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Large Scale Fabrication of Self-Powered Sensor Array Using Low-Cost Roll-to-Roll UV Embossing

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Abstract

This paper presents roll-to-roll UV embossing based fabrication of self-powered large scale pressure sensors arrays utilizing triboelectric mechanism. The pressure sensor array demonstrated a pressure detection sensitivity of 1.33 V kPa^{-1}. These sensor arrays have application in remote monitoring, sleep pattern detection, motion tracking and electronic skin application. The application of large scale pressure sensor array for posture monitoring is also demonstrated.

***Keywords**:* Triboelectric nanogenerator, self-powered, pressure sensing, roll-to-roll process.

1. Introduction

As the electronic devices and sensors make advances in terms of technology and applications, the number of devices will keep increasing. Powering these devices have emerged as a major challenge. Currently, majority of the commercially available sensors are powered using batteries. In order to solve this challenge of powering sensors, it is imperative to develop sensors which require low power for operation. Triboelectric mechanism provides a potential method to achieve low power operation as it does not require external power supply for the sensing function unlike capacitance and piezo-resistance based sensors. These sensors basically generate an electrical signal in response to mechanical stimulus and hence are self-powered. This mechanism can be used to realize self-powered pressure [1, 2], vibration [3], acceleration [4, 5] and motion [6] sensor. One of the major problems for commercial application of these self-powered triboelectric sensors is lack of manufacturing techniques to fabricate these devices in a scalable manner. This work demonstrates scalable fabrication of self-powered pressure sensor arrays using roll-to-roll process for low cost production for commercial applications [7].

2. Device design and fabrication

2.1 Design

The pressure sensor array comprises of two triboelectric layers: patterned polyethylene terephthalate (PET) and aluminum film as shown in Fig. 1a. These two materials are chosen as triboelectric layer due to their relative tendencies to attract and donate electrons according to the triboelectric series [8]. The patterned PET film functions as the first triboelectric layer. Aluminum film serves dual purpose of second triboelectric layer and electrode. The working mechanism of device is explained in the next section. The aluminum electrode is patterned on top of commercially available stock paper.

2.2 Working mechanism

The operating mechanism of is shown in Figure 1b. Before coming into contact with each other, both the triboelectric layers are initially uncharged. When an external mechanical force is applied on a pixel of pressure sensor array, both the triboelectric layers come in contact with each other. The contact of two triboelectric layers leads to transfer of electrons from the aluminum film to patterned PET film due to aluminum's higher tendency to donate electrons relative to PET film. The amount of charges generated is enhance due to the micropatterns transferred on the PET film. The charges on the patterned PET film are preserved owing to its insulating properties. The charges on conductive aluminum film can flow through the load resistor connected to the ground as electric potential changes at the aluminum electrode due to relative movement between the two triboelectric layers. As the applied force is released, the patterned PET film with the negative charges separates from the aluminum film resulting into an increase in the potential at the aluminum electrode. This leads to flow of electrons from the reference ground electrode towards the aluminum electrode. As the patterned PET film reaches the maximum point of separation between the two triboelectric layers, electrostatic equilibrium is reached and there is no flow of electrons in the load resistor connected between electrode and ground. Thereafter, the patterned PET film again approaches towards the

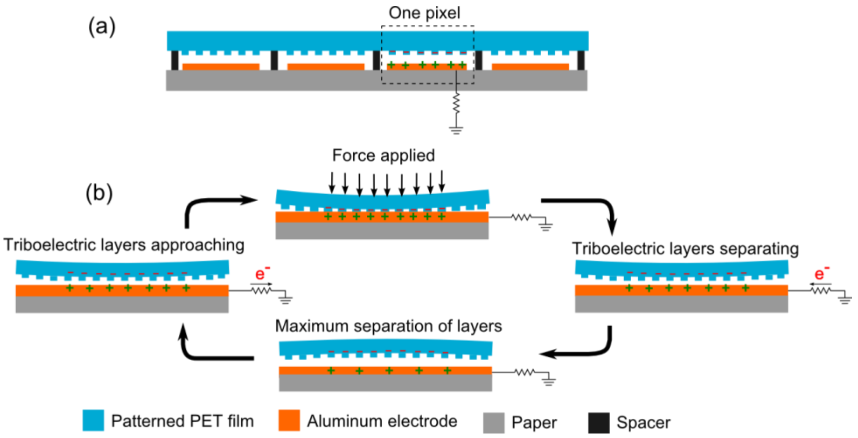

Fig. 1. (a) Schematic of pressure sensor array. (b) Working mechanism of a pixel of large scale pressure sensor array.

aluminum film due to periodic mechanical force. This leads to the flow of electrons in the load resistor in opposite direction. The flow of electrons in the load resistor can be used to sense the force applied on a pixel of the pressure array.

2.3 Fabrication of patterned polymer films

Large size patterned PET films are fabricated using roll-to-roll UV embossing process. The setup for roll-to-roll fabrication process is shown in Figure 2. The setup comprises of four parts. First part is the unwinding module that supplies the substrate PET film. The second part is the coating module to deposit UV curable resin on PET film using slot deposition process. The coating thickness of 20~60 µm with thickness uniformity better than +/- 10% can be obtained for the layer. Following the coating module is UV embossing module for patterning microstructures on PET film. This module uses a patterned roller to transfer the required patterns and uses UV lamp placed beneath the embossing roller to cure the transferred patterns on the PET film. The last part is rewinding module that provides web tension for separating the embossed PET film from the embossing roller and then rewinds for collecting the embossed PET film. A patterns fabricated on the PET film are shown in Fig. 3. These patterned PET sheets were used to increase the contact area between the triboelectric layers during contact electrification. These square patterns were designed to form pixel patterns on the PET films.

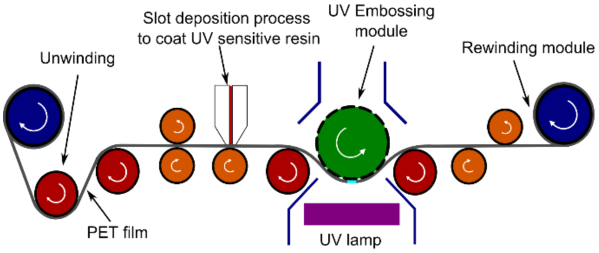

Fig. 2 Schematic of roll-to-roll fabrication setup for patterning polymer films

For the second triboelectric layer and electrodes for sensor array, commercially available stock paper was used as a substrate to make electrode patterns for individual pixels using aluminum foil. Both the triboelectric layers i.e. the aluminum electrode and individual PET patterns were separated using 200 µm thick spacers. The spacers separating all the individual pixels also helped in minimizing the cross talking between different pixels as external force is applied on the film. The fabricated sensor array can be used for motion tracking, tactile sensing, electronic skin, posture monitoring and various other applications.

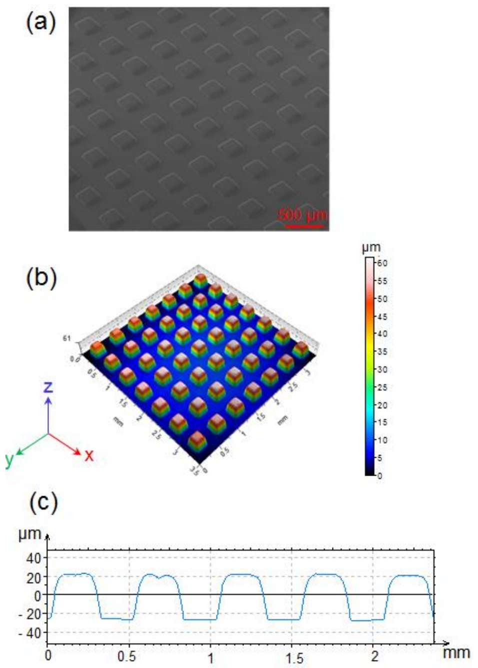

Fig. 3. (a) Scanning electron micrograph of the fabricated patterns. (b)-(c) Topography of fabricated patterns.

3. Results and discussion

A 7 x 3 pressure sensor array was fabricated using the aforementioned fabrication steps. A schematic of the sensor array is shown in Fig 4a. 10 MΩ resistors are connected between the aluminum electrode and common ground, in order to drop down the voltage generated from the pressure sensor pixels. The output across these load resistors were measured using individual channels of USB-6363 data acquisition (DAQ) board from National Instruments. The output from 21 channels from USB-6363 was acquired using Lab View to observe the individual output from individual pixels.

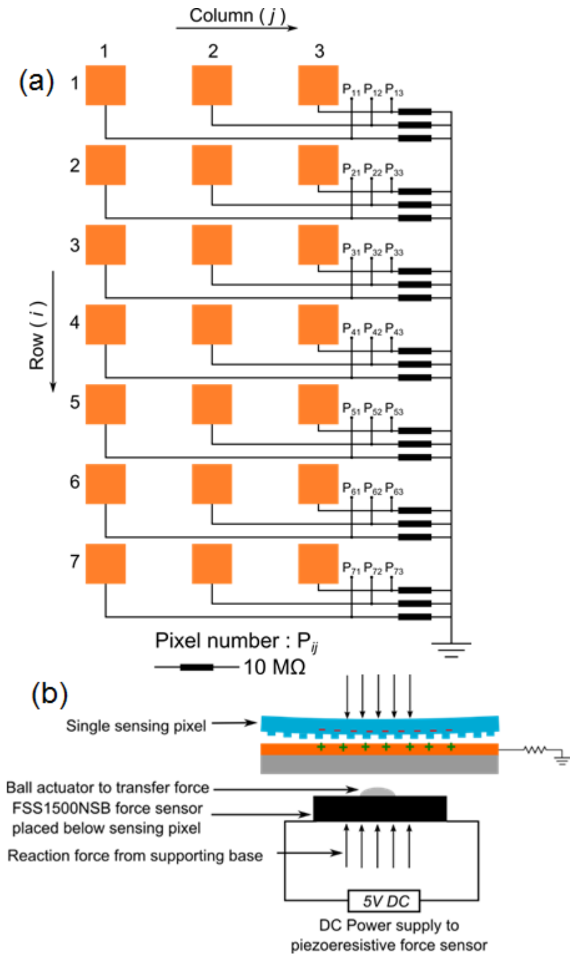

Fig. 4. (a) Schematic of pressure sensor array. (b) Setup for calibration of sensor pixels.

3.1 Sensor calibration and characterization

For sensor characterization, sensor pixels were first calibrated. For calibration of sensor array, commercially available FSS1500NSB sensor from Honeywell International Inc. was fixed below the sensor array pixel as shown in Figure 4b. The commercial sensor was biased using 5V direct current (DC) power supply. As the force was applied on the pixel, equal force reaction was applied to the commercial sensor. The output from the pixel and force sensor were then measured in real time as the sensor pixel was stimulated using external force.

As shown in the calibration setup, as pixel was stimulated using different levels of force, the signals were collected from both pixel output and the force sensor. The signals obtained in time domain from the pixel and force sensor are plotted on same time scale in Figure 5a. As the pixel is pressed, there is a negative peak observed in the voltage signal generated across the 10 MΩ resistor. Thereafter, as the force reaches a maximum value, two triboelectric layers come in contact with each other and measured voltage across 10 MΩ resistor reaches zero. As the force is released, a positive peak is observed in the voltage signal generated across the 10 MΩ resistor. The calibration curve for the sensor array pixel is shown in Fig. 5b. in The calibration curve, peak-to-peak voltage values generated by the pixel are plotted for different values of force applied. The peak-to-peak voltage was observed to increase linearly with the force applied. The force sensitivity of the sensing pixel was characterized to be 0.935 V N^{-1} which was equivalent to pressure detection sensitivity of 1.33 V kPa^{-1}. This shows that the large size pressure sensor array can be used for various pressure sensing applications such as security applications, motion tracking, posture correction and tactile sensing. The large size pressure sensor array was utilized and demonstrated for object tracking and posture correction applications as discussed in the following sections.

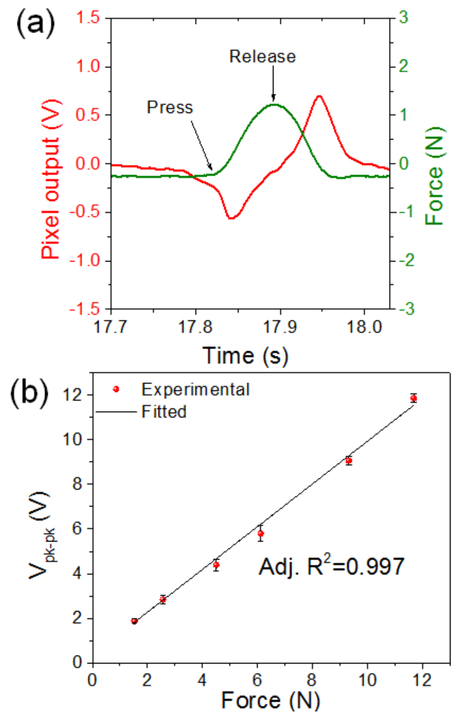

Fig. 5. (a) Time domain signal from a sensor pixel compared to a commercial force sensor. (b) Voltage output from a pixel for different value of external applied force.

3.2 Object tracking

To demonstrated the pressure sensor array for object tracking applications, the array was tested for motion tracking of a cylindrical object rolling over the array. A cylindrical object with a diameter of 9.2 cm, width of 1.9 cm and weight of 30 gm, was rolled on a linear array of six pixels from P1 to P6 as shown in Figure 6. As the object rolls over the sensors array, it leads to contact between triboelectric layers. This in turn leads to a negative peak observed in the voltage signal generated by the pixel, as shown in the time domain signals obtained from pixels in Fig. 6. As the object keeps moving and is on top of sensor array pixel, a maximum peak force is reached leading to maximum contact between the patterned PET film and aluminum electrode as shown in Fig. 6. Thereafter, the object leaves the pixel and triboelectric layers start separating from each other leading to a positive peak. This mechanism leads to a voltage signal generated, when the object rolls on top of the pixel. As shown in Fig. 6, the voltage pulse shifts to the right as object moves from pixel P1 to P6 and touches the pixels in sequence. The position data acquired using these time domain pulses can be utilized to calculate the velocity and acceleration of the object. These low cost and large size sensor arrays can potentially be used for movement tracking of objects with applications in security systems, sports/athletic training and remote patient monitoring.

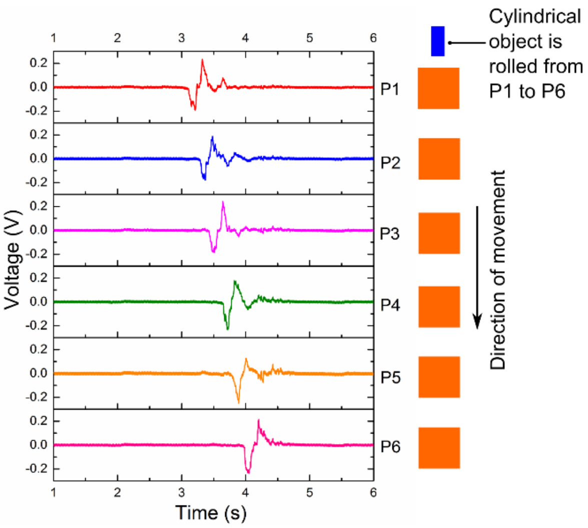

Fig. 6. Time domain output voltage signals generated by an array of 6 pixels as a cylindrical object is rolled from P1 to P6. The pixels generate a signal as the object contacts the pixel.

3.3 Posture monitoring and correction

The large size pressure sensor array was also demonstrated for application in posture monitoring. The sensor array was assembled at the back of a chair as shown in Figure 7g. As discussed earlier, the sensor array pixels generate an electrical output as the subject touches the pixels of sensor array. For the posture monitoring application, as human subject different pixels of the sensor array, the signal generated from the pixels can be used to monitor the posture. The heat map of the peak-to-peak voltage generated by the pixels is shown in Figure 7a-e for different positions of the subject. In position (a) the subject is not touching any pixels; as the subject moves to position (b), the subject contacts the majority of pixels in the lower half of sensor array (after row 3) that results in darker pixels in lower half as compared to the upper half. The output observed in the pixels observed above row 3 can be attributed to cross-talking between pixels, as the patterned PET film deforms when applied with an external force. In position (c), the subject straightens the back and pressure is applied on whole array. Thereafter, Figure 7d, e show the results obtained from the pressure sensor array as the subject tilts to right and left respectively (as seen from subject's position). The experiments demonstrate that the sensor array can be used for applications in posture monitoring, sleep pattern monitoring, walking pattern monitoring and electronic skin applications.

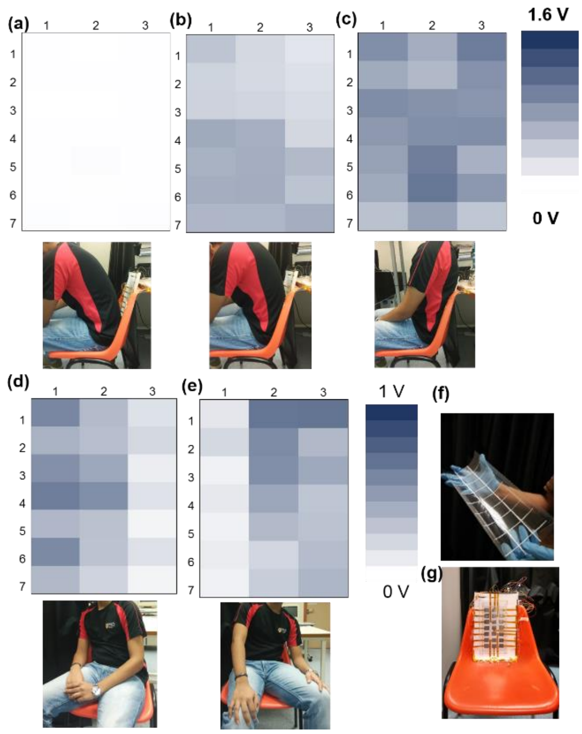

Fig. 7. Heat map of the sensor array for different posture when array assembled on back of chair. (a) Without touching the sensor array, (b) partially touching the sensor array pixels, (c) completely touching the sensor array pixels, (d) leaning on right side of the subject, (e) leaning on left side of the subject. (f) Photograph of patterned PET film fabricated using roll-to-roll fabrication process assembled with spacers. (g) Sensor array assembled on the back of a chair.

4. Conclusion

In summary, we have demonstrated a process flow for large size pressure sensor array based on triboelectric mechanism. Roll-to-roll UV embossing was utilized to fabricate large size patterned polymer films to realize the sensor array. The detection sensitivity of device was observed to be 1.33 V kPa^{-1}. The sensor array was demonstrated for applications in object tracking for remote monitoring and security applications. We also conducted experiments using the sensor array for posture monitoring by assembling the array at the back of chair. The fabricated large size sensor array can be used in patient monitoring, posture monitoring and electronic skin applications.

6. Acknowledgement

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7. References

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