Fabrication of Micro Gyroscope on the SOI Substrate with Enhanced Sensitivity for Detecting Vertical Motion

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ABSTRACT

Reactive ion etching lag is used to fabricate capacitance sensor to detect vertical movement in a gyroscope. Aspect ratio of each trenches are controlled by inlet opening width. In comparison to present gap closing-type sensors, the sensor structure fabricated with RIE lag on silicon on insulator wafer shows bigger sensitivity.

INTRODUCTION

Micromachined gyroscopes for measuring the rate and/or angle of rotation have found many application areas such as automotive safety and stability control systems, video camera stabilization, and 3-D input devices for computers and personal data assistance (PDA) systems [1]. Those wide applications require a smaller and cheaper gyroscope instead of bulky and expensive gyroscopes such as rotating wheel gyroscopes, fiber optic gyroscopes and laser gyroscopes.

Microsensors that consist of mechanical and electrical elements are commonly referred to as micromechanical systems (MEMS). MEMS sensors present the advantages of being light in weight, being small in size, having low power consumption and low cost, due to standard IC fabrication techniques. With these benefits, research in MEMS gyroscopes has been accelerated and the performance of MEMS gyroscopes has been improved. Most MEMS gyroscopes are silicon-based vibratory sensors, which utilize the energy transfer between two vibrating modes of a mechanical structure[2]. The principle most-often exploited in building micromachined gyroscopes is the Coriolis force, expressed by the $\Omega \times \upsilon$, term in the equation of motion. One effective way to use this force is to create resonant motion of fixed amplitude in a direction perpendicular to the axis of rotation. The Coriolis force then induces motion in the third direction perpendicular both to the direction of rotation and to the driven motion[3]. To sense this rotation in a MEMS device, the vibration of suspended mechanical structures, i.e. comb structure, beam, disk or ring structures is used. To fabricate comb structure on single crystalline silicon (SCS) wafer, bulk (TMAH, or KOH etching) and surface micromachining (Reactive ion etching) is used. Instead of using deposited poly silicon (p-Si) as structure material, SCS wafers are used to obtain uniform properties and parameters of micromachined structures since it takes several hours or more to deposit a 2- m thick film and the material properties of amorphous silicon (a-Si) and p-Si vary significantly. In this work, a fabrication process that can increase sensitivity of sensors is presented.

REACTIVE ION ETCHING (RIE)

RIE process is a critical process in the fabrication to define structural shapes since micro-structures with larger height and smaller gap are preferred because they enhance the device performance significantly by increasing the electrostatic force between elements. Typical trenches and structures in the range of 10-500 μm in the MEMS fabrication have been etched over the entire substrate and processes are becoming well controlled. In the trench formation by RIE, etch rate is dependent on feature opening width. This is called RIE lag. Figure 1 shows etch rate depends on the opening width. Therefore, trench depth can be controlled by opening width defined by a lithography step.

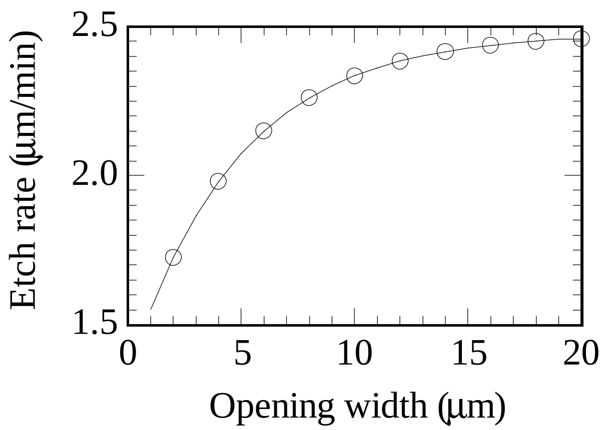


Figure 1 Etch rate dependence on opening width by RIE

APPLICATION OF RIE TO MICRO-GYROSCOPE FABRICATION PROCESS

SCS wafers are widely used in fabrication of microgyroscope since stable and reproducible mechanical properties provide enhanced productivity and reliability and it is easy to fabricate high-aspect-ratio microstructure for enhanced performance. However, gap closing type sensors shown in Figure 2 have several disadvantages: Metal deposition for the bottom electrodes, stiction problem and etc. Figure 3 shows process flow for SOI wafer technology. As shown in Figure 3(d) those comb structures vibrate in a way of gap closing mode. Therefore reverse biased p-n junction can be used to isolate two electrodes. To increase the sensitivity for vertical motion detection in a microgyroscope, following technology for fabricating vertical comb structure with RIE is provided. The depth of trenches are different by utilizing RIE lag in Si etching process as shown in Figure 4(a). As presented in Figure 4(e), the gap between moving cantilever beams and an oxide layer increases compared to the microgyroscope sensor structures shown in Figure 2 & 3. Therefore, the stiction problem can be overcome. Since the bigger deflection can be allowed in the moving cantilever beam, detection area can be enlarged. Moreover, in comparison to the micro comb structure shown in Figure 3 shown, by enlarging the surface area and increasing numbers of capacitors, the sensitivity of sensor can increase.

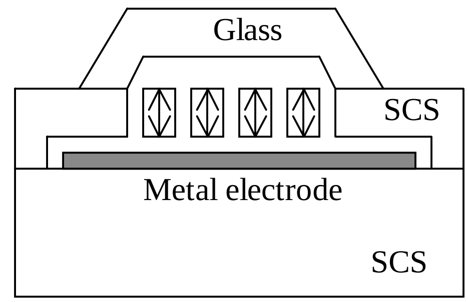


Figure 2 Microgyroscope fabricated on SOI or SCS wafers

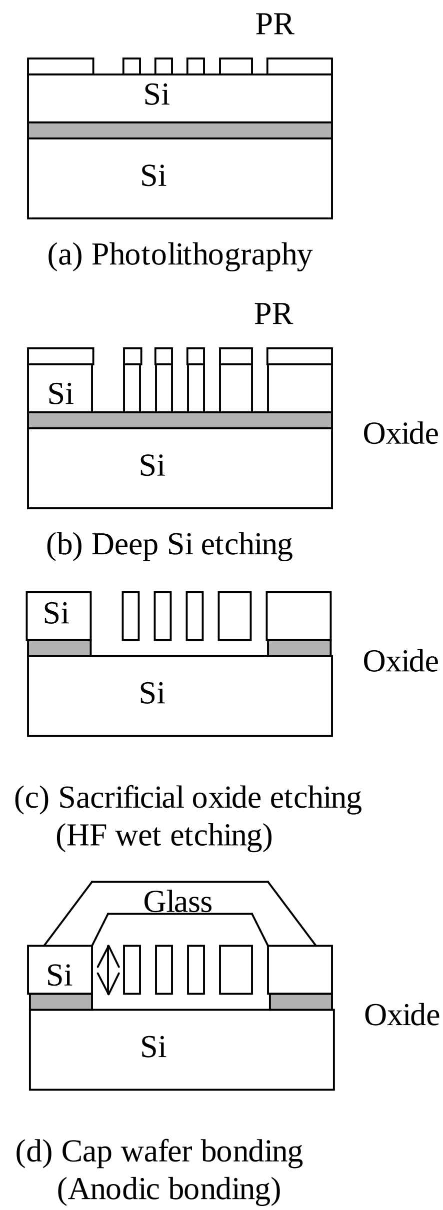
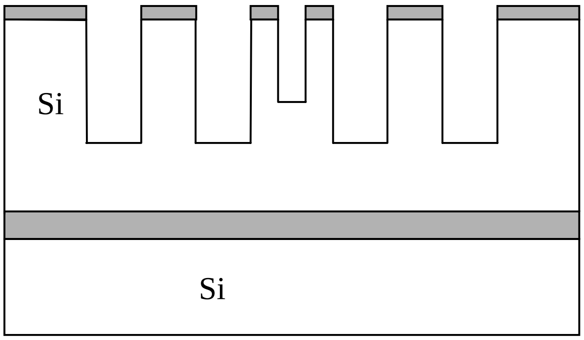
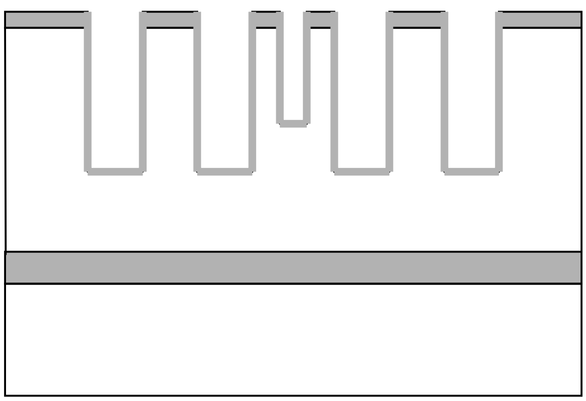


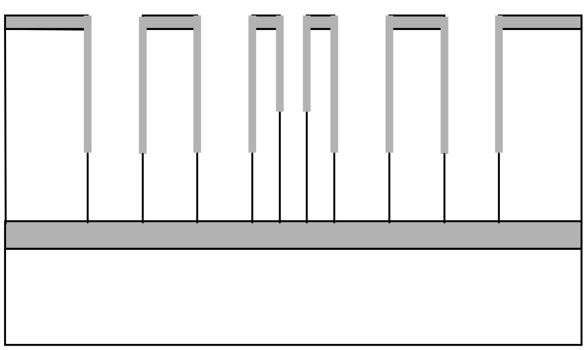
Figure 3 Process flow for SOI technology



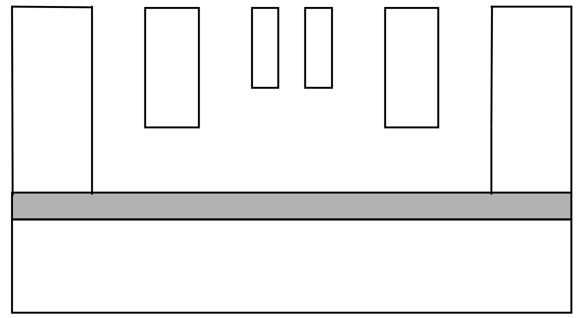
(a) Oxide patterning and deep Si etching



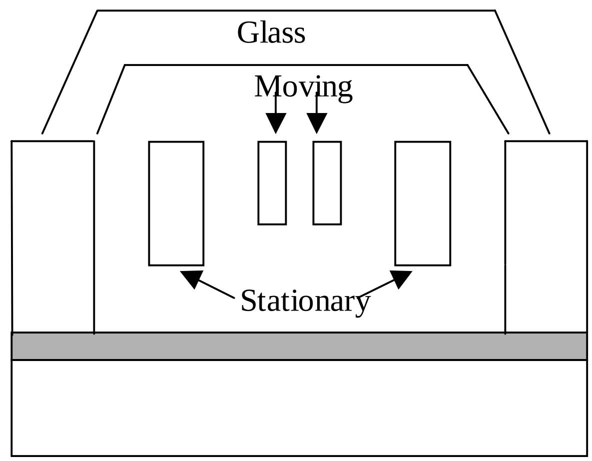
(b) Thermal oxidation for trenches



(c) Deep Oxide and Si etching



(d) Sacrificial etching (TMAH) of Si;
oxide mask and passivation layer etching



(e) Cap wafer bonding (Anodic bonding)

Figure 4 Process flow chart of fabrication of vertical comb structures on SOI wafer.

EXPECED RESULTS

Figure 5 presents simple model to compare the capacitance increase calculation by applying RIE lag technology. Vertically-placed parallel plates are shown in Figure 5(a) and vertical combs in Figure 5(b). The thickness of a cantilever is 5 μm and a gap between two electroplates is a minimum feature size of lithography, 2 μm. Therefore, N_g is 60, i.e. 60 capacitors. The deflection dz = 1 μm in the estimation. Capacitance between 2 electroplates is as follows:

$$C = \varepsilon_o \frac{A}{d}, \qquad (1)$$

where, ε_o is permittivity in the air gap, A is area of capacitor and d is a gap between electroplates. The C_o is calculated as follows:

(a)

$$\begin{aligned} C_o &= \varepsilon_o \frac{A}{d} \\ &= 8.85\times10^{-12}\,\mathrm{F/m}\frac{1000\mu\,\mathrm{m}\times 210\mu\,\mathrm{m}}{4\mu\,\mathrm{m}}, \\ &= 0.464\mathrm{pF} \end{aligned}$$

(b)

$$\begin{aligned} C_o &= \varepsilon_o \frac{A}{d} N_g \\ &= 8.85\times10^{-12}\,\mathrm{F/m}\frac{1000\mu\,\mathrm{m}\times 10\mu\,\mathrm{m}}{2\mu\,\mathrm{m}} 60 \\ &= 2.66\mathrm{pF} \end{aligned}$$

The sensitivity of sensors ΔC with displacement of dz = 1 μm:

(a)

$$\begin{aligned} \Delta C &= \varepsilon_o \frac{A}{d} - \varepsilon_o \frac{A}{d+dz} \\ &= \varepsilon_o \frac{Adz}{d(d+dz)} = 92\mathrm{fF} \end{aligned},$$

(b)

$$\begin{aligned} \Delta C &= N_g \varepsilon_o \frac{L\times w}{d} - N_g \varepsilon_o \frac{L\times(w-dz)}{d} \\ &= N_g \varepsilon_o \frac{L\times dz}{d} = 265\mathrm{fF} \end{aligned}.$$

By simple calculation, the sensitivity of the sensors made with RIE lag technique is around 3 times higher.

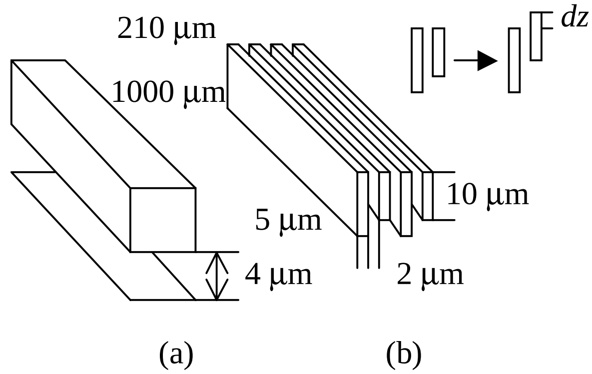


Figure 5 Comb structure capacitance calculation models

SUMMARY

Vertical comb sensor structure is fabricated on SOI wafers by RIE lag method. The obtained capacitance is 3 times greater in same unit area.

REFERENCE

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