High flexible piezoelectric PZT thin films deposited on stainless steel mesh

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Abstract. This paper describes high flexible piezoelectric vibration energy harvesters (PVEHs) composed of PZT thin films on stainless steel (SS) mesh. The PZT thin films were deposited on Pt/Ti-coated SS mesh substrates which were plain-woven with the SS wire diameter of 15 μm and 30 μm, respectively. Relative dielectric constant of the PZT thin films on the SS mesh of φ15 and φ30 was measured to be 475, 263, respectively. In φ15 device, the remnant polarization and the coercive field was 11.9 µC/cm² and 48.7 kV/cm, respectively. For the measurement of the piezoelectric response, we attached conductive rubber sheets to the rectangular top electrode. The maximum output voltage of about 30 mV was measured in each bending motion. We confirmed the capability of the PZT thin films on SS mesh for the PVEH applications.

1. Introduction
In recent years, wearable devices have attracted considerable attention as the next generation portable electronics, however, power supply to those devices are one of the critical issues for the practical applications. Piezoelectric vibration energy harvesters (PVEHs) have been thought to be the key technologies as the power sources to practical wearable products [1,2]. One of the most distinct features of the mechanical human motion is the large displacements [3]. To utilize such mechanical energy effectively, the required specification of PVEHs for wearable devices are not only high-efficient power generation but also reliability, light weight and flexibility. We confirmed the reliability of PVEH using stainless substrates [4], for that reason it is useful to design stainless substrate structures which reduce its rigidity.

In this study, we tried to prepare piezoelectric PZT thin films on flexible metal texture with sufficient flexibility. The PZT thin films were deposited on mesh substrates composed of small SS fibers. We evaluated their electric properties including piezoelectric response by bending motion and examined the capability for the wearable PVEH applications.

2. Experiments
The PZT thin films with a composition of Zr/Ti = 53/47 were deposited on the Pt/Ti-coated SS mesh by rf-magnetron sputtering. The mesh substrates used were plain-woven meshes with the SS wire diameter of 15 μm (φ15) and 30 μm (φ30), respectively. The number of φ15 and φ30 wires in mesh is 640 and 300 per inch, respectively. They were heated up at around 600 °C during the deposition. Prior to the PZT deposition, (Pb,La)TiO₃ (PLT) seed layers were deposited at the interface of PZT and Pt/Ti/SS mesh to improve the crystal growth of the PZT [5]. The thickness of PZT thin films was about 2.2 μm.
After the PZT deposition, post annealing was conducted to complete the crystallization of the PZT thin films to perovskite phase. After the PZT deposition, Pt top electrode was prepared through a shadow mask and evaluated their dielectric, ferroelectric and piezoelectric properties. Fig. 1 shows the schematic illustration and an optical image of PZT thin films deposited on SS mesh substrates.

3. Results and discussion

3.1 PZT layer on SS mesh

Crystal structure of the PZT thin films on mesh substrates was examined by x-ray diffraction (XRD) measurements. Fig. 2 shows the XRD patterns of the PZT thin films on φ15 and φ30 mesh substrates, respectively. The measurements indicated that the pyrochlore-free polycrystalline PZT layers were successfully grown on the SS mesh substrates. Fig. 3 shows the surface and cross-sectional SEM micrographs of the PZT thin films on SS mesh substrates. We confirmed that the surface of SS wires in meshes were coated by the dense PZT layers of about 2.2 μm in thickness without any cracks or pin-holes.

Figure 2. XRD patterns of PZT thin films on φ15 and φ30 mesh substrates.
3.2 Dielectric and ferroelectric properties
Relative dielectric constant of the PZT layers on the SS mesh of φ15 and φ30 was calculated from the capacitance of PZT layers coated by Pt dot electrodes of 0.3 mm. In the measurements, we took into account of the wire density of each mesh substrate, while the surface area was assumed to be flat plane neglecting round surface net area of the wires. The apparent relative dielectric constant of the PZT layers on φ15 and φ30 meshes were measured to be 475 and 263, respectively. The difference of the electric properties is attributed to the difference between apparent and net electrode areas. Dielectric loss of the PZT layers on the SS mesh of φ15 and φ30 was measured to be 0.33 and 0.20, respectively. Although the value was slightly higher than that of PZT thin films on the flat SS substrates, we could not observe apparent short circuit between top and bottom electrodes [6, 7].

Fig. 4 shows the P–E hysteresis loops for PZT layers on φ15 and φ30 SS mesh. In the φ15 PZT device, the remnant polarization and coercive electric field were 11.9 µC/cm² and 48.7 kV/cm, respectively. Although the ferroelectric properties of the φ30 PZT device were almost same as that of the φ15 PZT device, the remnant polarization of φ30 SS mesh was smaller than that of φ15 SS mesh because of the difference net electrode area.

3.3 Power generation
Power generation performance was measured by bending PZT layers on SS meshes. In order to extract the generated power on the rectangular Pt top electrodes, conductive rubber sheet was bonded on it as shown in

Figure 3. Surface and cross-sectional SEM images PZT layers (a) φ15 mesh and (b) φ30 mesh.

Figure 4. P–E hysteresis loops of stainless steel mesh.
Fig. 5. (a) The schematic illustrations of measurement set up and (b) the output voltage of φ30 stainless steel mesh.

Fig. 5 (a). The output voltage of the mesh structure PVEHs in φ30 device are shown in Fig. 5 (b). The output voltage of approximately 30 mV was measured by each bending motion. It was lower than expected because of relatively high resistance (about 20 Ω) of the conductive rubber sheets, however, we could measure stable power generation from the PZT layers on flexible SS mesh substrates.

4. Conclusions

We successfully deposited high flexible piezoelectric PZT thin films on SS mesh of 15 μm and 30 μm in diameter by rf-magnetron sputtering. The PZT layers on SS mesh substrates showed typical ferroelectric properties. By each bending motion, we confirmed stable output voltage of 30 mV from the PZT layers. The results suggests that the PZT thin films on the flexible SS mesh are promising power sources for wearable devices.

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