Optimization Model for Flexible Piezoelectric Film in Self-Powered Pressure Sensor

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***Abstract*—A flexible pyramidal piezoelectric structure composed of a PVDF-TrFE piezoelectric film which can generate high output voltage is simulated and fabricated. Compared to the flat, square columnar and trigonal-line micropatterned thin films, the pyramidal structure has stronger variation strain and produces higher piezoelectric signals. When they are subjected to the same mechanical load, the pyramidal structure generates output voltage that is 9 times larger than that of the planar film. The optimized flexible piezoelectric film has broad application in self-powered pressure sensors.**

Keywords*—*flexible piezoelectric film; PVDF-TrFE; self-powered; pressure sensor; pyramid structure

I. INTRODUCTION

As portable and sustainable electrical devices are becoming more popular, generation of self-power from the ambient environment is attracting more attention. Compared to conventional pressure sensors such as the electrostatic, piezoresistive, and capacitive types, piezoelectric pressure sensors boast advantages such as the simple structure, self-power, and energy saving. Piezoelectric polymer polyvinylidene fluoride - trifluoroethylene (PVDF-TrFE) has attracted much interest because of the better flexibility and transparency compared to other piezoelectric ceramic materials such as lead zirconate titanate (PZT) and so it can be processed into various shapes and endure a large pressure [1-6].

In this work, various piezoelectric films made of PVDF-TrFE including flat, square columnar, trigonal-line, and pyramidal ones are simulated and analyzed. Based on the simulation results, the flat and pyramidal PVDF-TrFE structures are fabricated and characterized and the performance of the piezoelectric pressure sensors is assessed and compared experimentally.

II. SIMULATION

PVDF-TrFE films can be shaped in different ways to enhance the piezoelectricity. The finite element analysis (FEA) software ANSYS is adopted to simulate different shapes and the simulation results are shown in Figure 1. The variation strain and output voltage generated by different structures are shown in Table I.

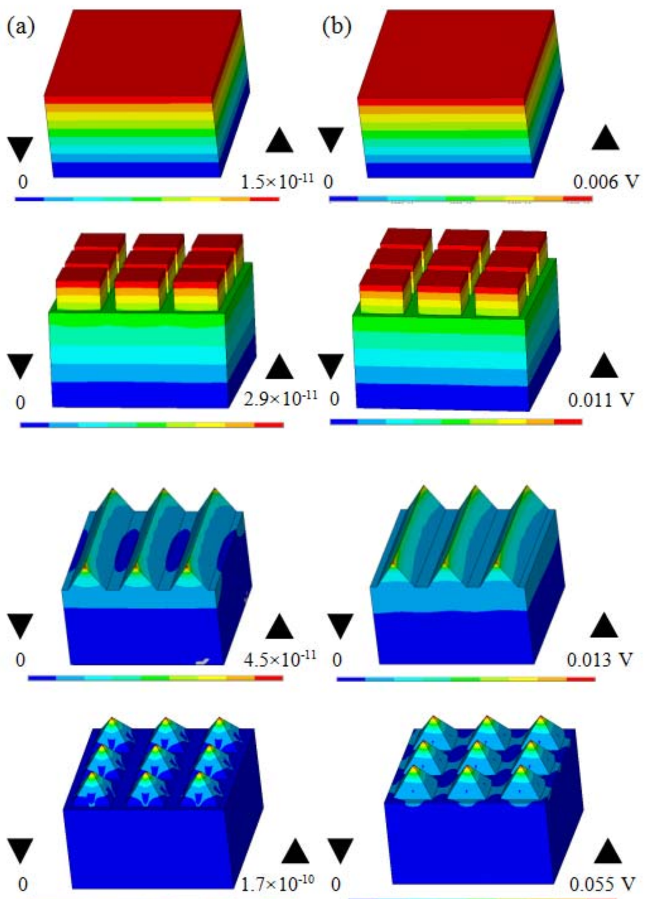

Fig. 1. ANSYS simulation results of the flat, square columnar, trigonal-line and pyramidal structures. The pyramidal structure yields the highest output voltage.

TABLE I. Comparison of strain and output voltage for the four structures under same compression load of 0.2 N per square centimeter.

Structure	***Flat***	***Square column***	***Trigonal line***	***Pyramid***
Strain	1.5×10^{-11}	2.9×10^{-11}	4.5×10^{-11}	1.7×10^{-10}
V_{out} (V)	0.0062	0.011	0.0134	0.0547

Normally, larger strain produces a higher output voltage under the same compression load. In the simulation, the total height of different structures is 13.18 µm which includes 10 µm base and 3.18 µm various top structures, and the compressive load is 0.2 N per square centimeter. The pyramidal structure generates the highest strain of 1.7×10^{-10} and output voltage of 0.055 V, which is 9 times larger than that of flat structure.

III. EXPERIMENTAL SECTION

The PVDF-TrFE powder with mole ratio of 75:25 was selected because of its good d_{33} and low annealing temperature. It was dissolved in *N*,*N*-dimethylformamide (DMF) with a concentration of 20 wt% and stirred for 12 h at room temperature. The PVDF-TrFE thin film was fabricated by spin-coating, followed by drying at 80 ℃ for 5 minutes to remove the DMF solvent. The PVDF-TrFE film was annealed at 140 ^{o}C for 5 minutes and cooled to room temperature gradually in order to enhance the degree of crystallinity of the β phase.

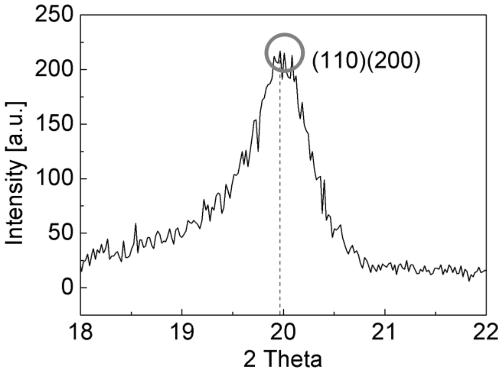

Fig. 2. Characterization of β phase of PVDF-TrFE: XRD results of the PVDF-TrFE thin film.

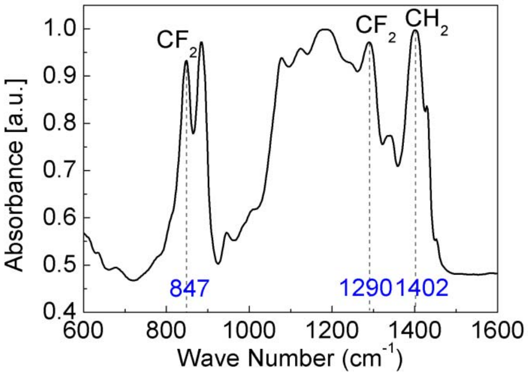

Fig. 3. Characterization of β phase of PVDF-TrFE: FTIR results of the PVDF-TrFE thin film.

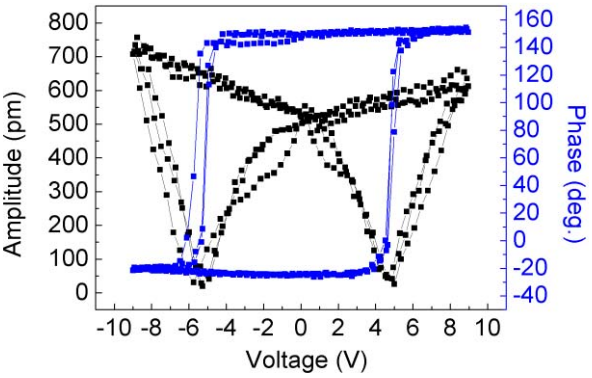

Fig. 4. PFM hysteresis loops in amplitude and phase for PVDF-TrFE thin film.

The XRD spectra of PVDF-TrFE film in Figure 2 reveals diffraction peaks at 2θ of 19.9°, which reflects the (110) and (200) orientation planes and indicates the high degree of crystallinity. The FTIR spectrum of the PVDF-TrFE thin film (Figure 3) shows three bands associated with the β phase. The 1290 and 847 cm^{-1} peaks stem from CF_2 symmetric stretching with the dipole moments parallel to the polar *b* axis and the 1402 cm^{-1} band is assigned to CH_2 wagging vibration with the dipole moment along the *c* axis [7]. Piezoelectric force microscopy (PFM) loop measurement is carried out. Figure 4 shows that the fabricated PVDF-TrFE thin film has superior piezoelectric response.

To verify the simulation results, flat and pyramidal PVDF-TrFE films were fabricated and characterized. The inverted pyramidal silicon mould was anisotropically etched by tetramethylammonium hydroxide (TMAH) and patterned with 4.5 µm × 4.5 µm windows and spacing of 1.5 µm. The PVDF-TrFE solution was spin-coated on the flat silicon wafer and inverted pyramidal silicon mould, respectively, at 1,500 rpm for 60 seconds. After drying and annealing, both films were taken from the moulds and aluminum electrodes about 100 nm thickness were deposited on both sides by sputtering.

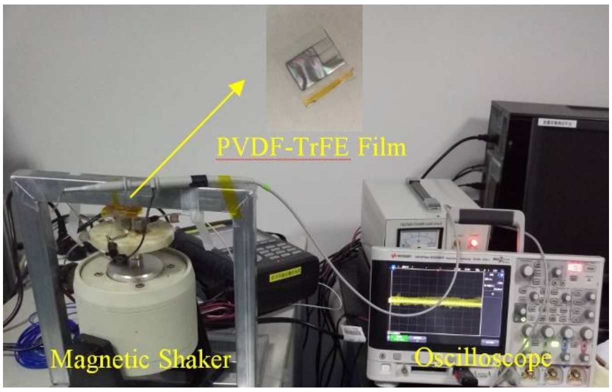

Fig. 5. Piezoelectric testing equipments of PVDF-TrFE film include oscilloscope and magnetic shaker.

To assess the piezoelectric performance of the two PVDF-TrFE films, magnetic shaker and oscilloscope are selected. The piezoelectric testing equipments are shown in Figure 5. When the same vertical compression of 10 N at 5 Hz is applied, the peak-to-peak voltage of the pyramidal structure is about 1.4 V (Figure 6) that is approximately 9 times larger than that of the flat structure which produces a peak-to-peak voltage of 0.15 V.

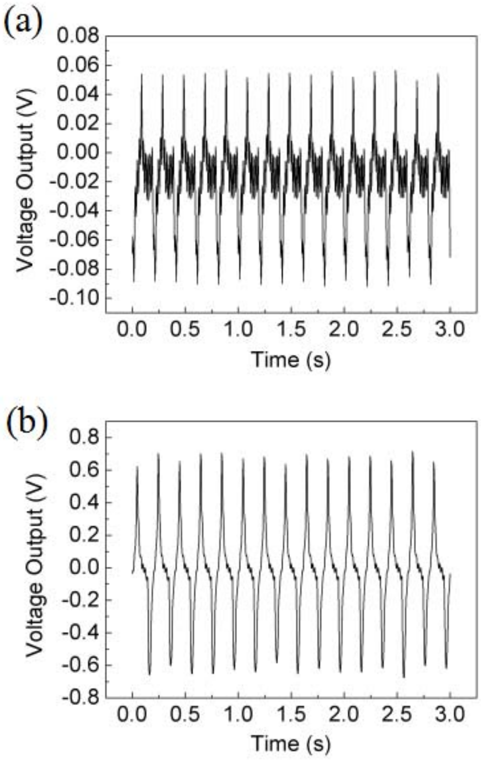

Fig. 6. Comparison of the output voltage between the flat and pyramidal structures under a force of 10 N at 5 Hz: (a) Output voltage of the flat structure of about 0.15 V and (b) Output voltage of the pyramidal structure of about 1.4 V that is approximately 9 times larger than that of the flat structure.

IV. CONCLUSION

The piezoelectric performance of the PVDF-TrFE thin film is enhanced by micropatterning. The flat, square columnar, trigonal-line and pyramidal structures are simulated. The output voltage of the pyramidal structure is the highest under the same compression force. The piezoelectric pressure sensors based on the flat and pyramidal structures are designed and fabricated and the piezoelectric performance is evaluated. The output voltage of pyramidal structure is about 1.4 V that is approximately 9 times larger than that of the flat structure which shows an output voltage of 0.15 V under the same force. The experimental and simulation results are consistent. The flexible piezoelectric structure based on pyramidal PVDF-TrFE thin film has large potential in various self-powered pressure sensors.

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