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PSZT ceramics with pillar structure for the energy harvester

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There has been a significant increase in the research on the vibration-based energy harvesters in the recent years. Most researches are focused on the particular technology, and it is often difficult to compare different designs and approaches to vibration-based energy harvesters. This work aims to manufacture a pillar structure of composite material using the $PbSrZrTiO_3$ piezoelectric materials which can convert mechanical energy to electrical energy by employing the ambient vibration. With this energy harvester, electrical energy that can be stored used to power other devices. In this research, the pillar structure of composite material was employed for the energy harvester. Here, the fabrication process and characterization for this energy harvester and its applications will be discussed.

Key words: Lead-free piezoelectric, Ferroelectrics.

Introduction

The increased power consumption in electronic devices has led find additional energy supplying system to use in the ultimate atmosphere. Instead of finding an alternative battery system, researchers have begun investigating methods of obtaining electrical energy from the ambient energy surrounding the device. Energy harvesting method employs light, heat, and kinetic energy, which are available in the ubiquitous surrounding. These energy harvesters convert surrounding energy into electrical energy. Even though the amount of harvested energy is in-finitesimal, these systems offer the potential of renewable energy sources which can be used to directly replace or multiply the primary battery. Surrounding energy can be converted into electrical energy employing electromagnetic, pie-zoelectric or electrostatic transduction mechanisms [1]. Energy harvester can converts mechanical energy into electrical energy by employing piezoelectric ceramics.

As a representative piezoelectric ceramic, $Pb(Zr_xTi_{1-x})O_3$ have been intensively investigated for their high piezoelectric constant d_{33} of 289 pC/N, and Curie temperature Tc of 328 °C. Near the morphotropic phase boundary between tetragonal and rhombohedral phase, they show excellent piezoelectric properties [2]. To improve the piezoelectric properties, dopants were added to the PZT system. Also more complicated components were researched for the high piezoelectric performance such as $Pb(Zn_{1/3}Nb_{2/3})O_3$-$PbTiO_3$ (PZN-PT) [3], $Pb(Mg_{1/3}Nb_{2/3})O_3$-$PbTiO_3$ (PMN-PT) [4], $Pb(Mg_{1/3}Nb_{2/3})O_3$-$PbZrTiO_3$ (PMN-PZT) [5], and $Pb(Ni_{1/3}Nb_{2/3})O_3$-$PbTiO_3$ [6]. Especially Sr doped PZT ceramic showed higher piezoelectric constant d_{33} of 600 pC/N and relative dielectric permittivity of 2000 at room temperature than those of PZT system [7]. Therefore, in this study, we have focused $Pb_{0.95}Sr_{0.05}Zr_{0.52}Ti_{0.48}O_3$ ceramics. Willian reported that Sr dopant can place on the A site of perovksite PZT structure, which results in an increase in degree of tetragonality. Therefore, Sr doped PZT can have the increased dielectric permittivity and piezoelectric properties [8].

Many papers have investigated different methods to improve the efficiency of energy harvesting by altering the configuration of the piezoelectric device in order to maximize the energy extracted from the ambient source. Ambient vibrations were characterized by the low frequency with high amplitude displacement, and were found in numerous applications including common household good (fridges, washing machines, and microwave ovens), industrial plant equipment, moving vehicle such as automobiles and structures such as builds and bridges [9]. Several type energy generators can be used at such ambient vibrations: piezoelectric generator, electromagnetic generator, electrostatic generator and so on. Among these generators, piezoelectric composite can be a best choice due to it structural flexibility and high energy conversion.

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Experimental

The $Pb_{0.95}Sr_{0.05}Zr_{0.52}Ti_{0.48}O_3$ (hereafter referred to as

PSZT) ceramics were fabricated by using the conventional solid state reaction. High purity (> 99.0% purity), Pb_3O_4, ZrO_2, TiO_2, $SrCO_3$ powders were employed. They were ball-milled for 24 hrs with ethyl alcohol and a zirconia ball. To obtain the high uniformity and good crystal properties of the ceramics, two-steps calcination processes were employed. The dried mixture was sieved to 100 mesh. These powders were mixed with a PVA binder. 12 mm diameter pellets were uniaxially pressed under 294 MPa and then sintered at 1100 °C with a heating rate of 5 °C/min. Then, the specimens were polished and silver electrodes were screen-printed on both sides. The samples were poled under a 30 k*V*/cm of DC electric field. The poled PSZT ceramic bulks were cut into pillar shape. The ceramic pillars were attached to the aluminum substrate. The inter-pillar space was filled with polydimethylsiloxane (PDMS). The pillar structure was constructed of PDMS about 36% fill ratio. Fabrication process and device picture for the PSZT ceramic pillar devices is presented in Fig. 1

To determine electromechanical properties of the PSZT ceramic pillar structure, pieozo-d_{33} meter (YE 2730A, USA) was used to measure the piezoelectric constant d_{33} at 100 Hz. The pseudo electro-mechanical coefficient was calculated by measuring the resonance and anti-resonance frequencies by employing an impedance analyzer (HP 4194A Impedance Analyzer).

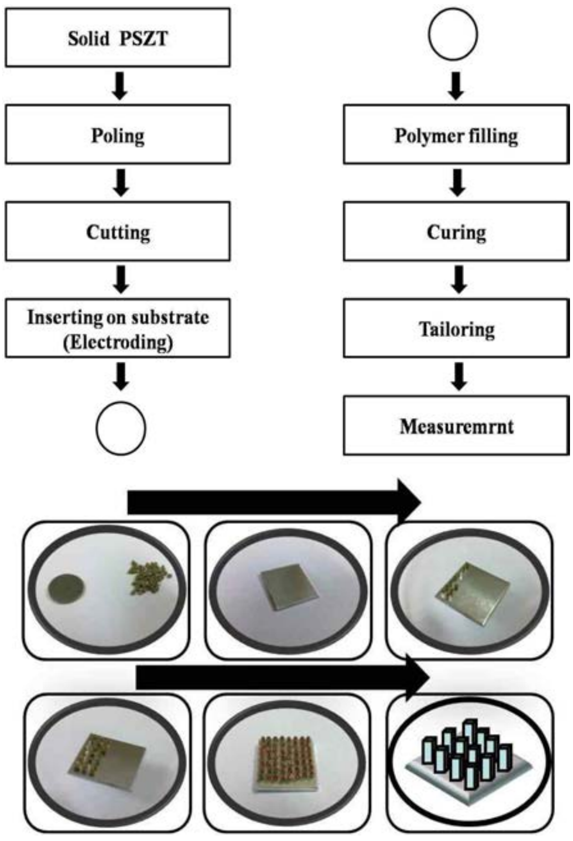


Fig. 1. The fabrication process for the PSZT ceramic pillar composite and its photographs.

The pseudo electromechanical coupling coefficients were calculated through the Onoe's formulas [10]. Dielectric properties were determined using an precision LCR meter (Hp 4284A). The coercive electric field E_c and remnant polarization P_r were determined from the P-E hysteresis loops obtained by a standard Sawyer-Tower circuit at 50 Hz.

Results and discussion

Table 1 shows dielectric and piezoelectric properties for PSZT ceramic pillar polymer composite material. The PSZT ceramic pillar polymer composite has reasonable relative dielectric permittivity ε_r of 1992, and electro-mechanical coupling coefficient k_p of 44, high piezoelectric coefficient d_{33} around 520 pC/N, and piezoelectric voltage coefficient g around 37.5×10^{-3} Vm/N. Although the considerable amount of polymer was added to the composite, the d33 of composite reached to 80% of pure ceramic. Therefore, we believe that ceramic pillar polymer composite devices can be applied the energy harvester applications.

Fig. 2 showed the SEM image of PSZT ceramics. It is seen that the PSZT ceramic has the uniform grain distributions. This uniform grain distribution is believed to play a important role for the high piezoelectric performance. The grains were closely packed and it seems that average size is approximately 1 μm.

Fig. 3 reveals the frequency-dependent relative dielectric permittivity of the PSZT ceramic pillar-polymer composite and PDMS polymer. The relative dielectric permittivities of the PSZT ceramic pillar polymer composite and PDMS polymer continuously decreased

Table 1. Relative dielectric permittivity ε_r, electromechanical coupling coefficient k_p piezoelectric coefficient d_{33}, and piezoelectric voltage coefficient g_{33} values of PSZT ceramic pillar polymer composite energy harvester.

	ε_r	k_p (%)	d_{33} (pC/N)	g_{33} (10^{-3} Vm/N)
Values	1573	44	523	37

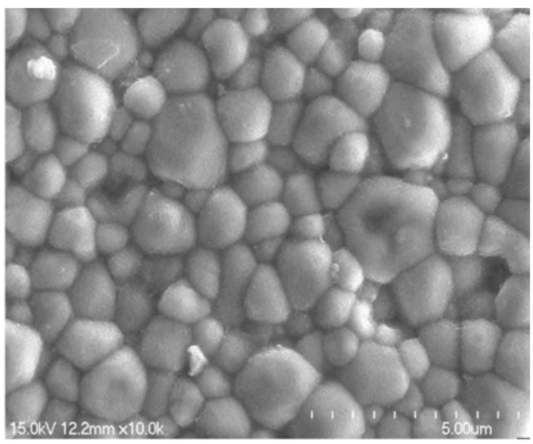


Fig. 2. SEM image of PSZT ceramics for the pillar structure.

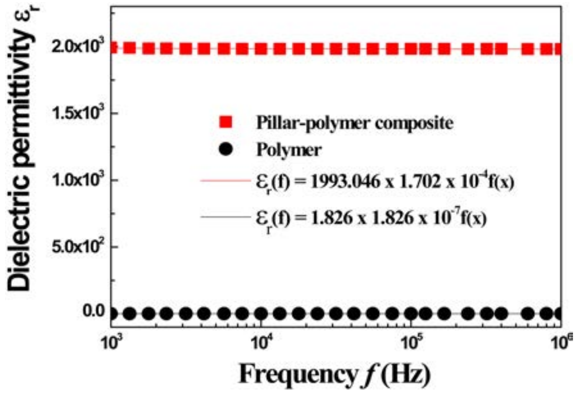


Fig. 3. Frequency-dependent relative dielectric permittivity of the PSZT ceramic pillar polymer composite and PDMS polymer.

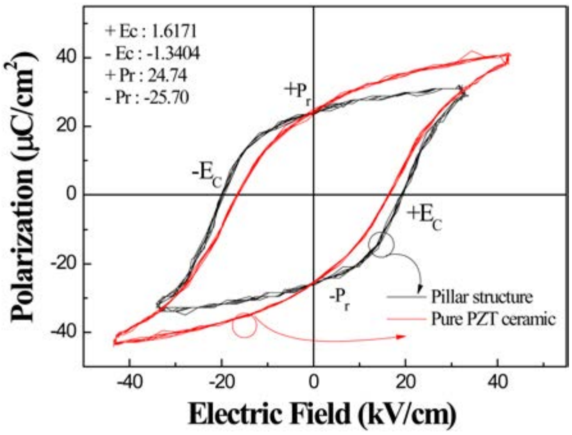
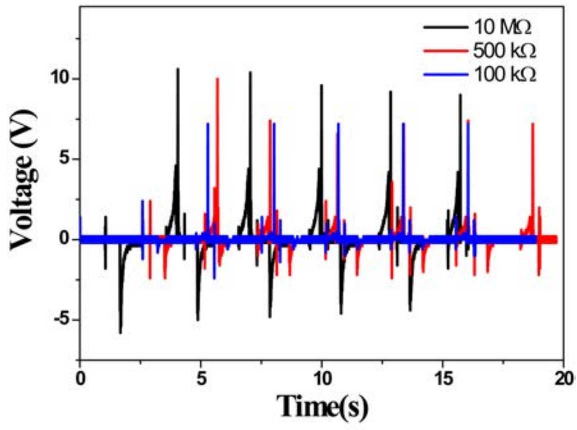


Fig. 4. The P-E hysteresis loops of the PSZT ceramic pillar polymer composite and pure PSZT ceramic bulk.

as the frequency increasing. The frequency dispersion of PSZT ceramic pillar polymer and polymers were 1992.21-1981.86 and 1.606-1.418, respectively in the frequency range 1 kHz - 1 MHz. We found that the relative dielectric permittivity of PSZT ceramic pillar polymer composite has a high value of 1992. Even though these devices were composed of ceramic and polymer component, the relative dielectric permittivity did not decreased rapidly. As shown in Fig. 3, with increasing the frequency, relative dielectric permittivity of the PSZT ceramic pillar polymer composite was continuously decreased from 1992.21 to 1980.44 ($\Delta\varepsilon$ 0.59%). The frequency-dependent relative dielectric permittivity of PSZT ceramic pillar polymer composite was fitted by the power law: $\varepsilon_r(f) = 1993.046\text{-}1.702 \times 10^{-7} f(x)$. The relative dielectric permittivity of the polymers was continuously decreased from 1.606 to 1.418 ($\Delta\varepsilon$ 11.7%). The frequency-dependent relative dielectric permittivity was fitted by the power law: $\varepsilon_r(f) = 1.826 - 1.684 \times 10^{-7} f(x)$.

Fig. 4 displays P-E hysteresis loops of the PSZT ceramic pillar polymer composite structure and pure PSZT ceramic bulk. These P-E hysteresis measurements were carried out at room temperature. PSZT ceramics pillar polymer composite devices have the same remanent polarization Pr of 24.7 μC/cm^2 as PSZT ceramics. In addition, the shapes of P-E hysteresis loops are very similar for the ceramic pillar polymer composite and bulk ceramics. From this comparison, we can similar ferroelectric properties for the ceramic pillar polymer composite and bulk ceramics.



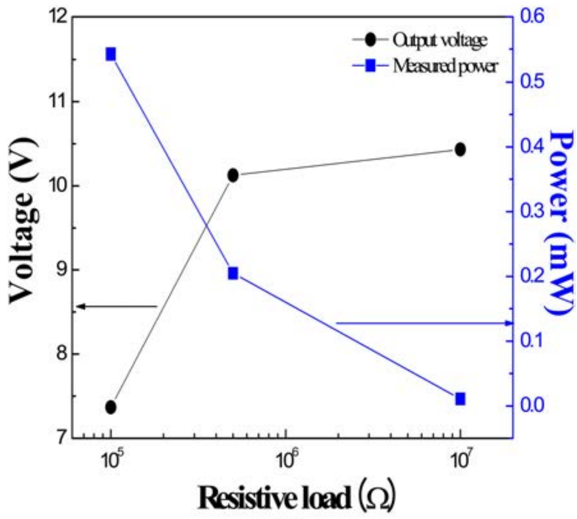


Fig. 5. Generated output voltage (a) and generated output power (b) according to the resistive load in the PSZT ceramic pillar polymer composite energy harvester.

Fig. 5 (a) exhibits the generated output voltage from the PSZT pillar polymer composite energy harvester by varying the load resistance. The external force was 980 N, which was given to the composite for 1 second. Load resistors were varied to calculate the generated energy from the PSZT pillar polymer composite energy harvester. Load resistors were varied to estimate the generated energy from the PSZT pillar polymer composite energy harvester. The generated maximum output voltage from these devices is around 10.74 V. From the generated output voltage, energy power can be calculated. In Fig. 5, the extracted output power was calculated. The generated output power of PSZT pillar polymer composite energy harvester is around 0.4 mW. The diameter and height of this energy harvester is around 2.25 cm^2 × 0.3 cm.

Conclusions

Energy harvesting technology is the key issue for the self-powered systems in the growing portable and wireless electronics market. Piezoelectric materials can be easily incorporated into many systems that are subjected to dynamic energy. In this research, we have fabricated the PSZT ceramic pillar polymer composite structure. It is capable of producing useful power around 0.4 mW from the vibration level of resistive load of 100 k ~ 10 M. This PSZT ceramic pillar polymer composite energy harvester can be an alternative to rechargeable battery for portable electronics.

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