FPD Photomask ESD Sensitivity Testing Experiments for Various Design Concepts

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Abstract – ESD damage on photomask is well-known issue and still on-going problem when technology changes on semiconductor device and flat panel displays which are mostly simpler process of semiconductor device manufacturing processes. There are design ideas and concepts to increase ESD robustness of metal layers (chrome) on quartz as it still maintains same physical distance on design patterns. In this study, we'll demonstrate how such combination design ideas can make ESD robustness differently and has physical damage threshold of metal layers between pure Cr design layers and alternative Cr+ design layers.

I. Introduction

ESD damage on the mask is one of major issue within semiconductor device fabrication process and can give huge mass production impact device yield. It is same critical issue for flat panel display mask manufacturing and actual in-use situation within flat panel display photolithography process.

Photomask constructed metal layers (typically chrome) on quartz and most of ESD event occurs between metal layers due to their capacitance and electrical field differences through lateral breakdown levels.

There are several alternative design concepts with oxide and nitride compositions. In this study, we'll demonstrate how such additional material composited combination design ideas can make ESD robustness differently and has physical damage threshold of metal layers between pure Cr design layers and alternative Cr+ design layers. Initial testing has conducted with 6" mask and it will be conduct actual one-to-one ratio photolithography mask for flat panel displays which size over 850 x 1400 mm square (65").

II. Sample Preparation

A. Three Design Concept Samples

6" masks are prepared in three different design concepts with same physical distances and line widths for initial ESD robustness testing. There is metal guide ring at each quad-side area. On top of middle area has large metal layer (pink color) and give induction field from the electrode pad underneath of large metal layers at 1 mm distance.

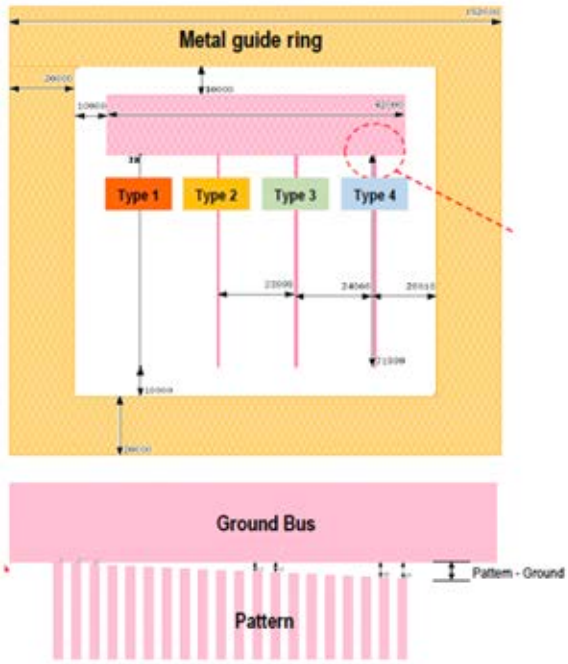

Figure 1: Test Sample Mask

Sample mask pattern has 4 different thickness thin antenna lines has constructed near large metal layers

from 1 µm up to 20 µm distances and different spaces between lines from 10, 20 and 40 µm. See figure 1.

In the same physical mask pattern, three different design concepts have prepared and tested for ESD robustness by these material conductivity differences. See table 1.

Table 1: Mask Pattern Line and Space

ESD Test(6")	PTN Type 1	PTN Type 2	PTN Type 3	PTN Type 4
PTN Line / Space(㎛)	10 / 10	10 / 20	20 / 20	20 / 40
Space (PTN-Ground Bus, ㎛)	1 ~ 20 ㎛	1 ~ 20 ㎛	1 ~ 20 ㎛	1 ~ 20 ㎛
	20 Lines of 1㎛ gap			

Three different design concepts have constructed chrome-based material compositions with oxide and nitride combination at different conductivity levels. Electrical conductivity of Cr is 2,797,359 S/m, Cr+1 is 3,296 S/m and Cr+2 is 134,481 S/m.

Table 2: Sample Composition

	Concept 1 (4.99 ohms/sq)	Concept 2 (33.2 ohms/sq)	Concept 3 (44.3 ohms/sq)
Layers Materials	Cr +1	Cr +1	Cr +1
	Cr	Cr +2	Cr +2
	Cr +1		Cr +1

B. Test Apparatus

1. Test Fixtures

Test fixtures has height adjustable electrode support which is polycarbonate material with copper metal electrodes and Trek Model 542-1 electrostatic voltmeter for measuring voltage level on large metal layer on mask pattern. Electrostatic field on mask pattern aren't not equal value due to field suppression of quartz thickness. So, test will conduct in two different way that will actual applied voltage levels and measured voltage levels on masks. HVPSI's HVM40B high voltage contact meter used to measure actual applied voltage value to compare with measured electrostatic voltage value by Model 542-1.

Test fixture also has designed minimum contact area with mask for minimize voltage suppression affect. See Figure 2.

2. Test Equipment Setup

Tektronix TDS7014 oscilloscope, 1GHz frequency range of measurement instrument used for detecting ESD event occurrences with ETS Lindgren Model 7405-904B E-field antenna and CT-1 probe choose.

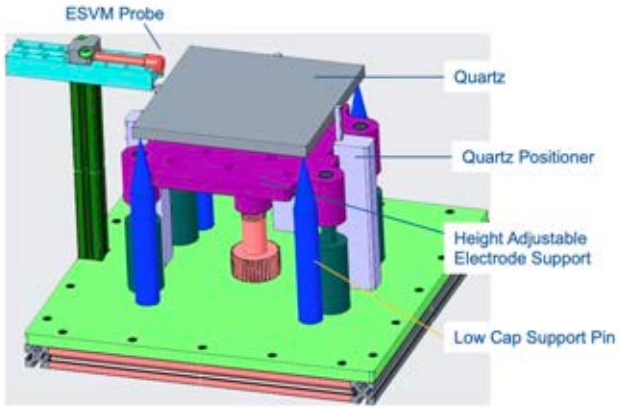

Figure 2: Test Fixtures

E-field antenna has located 100 mm distance from the center of mask and Model 2K10 power supply unit provide DC high voltage to bottom electrode. HVM40B high voltage contact meter has verified applied voltage on electrode and Model 310E steady-state DC ionizer in place to neutralize charge/residual charge on quartz before and after discharge. Model 542-1 probe has located in middle of voltage applied electrode on top of the mask to verify what voltage applied for each experiment.

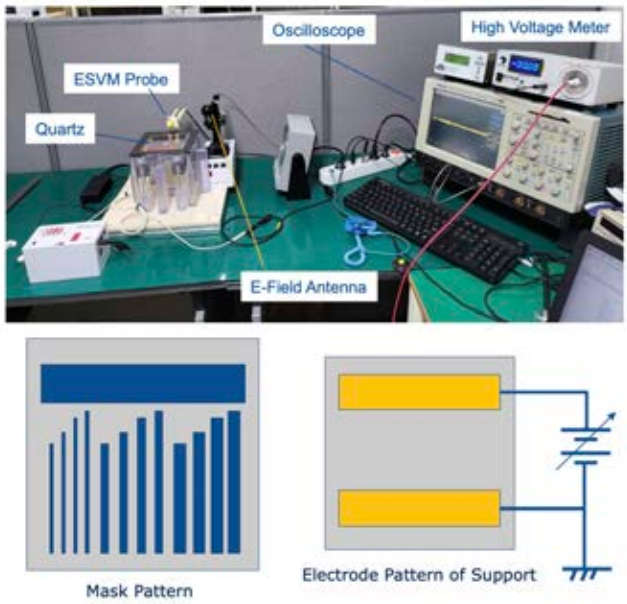

Figure 3: Test Setup and Electrode Pattern

3. Test Procedures

Top electrode on support will have high voltage from Model 2K10 power supply from +100 volts to +2000 volts at 100 volts steps and bottom electrode connected to ground lead to ESD event occurs when voltage exceeded lateral ESD threshold level between large metal layer to thin antenna patterns. This has categorized ESD event "On-Time", and this even occurs when voltage constantly applied on the voltage electrode. Also, another ESD event occurs when constant power supply turn-off and disappeared field on mask after initial ESD event occurs as double jeopardy phenomena. This has categorized ESD event "Off-Time".

II. Initial Test Experiment

A. Concept 1 – Test Results

As initial testing with first samples, ESD event detection test experiments has conducted 10 times at each voltage levels and found all ESD events occurs and observed at the shortest distance electrodes between different thickness thin antenna electrodes. Follows are the experiment summary.

Concept 1 design sample has placed and neutralized by steady-state DC ionizers and verified the voltage on mask down to near 0 volt. Electrodes approached to the mask at 1 mm distance at the bottom and applied voltages for induction charge on mask pattern to lead ESD events. First two steps, +100 volts and +200 volts, ESD event does not occurs or detected at 10 mV trigger level. Between each voltage step, steady-state DC ionizer neutralizes residual charge on mask and 10 times of testing conducted at each individual voltage levels.

ESD event start occurs and detected at first +300 volts and does not occur at the same level. Then, ESD event occurs and detected repeatable starting at +400 volts and beyond. As an ESD event signature, E-field antenna has detected 25.6 mVp-p value and the RF signal detected values are also increased as applied voltage increased proportionally. See Figure 4.

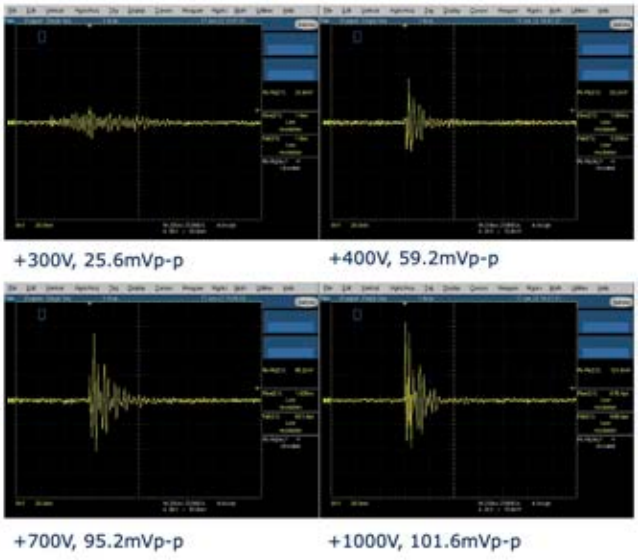

Figure 4: ESD Event Detection – Concept 1

In this case, most of events occurs at the shortest gap between large metal layer and thin antenna patterns. As voltage increased, ESD damage features grows much largely and severely. See Figure 5.

Figure 5: ESD Damage – Concept 1

Another ESD event start occurs and detected when power supply turn-off or field disappeared situation over +1100 volts.

Table 3: Concept 1 - Test Results Summary

	Concept 1			
	ESD Events		542A (kV)	HVM40B (kV)
Voltage	ON	OFF		
100	X	X		
200	X	X	0.30	
300	1/10	X	0.36	
400	10/10	X	0.46	
500	10/10	X	0.49	
600	10/10	X	0.53	
700	10/10	X	0.59	
800	10/10	X	0.63	
900	10/10	X	0.66	
1000	10/10	X	0.75	1.05
1100	10/10	2/10	0.76	1.15
1200	10/10	2/10	0.80	1.22
1300	10/10	X	0.87	1.30
1400	10/10	2/10	0.92	1.40
1500	10/10	4/10	0.98	1.50
1600	10/10	10/10	1.03	1.59
1700	10/10	10/10	1.05	1.69
1800	10/10	10/10	1.06	1.78
1900	10/10	10/10	1.12	1.86
2000	10/10	10/10	1.16	1.96

B. Concept 2 – Test Results

Concept 2 design sample, as second test, has placed on the fixture and prepared same condition as above. First two steps, +100 volts and +200 volts, ESD event does not occurs or detected at 10 mV trigger level. When voltage exceeded at +300 volts as initial, ESD event does not occurs or detected. But +300 volts has applied second time, ESD events occurs and detected. After this, there is no other ESD events detected at +300 volts level. Then, voltage increased at +400 volts and ESD events does not occurs up to 3rd times. When +400 volts applied to the electrode at 4th times, ESD events occurs and detected at much lower level than Concept 1. Then, ESD event occurs and detected repeatable starting at +500 volts and beyond. As an ESD event signature, E-field antenna has detected 16.0 mVp-p value at +300 volts and the RF signal detected values (strength) are does not much increased as applied voltage increased proportionally. This is much different between two design concepts. See Figure 6.

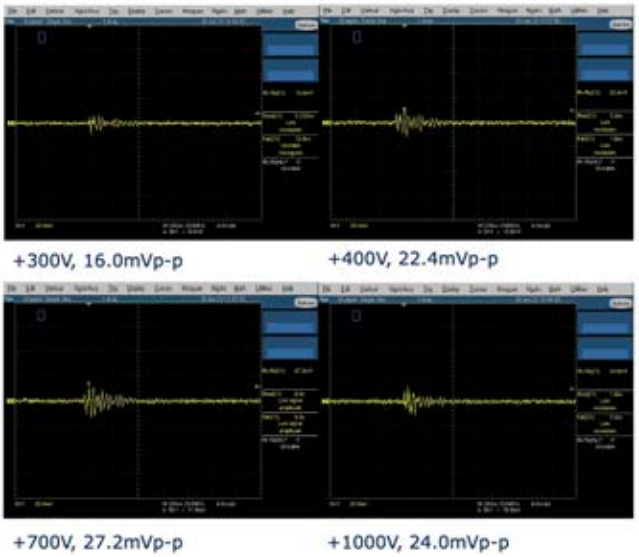

Figure 6: ESD Event Detection – Concept 2

Table 4 – ESD Detection Value Differences

Voltage	Concept 1	Concept 2
+300V	25.6 mVp-p	16.0 mVp-p
+400V	59.2 mVp-p	22.4 mVp-p
+700V	95.2 mVp-p	27.2 mVp-p
+1000V	101.6 mVp-p	24.0 mVp-p

ESD detection value from E-field antenna could represents the strength of ESD event as applied voltage level increased as proportionally as above Concept 1 test experiment. This could represent that Concept 2 ESD event experiment was much weaker or low current flowing test results to provide better robustness design. Damage features are different and smaller area at the same +300 volts and similar at +400 volts.

Figure 7: ESD Damage – Concept 2

Table 5: Concept 2 - Test Results Summary

	Concept 2			
	ESD Events		542A (kV)	HVM40B (kV)
Voltage	ON	OFF		
100	X	X	0.11	0.18
200	X	X	0.26	0.27
300	2/10	X	0.29	0.37
400	4/10	X	0.39	0.48
500	10/10	X	0.50	0.57
600	10/10	X	0.47	0.68
700	10/10	X	0.62	0.77
800	10/10	X	0.66	0.87
900	10/10	2/10	0.67	0.96
1000	10/10	6/10	0.71	1.05
1100	10/10	7/10	0.74	1.14
1200	10/10	10/10	0.77	1.22
1300	10/10	10/10	0.81	1.31
1400	10/10	10/10	0.87	1.38
1500	10/10	10/10	0.89	1.48
1600	10/10	10/10	0.95	1.58
1700	10/10	10/10	1.02	1.68
1800	10/10	10/10	1.03	1.77
1900	10/10	10/10	1.07	1.86
2000	10/10	10/10	1.07	1.96

C. Concept 3 – Test Results

Concept 3 design sample, as a third test, has placed on the fixture and prepared same condition as above. First four steps up to +400 volts, ESD event does not occurs or detected at 10 mV trigger level. When voltage exceeded at +500 volts as initial, ESD event does not occurs or detected. But +500 volts has applied second time, ESD events occurs and detected. After this, there is no other ESD events detected at +500 volts level as similar concept 2. Then, voltage increased at +600 volts and ESD events does not occurs up to 3rd times. When +600 volts applied to the electrode at 4th times, ESD events occurs and detected at similar level with Concept 2. Then, ESD event occurs and detected irregularly up to +2000V as in Figure 8 and Table 6.

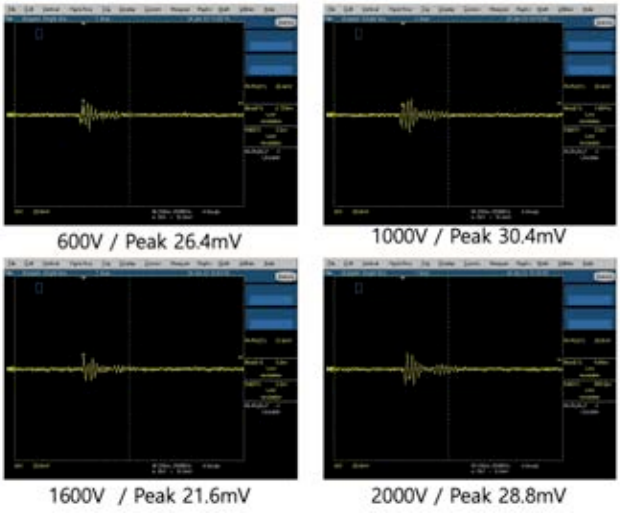

Figure 8: ESD Event Detection – Concept 3

Table 6: Concept 3 - Test Results Summary

	Concept 3			
	ESD Events		542A (kV)	HVM40B (kV)
Voltage	ON	OFF		
100	X	X	0.19	0.18
200	X	X	0.24	0.28
300	X	X	0.29	0.38
400	X	X	0.43	0.49
500	2/10	X	0.45	0.58
600	4/10	X	0.58	0.69
700	4/10	X	0.66	0.79
800	2/10	X	0.71	0.88
900	X	X	0.74	0.96
1000	4/10	X	0.78	1.06
1100	7/10	1/10	0.74	1.16
1200	2/10	1/10	0.78	1.23
1300	2/10	X	0.84	1.32
1400	X	X	0.89	1.41
1500	1/10	X	0.96	1.50
1600	4/10	X	0.99	1.59
1700	4/10	3/10	1.07	1.68
1800	3/10	3/10	1.09	1.78
1900	5/10	4/10	1.14	1.87
2000	8/10	10/10	1.14	1.97

Damage features are smallest within the three concepts compositions although it has applied up to +2000V as repeated voltage applied.

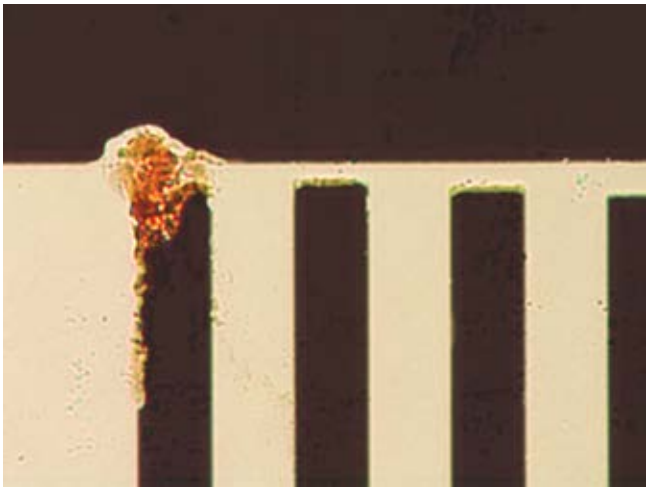

Figure 9: ESD Damage – Concept 2

III. Extended Test Experiment

As above initial test experiments, ESD events occurs at every design concept with different composition, but different damage signatures. To make it clear when the initial ESD events occurs and its damage severity comparison, extended test experiment has set same test set up and sample has prepared with single thin antenna line along with large metal layer.

A. Concept 1 – Test Results

Concept 1 sample prepared on 6" mask with single antenna line at 3**µ**m gap for better design accuracy and was available to detect and observed ESD damage at +200V applied. Damage features are very small and side area of thin antenna line.

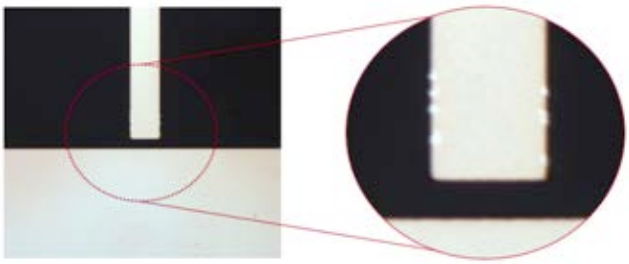

Figure 10: ESD Damage of Concept 1 at 200V

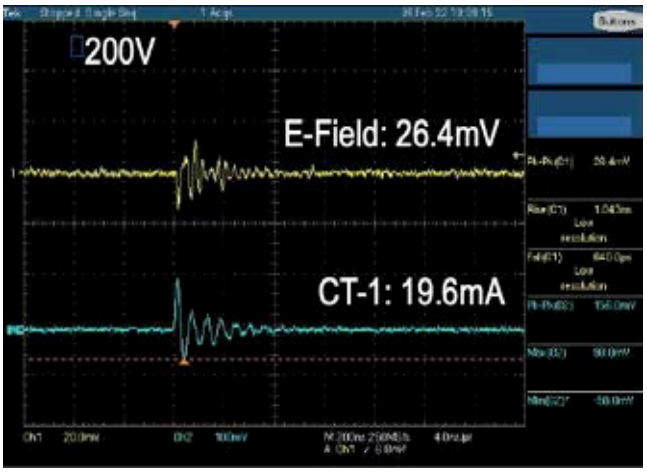

Figure 11: ESD Event Strength of Concept 1

ESD event detection signal similar level was 26.4mV as initial test experiment above. In this case, CT-1 current probe has connected ground electrode and observed discharge current at 19.6mA which may reflection signal or discharge current changes between instruments ground connections.

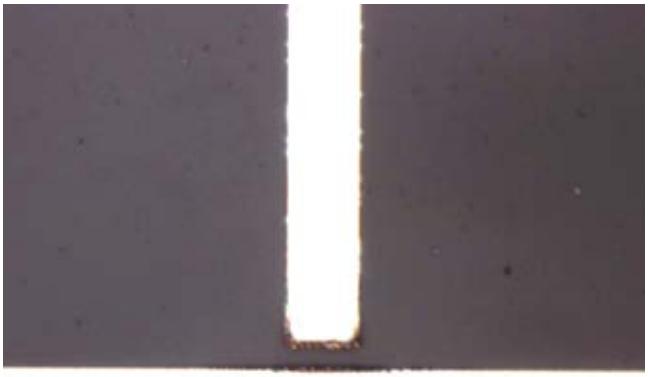

Figure 12: ESD Damage of Concept 1 at 500V

ESD damage signature at +500V has more obvious and wide area damage than +200V level. It has also side area small damages vertically.

B. Concept 2 – Test Results

Concept 2 sample prepared with single antenna line and ESD damage observed same at +200V discharge level as Figure 13 and event detected strength at 19.2mV are 27% lower level than concept 1 design and compositions as Figure 14. CT-1 also has detected signal from ground connection and measured at 2.4mA.

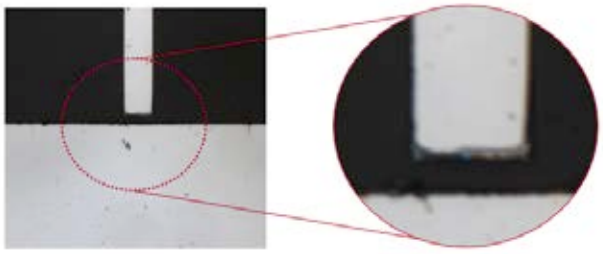

Figure 13: ESD Damage of Concept 2 at 200V

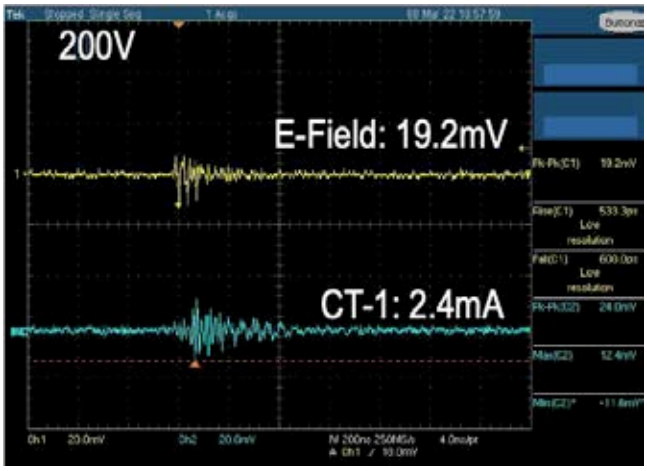

Figure 14: ESD Event Strength of Concept 1

C. Concept 3 – Test Results

Concept 3 sample has prepared with single antenna line and ESD damage can't observed up to +800V and observed very clean images as Figure 15. It was only 13.2mV signal and can't enough energy to give damage to this pattern in Figure 16.

When voltage increased to +1000V and applied, ESD event observed, and damage can be found as Figure 17 which has severely damage.

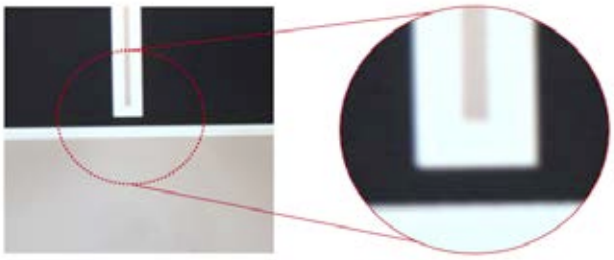

Figure 15: No ESD Damage of Concept 3 at 800V

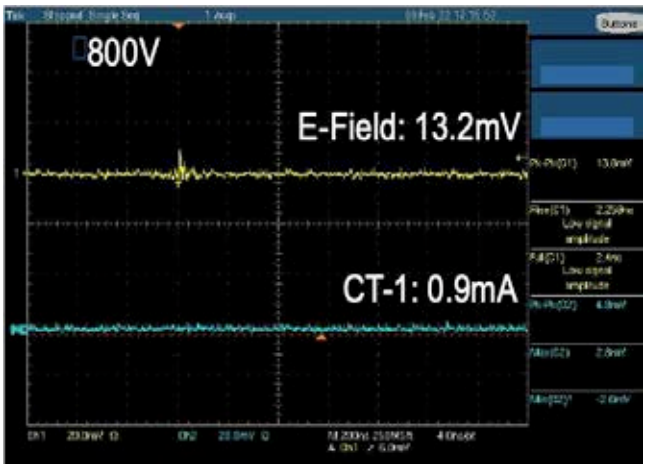

Figure 16: ESD Event Strength of Concept 3

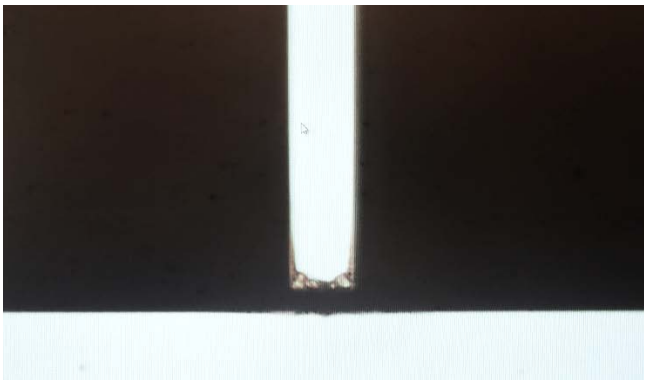

Figure 17: ESD Event Strength of Concept 3

IV. Conclusion

Repeatable ESD testing shows that ESD event only occurs at the shortest gap between metal layer and thin antenna lines until the gap become larger than 2nd shortest distance to next thin antenna as a system.

All three design concepts of photomask have different conductivity of Cr and Cr+ composition as follows.

Cr	Cr+1	Cr+2
2,797,359 S/m	3,296 S/m	134,481 S/m

Concept 1 is a composition of Cr and Cr+1 design in half and half levels. Concept 2 is a composition of Cr+1 and Cr+2 design also half share. Concept 3 has multiple layers of Cr+1 and Cr+2 that has higher ESD sensitivity level than other concepts. Concept 3 design has almost 4 times higher ESD sensitivity level at +800V than concept 1 composition design at +200V. Conductivity changes and adjustment while metal layer deposition process can make better ESD robustness design while maintain same physical gaps and line width through this study.

V. References

[1] Julian M.[1], Larry L.[2], Andreas F.[3], "A Study of the Mechanism for ESD Damage to Reticles," Intel[1], Ion Systems[2] and Dupont Photomask[3], 2000 EOS/ESD Symposium

[2] Dongsun Kim, "Minimizing Electrostatic Charge Generation and ESD Event in TFT LCD Production Equipment", LG Display, 2012 EOS/ESD Symposium

[3] James Wiley and Arnold Steinman, "Investigating a new generation of ESD-induced reticle defects." April 1999, Micro Magazine

[4] K.C. Wang, "ESD and Reticle Damage" October 2000, International SEMATECH Electrostatic Discharge Impact and Control Workshop

[5] Gavin R, "Zero Yield – The Price of Field-Induced Reticle Damage" Future Fab International, Issue 22