Fabrication of Silicon Condenser Microphone Using Oxidized Porous Silicon as Sacrificial Layer

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Abstract: A new technique to fabricate silicon condenser microphone is presented. The technique is based on the use of oxidized porous silicon as sacrificial layer for the air gap and the heavy p^+-doping silicon of approximately 15μm thickness for the stiff backplate. The measured sensitivity of the microphone fabricated with this technique is in the range from −45dB(5.6mV/Pa) to −55dB(1.78mV/Pa) under the frequency from 500Hz to 10kHz, and shows a gradual increase at higher frequency. The cut-off frequency is above 20kHz.

Key words: silicon condenser microphone; oxidized porous silicon; sacrificial layer

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1 Introduction

In the last few years, many types of small-sized condenser microphones have been fabricated using silicon micromachining techniques. The advantages of micro-eletro-mechanical-system (MEMS) technology introduced for these applications include that notably patch-processes, high degree of control of device dimensions, miniaturization of the devices and integration of the microphone with integrated circuits. The fabrication of the microphone consists of deposited layers for the active flexible diaphragm, the sacrificial layer for the air gap and for the fixed backplate, which should not respond to the sound pressure for maximum signal output. The stiffness of backplate can only be achieved if the thickness is deeper than 3μm. However, such thickness is difficult to achieve by deposition[1,2], because internal stress causes cracks and deposition time is often long. In addition, insufficient flatness and poor metal step coverage also cause problems. The choice of the sacrificial layer is difficult as well. If SiN_x membrane is used for the acoustic diaphragm, only SiO_2 or polysilicon can be chosen due to the preclusion of post-high-temperature processing. These materials have low etch rates, which limit the lateral underetching of the sacrificial layer. Porous silicon with high dissolution rate in 1% KOH can be used[3]. But hydrogen generated during the etching often causes cracks of SiN_x membrane. Solutions to the problem are proposed in this paper. It describes the use of a stiff heavy p^+-doping silicon of 15μm thickness as backplate and the use of oxidized porous silicon as sacrificial layer with high etching rate in hydrofluoric acid solution.

2 Microphone fabrication

The microphones were made from ⟨100⟩ ori-

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ented double-sided polished p-doped wafers with resistivity of 8~ 12Ω·cm and thickness of 340μm, and with only five masks. The process started by oxidization of the wafer in high temperature. Then deep p^+-doping of the wafer front was structured as monocrystalline backplate of 15μm thickness (Fig. 1(a)). The p^+ layer was found to be a good etch-stop material of KOH alkaline solution. After removing the oxidized layers, the wafer was oxidized again in the high temperature of 1150℃. Then 2μm shallow p^+-doping of the double-side wafer was formed (Fig. 1(b)). The structured p^+-doping layer of the wafer front was used to form porous silicon under a 300nm LPCVD silicon nitride masking layer, and the p^+-doping layers of the wafer backside was used as contact electrode of the electro-chemical etching. For the anodized oxidization process a special reaction vessel was constructed which enable the wafers to be tightly sealed so that the electrical current flows only through the wafer in areas of porous silicon formation.

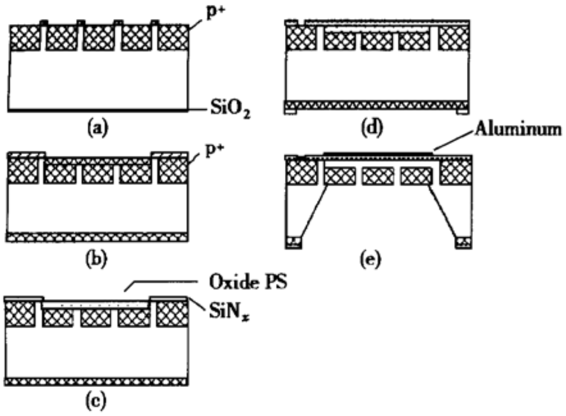

Fig. 1 Fabrication process of microphone

A reproducible porous silicon thickness and quality could be obtained only when leakage current was minimized. The porous silicon formed should be stabilized porous structure by annealing at 300℃ in nitrogen atmosphere. After the complete removal of the masking layer, the porous silicon was oxidized at low temperature of 700℃ (Fig. 1(c)). The oxidized porous silicon was used as sacrificial layer of the air gap because of its high etch-rate in hydrofluoric acid. A 400nm diaphragm layer of silicon-rich low-stress LPCVD nitride was then deposited at 850℃. The ratio of the dichlorosilane to ammonia ratio was 3.5∶1. The tensile stress of the SiN_x diaphragm deposited was approximately 26MPa, which is low in the range of the 10^{-7}~ 10^{-8}Pa[4]. The contact holes on the front side and the windows for KOH etching of the back volume cavity on the backside were then structured (Fig. 1(d)). Single-sided silicon etching in 40% KOH at 80℃ from the backside in a special etching tool formed the 15μm thick monocrystalline backplate. The structured deep p^+-doping was sufficient for etching-stop material, so the acoustical holes (size= 60μm×60μm) could be formed by silicon-etch. The depth of the heavy p^+-doping layer on the wafer defined the thickness of the backplate. The deep heavy p^+-doping layer was necessary for forming thick monocrystalline silicon backplate (> 10μm). Boron diffusing processes were experimented using box method and open-pipe method. The depth and concentration of the boron diffusing samples were measured by extend resistance method. Figures 2 and 3 show the measured results. The impurity diffused using open-pipe diffusing method shows Gauss function distributing but

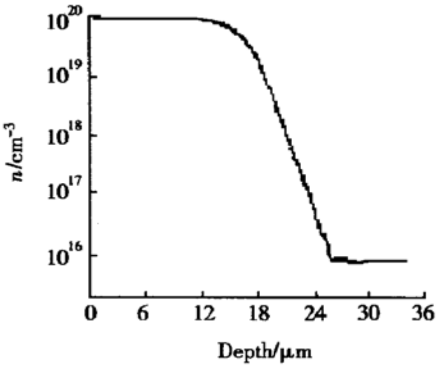

Fig. 2 Measured concentration of the sample diffused boron with box method

the impurity diffused using box-diffusing method shows complementary error function distributing. It is difficult to form deep heavy p^+-doping layer using open-pipe method. A 25μm p^+-doping layer with surface concentration as high as $10^{20}/cm^3$ can be formed by box method. Now the 15μm monocrystalline silicon backplates have been formed by this method. In the followed step the oxidized porous silicon was etched quickly in HF solution. Finally, a 100nm aluminum layer was evaporated on the front side and structured (Fig. 1(e)).

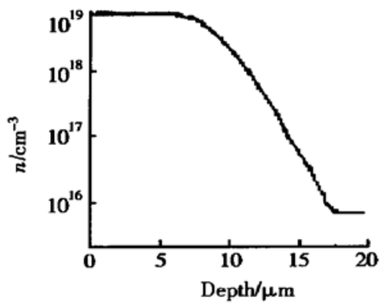

Fig. 3　Measured concentration of the sample diffused boron with open pipe method

3　Measurements and results

In order to test the sensitivity of the microphone, its simple encapsulation should be performed for better signal-to-noise. At first, the device was glued on the metal package having a hole in the middle. The size of the hole was equal to the size of the microphone back chamber. Then the package was fixed in a special metal tube including a 500MΩ load resistor and an impedance converter. Electric screen was realized using this set-up.

The acoustic measurement was operated in the anechoic room. The measurement setup included signal source, reference microphone, and dynamical signal analyzer. The microphone was driven with a speaker connected to an Agjient 35670A dynamic signal analyzer. The test microphone or the reference microphone was connected to a preamplifier which converted the capacitance variation to the voltage output. A calibrated Brüel & Kjaer 4189 microphone was used as the reference microphone. For the device condenser microphone, the bias voltage was loaded through a 500MΩ load resistor externally. The Agjient 35670A dynamic signal analyzer provided an internal DC polarization voltage of 200V for the reference microphone. The output voltage was recorded using the Agjient 35670A dynamic signal analyzer. The measurement setup is shown in Fig. 4. The acoustic measurements were made in the frequency range from 500Hz to 25kHz. The microphone under test was biased by a DC voltage of 9V. Figure 5 shows the frequency response of the microphone with an air gap of 2μm. As seen from the figure the sensitivity is in the range from − 45dB (5.6mV/Pa) to − 55dB (1.78mV/Pa), and shows a gradual increase at higher frequency. The cut-off frequency is above 20kHz. Figure 6 shows the noise of the environment. From the figure it can be seen that the noise is quite high, the lowest noise value is − 72dB. For the microphone, the environment noise is dominated by the preamplifier and its environment. If the microphone and the preamplifier could be put on the same metal package, the noise will be greatly decreased.

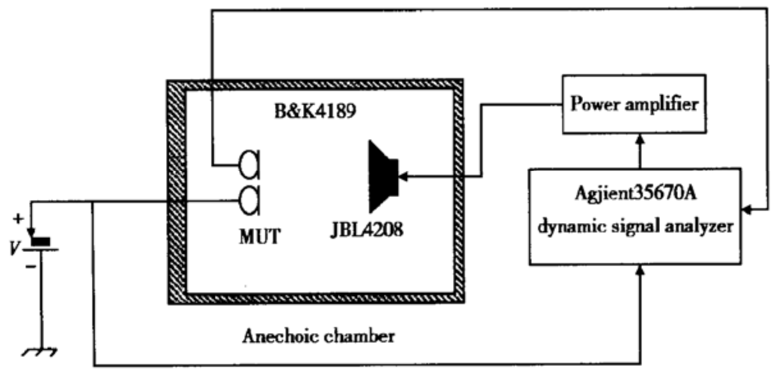

Fig. 4　Block diagram of the microphone measurement setup

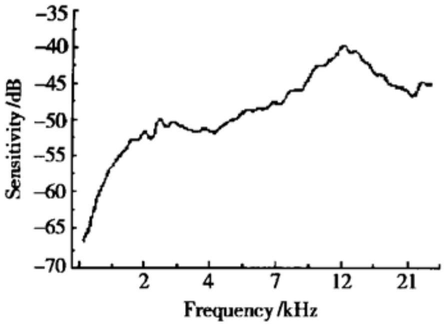

Fig. 5 Measured frequency response of the microphone

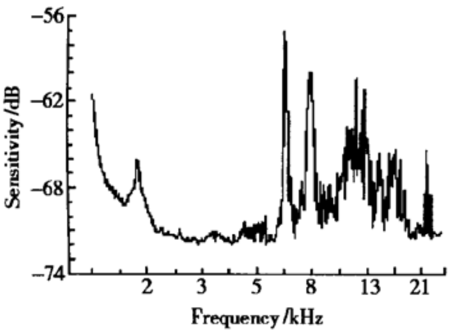

Fig. 6 Measured noise spectrum of the environment

4 Conclusion

In this paper, a new technique of the fabrication for silicon condenser microphones has been presented. The technique is based on the use of oxidized porous silicon as sacrificial layer to fabricate air gap and the use of heavy p^+-doping silicon as backplate. The oxidized porous silicon can be etched quickly in hydrofluoric acid solution. The quick etching of sacrificial layer prevents the attack of etching solutions on the diaphragm. During the etching, the oxide porous silicon does not generate hydrogen, which often cause the break of the acoustic diaphragm like porous silicon. In addition, the technique can solve the problem that backplate deposited responding to the sound pressure by using heavy p^+-doping silicon as backplate. The acoustic holes can be formed during the etching of silicon using heavy p^+-doping silicon as etch-stop material, which omits a necessary nonstandard photolithographic process used to etch the acoustic holes from the backside in the deep backvolume cavity[3]. To form the stiff backplate and define the size of the acoustic holes, the wafer front is structured and diffused boron with box method at the beginning of the process.

The sensitivity of the microphone fabricated with this technique is in the range from - 45dB (5.6mV/Pa) to - 55dB (1.78mV/Pa) under the frequency from 500Hz to 11kHz. The environmental noise is quite high, and the lowest noise value is - 72dB. If the microphone and the preamplifier could be put on the same metal package, the noise will be decreased greatly and the sensitivity of the microphone will be increased greatly.

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用氧化多孔硅作牺牲层制备硅基电容式微传声器

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摘要: 提出了一种新的工艺方法制备硅基电容式微传声器. 用氧化多孔硅作牺牲层制备空气隙, 用约 15μm 厚的浓硼掺杂硅作为微传声器的刚性背极板. 采用该方法制备的微传声器, 在 500Hz 至 11kHz 的工作频率下, 灵敏度范围为 - 55dB(1.78mV/Pa) 到 - 45dB(5.6mV/Pa), 随着频率的升高, 灵敏度呈上升趋势, 截止频率超过 20kHz.

关键词: 硅基电容式微传声器; 氧化多孔硅; 牺牲层

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