A Novel Structure for PZT-Based Piezoelectric Microphone

Hong-Jin Zhao, Tian-Ling Ren, Jian-She Liu, Li-Tian Liu, Zhi-Jian Li

Institute of Microelectronics, Tsinghua University
Beijing 100084, P. R. China, zhaohongjin99@mails.tsinghua.edu.cn

ABSTRACT

This paper proposes a novel lead-zirconate-titanate (PZT)-based structure used for the integrated microphone. The performance of the PZT thin films and the devices were improved due to adoption of the lead-titanate (PT) layer as the seeding layer. The PZT-based piezoelectric microphones with conductor-piezoelectric-conductor sandwich structure were fabricated. The size of the finished microphone ranged from 600×600 μm^2 to 1000×1000 μm^2. A high sensitivity of 38 mV/Pa can be obtained. This quality was prominent in the existed microphones. The frequency response of the microphone was very flat in the audio frequency range. The novel piezoelectric microphones should be very promising for acoustic applications.

Keywords: Microphone, PZT, Piezoelectric, Ferroelectric, Sandwich structure

1 INTRODUCTION

Microphone is one of the most challenging and developing areas and markets in the field of microsensor technology. Which is required in a diverse range of activities in everyday life and industries and the need for cost-effective reliable sensors with reduced dimensions is ever increasing.

In recent years, various methods of fabrication of microphones have been proposed, such as capacitive [1], piezoresistive [2], piezoelectric [3]. Each approach has its inherent limitations and advantages. Piezoelectric microphones have the advantages of simple fabrication process and easiness to be integrated into semiconductor devices, and are paid more and more attentions. The sensitivity of diaphragm-based MEMS acoustic transducers is a function of the diaphragm deflection, which is greatly affected by the residual stress in the diaphragm [4]. For the cantilever structure, freeing up three edges (thus forming a cantilever) would improve the deflection greatly, but the mechanical stiffness is weak. In order to resolve the above problems, this paper proposes a novel piezoelectric-based structure used for the integrated microphone.

At the same time, ferroelectric materials, such as PZT, PT, or PMN-PT, have much larger piezoelectric constant than usual piezoelectric material. As a kind of important ferroelectrics, PZT exhibits the strongest piezoelectric activity when its composition is close to the morphotrophic phase boundary between rhombohedral and tetragonal phase fields. The piezoelectric constant of PZT materials is known to be dramatically larger than that of ZnO. In the case of bulk materials, the PZT (53/47) ceramics possess the transverse piezoelectric coefficient, d_{31}, with -93.5 pC/N, while the ZnO single crystal exhibits the transverse piezoelectric coefficient, d_{31}, with -5.4 pC/N. The use of PZT materials to replace the ZnO materials as the piezoelectric layers of the microphone structure was proven to be a simple and effective way to improve the sensitivity of the cantilever microphone [5].

In this paper, the performance of the PZT thin films and the devices were improved due to adoption of the PT layer as the seeding layer. The PZT-based piezoelectric microphones with the conductor-piezoelectric-conductor sandwich structure were fabricated. The fabrication process revealed high yield, allowing a low cost production of high performance microphones capable of on-chip integration of signal processing electronics. The acoustic outputs of the fabricated microphones had been measured. This quality was prominent in the existed microphones. The frequency response of the microphone was very flat in the audio frequency range. The novel piezoelectric microphones should be very promising for acoustic applications.

2 EXPERIMENTS

The core structure of the PZT-based piezoelectric microphones is conductor-piezoelectric-conductor sandwich structure. Considering its high piezoelectric constant, PZT thin film has been used as the main functional part of the sandwich structure. Figure 1 shows the top-view and cross-section of the PZT-based microphone on silicon substrate.

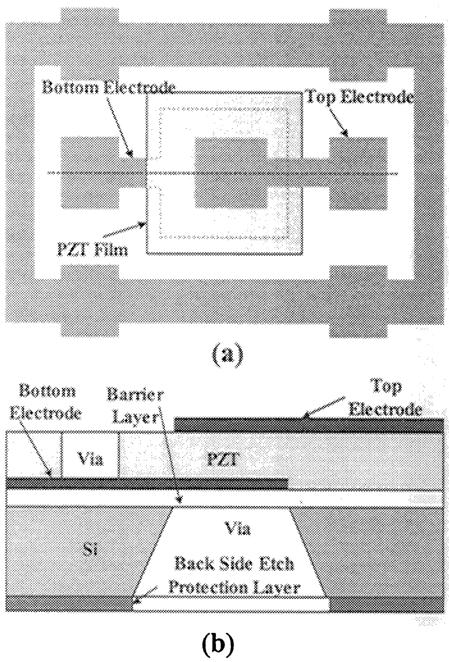

Figure 1: Structure of the PZT-based microphone: (a) Top-view; (b) Cross-section.

Bulk micromachining technology was applied to sculpt the structure of the microphone. The fabrication flow chart is shown in Figure 2. The processes include lift-off technique, reactive ion etching (RIE), sol-gel, wet chemical etching, etc.

The process starts with a double side polished P-type (100) silicon wafer. The major fabrication steps as shown in Figure 2 are described as follows:

1. Silicon nitride is deposited on thermal oxidized silicon substrate by low-pressure chemical vapor deposition (LPCVD). It will be used as the masking layer during the silicon bulk micromachining and the membrane to support the sandwich structure.
2. The back windows for back chambers are patterned and etched using RIE.

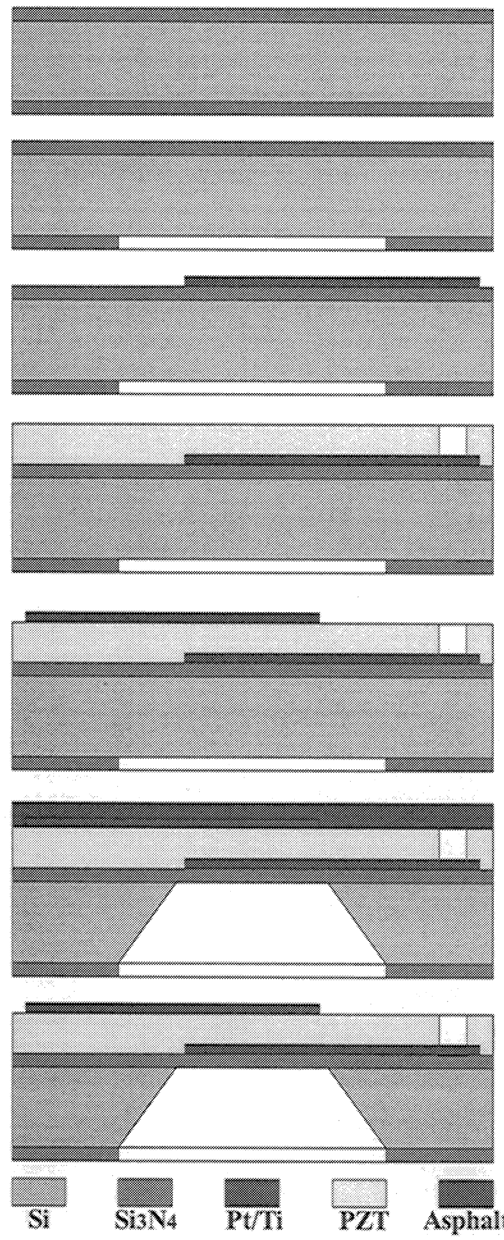

Figure 2: Fabrication processes of PZT-based microphone.

3. The bottom electrode is formed using the sputtering technique. The patterns of the electrode are realized using lift-off process. The platinum (Pt) layer of 150

nm is used to guarantee excellent chemical stability during the deposition and the titanium (Ti) layer of 27nm to enhance the Pt adhesion to SiO_2 layer.

4. Sol-Gel derived PZT (100) thin film of 0.5 μm thick is deposited on the bottom electrode with a 60 nm $PbTiO_3$ (100) seeding layer. The PZT/PT etchant is obtained by mixing HCl, HF and H_2O together. PZT thin films are etched using different etchants by varying the ration of HCl and HF solutions and the etching condition is optimized. When the HCl: H_2O rate is 3: 7 with a very small HF percentage, the etching time is about 1 min. The HF percentage strongly affects the etching rate, so the concentration must be adjusted very carefully.
5. Pt top electrodes of 150nm are then sputtered and structured by lift-off process.
6. Bulk silicon under the Si_3N_4 film is removed to a depth of about 370μm by anisotropic etching in aqueous KOH. In this process, the front side of the wafer is properly protected using the asphalt. The other single crystal silicon membrane is further etched by tetramethylammonium hydroxide (TMAH) solutions.
7. The asphalt is removed. The typical poling condition of the ferroelectrics film is the voltage of 3KV/mm, applied for 20min at 120±2℃. The process resulted in a PZT-based microphone with a novel conductor-piezoelectric-conductor sandwich structure.

The process is simple, efficient and has good reproducibility, and is compatible with standard CMOS process. Integration of signal conditioning circuitry is expected to make a complete micro-acoustic system.

3 RESULTS AND DISCUSSION

Using the above fabrication process, the sandwich structures with different sizes have been fabricated for microphone applications. The size of the fabricated microphone ranges from 600×600 μm^2 to 1000×1000 μm^2.

Figure 3 shows the XRD pattern of PZT thin films. Normally, PZT thin films on Pt/Silicon substrates were reported to be (110) or (111) oriented. The PZT thin films with (001) preferred orientation for microelectronic applications have the advantages of large piezoelectric constant d_{33} and longitudinal vibration electromechanical coupling factor k_{33}. Therefore, the fabrication technique of the (001) orientated PZT films is one of the key points for the device applications of the PZT thin films.

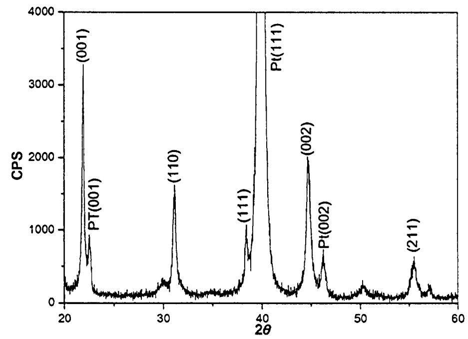

Figure 3: XRD pattern of the PZT thin films.

In this paper, the PZT thin films preferentially crystallized in (001) direction are fabricated using an improved sol-gel process and the PT film as the seeding layer. As for the growth mechanism for (001) orientated silicon-based PZT films, it is proposed that the Pt layer deposited on the Si (001) is high (111)-orientated. The PZT thin films without PT seeding layer would prefer to crystallize in a (111) orientation since the PZT layer is lattice-matched to the Pt layer. On the other hand, the lattice constant of PT is close to that of Pt. The initial growth of the PT seeding layer on the Pt layer is expected to have a (111) orientation. However, it is interesting to point out that the upper side of the PT film on Pt tends to a (001) orientation. So, the PZT thin films with the PT seeding layer tend to be highly (001)-orientated.

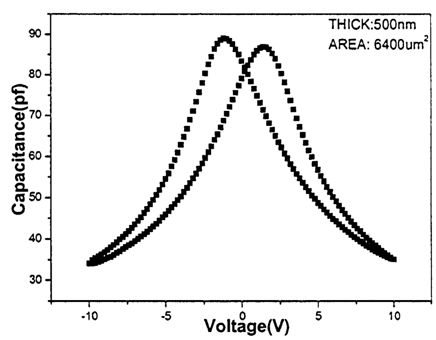

Figure 4: C-V characteristic of the PZT thin films.

Figure 4 shows the C-V characteristic of the PZT thin films. The result reveals that the ferroelectrics properties of PZT films are excellent. The experimental results show that the PZT films are suitable for the PZT-based microphone application.

Figure 5 shows the optical picture of the finished PZT-based microphone. The top and bottom electrodes have been conducted to the surface of the bulk silicon for electrical measuring.

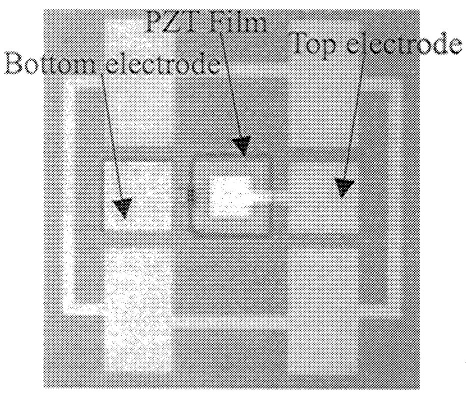

Figure 5: Optical picture of the finished microphone.

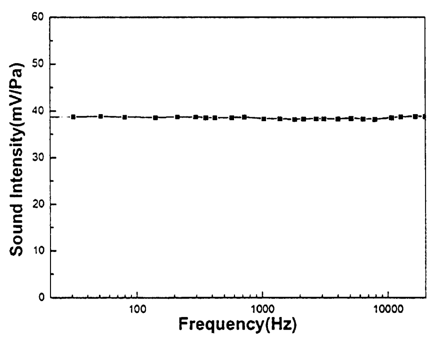

Figure 6: Frequency response of the fabricated PZT-based microphone.

Wafer level measurement has been carried out using a Norsonic 840 real time acoustic analyzer with a standard microphone as a reference. The measurement results have shown that the sensitivity ranges from 35 mV/Pa to 38 mV/Pa for the finished microphones with different sizes and layer thickness. The 38mV/Pa sensitivity is much higher than the usual micro-manufactured microphone as it is known. It is interesting to point out that the frequency response the PZT-based microphone is very flat in the audio frequency range. This quality is prominent in the existed microphones.

As an example, the measuring result of a microphone is shown in Figure 6. The sensitiviy is about 38 mV/Pa, and the frequency response is flat up to 20 kHz. It is interesting to point out that the fabricated structure can also be used as a microspeaker, and an integrated microphone and microspeaker acoustic system can be realized.

4 CONCLUSIONS

In this paper, a PZT-based structure used for the integrated microphone is proposed. The performance of the PZT thin films and the devices are improved due to adoption of the PT layer as the seeding layer. The acoustic outputs of the fabricated microphones have been measured and a high sensitivity of 38 mV/Pa can be obtained. This quality is prominent in the existed microphones. The frequency response of the microphone is very flat in the audio frequency range. The novel piezoelectric microphones should be very promising for acoustic applications.

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