific thickness correction using Gas Cluster Ion Beam (GCIB) etching. We also present the effect of the location specific process on the chemical composition and optical quality of Si surface.

II. Effect of thickness variation

Grating fiber-chip couplers are simple yet an essential device in a PIC to couple light in and out of a chip. A grating coupler at 1550 nm is defined by a linear grating with a pitch of 630nm and 50% fill factor. The grooves were 70 nm shallow etch in 220 nm thick Si to create the refractive index modulation [1]. Any deviation in these dimensions would shift the peak wavelength of the coupler. Fig. 1 depicts simulated effect of linewidth, etch depth and thickness variation on the peak wavelength of the coupler. As mentioned earlier, the effect of thickness variation is one order of magnitude higher than the width variation.

III. Experiment

A. Thickness correction process

Location specific thickness correction is a process though which a predetermined amount of thickness is removed by scanning an ion beam to reach a targeted Si thickness. The etching ion beam is generated by a CHF3/O2 plasma and directed toward the wafer [2]. Since our devices are designed for 220 nm thick silicon we need to increase first the layer thickness by using epitaxy to 245nm in order to eventually reach 228 nm after thickness correction process. After thickness correction, the contamination created by the plasma on the surface is cleaned by a curing process involving thermal oxidation (at 900 C) and subsequent removal of that layer using buffered hydrofluric acid resulting in final SI thickness of 220 nm. Grating couplers and waveguides were patterned by etching 70 nm and 220 nm into Si respectively both using 193 nm optical lithography and dry etch process. We also fabricated same devices in un-corrected wafer as reference. The chemical and physical property of the Si surface after correction and defect curing process was also done using X-ray photoelectron spectroscopy and atomic force microscopy respectively. The optical quality of Si was evaluated through propagation loss measurement in the photonic wire waveguides.

IV. Results and discussion

A. Si thickness uniformity

Fig. 2 shows Si layer thickness over a 220 mm wafer before and after the correction process. Using a thickness correction process, we were able to reduce the NU (3σ) from 3% to 1% while the range is reduced from 11.5 nm to 5.1 nm. It has to be noted that defect curing process did not change NU of the Si layer.

B. Post-correction surface and optical quality

Fig. 3a shows the chemical contamination (C anf F) originating from the plasma source on the Si surface. We clearly observed reduction in contaminants after defect cure process. With AFM, we measured a surface roughness of 0.4 nm, slightly higher than the virgin wafer roughness of 0.1 nm. However, low enough to achieve low-loss waveguides

We measured a loss of 1.77±0.3 and 1.46±0.16 dB/cm (Fig. 3b) for corrected and un-corrected wafer. Compared to un-corrected wafer an excess loss of 0.29 dB, which is well within

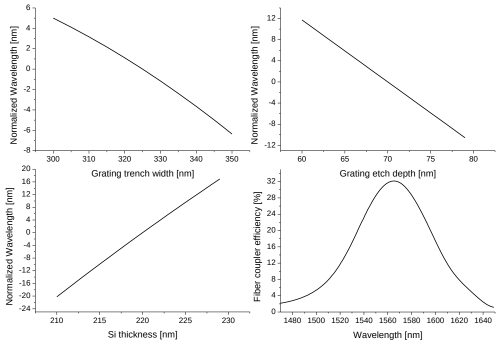
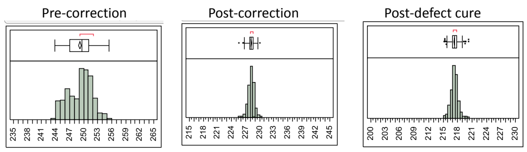


Fig. 1: Effect of dimensional variation on fiber coupler characteristics.



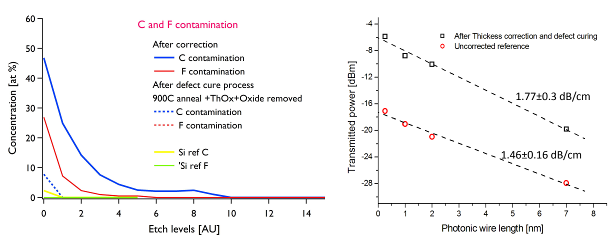
	Pre-correction	Post-correction	Post-defect cure
Mean (nm)	249	228	220
Range (nm)	11.5	5.1	6
1σ (nm)	2.5	0.8	0.8

Fig. 2: Si thickness distribution over a 200mm wafer (361 sites).

measurement error margin. Through this low-loss waveguide we confirm that physical and chemical quality of Si is not degraded due to the correction process.

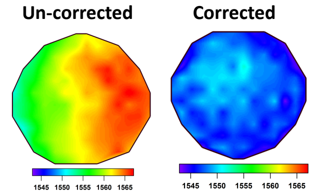
C. Grating fiber coupler uniformity

Uniformity of the grating fiber coupler was extracted from the transmission spectrum of a 2 mm long waveguide with identical coupler at both the ends of the waveguide. Fig. 4 shows the peak wavelength map of the fiber couplers from thickness corrected and un-corrected wafer. Since the final Si thickness of the corrected wafer was 217 nm there is a red shift in the average peak wavelength compared to the un-corrected wafer whose mean Si thickness was 221 nm. Nevertheless, it can be clearly seen that the range and standard deviation of the corrected wafer is 2 fold better than the un-corrected wafer.



(a) (b)

Fig. 3: (a) Carbon and Fluorine contamination. and (b) Photonic wire loss of corrected and un-corrected wafer.



	Un-corrected	Corrected
Mean (nm)	1561.31	1547.49
Range (nm)	16	8.5
1σ (nm)	3.76	1.80

Fig. 4: Grating fiber coupler peak wavelength over a 200 mm wafer.

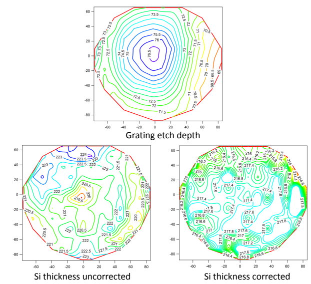


Fig. 5: Etch depth and Si thickness Non-uniformity

We observe an interesting distribution between corrected and un-corrected wafers. In the un-corrected wafer, the peak wavelength has a red shift from east-to-west, while we observe a familiar radial pattern in corrected wafers. Correlating the spectral response with the etch depth and thickness data collected during fabrication (Fig. 5), we observe that overlap of radial yet tilted (east side of the wafer has higher etch depth compared to west) NU of etch depth of the gratings and radial Si thickness NU is causing an east-to-west shift in peak wavelength in uncorrected wafer. The corrected wafers do not have the radial pattern of the silicon thickness which makes etch depth NU emerges clearly from the spectral response. Hence, in corrected wafer etch depth NU is identified as the dominant NU source, while in uncorrected wafer combination of both thickness and etch depth affect device NU. We also show the spectral response correlated well with the simulated spectrum from measured device dimensions.

V. Conclusion

We have shown a pre-pattern thickness correction using location specific processing though which we achieved 50 % reduction in fiber coupler non-uniformity over a 200mm SOI wafer.

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