Signal Detection of Object Slippage using Printed Soft Robotic Sensor

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ABSTRACT

Tactile sensing is required for skillful object handling in several soft robotic. Especially, real-time signal detection and identification of dynamic shear forces are important issue for slip recognition and object interaction. In this study, we report a printed soft robotic sensor for detecting of a signal detection of object slippage.

1 INTRODUCTION

Industrial robots have made innovative component assembly in the fields of manufacturing in automotive and electronic device components [1,2]. In recent years, soft robots with functional soft sensors have attracted research attention. Here, functionalized flexible and soft sensors enable tactile sensing [3], touch sensing [4] optical sensing [5], and vision sensing [6] on robots have been achieved to reappear human cutaneous senses. In soft robotics fields, this makes them potentially useful in sensing applications [7]. Moreover, robots with the above sensors can be adopted for applications in artificial intelligence (AI) and big data [8]. Therefore, they have become usable in the issues.

Soft robots can be expected to apply various industrial applications. To implement precise control using soft robots, understanding object behaviors once they are grasped is essentially. However, current soft robots do not incorporate high ability-soft sensors yet. Recently, some research for soft sensors have started that are developing to various technologies such as axial compression [9,10], temperature [11,12], stretching strain [13] and bending strain [14]. In particular, shear force sensing has attracted attention because it realizes an important issue in haptic and tactile controls [15]. Therefore, a dynamic shear force still needs to be evaluated. Further, acquired signals of slippage behavior depend on a slipping condition, which depends on an object shape [16].

In this study, we fabricated a highly sensitive printed soft sensor composed of a ferroelectric polymer to detect slippage shear force. A printing process such Screen technology can combine several functional materials to fabricate a soft device. Our sensor can be mounted on a soft gripper, and it can measure a slippage event to apply a tactile feedback system.

2 EXPERIMENT

In our study, we dissolved all materials used for fabricating the sensor in solvents. The printed soft sensor for shear force detection was fabricated on a flexible film (polyethylene terephthalate, PEN) with the ferroelectric polymer of a Poly(vinylidene fluoride-co-trifluoroethylene) [P(VDF-TrFE)] by Screen printing method. Frist, a cross-linked poly(4-vinylphenol) (PVP) solution mixed with the PVP and the melamine resin in 1-methoxy-2-propyl acetate was formed by spin-coating onto the substrate as the planarization layer. Lower and upper electrodes of the sensor were formed using a conductive polymeric material of poly(3,4-ethylenedioxythiophene):poly(4-styrenesulfonate) (PEDOT:PSS) and annealing at 135 °C for 30 min. The P(VDF-TrFE) layer was formed as the detecting layer of shear force by screen printing and annealed at 135 °C for 1 h. As a passivation layer, polyimide film was attached on the film. Finally, the fabricated sensor was mounted on the soft gripper. This pneumatic gripper made of dimethylpolysiloxane can withstand a pressure of up to 100 kPa. The fabricated sensor was shown in Fig. 1 (a) and (b).

3 RESULTS

Fig. 2 shows fundamental characteristics of the sensor. In Fig. 2 (a) shows a cross-sectional scanning electron microscopy (SEM) image of the sensor. The sensor includes two electrodes (PEDOT:PSS) and a 2-μm-thick ferroelectric layer consisting of P(VDF-TrFE). The surface topography image of the ferroelectric layer is shown in Fig. 2 (b) using atomic force microscopy (AFM). In the topography image, the root mean square (RMS) surface roughness was 9.6 nm. Fig. 2 (c) shows the polarization–electric field (P–E) hysteresis loop of our sensor. The larger the hysteresis window, the higher is its performance. The polarization and the coercive electric field were 7.0 μC cm^{-2} and 48 MV m^{-1}.

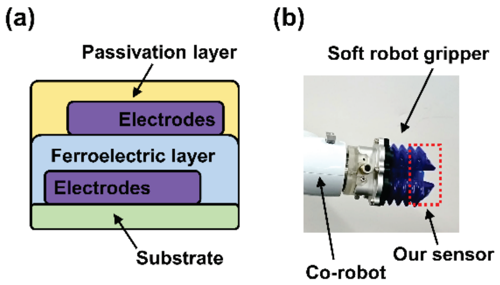

Fig. 1 Fabrication of the soft sensor for shear force detecting with a soft gripper. (a) Schematic image of the device fabrication using P(VDF-TrFE) and PEDOT:PSS. The sensor consists of substrate, planarization, electrodes, ferroelectric layer, and passivation layer. (b) Enlarged view of soft gripping system with our sensor and co-robot.

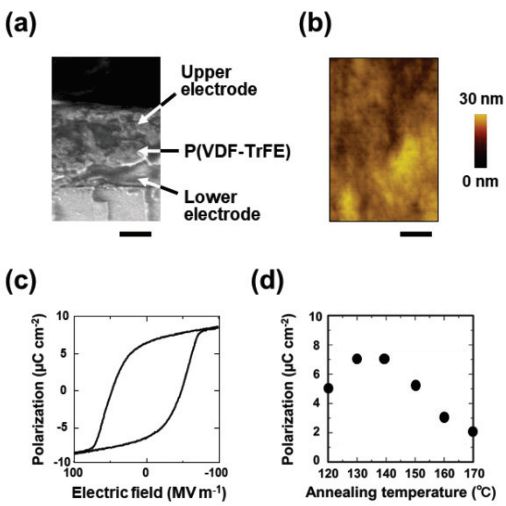

Fig. 2 Fundamental characteristics of the sensor. (a) Cross-sectional SEM image of the printed soft sensor; scale bar: 1 μm. (b) Surface AFM image of the P(VDF-TrFE) layers; scale bar: 1 μm. (c) P-E hysteresis loop between the polarization and applied electric fields. (d) The changes of polarization values as a function of annealing temperature.

The changes of polarization values as a function of annealing temperature are shown in Fig. 3 (d). The highest value was generated when temperature was 130 to 140 °C. These performances are reasonable as printed ferroelectric devices. These good polarization values indicate that our sensor can show high sensitivity against to applied strains. Thus, the outcomes indicate that it enables high-sensitivity detection for slippage events.

Next, we detected the slippage events of objects. In Fig. 3 (a) shows the schematic sensing system for shear force detection using our soft sensor and soft gripper. First, the gripper with our sensor grasped the object of a glass substrate by an inflation pressure of 30 kPa (Hold-state). Next, the object slipped owing to decompression (Slip-state). Finally, the object was completely released by the gripper (Release-state). Fig. 3 (b) shows the detected shear force signals using the sensor when the object slipped. The signals obtained from the sensors had related with slippage behavior; the signals consisted of hold, slip, and release phases. In the slip phase, periodic stick-slip (S-S) signals were generated owing to a spontaneous jerking motion [17,18]. The S-S spectra of the voltage features exhibit time-dependent variations, as shown in Fig. 3 (c). We found that the glass bottle with a low frictional coefficient produces S-S signals with a frequency of ~200 Hz.

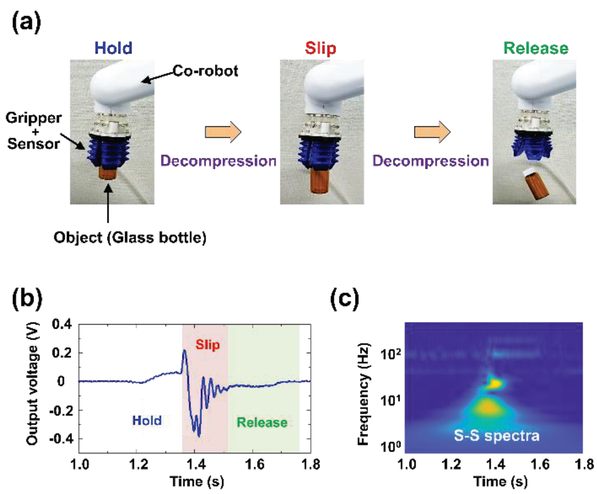

Fig. 3 Signal detection of object slippage using our soft sensor. (a) Photographs of sensing system with the soft gripper, our sensors, co-robot, and object. (b) Detected shear force signal by using sensors. The detected signal indicates hold, slip, and release states during object slipping. (c) S-S spectra of piezoelectric voltage signals for several frequency ranges.

4 DISCUSSION

By using the printed soft sensor including the ferroelectric polymer, we produced detection system of slippage events of the object with the soft gripper. These results indicate a successful experimental demonstration of the high-sensitivity and high-speed response of the tactile sensing for soft robots. This soft sensing system will be candidate a novel control system for operations without the need to train for various tasks. In future, we can show an experimental setup with the outcomes and a tactile feedback algorithm to realize making automatically gripping systems.

5 CONCLUSIONS

In this paper, we fabricated a printed soft sensor using a ferroelectric polymer that enable determine and detecting shear forces with a high-speed response. This sensor showed high abilities in fields of ferroelectric capabilities. Especially, in this work, the larger the hysteresis window of our soft ferroelectric sensor, the higher is its performance. The polarization and the coercive electric point of the sensor were 7.0 μC cm^{-2} and 48 MV m^{-1}. Our soft sensor is advantageous because when fixed on a soft gripper, it can well grasp objects. Moreover, we measured the shear force in real time by attaching our soft sensor on the robot gripper. This soft sensing system will be candidate a novel control system for operations without the need to train for various tasks. Thus, demonstrating the potential for novel soft robotics applications such as a biomimetic electronic skin.

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