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Flexible Pressure Sensing Device using Blended Nano-Carbon-Black / P3HT Solution Process.

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ABSTRACT

Pressure sensing is an important environmental factor in different applications, such as chemo-mechanical instruments and combusting actuations. Therefore, it has become a major research fields in material and engineering for decays. Various materials have been proposed and demonstrated to have the pressure sensing capability. In this report, we have developed the new pressure sensing material based on polymer semiconductor materials. The developed sensor can be fabricated the pressure sensing device by homemade ink-jet printing technology and dip coating process. The developed material will widely reduce the cost of the pressure sensor implementation even in large scale area manufacturing.

Keywords：P3HT、carbon black、pressure sensor

1. INTRODUCTION

The pressure sensors are widely used in many applications. To obtain the cost-effective pressure sensing device, the manufacture processes and materials have been the one of the major engineering research fields. Among the various pressure sensing materials, the development of organic materials has become an attractive aspect because of its low cost, flexibility, and compatibility with soft-electronics. In specific, Takao Someya[1] is one of the researchers who devote to soft electronics and achieve astonishing achievement. He combines organic thin film transistors with pressure sand thermal sensors to produce the electronic artificial skin. In addition to the organic thin film transistor as the structure of the pressure sensor, silicone rubber or other colloid mixed with carbon nanotube or carbon black are used as the pressure sensor[2 3]. The resistance of the pressure sensor composed of the superelastic carbon microcoil and silicone rebbuer is changed by compressing the sensing device to make it to be conductible. On the other hand, K. Arshak and his colleagues use the screen-print technology to print the copper electrodes, then dip the polymer solution mixed with carbon black on the surface of interdigitated electrodes to produce pressure sensor[4、5]. However, most of the previous works suffer from the high fabrication cost and lack of the large area process capability. To overcome this obstacle for the next generation technology, the newly developed organic pressure sensor based on ink-jet printing technology will be proposed, implemented and examined in this work. This technique will offer a new method to pave the way toward the low-cost/high volume pressure sensor technology.

2. MATERIALS AND EXPERIMENTS

The home-made ink-jet printing system was adopted in the development of this series of pressure sensors. The organic thin film pressure sensor was implemented by ink-jet printing technique with dip coating process. In detail, the thin film pressure sensor was composed by a flexible polyimide (PI) substrate, PEDOT/PSS organic electrodes, and semiconductor polymer (P3HT) based pressure sensing material. The PEDOT/PSS was printed as interdigitated electrodes on the PI tape. After the electrode layer, the pressure sensing material was patterned on the top of the electrodes by drop coating on the interdigitated electrodes. The sensing material was the mixture of semiconductor polymer (P3HT) and carbon black(CB). Finally another thin layer of polyimide was used as encapsulation layer.

The detail fabrication process of the developed pressure sensor can be listed as following. We take the PI tape made from Taiwan Super Stick Tech Materials Co., Ltd. as the substrate. The surface roughness of the PI tape is approximately 5 nm and it can be operated at temperature from 20℃~260℃. These characteristics are suitable for the following processes. Followed by acetone/methyl alchol/DI cleaned glasses as the fabrication carrier, the PI tape is pasted to the glass carrier. After the preparation of the flexible substrate, PEDOT/PSS is used as the electrode material. PEDOT/PSS, named as Poly (3, 4 - ethylenedioxythiophene) poly (styrenesulfonate) in aqueous dispersion form, is bought from H.C.Starck, German. It is mixed of two kinds of single polymers, made up of PEDOT and PSS separately. PEDOT with π -π conjugated bonds is a kind of high conductivity organic material and its conductivity is 500 S/cm. This characteristic of PEDOT is not influence by moisture and light. However, the PEDOT is not soluble. To improve the processibility, PSS is employed to improve the water solubility of PEDOT with the sacrifice of decreased conductivity to 10 S/cm. In order to promote the conductivity of PEDOT/PSS, we added ethylene glycol (EG) containing polar molecule into the PEDOT/PSS aqueous solution. In our devices, the formulation of PEDOT/PSS：EG：DI water (Volume percentage) is 1%：20%:：79%. In the device implementation, we print interdigitated electrodes by using PEDOT/PSS by ink-jet printing. The deposit thin film is cured at 80℃ on hotplate for 5 minutes. The conductivity can reach 200 S/cm. The fabricated interdigitated electrodes area was 2mm by 2mm, the length, interval and width were 1200um, 350um and 60um, respectively, as shown in Fig. 2.1. The pressure sensing layer was composed with organic semiconductor (P3HT) and carbon black. The P3HT full name is poly (3 - hexylthiophene), regioregular 98.5%, bought in Aldrich U.S. The solvent of P3HT is p-xylene and its boiling point is 138℃. The concentration of P3HT was 0.1wt% dissolved in p-xylene and mixed varied weight ratio of carbon black.

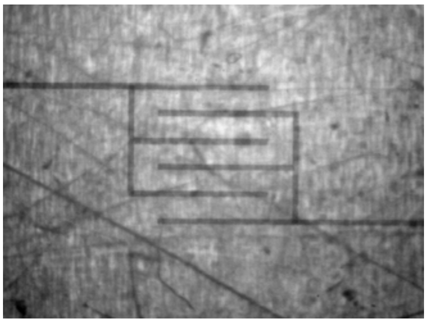

Figure2. 1 PEDOT/PSS finger-shaped electrodes

In this work, we study the relationship between the number of the pressure sensing layer and the pressure sensitivity respected to the device resistance. In addition, we also study the relationship between the concentration of the different weight ratio of carbon black and the pressure sensitivity respected to the device resistance. In specific, the ratio of weight for CB/P3HT are 0.2/100, 1/100, 5/100 and 10/100, respectively. It should be noted that P3HT has to be mixed with its solvent, p-xylene, in nitrogen ambient because it is easily influenced by the moisture and oxygen in atmospheric environment. After mixing with p-xylene, we use the paraffin paper to encapsulate P3HT and put it in the drying cabinet. To mix with carbon black, we put the carbon black on hotplate for 40℃ in half an hour to remove the aqueous vapor. Afterward, the dried carbon black is added into P3HT solution. Because the solubility of P3HT in p-xylene is not very good, we shall put P3HT solution in the ultrasonic oscillator with 80~100℃ hot bath until P3HT is totally dissolved in p-xylene. Finally, we use micro-pipet to disperse the mixed solution which is made of P3HT and CB on the interdigitated electrode. The 70℃ bake is used for an hour in the nitrogen oven to remove solution and followed by 150℃ baking for 10 minutes.

After fabricating the pressure sensing layer, we drip PI on the surface of the pressure sensing layer as encapsulation layer by curing at 60℃ for 10 minutes to remove solvent in the vacuum oven and followed 120℃ for 60 minutes.

3. EXPERIMENTAL RESULT

First we chose CB/P3HT=10/100 to study the relations between the numbers of the pressure sensing layers and the resistance change of the pressure sensor, and the number of layers was respectively 1, 3 and 5, and the experiment data was respectively Fig.3.1, Fig.3.2, and Fig.3.3. It was found from the figures that when the numbers of the pressure sensing layers increased, the change of resistance because of pressure decreased. As the consequence, we chose single-layer pressure sensor, and studied different CB/P3HT ratio to the resistance change of the pressure sensor.

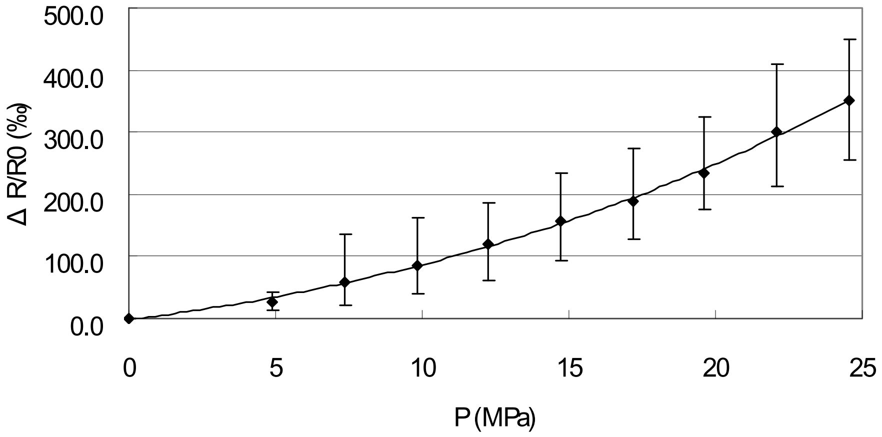

Figure3. 1 Pressure to resistance change per mille , P3HT：CB=100：10 , layer=1

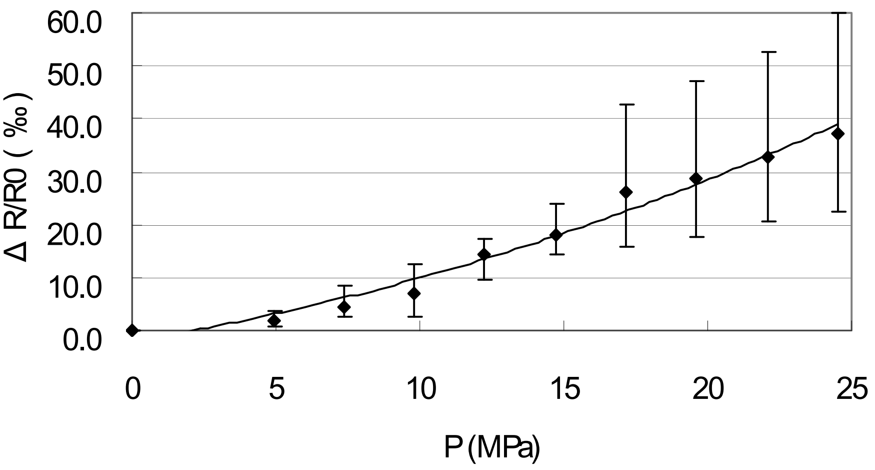

Figure3. 2 Pressure to resistance change per mille ,P3HT：CB=100：10，layers=3

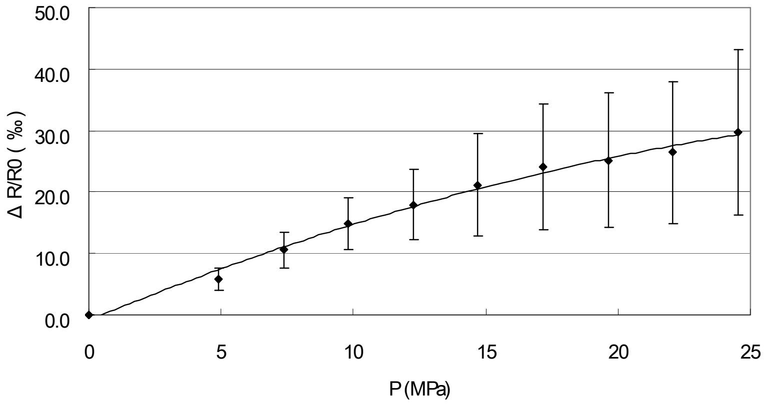

Figure3. 3 Pressure to resistance change per mille, P3HT：CB=100：10，layers=5

The pressure sensors, CB/P3HT=0.2/100、1/100、5/100 and10/100, were composted of only one pressure sensing layer. The figure showed pressure sensor sensitivity, namely resistance change per mille. For P3HT：CB = 100：0.2, the maximum value of resistance change per mille was 299.7 ‰. For P3HT：CB = 100：1, the maximum value of resistance change per mille was 505.1 ‰. For P3HT：CB = 100：5, the maximum value of resistance change per mille was 460.2 ‰. And for P3HT：CB = 100：10, the maximum value of resistance change per mille was 350.5‰. According to the reference, the destruction and the accretion of the conducting path of the carbon black occurred under pressure. By experimental datum at this structure design, the main affect was destruction of the carbon black's conducting path in the process of compressing along with pressure sensor distortion, so four kind of different densities, the resistance of the pressure sensor all increased with increased the pressure. By Fig. 3.10, it is clear that the resistance change of the organic thin film pressure sensor increased along with carbon black density gradually increases. Until a specific density, the resistance change per mille maximum value decreased along with carbon black density gradually increases.

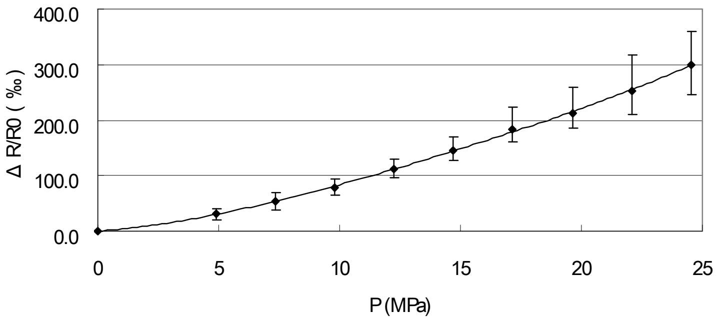

Figure3. 4 Pressure to resistance change per mille, P3HT：CB=100：0.2，n=4

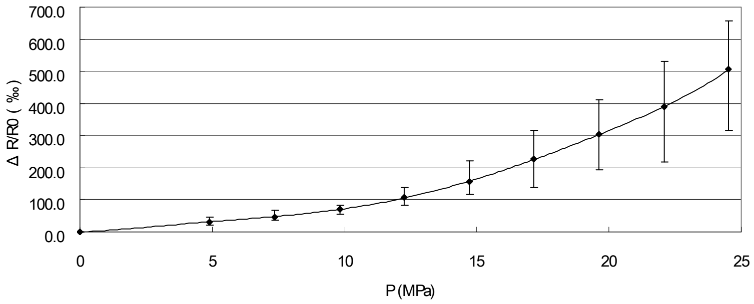

Figure3. 5 Pressure to resistance change per mille, P3HT：CB=100：1，n=7

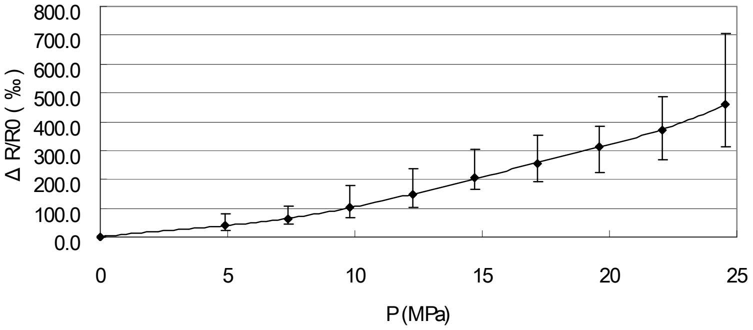

Figure3. 6 Pressure to resistance change per mille, P3HT：CB=100：5，n=4

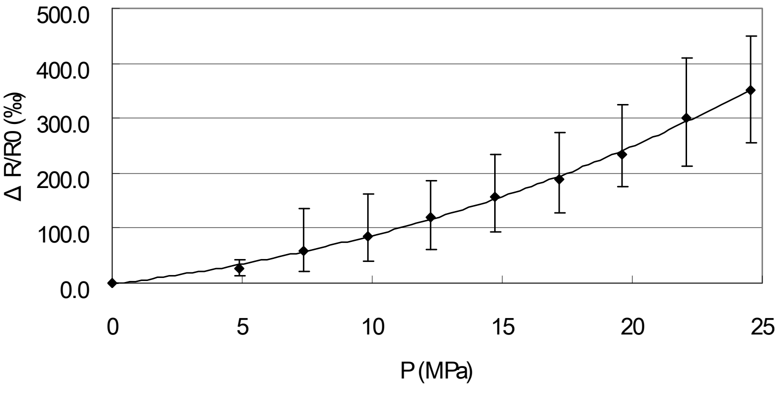

Figure3. 7 Pressure to resistance change per mille, P3HT：CB=100：10，n=7

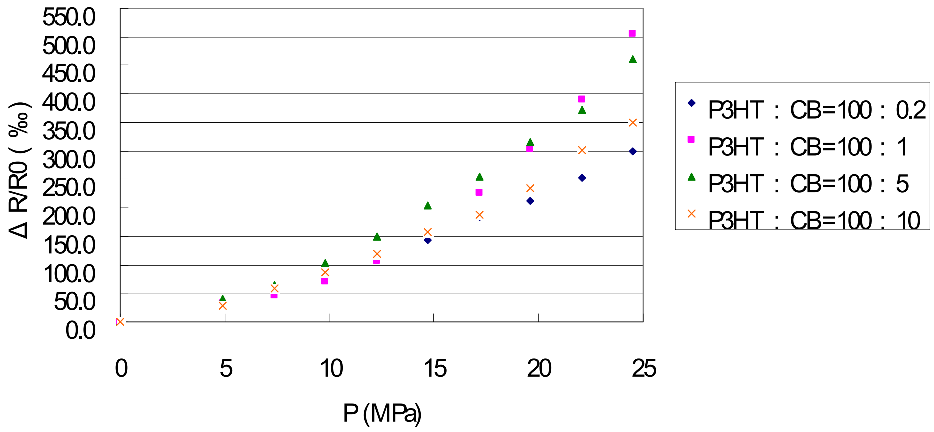

Figure3. 8 Four kind of different carbon black density, pressure and resistance value change per mille

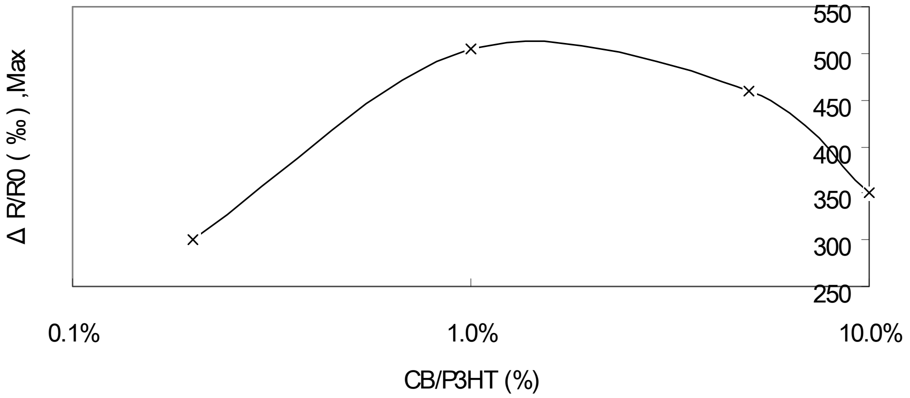

Figure3. 9 The maximum value resistance change per mille for different carbon black density

To understand the reason why P3HT:CB=100:1 sensitivity is the highest, it can be explained as follows. According to the reference, if we made a pressure sensor by two materials mixed which had very different electric conductivity, the electric conductivity of pressure sensor will dominate by low- electric conductivity material when the ratio of the high-electric conductivity material was lower. Otherwise, as the ratio of the high-electric conductivity material was higher, the electric conductivity of pressure sensor will dominate by high-electric conductivity material showed by Figure 3.10. If we want to increase the sensitivity of pressure sensor, we have to control the mix ratio in specific density scope. Once the density is lower or higher the specific density, the sensitivity of pressure sensor will decrease showed by like Figure 3.11.

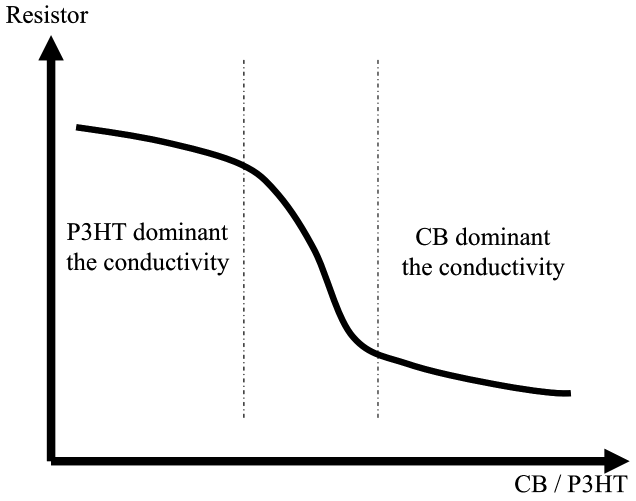

Figure3. 10 Different material mixture strength and resistance relations

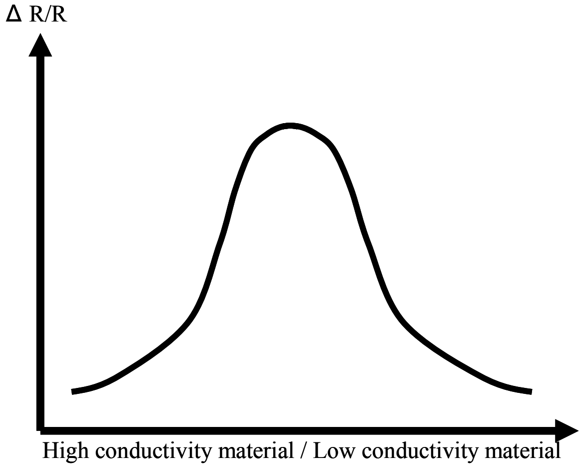

Figure3. 11 The relationship betwwen different material mixture density and change of resistance

Besides we studied the resistance change of pressure sensor that caused by pressure, and we discussed the relationship of the stress effect and the organic thin film pressure sensor. So we chose CB/P3HT = 1/100、5/100 and 10/100 and made a series of radius of curvature and the change of resistance research. All pressure sensor were composed with one pressure sensor layer. After testing by the same radius of curvature, we found that the resistance change per mile of the three different densities organic thin film pressure sensors were very small showed by Figure3. 12~Figure3. 14 . It means that the influence of stress by curving the sensor was not big to the pressure sensor. Because the strain caused the change of the carbon black of the pressure sensor in space distribution wasn't as big as pressure caused, therefore the element strain caused by the radius of curvature was unable to let the organic thin film pressure sensor element have the great resistance change.

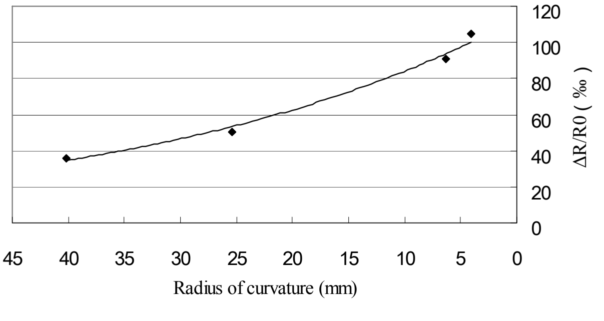

Figure3. 12 Radius of curvature and change of resistance per mille , P3HT：CB=100：1

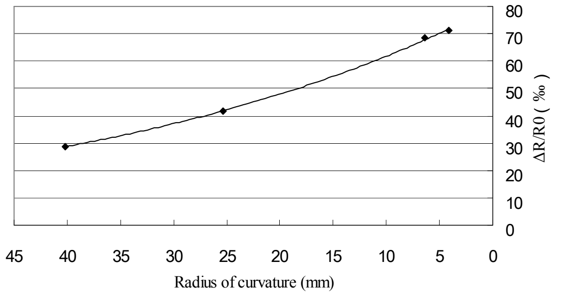

Figure3. 13 Radius of curvature and change of resistance per mille, P3HT：CB=100：5

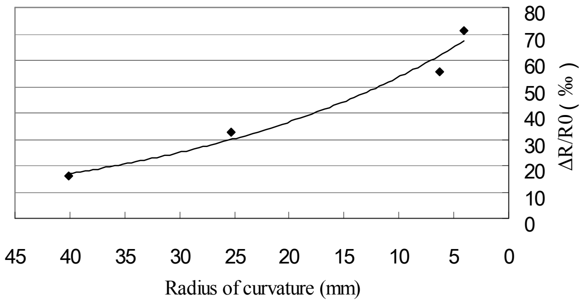

Figure3. 14 Radius of curvature and change of resistance per mille , P3HT：CB=100：10

4. CONCLUSION

In this work, we have developed a organic based pressure sensor based on ink-jet printing technology. The experimental result showed the highest pressure sensitivity with P3HT:CB=100:1. This developed material and fabrication technology have demonstrated the capability of integration of ink-jet printeing technology and various materials as flexbile sensing devices. This technique will offer a new method to pave the way toward the low-cost/high volume pressure sensor technology.

5. REFERENCES

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