Microfabrication, Strain Characterization by Raman Spectroscopy and FEM Simulation of Suspended Strained Silicon Micro-bridges

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1. Abstract

Suspended silicon micro-bridges were fabricated using current CMOS processes on sSOI (Strained Silicon on Insulator) wafers in order to achieve greater strain than then one originally embedded in the sSOI wafer, which had 0.8% biaxial tensile strain. Then a maximum strain of 2.3% was obtained by measurements using Raman spectroscopy with a laser wavelength of 514nm. The experimental result was then compared with FEM simulations using COMSOL®, which showed matching results, thus demonstrating great accuracy.

2. Introduction

Strained silicon has become an alternative for the continuing process of scaling MOS transistors due to enhancement of carrier mobility which is caused by strain, which in turn improves the transistor's operation velocity[1].

Techniques using lattice mismatch has been developed to get thin strained silicon films with strain up to ~1.2%[2]. Reference[2] proposed the nanofabrication of suspended structures on a pre-strained silicon substrate of 15nm thickness (sSOI) in order to obtain a highly strained silicon Nano bridge (with strain up to 4.5%) using CMOS compatible processes. In this work was used the same approach of [2] to obtain structures at the micro scale. The strain characterization was performed by Raman spectroscopy due to its easy operation, high resolution for local strain measurements, high sensitivity and a non-destructive methodology[3].

For the validation of the experimental measurements and a complete understanding of the strain distribution at the micro bridge, FEM simulations were performed using COMSOL®.

3. Results and Discussion

1. Fabrication of suspended strained silicon micro bridges

The micro-bridges were fabricated using an sSOI wafer that consists of a thin pre-strained silicon film of 15nm width (biaxial strain of ~0.8%) [4] on top of a 145nm layer of SiO_2.

For the fabrication of the microstructures, a two-stage process using conventional photolithography was performed. In the first step, the patterns of the micro-bridges were transferred to the wafer with posterior Reactive-ion etching (RIE) of the exposed silicon film. On a subsequent step, we removed the photoresist film and then performed a wet etching of the exposed SiO_2 layer using a 7% HF buffer as shown in Figure 1.

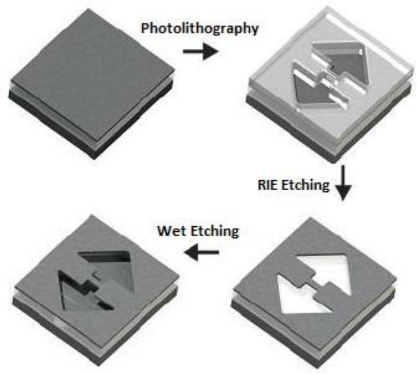

Figure 1. *Simplified micro-fabrication process*

In order to control the wet etching process under the micro-bridge, we make use of a second mask in a photolithographic process. This part of the process achieves the final goal of suspending our microstructure and thus obtaining a highly strained micro-bridge.

The result of the process described above, is the suspended micro-bridge shown in Figure 2.

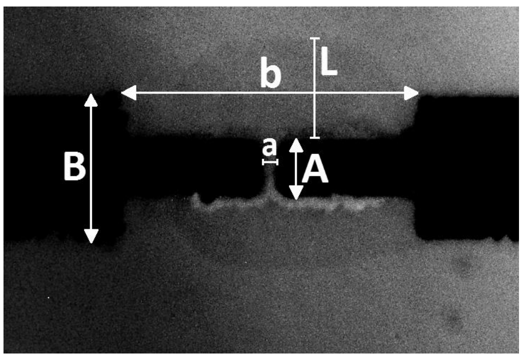

Figure 2. *Suspended and strained Si micro-bridge with dimensions A= 3.88μm, a=1.19μm, B=9.76μm, b=21.11μm and L=5.5μm.*

2. Strain characterization using Raman Spectroscopy

Micro-Raman measurements were performed both at the center of micro-bridge and at un-patterned locations in the sSOI wafer using a Raman Spectrometer with a 514nm laser wavelength. This results in the graph shown at Figure 3.

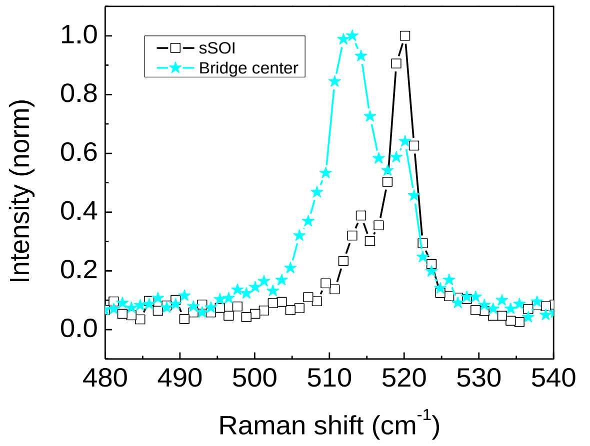

Figure 3. *Raman spectrums of the sSOI wafer (square) and the micro-bridge center (star).*

The strain at the center of the micro-bridge can be determined by the semi-empirical equation for uniaxially strained silicon[2]:

$$\Delta\omega = -3.27 cm^{-1} \times \varepsilon_{xx} \qquad (1)$$

Where:

$\Delta\omega$: Raman shift between the reference peak of a regular silicon substrate (~520 cm^{-1}) and the measured peak at the micro-bridge center (~512.5 cm^{-1}).

ε_{xx}: Strain at the micro-bridge center in percentage (%).

Using the equation presented at (1), a strain of approximately 2.3% is calculated at micro-bridge center. As an additional measurement, the biaxial strain on unused areas of the sSOI wafer is ~0.8% with a peak at ~514.5cm^{-1}[2].

4. FEM Simulations

The COMSOL® Model for our study has the following characteristics: Area = 30µm x 30µm, Si film thickness = 15nm, SiO_2 thickness = 145nm.

For the Structural Mechanics study, an initial strain of -0.8% (0.8% tensile strain) was configured for the thin Si Film, this value is in agreement with the sSOI wafer characteristics used in our experimental study.

Following that initial simulation run, we then modeled the structure similar to the one fabricated experimentally as shown in Figure 2, with same dimensions A= 3.88µm, a=1.19µm, B=9.76µm, b=21.11µm and L=5.5µm. Next, some of the results processed from the COMSOL simulations are shown below in Figure 4 and Figure 5.

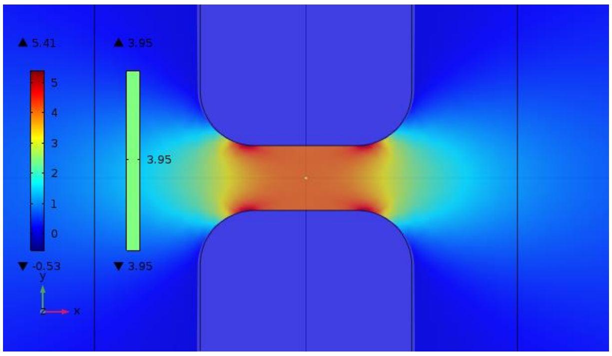

Figure 4. *Micro-bridge stress ranging from 0GPa to 5.4GPa. The value of stress at the micro-bridge center is 3.95 GPa.*

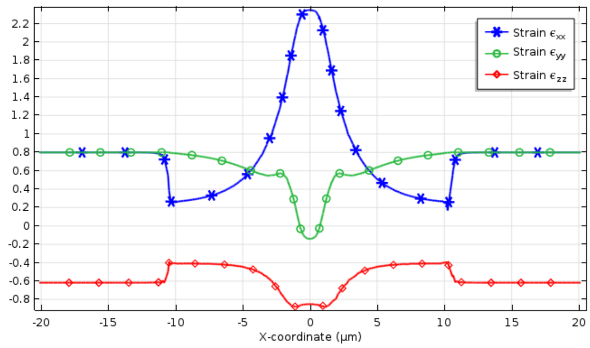

Figure 5. *Strain values at the cross section that goes through the micro bridge center. A uniaxial strain value of 2.35% is also maximum at the bridge center.*

5. Conclusions

From the obtained results, both computational and experimental, we verify that by creating a suspended structure or micro-bridge on a thin pre-strained Si film achieves an increase in the strain of the structure from its initial 0.8% (biaxial strain) to 2.3% (uniaxial strain) which corresponds to an increase of stress from 1.45 GPa to 3.95 GPa.

Acknowledgments

We thank the support by FAPESP and CAPES.

References

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