Integrated Self-Capacitance On-cell Touch Panel in Flexible OLED Display

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Abstract

Designs of self-capacitance "on-cell" touch panel were implemented in a 6.2inch foldable OLED panel with single-layered sensor pattern. The test results showed that the self-capacitance "on-cell" touch panel has high sensitivity even with TFTs connected in serial of the sensor channels. Signal degradation and retransmission effect in thinner stack-ups were also studied and compared with its mutual-capacitance counterpart. The self-capacitance touch panel has shown great potential of application in future OLED display products.

1. Introduction

Since the concept of "in-cell" touch panel was first proposed in 2012, the mainstream of touch panel technology has gone through a remarkable transition in the past 10 years. The first "in-cell" touch panel in iPhone5 was mutual capacitive with all the electrodes embedded in the cell, only to make the LCD module the most compact. Later, another solution called "hybrid in-cell" was brought up with the receiving electrodes out of the cell. The mutual-cap. "hybrid in-cell" touch panel takes a good balance between touch performance and module thickness. A turning point came in 2015 when the pure self-capacitance solution emerged. In the self-cap. "in-cell" touch panel, each sensor addresses a specific location with one signal line tracing out of the active area (AA). In this way, the full panel addressing was executed to avoid "Ghost Touch". The massive number of sensor traces are all connected directly to the Touch Display Driver IC (TDDI). TDDI acts as the display driver as well as touch driver. Today, the self-cap. TDDI has become a dominate touch solution in consumer LCD products. The self-cap. sensing is superior in touch performance. And with all the touch electrodes fully "in-cell", it maintains the advantage in module compactness as well.

Tthe rise of OLED display technology also brought up the so-called "on-cell" touch panel. In flexible OLED display panel, the "on-cell" touch panel was fabricated on the thin-film-encapsulation (TFE) layer with metal mesh patterns surrounding each of the emitting pixel. Although such "on-cell" structure improves the module compactness, the panel size was limited due to the degradation of touch performance. The difficulties mainly come from the low thickness of TFE.

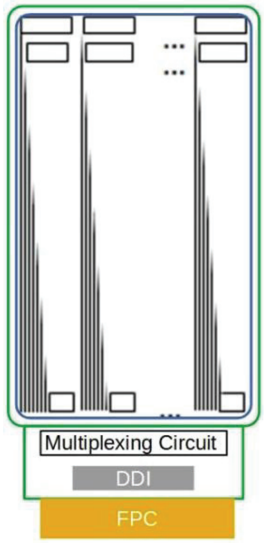


Figure 1(a). The schematic diagram of the single-layered self-cap. "on-cell" touch panell.

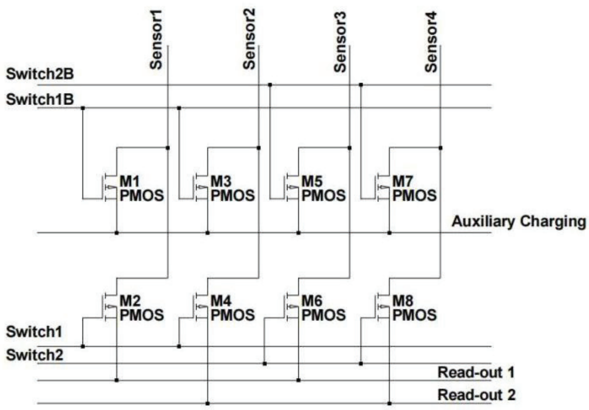


Figure 1(b). An example of the connection from the sensor traces to the multiplexer.

The resent mutual-cap. "on-cell" touch panel is very sensitive to the capacitive loading along the signal transmission path. The very low thickness between touch sensor and cathode results in heavy capacitive loading. Thus the measurement of touch suffers from huge signal loss all along the transmission line. Meanwhile, the emerging technologies in OLED ask for even thinner TFE and larger panel size. Demand of better the touch performance in report rate and active pen increases simultaneously as well. A pure self-cap. "on-cell" touch panel is highly expected as a possible solution for all these problems. In this paper, test results from several experimental designs of self-cap. "on-cell" touch panels are presented. For self-cap. "on-cell" technology, comparison with the mutual-cap. type, problems and potential use for future OLED products are also discussed.

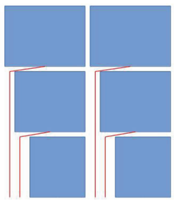
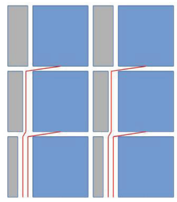
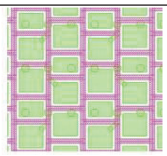
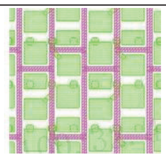
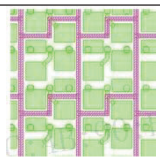
Mark	A1		A2		A3		A4		A5	
Sensor Pattern			Same as A1		Same as A1				Same as A1	
Filling Ratio	 100%		 65%		 53%		Same as A1		Same as A1	
Multiplexer W/L	240/4		Same as A1		Same as A1		Same as A1		120/4	
Sensor Location	*TOP*	*BOT*	*TOP*	*BOT*	*TOP*	*BOT*	*TOP*	*BOT*	*TOP*	*BOT*
ΔC (pF)	2.3	1.8	1.6	1.3	1.3	1.1	1.8	1.8	2.3	1.8
C_{BG} (pF)	52.3	30.6	45.6	26.9	39.6	23.7	30.6	30.6	52.3	30.6
SNR (dB)	50.1	48.4	44.8	41.6	45.5	42.8	48.2	48.04	50.7	47.5

Table 1. Test results from different designs of touch sensor and multiplexer circuits in 6.2inch experiment.

2. Design of experiment

2.1 Single-layered self-cap. pattern design: The experimental design was based on a 6.2inch FHD flexible OLED panel. The "on-cell" touch sensor was fabricated with only one layer of metal electrode on the TFE and connected to the display layers in the downside border area. The single-layered self-cap. pattern was a classic one as shown in Figure 1(a). Each sensor in AA had a signal trace extending downwards to the downside border on the same layer of the other sensors. For each column of sensors, there was a "dead-zone" for tracing, causing unwanted signal and asymmetry to the touch panel. The sensor pitch was 5mm*5mm, and the total channel number was 12 columns and 30 rows. Hence, there were totally 360 traces extending downwards out of AA.

2.2 Multiplexing circuit design: In the downside border, the traces were connected to the LTPS multiplexing devices. This was to minimize the total number of the read-out lines. As illustrated in Figure 1(b), the multiplexing circuits connected each sensor trace with two TFTs. One was for selection of the signal read-out. The other was connected to an auxiliary discharging network to cancel the capacitive loading on the other sensors. The states of the two TFTs were controlled by a pair of switch lines to ensure an exclusive relation for the two branches. The scanning strategy was determined by the circuit connection. For row-wise scanning, 30 pairs of switch lines was used to sequentially connect each of the 30 rows of sensors to the 12 read-out lines or the auxiliary discharging port. Designs of experiment were implemented in scanning strategy (circuit connection), TFT size in multiplexer, and sensor pattern, which are discussed in details in the following sections.

2.3 Test system: With the multiplexer to reduce the total number of the read-out terminals, it was possible to execute the self-cap. sensing with a commercial touch driver. In this experiment, ILI-2521 was used for the self-cap. signal read-out. The only problem was that most of the commercial touch driver can not provide high voltage to control the LTPS-TFT devices in the multiplexer. Hence, a level shifter circuit was designed on a PCB to pump higher voltages to the panel, and was also controlled by the ILI-2521 driver. The maximal driving voltage for self-cap. measurement in this experiment was

0.8V and the scanning frequency was 75kHz.

3. Test Results

Signal-to-Noise Ratio (SNR) was compared for different designs with module structure of foldable stack-up. The total thickness of the upper structure above touch electrodes was 155um including a polarizer and a cover-film. The touch test was executed with Φ10 grounded stylus. A first test result was listed in Table 1. There were 6 designs varying in sensor pattern, mesh filling ratio, multiplexer TFT size and scanning direction. The capacitance change in touch ΔC, background capacitance C_{BG} and SNR were recorded in both the far-end (TOP) and near-end (BOT) of AA.

3.1 Capacitive loading: The capacitive loading was studied in A1, A2 and A3 design with different metal mesh filling ratio, as shown in Table 2. The 100% filling ratio as in A1 stands for the metal mesh surrounding every sub-pixel. By canceling some connections of the mesh, the filling ratio was reduced to 65% and 53% as in A2 and A3 respectively. The estimated ΔC and C_{BG} had shown great difference from the mutual-cap. case. Usually, in mutual-cap. "on-cell" touch panel, the ΔC_m was in the range of 0.05pF to 0.25 pF. Here in the self-cap. case the ΔC was 10 times larger, which should be easier for measurement. C_{BG} in the self-cap. case was comparable to C1 in Figure 1 in mutual-cap. system. In this self-cap. design, the C_{BG} ranged from 30pF~50pF, 1/10 of that in the mutual-cap. panel, which was usually 300pF~500pF resulting in serious signal decay. The comparison between A1, A2 and A3 showed that as the density of metal mesh became lower, both of ΔC and C_{BG} decayed. However, ΔC showed a faster decay rate than C_{BG}. This resulted in a loss in SNR, because the noise was also positively correlated to C_{BG}. The drop of SNR from TOP to BOT here also showed the limitation of the single-layered pattern in panel size. The sensor in the bottom of AA will have to "sacrifice" its size for tracing, resulting in lower SNR.

3.2 Resistive loading: The effect from the resistive loading was also studied by comparison among A1, A4 and A5 design. In all the designs except for A5, W/L of TFT in multiplexer was set to 240/4. So the TFT equaled to a resistor of 2.5kΩ in ON-state. In A5 the W/L was 120/4 and the TFT equaled to a 5kΩ resistor in ON-state. No significant difference in SNR was found between A1 and A5. A4 had different sensor pattern from the other's. In A4 design, the effective area of sensor was kept unchanged from far-end to near-end, with the rest space filled with floating dummy mesh. The results from A4 panel showed little difference in SNR from TOP to BOT.The impact of the sensor trace seemed negligible. The results showed that current self-cap. touch panel design was more sensitive to the capacitive loading than resistive loading.

Type	Structure	Test Term	12um TFE	8.7um TFE	Drop
Self	1-Layer	ΔC	421	326	-22.8%
	2-Layer	ΔC	369	357	-3.25%
Mutual	2-Layer	ΔC_m	1372	1122	-22.3%

Table 2. Test results from samples with different TFE thickness. ΔC was tested and converted to ADC counts as touch signal.

3.3 Reduction of TFE thickness: In a supplementary experiment, a multi-layered self-cap. sensor design was also introduced to study the adaptability of the self-cap. on-cell touch panel with thinner TFE structure. As shown in Figure 2(a), in the multi-layered self-cap. touch panel, the trace layer was fabricated beneath the sensor layer isolated by an inorganic insulator. As shown in Table 2, TFE thickness was adjusted from 12um to 8.7um, and the touch signal ΔC were compared in both the single-layered and multi-layered self-cap. panels. The touch signal dropped by about 22.8% in single-layered self-cap. panel when the TFE thickness decreased. However, the signal in the multi-layered self-cap. panel remained unchanged. As comparison, another 6.2inch mutual-cap. "on-cell" touch panel with the same stack-up of the multi-layered self-cap. panel was tested and the result is presented as well. The signal degradation was 22.3%, quite similar with the single-layered self-cap. case. Such difference could be understood through the transfer function from V_{drive} to ΔC with the equivalent model shown in Figure 2(b). In Figure 2(b), C_{sc} stands for the parasite capacitance from sensor to cathode electrode, which is directly related to the thickness of TFE. R_s is the trace resistance. ΔC is for the equivalent change of C_{sc} when the sensor is touched. C_{st} stands for the coupling between each sensor and the traces to the other sensors. V_{drive} is the charging signal in angular frequency ω for self-capacitance detection which will be added to all the sensors and traces. Finally the self-capacitance value of the sensor will be integrated and output as V_{out}. The final transfer function from V_{drive} to ΔV_{out} could be written as:

$$g = \frac{\Delta C}{1+\omega R_s(C_{sc}+C_{st})+\omega R_s \Delta C} \times \frac{1+\omega R_s C_{st}}{1+\omega R_s(C_{sc}+C_{st})}$$

For single-layered sensor, $C_{sc} >> C_{st}$, and $C_{sc} >> \Delta C$, the transfer function becomes

$$g_1 \approx \frac{\Delta C}{(1+\omega R_s C_{sc})^2}$$

The transfer function above is dramatically related to C_{sc}, and drops as the thickness of TFE decreases. But for multi-layered sensor, the sensor has much stronger coupling with all the other sensors through traces beneath. As a result, $C_{st} >> C_{sc}$, and $C_{sc} >> \Delta C$, the transfer function degrades to

$$g_2 \approx \frac{\Delta C}{1+\omega R_s C_{st}}$$

in which the TFE thickness has little impacts on the signal transmission. Therefore, it could be expected that the multi-layered self-cap. touch sensor will work better in the OLED panels with thinner TFE.

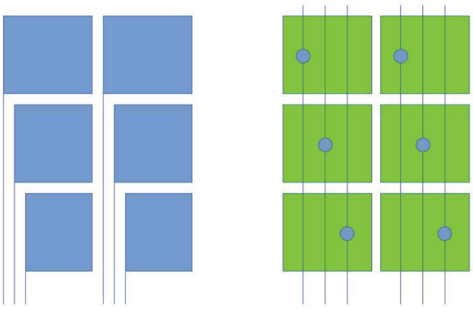


Figure 2(a). The left pattern is the single-layered sensor pattern, while on the right is the multi-layered self-cap. sensor pattern with all the traces (blue) fabricated beneath the sensor layer (green).

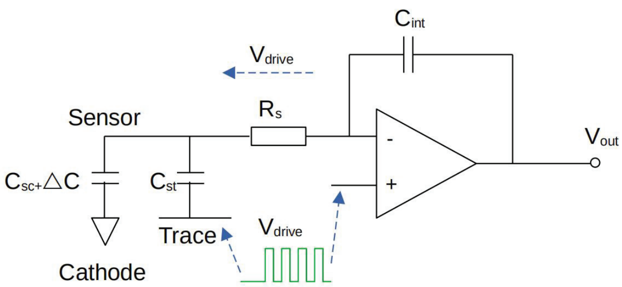


Figure 2(b). Equivalent model for signal transmission in self-cap. touch panel.

3.4 Retransmission: The retransmission effect, or Low-Gound-Mass (LGM) problem had been widely concerned in mutual-cap. touch panel especially in the foldable panels. The typical phenomenon of LGM problem is that negative signals appear when the panel if touched with a badly-grounded stylus. In Figure 3(a), an example of LGM problem is presented, which happened in another foldable OLED with mutual-cap. "on-cell" touch panel. The green points were touched areas, while the red points signified negative signal in the crossing nodes of the touched transmitters and receivers. Touches on those points with negative signal would probably not be recognized, resulting in miserable touch experience. One of the benefits for self-cap. touch panel is that even the signal drops in LGM state, the signal could never become negative because of the difference in the mechanism of capacitance measurement. The test result in Figure 3(b) also demonstrates that no negative signal was observed in the A1 panel with badly-grounded fingers. The LGM problem was greatly relieved in the self-cap. touch panel.

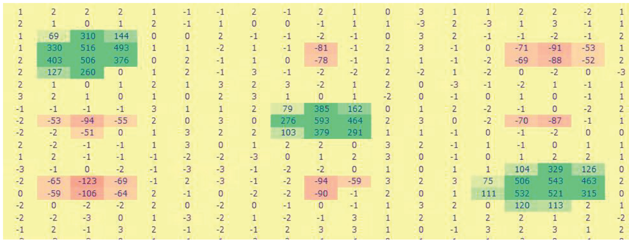


Figure 3(a). An example of LGM problem in another foldable OLED with mutual-cap. "on-cell" touch panel. Green areas were touched points, while the red areas showed negative values due to retransmission effect.

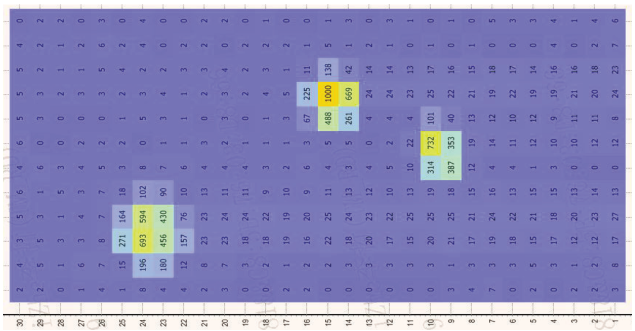


Figure 3(b). Multi-touch test in LGM state on self-cap. touch panel A1. No minus signal was observed.

4. Conclusion

In conclusion, several designs of experiments were implemented in foldable self-capacitance "on-cell" touch panels. The test results showed that the single-layered self-cap. touch panel has exhibited high sensitivity even with TFTs connected in serials. The potential of multi-layered self-cap.design of application with thinner TFE was proved experimentally and theoretically. The retransmission problem was also greatly relieved in the self-cap. touch panel as predicted.

5. References

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