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Flexible Pressure Sensor Driven by All-Printed Organic TFT Array Film

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Abstract

We have constructed a sheet-to-sheet (S2S) manufacturing line in order to prove the possibility and reality of production technologies and integrated processes of all-printed electronics devices[1, 2, 3]. In our automated and continuously operated manufacturing line, we operated the reverse offset printer for electrode pattern, digital inkjet printer for organic semiconductor layer, slit-die coater for insulator layer, and screen printer for electrode and inter-layer insulator.

The average mobility of organic TFT is 0.7 cm2/Vs, average ON current is 5 uA with less than 10% sigma in A4 size area, and ON/OFF current ratio is ten of order 6. We have been acquiring successful results of TFT array flexible film in a reasonable high yield.

These all-printed organic TFT array back-plane is applied to the flexible and light-weight pressure sensor which is driven in active matrix mode, and which is applied for a touch pad of writing with pressure grey scale or a commodity inventory system.

Results and Discussion

It is important to make a practical production run of organic TFT back plane in reasonably sufficient yield in a printed electronics field. To achieve the purpose we established the automated and continuously operated manufacturing line producing the all-printed organic TFT array flexible film.

Manufacturing Line

The automated and continuously operated manufacturing line was composed by use of main clean robot carried film substrates in class 10 clean tunnel connected various printers and heat process funnels as shown in Figure 1 and 2. We operated the reverse offset printer and gravure offset printer for various electrode patterns, inkjet printer for organic semiconductor layer, slit-die coater for insulator layer, and screen printer for electrode and inter-layer insulator.

In the manufacturing line, CIM production line system technology, automated substrate transporting system by robotics, localized clean zone control technology on minimum area, and fine alignment technologies in continuously printing process, layer by layer, were adopted.

Figure 1. *Substrate transporting robot in clean tunnel of automated print manufacturing line*

Figure 2*. Clean tunnel connected printers and curing funnels*

Organic TFT

We typically selected the bottom-gate/bottom-contact structure TFT as shown Figure 3. According to the application design, however, we are able to manufacture the top-gate/bottom-contact structure TFT arrays.

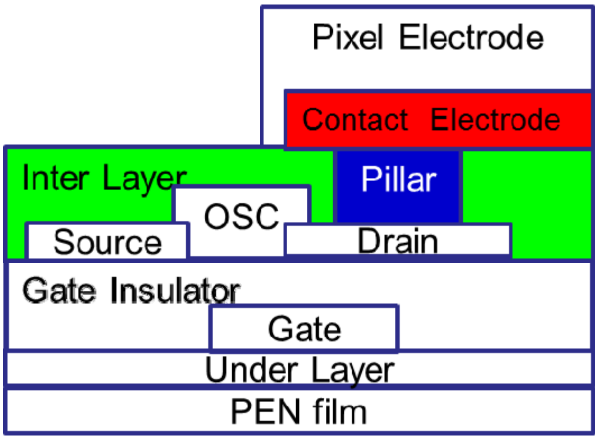

Figure 3. Cross sectional view of TFT element

Customized Ag nano particle ink for source/drain electrode and gate electrode, highly purified polymer ink for gate insulator and interlayer insulator, special Ag nano particle ink having large surface energy for interlayer-connection pillar, Ag paste for pixel electrode and connecting electrode, and organic polymer semiconductor ink for TFT active layer have been used after fine tuning of developed and formulated inks. We have developed the process technologies which were suitable to continuous printing layer by layer and curing fine pattern without vacuum process and photolithography process.

We operated the reverse offset printer for source/drain and gate electrode patterns, digital inkjet printer for organic semiconductor layer and interlayer-connection pillar, slit-die coater for gate insulator layer, and screen printer for pixel electrode and interlayer insulator. The maximum process temperature was less than 180 degree C. The good uniformity of all-printed TFT array film is represented by photograph of surface view in Figure 4.

The film size of TFT array was 300mm x 400mm x 50um. We used PEN film as a substrate. The density of produced TFT elements was from 85ppi to 150ppi. The finest electrode line width is 10um and line space is 10um; L/S=10/10 um.

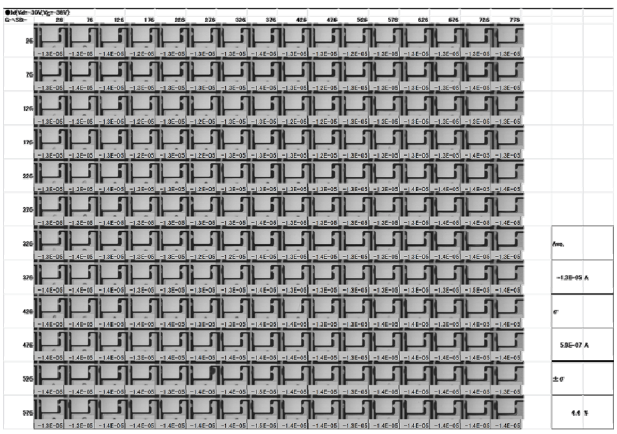

Figure 4. Surface view of TFT elements after printing gate electrode, selected from 480k elements through all area of one sheet.

The electrical properties of TFT array is shown in Figure 5 and described below; average mobility was 0.7 cm2/Vs at saturated region, average ON current was 5 uA with less than 10% sigma in A4 size area, and ON/OFF current ratio was 5 multiplied by ten of order 6. Typical transfer curve of TFT elements is shown in Figure 5. On current of drain electrode was over 50uA when gate voltage was applied -30V. It was enough current for driving e-paper modules or various pressure sensors.

The sheet yield of TFT array film was better than 90%. Open defect of bus line of electrodes connected TFT elements was less than 0.1%. Short defect of them was 0%. The interlayer short defect between stacked electrodes was less than 10ppm. These probability level of the defects was easy recovery level of array properties by simple repair processes.

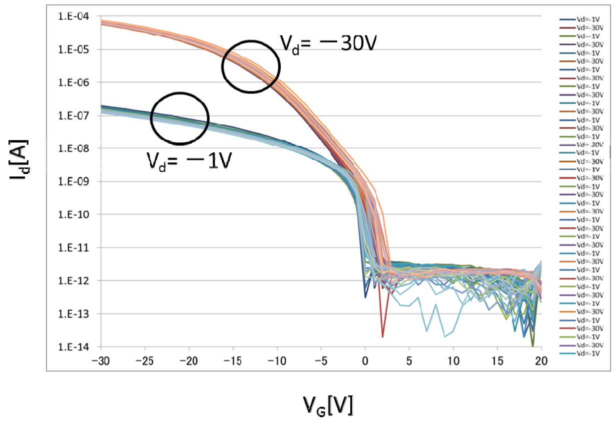

Figure 5. Electrical properties of TFT elements

The printed sample of flexible and bendable TFT array film is shown in Figure 6.

Figure 6. Printed sample of flexible and bendable TFT array film

Flexible Pressure Sensor

By using the automated continuously print manufacturing line, we were able to make flexible and light-weight sensors.

The cross sectional view of one pixel area of a pressure sensitive sensor is shown in Figure 7. The electrical resistance of layer of pressure sensitive rubber was changed by pressed force as shown in Figure 8, and a signal corresponding pressure was detected by selected TFT. In Figure 9 the equivalent circuit is represented.

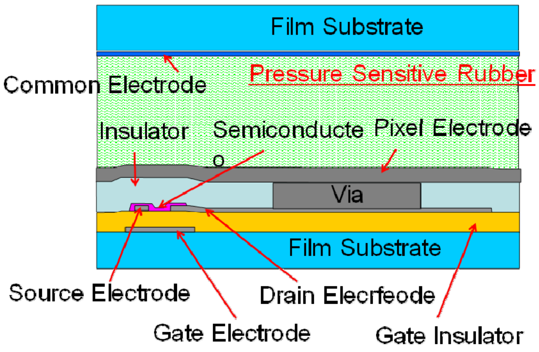

Figure 7. Cross sectional view of pressure sensitive sensor used bottom gate TFT

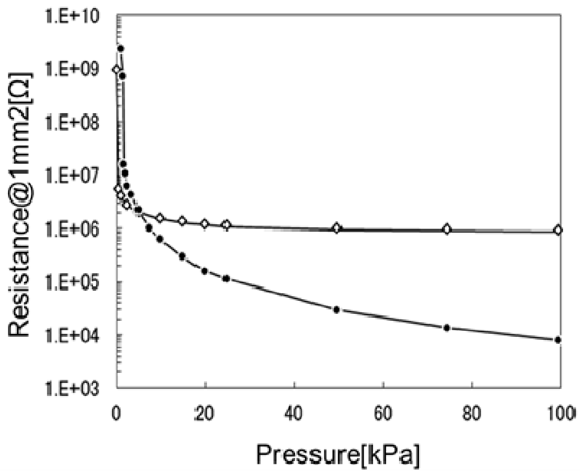

Figure 8. Correlation between resistance of pressure sensitive rubber and added pressure

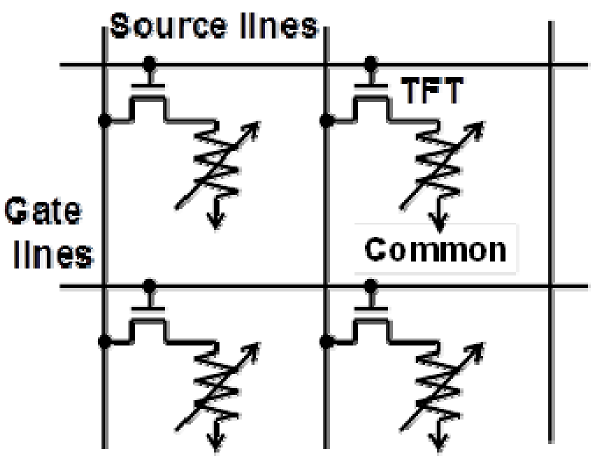

Figure 9. Equivalent circuit of pressure sensitive sensor

The sample of pressure sensitive sensor A4 size was demonstrated as shown in Figure 10 [4]. The resolution of the sensing device was 0.9mm square, which was composed by 3 x 3 TFTs. The multi-structure was effective for high sensitivity of the pressure sensor. Number of sensing pixels was 144 x 216 in a film sheet. Sensing frequency was 50kHz. Sensing grey scale was 8bit, 256 level. Sensing pressure range was from 0 to 50kPa.

By effective utilization of these performances of the pressure sensitive sensor driven in active matrix mode, advantages are as follows;

1) high resolution sensing in large area
2) fast sensing speed rather than passive matrix drive mode
3) sensing multi points in large area at same time in multi-graduation level
4) power consumption rather than passive matrix drive mode

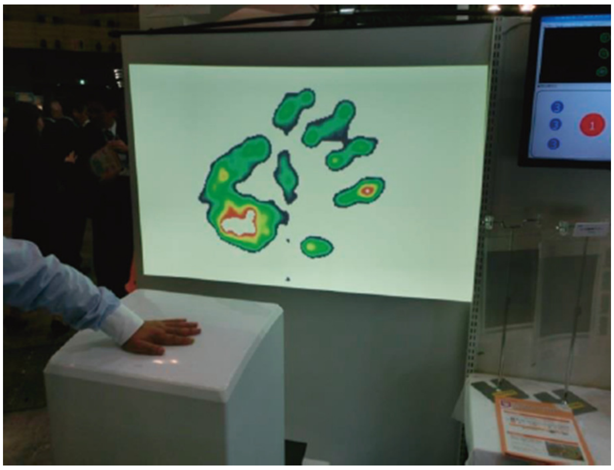

Figure 10. Flexible sheet input device and display of area distribution of pressure. Pressure level is represented by change of color, larger from white, red, yellow, green, blue.

These flexible and light-weight pressure sensors are easily applied to curved surface shaped devices for shoes sole sensor, floor mat sensor, seat sensor, cuff of blood pressure sensor, or interior finishing of vehicle, for examples.

Further advantages of all-printed devices are high productivity in short turn-around time, easily customized to device design and production volume, and low cost production.

Conclusion

We have constructed the automated S2S manufacturing line of all-printed flexible TFT array film. By using the line we made flexible and light-weight sensors driven in active matrix mode. Most valuable advantage was sensing multi points in large area at same time in multi-graduation level. We will develop various kinds of IoT devices having multi functions, for example sensor, display, and communication by use of printed electronics technologies.

Acknowledgment

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Author Biography

Shinichi Nishi received his doctor degree in engineering of applied chemistry from Tohoku University in Sendai Japan(1980). Since then he has worked in Konica. His work has focused on the development of the jisso of electric devices for printer, and inkjet printhead. He had managed supervisory development of digital inkjet printing technologies from 2008. In 2011 he also joined JAPERA and has been developing production technologies of printed electronics in organic TFT array film and sensor devices. He is a fellow of ISJ.