International Core Journal of Engineering
ISSN: 2414-1895

Volume 9 Issue 12, 2023
DOI: 10.6919/ICJE.202312_9(12).0022

MEMS Sacrificial Layer Release Technology

Xinming lv[a], Xinlong Wang[b]

Semiconductor Manufacturing Electronics (Shaoxing) Corp 312000, China

[a]xinming_lv@qq.com, [b]xinlong_wang@qq.com

Abstract

Sacrificial layer release technology is the most critical technology in MEMS surface process technology, which is mainly to form the cavity and movable space of MEMS devices. This paper briefly introduces the principle, advantages and disadvantages of the sacrificial layer release technology , introduce three type sacrificial layer materials: silicon oxide, polyimide and polysilicon. and discusses these three sacrificial layer materials application direction and application production. And do brief summary on the sacrificial layer release technology.

Keywords

MEMS; Sacrificial Layer; Oxide; Polyimide; Polysilicon.

1. Introduction

Micro-electro-mechanical system (MEMS) is a kind of process which combines traditional machinery and micro-electronic processing technology and miniaturizes traditional mechanical structure. According to the application of MEMS products, MEMS can be mainly divided into sensors and actuators. The sensors can be used to detect some physical signals in nature, and convert into electrical signals, such as gyroscopes, microphones, infrared sensors, etc. The actuator is mainly a device that converts the electrical signal emitted by the device into a certain micro-action, such as a micro-mirror, RF switch, micro-motor, etc. [1-4]. An important feature of both sensors and actuators is that the device must have a movable structure to sense or perform a certain action.

At present, there are two sets of process systems for the manufacture of movable structures in MEMS processing technology, Bulk silicon processing technology and surface processing technology respectively. The bulk silicon process is making part of the structure on each wafer, and after all the structures are completed, the structures are stacked through the bonding process, the etching process is generally used to release the movable structure, The alignment between the structure is affected by the bonding process, and the alignment accuracy is greater than 5μm. The surface process is stacked by thin film deposition. Deposited layers to make structure. The certain thickness sacrificial layer is made under the movable structure, can get movable structure by release sacrificial layer. The alignment between the structures is determined by the lithography process, and the accuracy is less than 0.2μm. Based on this advantage of surface silicon, more and more new MEMS devices are using surface silicon technology. This paper mainly studies the most important sacrificial layer release technology in surface silicon technology.

2. Sacrificial Layer Technique

Sacrificial layer release technology is to form a micromechanical structure cavity or movable space. During the fabrication of the microstructure, a sacrificial layer is deposited between the film of the movable structure [6-8].The size of the sacrificial layer is the size of the cavity or movable space. The structural layer is made by depositing the polysilicon film, and then the chemical etching agent

ISSN: 2414-1895
DOI: 10.6919/ICJE.202312_9(12).0022

corrodes the sacrificial layer without damaging the microstructure, and then the film structure is obtained by the sacrificial layer release technology, as shown in Figure 1.Because the removed film only acts as a separating layer, it is called the sacrificial layer.

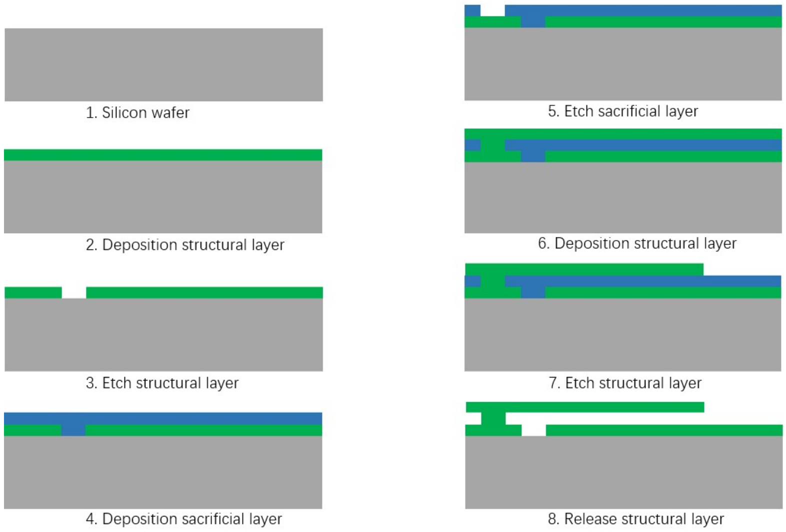

Figure 1. Basic process of sacrificial layer release technology

Common structural layer materials are polysilicon, silicon nitride, silicon oxide and metal, and common sacrificial layer materials are silicon oxide, polysilicon, polyimide, photoresist and so on. The sacrificial layer and the structural layer are selected in combination as shown in Table 1. The selection of the sacrifice layer mainly considers two aspects, the sacrifice layer process compatibility with other structural layers process, especially temperature compatibility and chemical compatibility; and no damage during the sacrifice release, during the process of releasing the sacrifice layer, there can be no damage to other film. This should be focus on the selectivity between the sacrifice layer and other layers. In this paper, the sacrificial layer technology and application of silicon oxide, polyimide and polysilicon are studied.

Table 1. Common structural layer, sacrificial layer and etchant combination

Seq	Structural layer	Sacrificial layer	Etchant
1	nitride	oxide	VHF/BOE
2	polysilicon	oxide	VHF/BOE
3	metal	polyimide	O_2 plasma
4	Metal	Photoresist	acetone
5	oxide	polysilicon	XeF_2
6	metal	polysilicon	XeF_2

2.1 Oxide Sacrificial Layer

The most commonly used common sacrificial layer of silicon-based MEMS devices is oxide, which contains various doping types of oxide. By the high etching selective ratio selectivity of oxide to polysilicon, nitride and aluminum, etc., Buffered silicon oxide etching solution (BOE) or Vapor hydrogen fluoride (VHF) is used for oxide wet or dry etching and the structural layer is released[9].

At present, the main products used the sacrificial layer of oxide including inertial products (accelerometers and gyroscopes), microphones. These two devices usually use PETEOS as the sacrificial layer material, low stress nitride (LSN) or polysilicon as the structural layer, LSN can also

ISSN: 2414-1895 DOI: 10.6919/ICJE.202312_9(12).0022

be used as the barrier layer, and aluminum is generally used as the pad and bonding material. In this paper, VHF and BOE release processes were respectively studied for the four materials. The etch rate of each material are shown in Table 2. The etch selectivity ratio of PETEOS to LSN for BOE release process is >150, the etch selectivity ratio of PETEOS to LSN for VHF release process is <50, and the etch uniformity of BOE is better than VHF. Therefore BOE is more suitable for sacrifice layer release. However, BOE has damage to the materials of Poly and aluminum, especially aluminum corrosion is particularly fast.

The microphone diaphragm material generally is Poly. After the release process, the thickness of Poly loss can be compensated by increasing the deposition thickness in advance, and the AL pad can be protected by coating photoresist. The Poly is used as the structural layer in the inertial device, including complex structures such as comb, beam, the pattern is complicated and difficult to be improved by thickness compensation. Besides wire pad, aluminum in the inertial device is also used as the material for bonding of aluminum and germanium [10]. The photoresist adhesive on aluminum will introduce organic contamination on the bonding ring, and abnormal sealing failure will occur in the contaminated area. Therefore BOE process cannot be applied to inertial devices.

Table 2. VHF and BOE etch rate

Film	VHF E/R(A/min)	BOE E/R(A/min)
PETEOS	900	1500
LSN	30	9
Poly	0	10
Aluminum	0	20000

Table 3. Key layer parameters for inertial devices and microphones

Microphones		Inertial device	
Release hole	High aspect<1	Release hole	High aspect>4
cavity	High aspect<1	comb	High aspect>10
Release film	Thickness>3um	Release film	Thickness<2um
Anchor	Ring	Anchor	Simple point

The key layer parameters of the inertial device and microphone are shown in Table 3. The high aspect of the microphone is <1, the wet release process is more suitable, and the high aspect of the comb position of the inertial device is >10. Due to the liquid tension, the solution is difficult to enter into the sacrificial layer, so wet process can not release it. In addition, comparing the anchor structure of the two devices, the microphone structure use ring anchor, the edge of the diaphragm is fixed by ring anchor, so the probability of the adhesion between diaphragm and backplane is low. But the inertial structure is only fixed at the single point of the comb, and the elastic beam connected by the moving comb is easy to move, also the overlap area of the comb is large,so the adhesion probability is high.

2.2 Polyimide Sacrificial Layer

The traditional silicon-based sacrificial layer (oxide, polysilicon) has some shortcomings, such as high process temperature and large stress introduced after release, which limits to some low temperature and low stress application fields. Therefore, organic sacrificial layers have been developed, the most typical material is polyimide, which has the advantage of low stress and low temperature processes. First of all, using the spin coating process, the surface sacrifice layer is easier to flatter, and secondly, polyimide temperature window is large (-270 °C ~ 400 °C) , and is compatible

ISSN: 2414-1895 DOI: 10.6919/ICJE.202312_9(12).0022

easily with other processes . Releasing by O2 plasma or RIE method [11-13], which is non-destructive to other structure layers.

At present, the main products using polyimide sacrifice layer is infrared devices, and the structure of infrared devices is shown in Figure 2. Firstly, the flow of infrared devices first completes the CMOS base readout circuit, then makes MEMS devices on the CMOS circuit. Considering process compatibility, MEMS devices generally adopt the low-temperature release process. Secondly, the infrared device requires good thermal insulation performance between the reflector and the substrate. So adopted the structural design of double-point interconnection and bridge thermal insulation layer. This will result structure has low stiffness, the wet release process is prone to adhesion, so it cannot be used. Finally, the key reflectors of infrared devices are titanium and LSN materials, titanium cannot be damaged, which key to RV, and LSN corrosion will also cause structural is weakening. Conventional oxide sacrificial layer released by hydrofluoric acid, which will corrode titanium and LSN, incompatible with this process.

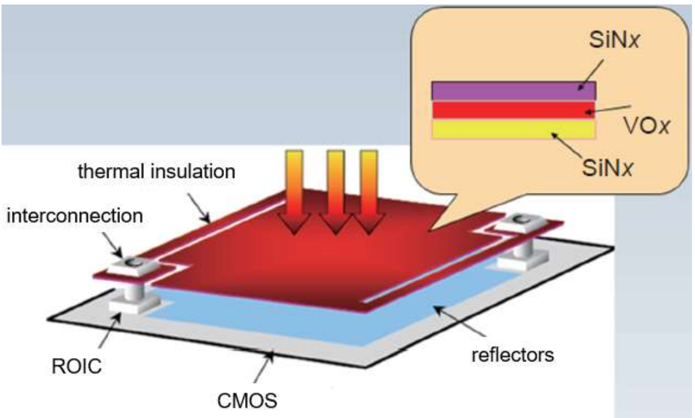

Figure 2. Schematic diagram of infrared device

The release of sacrifice layer of infrared device have many technical requirements, first of all, the insulation layer and the reflector should be complete and not tilt. Secondly, the polyimide should not have residue after release. The main difficulty in the release of polyimide is that after the release of O2 plasma, there will be residues, which will slowly release gas and affect the vacuum of device. Therefore, many researchers have conducted detailed studies on this part. At present, the enhanced version of O2 plasma can effectively solve the problem of residues.

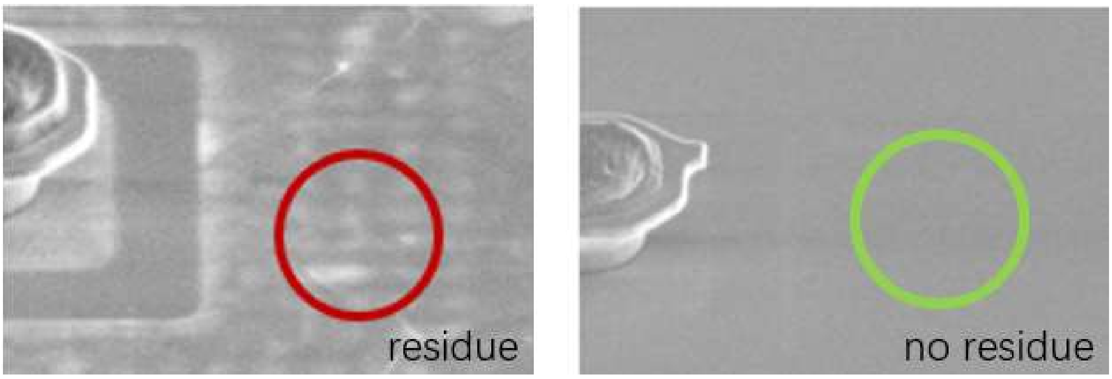

Figure 3. Release optimization of polyimide sacrificial layer

2.3 Polysilicon Sacrificial Layer

Recently, with the development of chemical etching technology, a new etching process using polysilicon as sacrificial layer has appeared. Polysilicon is used as the sacrifice layer, and oxide,

ISSN: 2414-1895 | DOI: 10.6919/ICJE.202312_9(12).0022

nitride and metal are used as the structural layer. The etching gas is XeF2, which is basically the same as the VHF process. The reaction principle is only chemical reaction, isotropic etching, and no plasma is involved [14].

Compared with the VHF release process, XeF2 has obvious advantages. Firstly, the etch rate is faster. When XeF2 at the chamber pressure of 4.5 ~ 5.5torr, the etching rate can reach 16000~19000Å/min, and the release efficiency is higher. Secondly, etching aspect is the high to aluminum, LSN, and oxide. The etching aspect ratio of polysilicon to oxide is >3000, and the etching selection ratio of silicon nitride is >20000. There is no loss of metal, so there is no need to consider the damage of other film layers when releasing polysilicon. At present, the main application products of polysilicon sacrificial layer are filters.

Table 4. the application of release technology

Release technology	Sacrificial material	Protective material	Application
BOE	Oxide	Nitride	Microphone, micro motor
VHF	Oxide	Nitride	Microphone, gyro, accelerometer, mirror
Plasma	Polyimide, photoresist	/	infrared sensor, RF switch
XeF2	polysilicon	Oxide	filters

3. Conclusion

The core of MEMS processing technology is the release of structural layer. This paper first briefly introduces the principle and advantages of the sacrificial layer release process, introduces three common sacrificial layer oxide, polyimide and polysilicon release technologies, and gives the main application direction and typical products by analyzing the advantages and disadvantages of the three type release process. It has certain reference value for the selection and research of other MEMS device release process.

References

[1] Di Shaoyan, Jiao Yishuo.Research on MEMS sensor technology industry and development path of China [J]. Telecommunication Network Technology, 2021, 047(003):66-70.

[2] Lin Wenhao, Chen Yu, Xia Man, et al.MEMS sensor technology development and application analysis [J]. Electronic Components and Information Technology, 2021, 5(7).

[3] Wang Wei.ST moves to Automotive and industrial markets to meet the next wave of MEMS development [J].Application of Electronic Technology, 2022(11).

[4] Zhen Zhen, Zhu Hong.Research on development and application of MEMS accelerometer [J]. Instruments and Equipment, 2022, 10(1).

[5] Ruan Y. Research on process standardization, key technologies and microstructure detection methods of bonding deeply etched MEMS bulk silicon [D].Peking University [2023-07-08].

[6] Zhang Yonghua, Ding Guifu, Li Yonghai, et al.Technology of sacrificial layer in MEMS [J]. Micro and Nano Electronic Technology, 2005, 42(2).

[7] Q Ma,P Cheng.Sacrificial layer technology for Gap formation in MEMS Structure application: CN02813191.6 [P].CN1522223 [2023-07-08].

[8] Li Jia, Sun Fuhe, Jin Wenchao, et al.Manufacturing method and testing structure of sacrificial layer of microelectromechanical system.CN202010814938.2 [2023-07-08].

[9] PANG Kejian. Gaseous hydrogen fluoride release System [J]. Special Equipment for Electronic Industry, 2021, 50(5).

[10] Liu Chen, Wen Yongxiang, Huang Rongsheng, Ji Feng, Rao Xiaojun, Zou Guangyi.Aluminum-germanium Bonding Technology and its Application in MEMS Accelerometer [J]. China Journal of Integrated Circuits, 2014, 23(10):65-69.

[11] Research on sacrificial layer technology of polyimide in RF/MW MEMS switches [J]. Microelectronics, 2005, 35(1).

[12] Du B. Research on cavity type bulk acoustic wave filter and its wideband technology [D].University of Electronic Science and Technology of China,2019.

[13] Zhang Zhongshan, Tang Liang.A high sensitivity MEMS condenser microphone prepared at low temperature [J]. Journal of Transducer Technology, 2018, 31(6).

[14] LIU Zhibin, Ma Yu, Zhou Yonghua.Research on sacrificial layer release technology of RF MEMS Devices [J]. Electronic Components and Information Technology, 2019, 19(01):63-65+68. (in Chinese).