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# SCREAM FOR MULTI-LEVEL MOVABLE STRUCTURES BY INDUCTIVELY COUPLED PLASMA PROCESS

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## ABSTRACT

A novel fabrication process to etch, to passivate, and to release single-crystal silicon structures totally in just only one process by inductively coupled plasma reactive ion etching (ICP-RIE) has been presented in this paper. Several kinds of movable actuators such as relay, comb-drive, and capacitance with thickness of 30 μm have been fabricated successfully to demonstrate this fabrication process. Here, experimental investigations about fabrication parameters to get well profile and suspension structures are performed in a STS ICP-RIE system.

Keyword: Inductively coupled plasma reactive ion etching (ICP-RIE), Micro-Electro-Mechanical Systems (MEMS), Actuators

## INTRODUCTION

Silicon etching is an essential process step for the fabrication of Micro-Electro-Mechanical Systems (MEMS). Silicon micromaching has been utilized since the early 1960's. In the early 1980's, surface micromaching using sacrificial etching gave rise to fabricate microsensors and actuators. Recently, reactive ion etching silicon micromaching was used to fabricate high aspect ratio microstructures or even movable structures by the use of isotropic etching [1,2]. RIE technology has given tremendous impetus to dry etching of single-crystal silicon. Single-crystal silicon has excellent mechanical properties. So, many fabrication methods have been developed to make microstructures out of single-crystal silicon, including single-crystal silicon reactive ion etch and metallization (SCREAM) and silicon-on-insulator (SOI) process [3,4]. This paper presents a fabrication process to make movable microstructures by accurate fabrication parameters control in only ICP one process.

## FABRICATION

All the experiments are done in the STS Multiplex ICP system. The Advanced Silicon Etch (ASE) is based on the technique invented by Lärmer and Schilp [5,6]. In this paper $SF_6$ and $C_4F_8$ are used as the etch and passivation gases respectively. Some crucial parameters in the process such as gas flow rate, etching cycle time, etching overrun time, process pressure, coil and platen power have been systematically explored [7,8]. In the SCREAM process, silicon dioxide is used for sidewall insulation film conventionally. Here, the $SiO_2$ has been replaced with the $(C_xF_y)_n$ polymeric passivating film that was deposited by $C_4F_8$ plasma. Different materials such as silicon dioxide, photoresist, nitride and metal could be chosen as etching masks. In this way, several multi-level movable structures have been successfully fabricated in seven steps within one ICP process. The entire fabricated steps are using ICP dry etching process, and the fact that stiction dose not exist makes this technique more reliable.

The fabrication process of multi-level comb-drive is summarized in Figure.1. The silicon dioxide film is patterned using first mask on a < 1 0 0 > silicon substrate. Then, the positive photoresist(AZ4620) is spun on the wafer and patterned using second mask. The silicon dioxide and photoresist are the etching masks in the ICP etching process. The thickness of structure is determined at the first ASE step. The polymeric passivating film $C_xF_y$ is deposited on the silicon structure and the thickness of the $C_xF_y$ polymeric passivating film is must enough to protect the structure from attack during the isotropic etching step for releasing the movable structure. Then, the $C_xF_y$ polymeric passivating film on the bottom is removed by anisotropic etching step. The microstructure is released by isotropic etching. After the movable structure is formed, the photoresist mask was removed by $O_2$ plasma. The various thickness of the spring construction is etched according to the $SiO_2$ etching mask. The polymeric $C_xF_y$ is deposited again both on the top and the sidewall of the structure as the isolated film. Finally, the metal layer is sputtered as the electrode on the structure's surface.

Among one of the implementations, the comb-drive is a typical example to demonstrate the performance of the process. The characteristics of the comb-drive actuator are determined by the spring thickness. The simulation results shown in Figure.2 indicate that the displacement and the nature frequency both can be tuned by changing the thickness ratio between the spring and the structure.

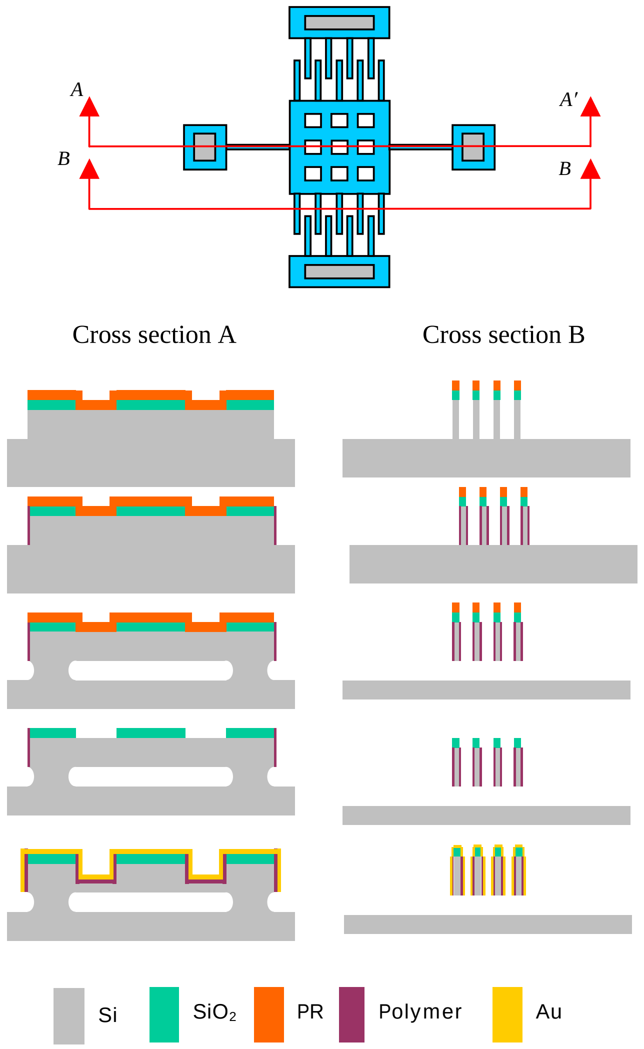



**Fig.1 Fabrication process of multi-level movable structure**

**Results and discussion**

Some crucial parameters in the etching process have been systematically experiment to get well structure profile and successful to release the structure using trench test mask. As a result, the structure with well profile and smooth sidewall can be achieved by accurate control of process parameters with platen electrode. And the movable structure can be released by isotropic etching without power applied on the platen electrode. The source plasma is generated by an inductively coupled coil, which is powered by a generator of 1 kW at 13.56 MHz.

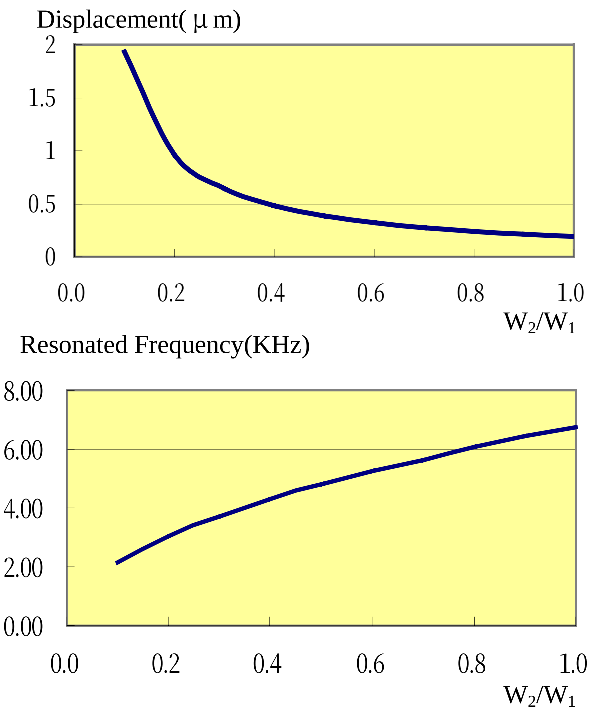



**Fig.2. Simulation results of (a) the displacement and (b) the frequency with the ratio of different spring and structure thickness. $W_2$ is the spring thickness and $W_1$ is the structure thickness.**

Another 13.56 MHz generator is utilized for the independent control of the bias potential of the wafer with respect to the source plasma. Typical base process pressure is around $10^{-6}$ Torr. Figure.3 shows the good trench profile with smooth sidewall due to Advanced Silicon Etching (ASE), in which the etching rate is about 1 μm/min, the linewidth is 10μm, the thickness of the trench is 40 μm and perpendicularity is 89±1˚.

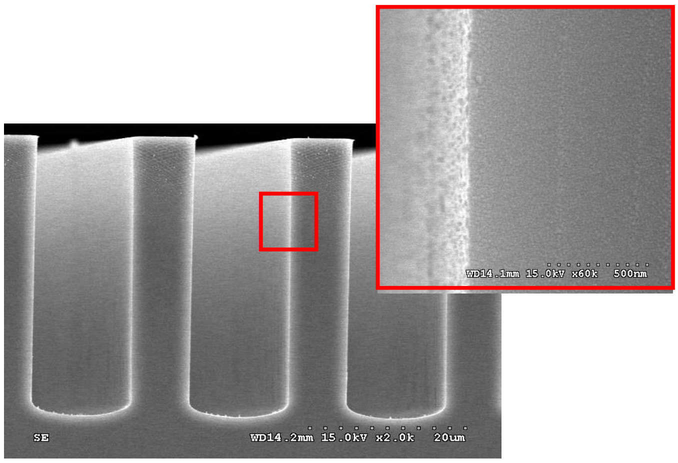


**Fig.3. SEM of trench structure and smooth sidewall**

To release the microstructure is other important issue that need to discussion in advance. Without the platen power supply, the condition of etching process is isotropic etching to get suspension structures. The different linewidth of the positive photoresist as the test pattern have been experiment. Figure.4 shows the lateral view of the 50μm width photoresist beam after about 18 minutes isotropic etching. The relation between the side directional etching depth and etching time is shown in Figure.5. The 50μm width suspension beam has been released after 20 minutes under the isotropic etching. The etching gases are $SF_6$ and $O_2$ and the gas flow rate are 195sccm for $SF_6$, and $O_2$ for 13sccm, respectively. The plasma is generated by a 800W RF coil generator without electric power applied on the platen electrode during the isotropic etching process.

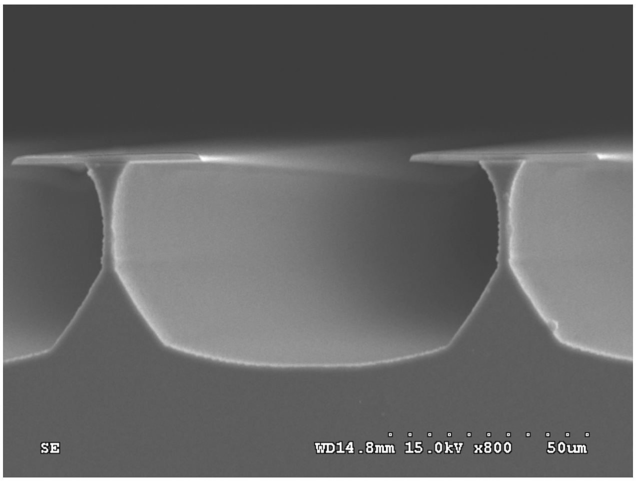



**Fig.4 SEM of 50μm width P.R beam after 18 minutes isotropic etching**

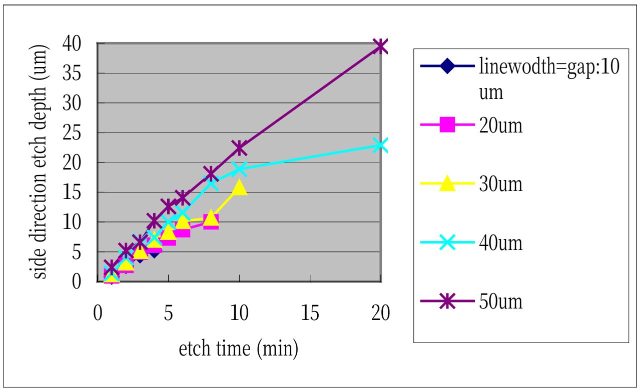
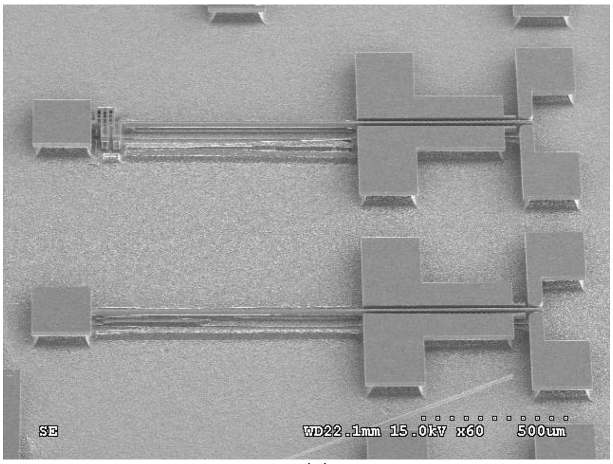
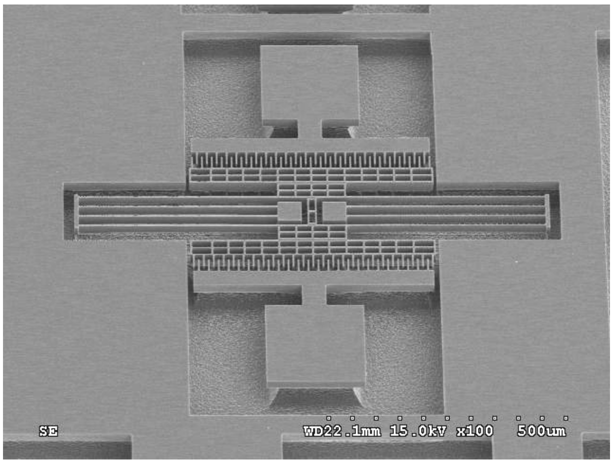



**Fig.5 The relation of side-direction etching depth and isotropic etching time.**

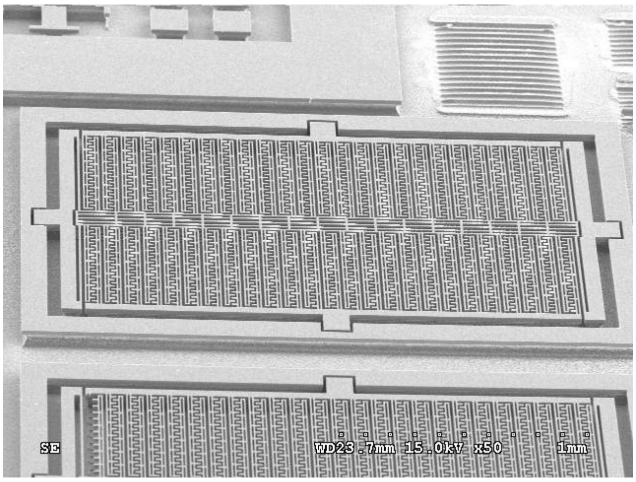
Several kinds of actuators such as relay, comb-drive and capacitance with single mask have been fabricated successfully in this process as shown in Figure.6(a~c). Figure.7 shows the lateral view of the suspension com-drive structure. The thickness of the actuator is 30μm. Figure.8 shows the multi-level comb-drive actuator with two masks. The thickness of the spring structure has been reduced obviously to get lower stiffness.




**(a)**




**(b)**




**(c)**

**Fig.6 SEM of Relay(a), Comb-drive(b) and Capacitance(c) with single mask.**

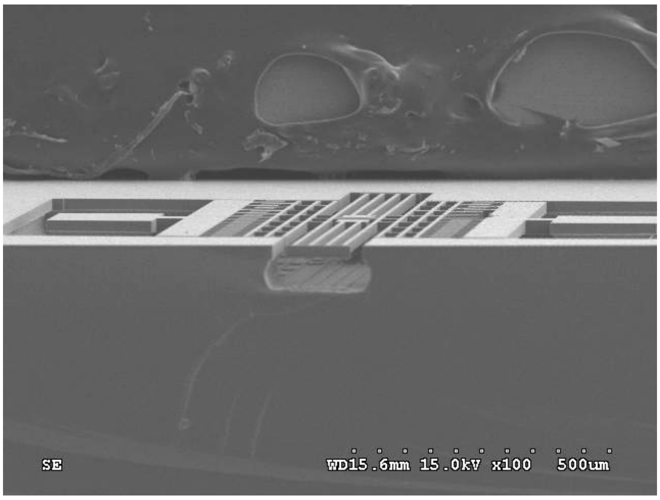



**Fig.7 SEM of suspension comb-drive structure with single mask.**

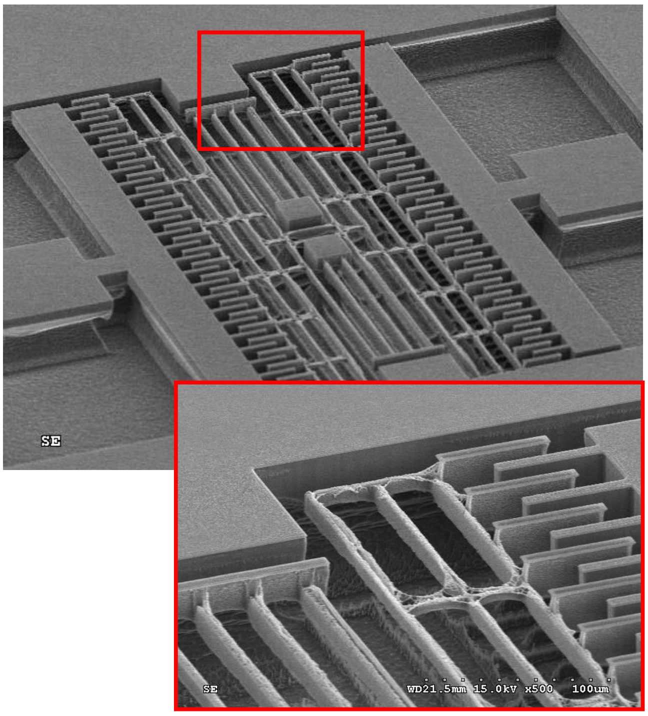



**Fig.8 SEM of Multi-level movable comb-drive structure with two masks.**

## Conclusions

Experimental investigations about fabrication parameters to get well profile and suspension structures have been systematically explored in ICP etching process.

The process takes advantage of the multi-level single-crystal silicon structures in only one ICP fabricated process. Some important devices such as relay, comb-drive, and capacitor etc have also been successfully implemented by the novel technology presented in this paper.

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