Proceedings of MicroNano08
MicroNano2008
June 3-5, 2008, Clear Water Bay, Kowloon, Hong Kong

MicroNano2008-70116

Characterizing Metallization Introduced Polysilicon Corrosion of Surface Micromachined Structures with Submicron Capacitive Gap

Yunda WANG, Ming CAI, Ying WANG, Jing CHEN†

(National Key Laboratory of Nano/Micro Fabrication Technology, Institute of Microelectronics, Peking University, Beijing 100871, China)

(†Corresponding author Tel 86-10-62752536, Fax 86-10-62751789, Email jchen@ime.pku.edu.cn)

Abstract

Corrosion of polysilicon occurs during the HF release, which may change the surface morphology, film thickness and even its mechanical strength; furthermore, long time exposure to HF and the presence of Au metallization appear to promote this corrosion. In this paper, clamp-clamp beams with a capacitive gap of 100nm have been manufactured to characterize this unusual phenomenon. Changes of the surface morphology are revealed, and the influence on electrical performance of the structure is evaluated. By changing the concentration of the HF, different releasing time thresholds are obtained. Although the origin of this effect is still under investigation, a simplified explanation based on the galvanic is presented. Finally, a novel method is developed to reduce the polysilicon corrosion. A parylene layer is deposited and patterned on top of the metal electrode, which proved to be very effective for isolating the Al layer.

Key words: HF release; Polysilicon corrosion; Au; parylene

1. Introduction

Polysilicon dominates the surface micromachining technology as a mechanical material, while Au (with an adhesion layer such as Cr/Ti/TiW) and Al are the most popular metallization layer for making electrical contacts. As is common for the whole process, the final step is usually to dissolve the sacrificial oxide in concentrated HF. However, it is reported that corrosion of polysilicon occurs during the HF release, which may change the surface morphology, film thickness and even its mechanical strength; furthermore, long time exposure to HF and the presence of Au metallization appear to promote this corrosion. It is reported that polysilicon that were electrically connected to Au were etched in the HF release step such that those features became slightly thinner and rougher than the features that were not in electrical contact with Au[3][4]. On the contrary, no such changes were reported when the metallization layer is Al. Unfortunately, a device with submicron gap often requires a relatively long time to be fully released, in which case Au metallization is employed. Although, it is recognized that the influence introduced by polysilicon corrosion may jeopardize its performance, this phenomena has not yet been well investigated.

In this paper surface micromachined clamped-clamped beams (CC-beam) made of P-doped polysilicon with metallization layers of Cr/Au and Al are fabricated to characterize this unusual phenomenon. Changes of the surface morphology are revealed, and the influence on electrical performance of the structure is evaluated. The release criteria and the origin of this effect are discussed. Finally, a novel method is developed to reduce the polysilicon corrosion.

2. Experiment

Clamp-clamp beam with a capacitive gap of 100nm have been manufactured using 2-layer polysilicon (N-doped) surface micromachining process in the National Key Laboratory of Nano/Micro Fabrication Technology, Peking University. Cr/Au and Al are sputtered and patterned respectively for making the electrical contacts. [5]. Fig1 shows the schematic cross section of the CC-beam. The thickness of poly1 is 0.3μm and poly2 is 2μm. Both polysilicon layers are P-doped by implantation(Poly1: dosage $1e^{16}cm^{-2}$; energy 80KeV; Poly2: dosage $2e^{16}cm^{-2}$; energy 80KeV). The sacrificial layer is LPCVD SiO_2 of 100nm.

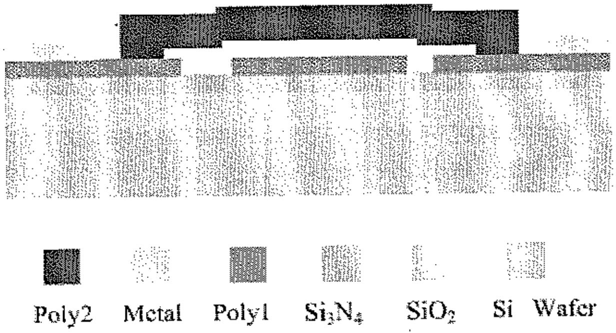
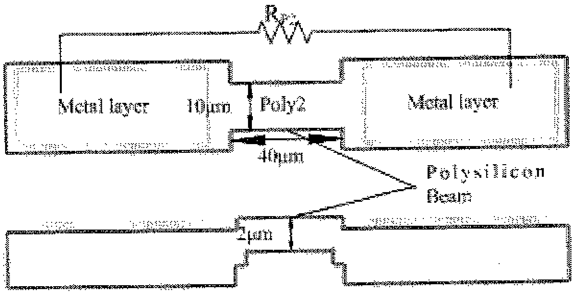


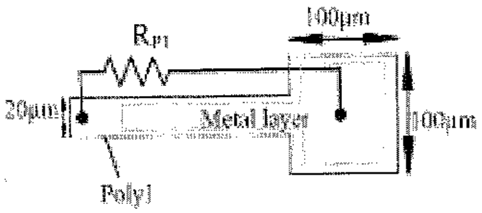
Figure 1. Cross section of the CC-beam

Samples are released in HF solution of different concentrations. The surface features are observed with optical microscope and SEM.

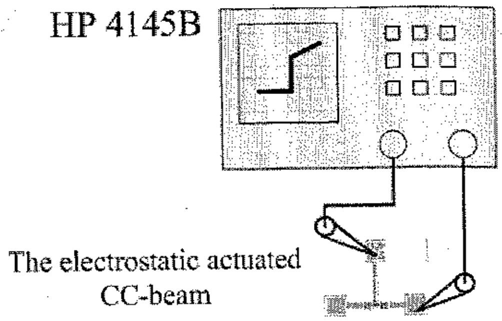
The electrical resistance of poly1 and poly2 are tested on a probe station after releasing, as shown in Fig.2. R_{p1}.is the resistance of poly1, R_{p2} is the resistance of poly2. The I-V curve are obtained by a semiconductor network analyzer[5] HP 4145B as shown in Fig2, pull-in voltage can be determined.



a. **Resistance of Poly2**



b. **Resistance of Poly1**



c. **I-V curve**

Figure 2. Schematic of the electrical test

3. Results

Samples with Au/Cr metallization are released in concentrated HF (40%) with time varying from 2min to 18min. An obvious color change of Poly1 can be observed in the microscope, as shown in Fig 3. The color of poly1 changes to green after 6min's releasing and grows darker when the releasing time further increased. Poly1 is almost invisible after 18min. However, Poly2 does not change much under the microscope.

Fig. 4 (a) shows the SEM photograph of a CC-beam with Cr/Au released by 4min, whose poly1 electrode becomes green in Fig.3. The dark parts verify the color change. Fig. 4 (b) is the SEM photograph of the poly1 electrode released in HF for 18min, apparently the surface roughness greatly increases.

Thickness of ploy1 is measured by the surface profiler after releasing, Fig. 6 shows the results. It is depicted that the thickness of poly1 slightly increases when the release time is less than 16min but decrease dramatically after the releasing time exceeds 16min, when the poly1 might be completely etched off.

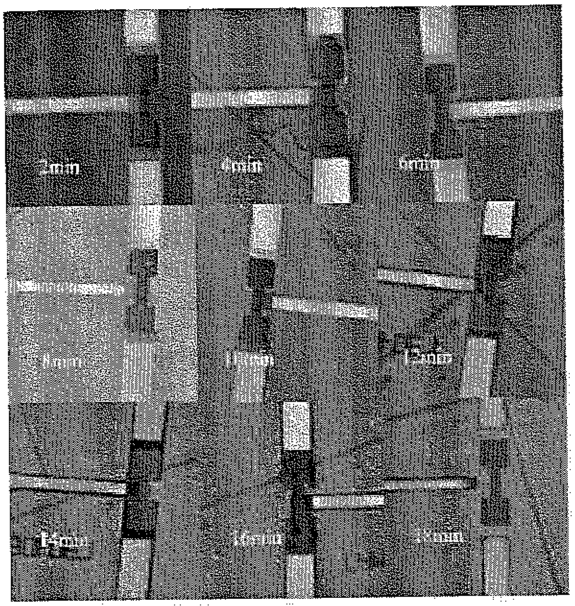


Figure 3. Surface change of polysilicon after release

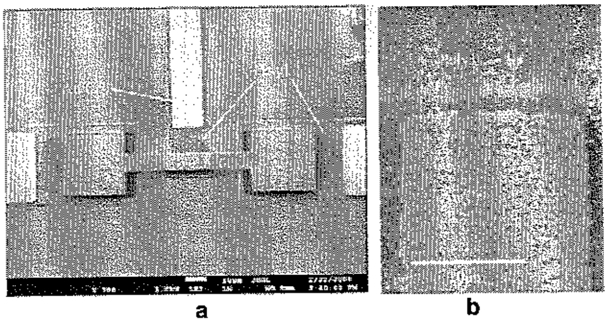

a b

Figure 4. SEM image of the released cc-beam

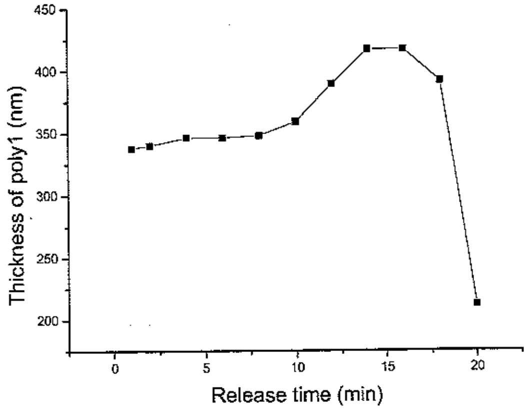


Figure 5. Relationship between Poly1 thickness and releasing time

Electrical tests are also conducted, while the samples are released in HF solution of 3 different concentrations, the results are listed in table 1-3. Changes of R_{p1} and R_{p2} are presented in the tables, with the pull-in test results, where "F" means the device fails the test, "P' means pull-in can be detected.

Table 1. Electrical Characterization (40% HF)

Release time(min)	2	4	6	**8**	**10**	**12**	14	16
$R_{p1}(\Omega)$	236	256	268	270	299	309	9k	∞
$R_{p2}(\Omega)$	214	218	219	222	230	236	253	263
Pull-in	F	F	F	**P**	**P**	**P**	F	F

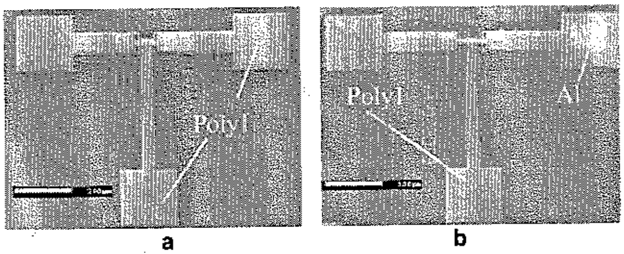
Table 2. Electrical Characterization (40% HF:H_2O=1:1)

Release time(min)	8	12	14	16	18	**20**	22
$R_{p1}(\Omega)$	225	229	240	298	343	453	∞
$R_{p2}(\Omega)$	217	226	240	246	298	308	316
Pull-in	F	F	F	F	F	**P**	F

Table 3. Electrical Characterization (40% HF:H_2O=1:5)

Release time(min)	10	20	30	40	60
$R_{p1}(\Omega)$	221	339	∞	∞	∞
$R_{p2}(\Omega)$	220	238	254	306	321
Pull-in	F	F	F	F	F

Samples with Al metallization are also released for comparison. There are detectable changes neither regarding the surface morphology nor the electrical performance of the polysilicon. Fig 6 shows the surface of a sample with Al releasing for 6min(a) and 8min(b) in 40%HF solution, although the Al layer was almost completely eroded the surface of poly1 remains unchanged.



a b

Figure 6. Surface of Al samples after HF release

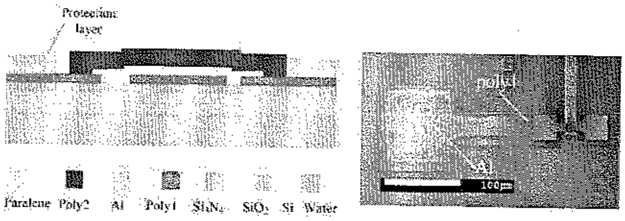
4. Discussion

It is clear that poly1 are attacked in HF for samples with Au metallization, for the changes of surface color, surface topography as well as the electrical properties. When the releasing time goes up, poly1 can be completely removed Moreover, this corrosion also has a relation with the locations, from Fig3 and Fig4, we can see that the corrosion of poly1 is more severe in the

location near to the beam.
The HF concentration also plays a role, a more concentrated solution can accelerate the erosion. But unfortunately, the releasing time has to be much longer to fully release the structure, which also induces the change of characteristics of polysilicon therefore lead to the malfunction of the whole device. It is important to find the appropriate process time window for the device release. From Table 1-3, we can see that the narrower the process window, the higher the HF concentration. Concentrate HF is favored in this regard. Certain design rules will impose to the devices.

One possible reason for this phenomenon is galvanic corrosion. The metallization plays an important role in this process[6], partial Au metallization appears to promote anodic oxidation, particularly in HF. When the polysilicon and Au are electrically connected in HF, galvanic corrosion happens. Electrochemical oxidation and subsequent dissolution of the oxide may explain the changes of poly1[7], [8]. However, the mechanism of this corrosion should be further studied.

For samples with Al metallization, exposure to HF does not change the properties of polysilicon, however, Al can't stand in HF for a long time. A novel process has been developed that use parylene to protect the Al layer, as shown in Figure7a, a parylene layer are coated on top of the metal and then the devices are released in HF solution with a chemical resistant protection. The parylene layer can be ashed in O_2 plasma after release. Figure 7b shows the SEM image of a sample covered with parylene, Al still exists after 12min in 40% HF. More details are still under investigation.



a

b

Figure 7 Schematic and SEM of parylene protection approach

5. Conclusion

Electrochemical (anodic) corrosion of polysilicon plays a heretofore unrecognized role in the surface micromachining, long time exposure to HF and the presence of Au metallization appear to promote this corrosion. In this paper, clamp-clamp beams with a capacitive gap of 100nm have been manufactured to characterize this unusual phenomenon. Changes of the surface morphology are revealed, and the influence on electrical performance of the structure is evaluated. The release criteria and the origin of this effect are discussed. Finally, a novel method is developed to reduce the polysilicon corrosion.

Reference

[1] Harold Kahn and Chris Deeb "Anodic Oxidation During MEMS Processing of Silicon and Polysilicon: Native Oxides Can Be Thicker Than You Think." IEEE J. MEMS, vol. 14, NO. 5, OCTOBER 2005

[2] I. Chasiotis and W. G. Knauss, "The influence of fabrication governedsurface conditions on the mechanical strength of thin film materials," in MRS Symp. Proc., vol. 657, 2001, pp. EE2.2.1–EE2.2.6.

[3] E. K. Chan, K. Garikipati, and R. W. Dutton, "Comprehensive staticcharacterization of vertical electrostatically actuated polysilicon beams," IEEE Design Test Comp., vol. 16, pp. 58–65, 1999.

[4] I. Chasiotis and W. Knauss, "The mechanical strength of polysilicon films: Part 1. The influence of fabrication governed surface conditions,"J. Mech. Phys. Solids., vol. 51, pp. 1533–1550, 2003.

[5] Tan Xiuying. Micromechanical resonators and filters D. Beijing：Peking University，2007

[6] I. Chasiotis, "Mechanics of thin films and microdevices," IEEE Trans. Device Mater. Reliab., vol. 4, pp. 176–188, 2004.

[7] F. Ronkel and J.W. Schultze, "Electrochemical aspects of porous silicon formation." J. Porous Mater., vol. 7, pp. 11–16, 2000.

[8] V. Parkhutik, "Porous silicon—Mechanisms of growth and applications." Solid-State Electron., vol. 43, pp. 1121–1141, 1999.