Reducing optical losses in Focused-ion-beam etched silicon by annealing

ePIXnet JRA Focused Ion Beam for Photonics

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What is Focused ion beam?

Introduction
Why exploit FIB in silicon?

Introduction

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How to reduce the GIGANTIC losses?

High optical losses in FIB etched silicon due to:

- Gallium implantation
- Crystal damage

What we propose to do:

- Preventive:
  - I$_2$ enhanced etching
- Regenerative:
  - Recrystallization and out-diffusion by annealing
  - Dry etching of a thin damaged layer
Outlook

1. Introduction
2. The experiment
3. The results:
   - I₂ etching
   - Annealing
   - Dry etching
Etching broad and narrow waveguides

2. The experiment

Dose: 5 x 10^{15} \quad 1 x 10^{16} and 1 x 10^{17} Ga/cm^2
Etch depth: 0 nm \quad 0 nm \quad 80 nm

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Measurement setup

2. The experiment

S-LED
Pol control
Spectrum analyser

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Iodine reduces losses

Dose $5 \times 10^{15} I_2$ enhanced etch

Losses (dB)

Implanted length ($\mu$m)

iodine etch: 1700 dB/cm

direct etch: 3500 dB/cm

3.1 $I_2$ etching
BUT iodine sticks and must be baked out

- Iodine desorbs by baking 2 hours in N₂ at 300°C
- Energy Dispersive X-ray spectroscopy (EDX) supports this

Confirmed by X-ray Photo-electron Spectroscopy (XPS)!!

3.1 I₂ etching
Iodine desorption reduces the losses

3.1 $I_2$ etching

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Annealing: what do we expect?

FROM SEMICONDUCTOR WORLD:

2h @ 500-600°C:
- Recrystallization of the amorphized region (Solid Phase Epitaxy)
  - Might reduce losses
- Electrical activation of gallium
  - Increases losses

2h @ 800-1000°C:
- Diffusion of Ga in Si over > 100 nm
- Diffusion of Ga in SiO₂ over > 1000 nm
BUT: Semiconductor world??

5 \times 10^{15} \text{ Ga/cm}^2 \sim \text{peak concentration of } 3.5 \text{ at}\% \text{ Ga in Si}

1 \times 10^{17} \text{ Ga/cm}^2 \sim \text{peak concentration of } > 20 \text{ at}\%

= \text{Very High} !!
Annealing reduces the losses

1 \times 10^{17} \text{ on wire}
1 \times 10^{16} \text{ on wire}
5 \times 10^{15} \text{ on slab}
5 \times 10^{15} \text{ on slab with I}_2
Reactive ion etch removes damaged layer

- Ga is implanted shallowly into Si (<70 nm)
- This shallow layer is removed by dry etching in CHF$_3$/O$_2$ plasma

3.3 Dry etching
JRA FIB for Photonics:
Loss reduction of FIB etched silicon by annealing

- The experiment

- The results:
  - $I_2$ etching: $200 \text{ dB/cm} @ 300^\circ\text{C}$
  - Annealing: $75 \text{ dB/cm} @ 1000^\circ\text{C}$
  - Dry etching: $1000 \text{ dB/cm}$
3.1 $I_2$ etching

Confirmed by SIMS

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