Fabrication of High-Performance Piezoelectric Thick Films on Si for a Micropump of the Ink-jet Printer Head

***Jong Min Kim*[1], *Hyeong Sik Park*[2], *Jwayeon Kim*[3], *Eui-Jung Yun*[2],**
***Jeong Seog Kim*[1] *and Chae Il Cheon*[3]**

[1]Dept. of Digital Diplay Eng., Hoseo Univ., Asan, Chungnam ,336-795, Korea
[2]Dept. of Information & Control Eng., Hoseo Univ., Asan, Chungnam ,336-795, Korea
[3]Dept. of Materials Science & Eng., Hoseo Univ., Asan,
Chungnam, 336-795, Korea
Phone: +82-41-540-5763, E-mail: cicheon@office.hoseo.ac.kr

Abstract

The piezoelectric thick films were fabricated on silicon substrates by screen printing method. By developing a low-temperature sinterable piezoelectric composition and a new poling technique, we fabricated the high-performance piezoelectric thick films on silicon which can be applied for piezoelectric MEMS applications such as micropumps of the ink jet printer heads.

1. Objectives and Background

Ink-jet printing technology has being applied to many industries including flat panel display and microelectronics. These days, several companies are manufacturing micropumps of the ink jet printer heads using the silicon micro-machining technology, which makes the scaling down and performance enhancement of the micropumps possible. Mechanically-machined thin bulk piezoelectric plates, of which thickness are a few tens of micrometers, are attached on the silicon MEMS structure in most cases. Piezoelectric thin or thick films with the various thickness could be deposited directly on silicon MEMS structures instead of attaching the mechanically-machined bulk piezoelectric plates. Piezoelectric films thicker than a few micrometers are required in the applications which need large strains or forces like a micopump of the ink-jet printer head.

PZT thick films can be fabricated directly on silicon substrates by screen printing, jet printing, sol-gel spray, and so on. Screen printing method is the one of the most effective method for piezoelectric MEMS devices because of the low production cost and simple and flexible manufacturing process.[1-3]

$Pb(Zr,Ti)O_3$ (PZT) is the most widely applied piezoelectric material because of its superior piezoelectric properties. The sintering temperature of PZT ceramics is about 1250℃. PZT thick films should, however, be fired at the temperature lower than 900℃ for compatibility with silicon micro-machining technology. And the low green density of a screen-printed thick film produces thick films with low density. Large porosity of the screen-printed PZT thick film requires high poling field, but high electric field often brings about electrical breakdown of the thick film during poling process. Because of low density, low poling efficiency and rigid clamping by the substrate, PZT thick films have inferior piezoelectric properties to the bulk ceramics with the same composition. Therefore, the more efficient poling method than the conventional dc poling is required for high-performance PZT thick films.

In this work, the piezoelectric composition, which could be fired at the temperature lower than 900℃, was developed.[4] The paste composed of the low-temperature fired piezoelectric powder were screen-printed directly on silicon substrates and sintered at 850℃. And the electric field were applied to the piezoelectric thick films for the dipole alignment, which is called poling, by the conventional DC poling process and the thick films were also poled by more efficient poling method, which is the corona discharge technique.

2. Experimetal procedures

The piezoelectric composition used in this work was $0.25Pb(Ni_{1/3}Nb_{2/3})O3\text{-}0.35PbZrO3\text{-}0.4PbTiO3$ in which 2 atomic % Pb was substituted by Cd. The preparation method of the piezoelectric powder was explain in the reference 4 in detail. For the preparation of the thick film paste, the piezoelectric powder was mixed with organic vehicle consisting of ethyl-cellulose and α-terpineol in a three roll mixer. Yttrium stabilized zirconia (YSZ) was deposited at 600℃ on the SiO2(300nm)/Si substrate as a diffusion barrier by RF magnetron sputtering. PZT paste was screen-printed on the Pt(450nm)/YSZ(110nm)/SiO2(300nm) /Si substrate, leveled at room temperature for 10 minutes, and dried at 150℃ for 15 minutes. This process was repeated three times. PZT thick films were fired at 850℃ for 1 hour after organics were burned out at 500℃ for 1 hour in air. The thickness of the fired PZT thick film was 10～20㎛. Pt top-electrodes were deposited on the fired PZT thick films at room temperature using a shadow mask.by DC magnetron sputtering. The PZT thick films were poled in the silicon oil bath at 120℃ for 10 minutes by applying DC electric field using the conventional DC technique. For corona discharge poling, the electric field was applied for 5 minutes to the sharp metal-tip which was a few centimeters above the unmetallized top surface of the thick film. The thick film was on the hot plate of 80℃ and the bottom of the thick film was grounded during corona discharge poling.

Phases were identified using an X-ray diffractometer (Shimadzu, XD-D1) and microstructures were observed using a field emission scanning electron microscopy (Hitachi, S-4300). Capacitances and dielectric losses were measured using an impedance analyzer (HP4192A). Ferroelectric P-E hysteresis loops were measured using a ferroelectric tester (Radiant Technologies, Inc., RT66A) and a high voltage amplifier (Radiant Technologies, Inc., RT66A HVI). The piezoelectric constants of the thick films on silicon substrates were measured using pneumatic loading method.[5]

3. Results and Discussion

Figure 1 shows X-ray diffraction patterns of PZT thick films fired at 850℃. PZT perovskite phase was well crystallized and any second phase was not observed, as shown in the figure 1. Figure 2 shows that the PZT thick film prepared in this work has the microstructure with a flat and clear interface between the thick film and the bottom. Any interdiffusion or chemical reaction is not observed at the interface. It implies that YSZ is a good diffusion barrier at the interface. The thick film sintered at 850℃ shows comparatively dense microstructure. As mentioned in the introduction, the screen printed thick film generally has a low density because of a low green density compared to ceramics which are formed by pressing. The ferroelectric P-E (polarization-electric field) hysteresis of the thick film was measured and are shown in figure 3. The P-E curve in the figure 3 looks very typical and well developed, which means that the piezoelectric thick film has a superior ferroelectric property.

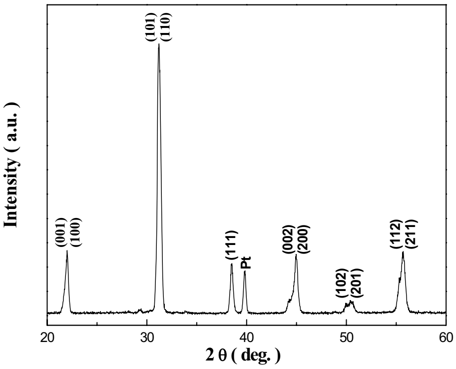

Fig.1 XRD pattern of the PZT thick film.

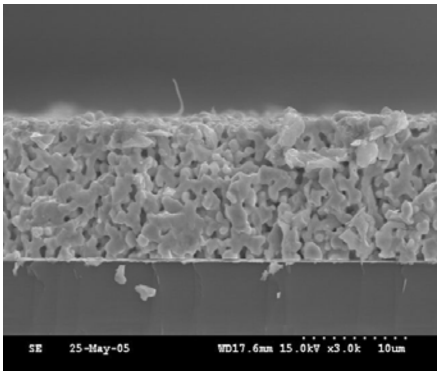

Fig.2 Cross-sectional morphology of the PZT thick film.

The electrical properties of the PZT thick film are as follows; dielectric constant (ε_r) of 1155, remanent polarization of 14.1 μC/㎠ and coercive electric field of 18.3 ㎸/㎝.

Table 1 shows the effective d33 values of the thick films poled by the conventional DC technique. The thick films were electrically broken down when the DC field was above 15 kV/mm. The maximum d33 value, 57 pC/N, was obtained at 15 kV/mm in this work and that is the typical value in the PZT thick films.

Corona discharge poling technique has been applied successfully to the poling of polymer-ceramic composite piezoelectrics with a large area.[6] The discharged ions with low kinetic energy are accumulated on the exposed top surface and develops the electric field. Local current is strongly limited due to small lateral conductivity on the exposed insulator surface and high electric field is created without the electrical breakdown, while local breakdown at weak spots short-circuits the electrodes in conventional poling with dc electric field.[7] The effective d_{33} values of the thick films poled by corona discharge poling technique are shown in the table 2. The effective d33 value increased by decreasing the distance between the metal tip and the surface of the sample. The highest effective d33 of 163 pC/N was obtained when the corona discharge field of 10 kV was applied at the metal tip 1 cm above the top surface of the thick film. The thick film poled by corona discharge technique shows about three times higher effective d33 value than that poled by conventional DC method. The corona discharge poling technique is much more effective than the conventional DC poling method in poling the piezoelectric thick films.

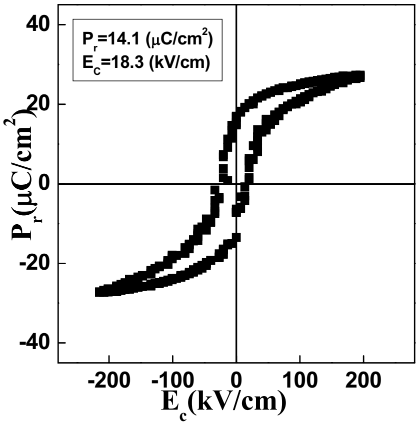

Fig. 3 P-E hysteresis curve of the PZT thick film

Table 1 The effective d_{33} values of the thick films poled by the conventional DC poling method

Electric Field(kV/mm)	d_{33} (pC/N)
10	26
15	57
20	breakdown

* Poling Condition : 120℃, 10 min.

Table 2 The effective d33 values of the thick films poled by the corona discharge poling technique.

Distance(cm)	d_{33} (pC/N)
1	163
2	144
3	33
4	25
5	18

* Applied Voltage to the Corona Point : 10kV, Substrate Temperature : 80℃

The PZT thick films prepared in this work shows very promising property for piezoelectric MEMS applications such as micropumps of the ink jet printer heads.

4. Conclusions

Piezoelectric thick films was prepared by screen printing on Pt/YSZ/SiO_2/Si . The thick film showed a single phase and a comparatively dense microstructure at the low sintering temperature of 850℃ Electrical properties of PNN-PZT thick films sintered at 850℃ were as follows; ε_r =1155, P_r = 14.1 μC/cm^2, E_c = 18.3 kV/cm.

The highest effective d_{33} was 163 pC/N when poled by corona discharge poling while 57 pC/N by conventional dc poling. We manufactured the piezoelectric thick film with high performance directly on silicon using screen printing method by developing a low sinterable piezoelectric composition and an efficient poling technique. The PZT thick films shows very promising property for piezoelectric

MEMS applications such as micropumps of the ink jet printer heads

4. Acknowledgments

This work was supported by grant No. RTI04-01-02 from the Regional Technology Innovation Program of the Ministry of Commerce, Industry and Energy(MOCIE)

5. References

[1] R.N. Torah, S.P. Beeby, N.M. White, ***Sensors and Actuators***, **A**[110], 378-384 (2004).
[2] Y. Jeon, J. Chung and K. No, ***Electroceramics,*** 4[1], 195-199 (2000).
[3] C. Lucat, F. Menil and R. Von Der Muhll, ***Meas. Sci. Technol.***, 8, 38-41 (1997).
[4] In Ho Whang, Jeong Seog Kim and Chae Il Cheon, ***Integrated Ferroelectrics***, 69, 231-238 (2005).
[5] Douglas Kim, 7B-416-P, ISIF (2006)
[6] D. Waller, T. Iqbal and A Safari, J. Am. ***Ceram Soc.***, 72[2], 322-324 (1989).
[7] Z.A. Weinberg, W.C. Johnson and M.A. Lampert, ***J. Appl. Phys.***, 47[1], 248-255 (1976).