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Fatigue Testing of Poly-SiGe Film Using Microresonator

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Abstract

This paper describes fatigue testing of poly-silicon germanium (SiGe) film using microresonator and its fabrication process. 20-µm-thick SiGe composed of 30 at% silicon and 70 at% germanium was successfully processed with a deep reactive ion etching (DRIE) with modified processing conditions, even on comb structures with an aspect ratio higher than 10. We report the fabrication process and first two trials of fatigue testing, which showed fatigue fractures at 2.7 GPa.

1. Introduction

Poly silicon germanium (poly SiGe) has received a lot of attention as a material available for a monolithic fabrication of microelectromechanical system (MEMS) devices with complementary-metal-oxide-semiconductor (CMOS) integrated circuits. The monolithic fabrication is an efficient way to improve performances and reliability of the devices. In order to realize the monolithic fabrication, processing temperatures during the whole fabrication processes are required to be kept low enough to suppress degradation of the CMOS circuits. Poly-SiGe film can be compatible with CMOS circuits, owing to its low deposition temperature using chemical vapor deposition (CVD); 460 °C, while deposition of silicon film requires a stress relaxation step at higher than 1000 °C.

This research investigates fatigue life of poly-SiGe film to ultrahigh cycle using a fan-shaped microresonator. Mechanical properties of poly-SiGe films have not been fully investigated especially on film with highly-concentrated Ge, while some MEMS device applications have been already reported [1]. In this research, fatigue life of 20-µm-thick SiGe films deposited using CVD process with 70 at% Ge is studied. Processing conditions for the deep reactive ion etching (DRIE) of the poly-SiGe films is also surveyed in the specimen fabrication to realize narrow-gapped comb structures to excite the microresonator.

2. Experiment

Specimen design

A fan-shaped microresonator was used for the fatigue testing of the poly-SiGe film. The testing method can apply cyclic loadings at a high frequency, which enables us to measure ultrahigh-cycle fatigue lives in a short time. The testing method has been widely used in measurements of single-crystalline silicon films [2] and other films.

Figure 1 shows a design of the specimen. The resonator has two sets of electrostatic comb structures on both sides

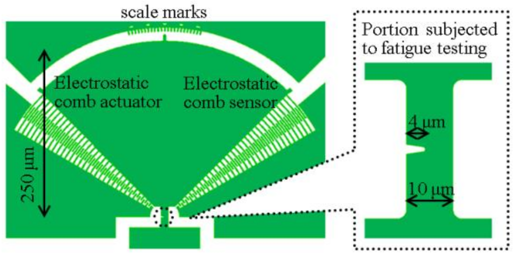

Fig. 1 Specimen design for fatigue testing using fan-shaped microresonator.

used as an actuator and a sensor for exciting the resonator and sensing the motion, respectively. The fixed end of the resonator where a notch was designed is subjected to cyclic loadings when the resonator is oscillated. The relationship between deflection angle and stress on the notch was calculated using finite element method (FEM) analysis. The resonator was oscillated around 25 kHz, which can achieve 10^8 cyclic loadings in about 1 hour.

Specimen fabrication

The specimens were fabricated from SiGe wafers, whose 20-µm-thick poly-SiGe film composed of 70 at% Ge was deposited using CVD processes on 675-µm-thick Si wafer coated with 1.8-µm-thick SiO_2 layer. Figure 2 shows the fabrication processes mainly using UV lithography and DRIE; Cr patterning for electrodes, SiGe patterning, silicon patterning from backside and SiO_2 wet etching.

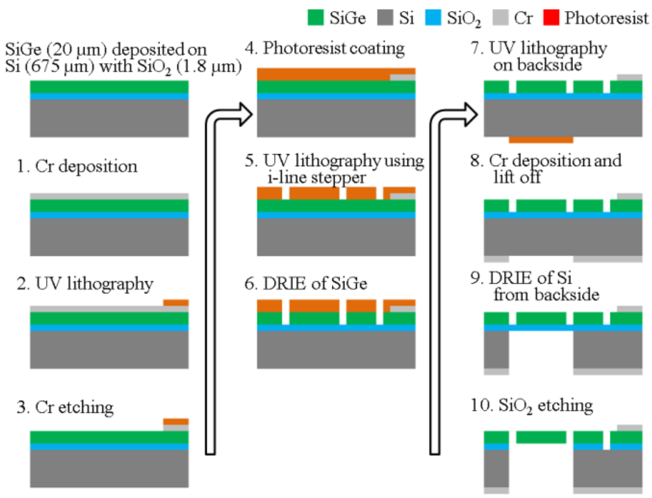

Fig. 2 Fabrication process of specimens for fatigue testing. SiGe and Si are patterned using UV lithography and DRIE.

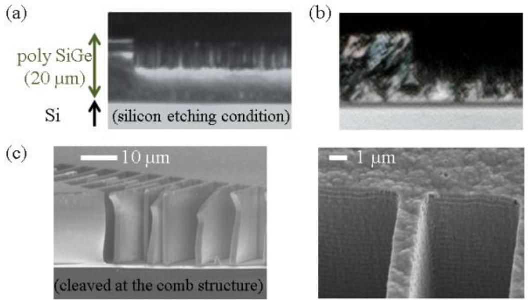

Fig. 3 Patterning results of SiGe using DRIE; (a) a process result using Si etching condition, (b) a process result using modified etching condition, and (c) comb structures patterned successfully.

DRIE of SiGe is a critical challenge in the fabrication, because DRIE processing conditions of SiGe films has not fully established, especially on films with a high concentration of Ge. The DRIE process was carried out using RIE-800iPBC at SAMCO Inc. Processing conditions were surveyed in detail to pattern the narrow-gapped electrostatic comb whose gap is 1.5 or 2.0 μm and aspect ratio is higher than 10.

Fatigue testing

The fabricated microresonator was oscillated by applying a direct-current (dc) and an alternate-current (ac) voltage under a microscope to monitor its deflection angle. A dc voltage of 40 V was applied for bias and ac voltage higher than 5 Vpp was applied to excite the resonator and control deformation amplitude of the resonator.

Two specimens were measured in the fatigue testing. In measurement of the first specimen, the deflection angle was increased every 10^7 cyclic loadings by 10 % increment of applied ac voltage. The second specimen was also tested with similar deflection increment until its deflection angle reached the angle at which the first specimen fractured, and then tested with constant deflection angle until its fatigue fracture happened.

3. Results

DRIE of poly-SiGe film

Figure 3 shows processing results of poly-SiGe films using DRIE. Processing conditions of DRIE were modified, because etching conditions for silicon were not suitable for etching the poly-SiGe film. The poly-SiGe film processed using silicon etching conditions had spikes starting near the top surface as shown in Fig. 3a, which indicates that the spikes occurred immediately after the DRIE started and prevent etching.

By modifying processing conditions of DRIE to have 20 %-higher bias power in a step for etching passivation layer on the bottom of etched trench, the spike occurrence was suppressed and showed small spikes on the bottom of trenches, as shown in Fig. 3b. In addition, applying processing conditions with 50%-longer etching time for the passivation layer and poly-SiGe film, 20-μm-thick poly-SiGe film was successfully patterned even on the narrow-gapped comb structures, as shown in Fig. 3c.

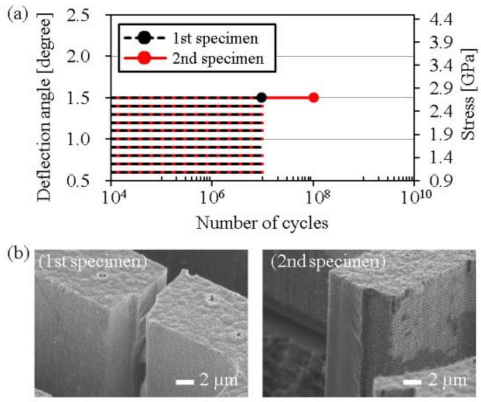

Fig. 4 Fatigue testing results; (a) fatigue lives, and (b) fractured specimens.

Fatigue testing results

Figure 4 showed fatigue testing results of the two specimens. Difference in these fatigue lives with deflection angle of 1.5 degree, corresponding to stress of 2.7 GPa in Fig. 4a, indicated a large dispersion in initial fracture strengths of the poly-SiGe film. Since the two fatigue fracture started at the side walls as shown in Fig. 4b, the fracture strengths were much affected by surface damage introduced during the DRIE. The two specimens had different roughness on the fracture surfaces, which indicated a possibility that the number of cyclic loadings affected the fracture progress.

4. Conclusions

Microresonator for fatigue testing of poly-SiGe film was successfully processed using MEMS process, and occurrences of fatigue fractures of poly-SiGe film were verified.

Fatigue testing up to 10^{10} cycles will be carried out with different stresses to obtain S-N (stress amplitude vs. number of cycles) curves.

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The DRIE process of SiGe was carried out using DRIE machine, RIE-800iPBC at SAMCO Inc. We appreciate their cooperation.

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