# A Batter test solution for LIB Jelly-roll Insulation Test V1.4


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# 0. Preface

It is well known that abnormal internal short circuit (ISC) of the cell could cause the explosion of LIB, but

- Why do the cells cause burning or explosion during charging processes in production line, but the insulation test can not detect the defects in the jelly-roll insulation test in front process?
- The cells sometimes burn or explode even after passed the first formation-charging process, why do that happen?
- There are still cases that the cells get burned or exploded in the normal charging process after the LIB are sold and shipped to the customers; why do that still happen?

The reason, and a better test solutions of insulation test for the LIB jelly-roll (dry cell) will be introduced.

# 1. Analysis of major causes to the explosion of LIB cells

## 1.1 Four ISC patterns of LIB and the dangerousness

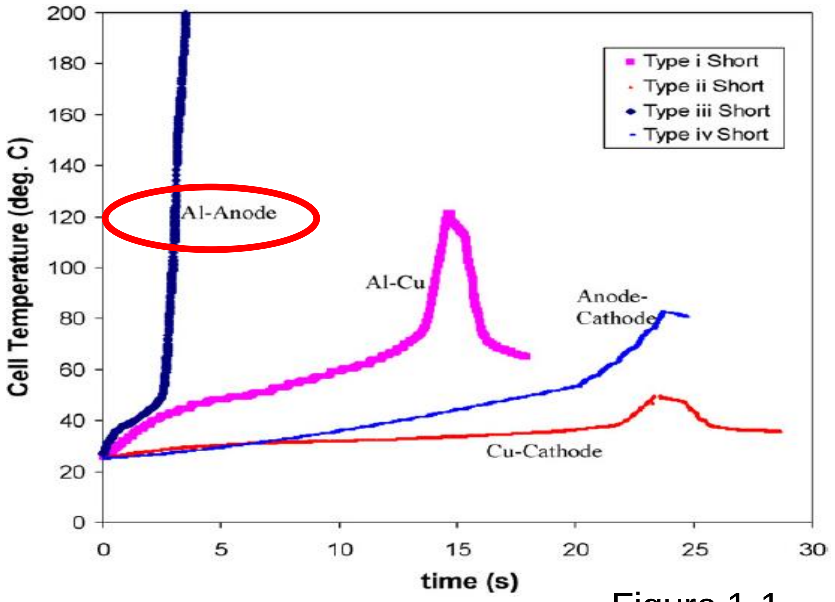



Figure 1-1

Figure 1-1: Four different kinds of ISC conditions of the LIB cell, and the temperature rising it may cause in the nearby area.

Type i, Short occurred between the positive electrode (Al) and negative electrode (Cu).

Type ii, between the negative electrode(Cu) and the coating of the positive electrode.

Type iii, between the coatings of the positive electrode and the negative electrode.

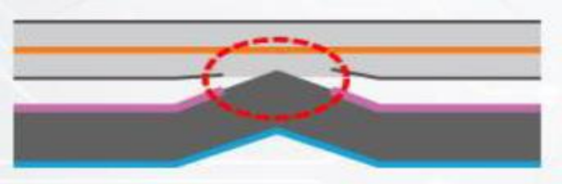
Type iv,. between the positive electrode(Al) and the coating of the negative electrode.

Note : Type i – distributed in large area, low temperature rise and is not easy to reach cause fire. Type ii – carrier of positive electrode material is not electron, low conductivity. Type iv– same reason as Type ii. Type iii – very high energy concentrated on ultra small spot, very rapid temperature rise and could easily ignite the electrolyte (burning point of the electrolyte is about 230° Celsius)

# 1. Analysis of major causes to the explosion of LIB cells

## 1.1 Four ISC patterns of LIB and the dangerousness

As shown in figure 1-1, thought all four conditions of the ISC lead to the battery failure, yet the major cause to the burning or explosion of LIB cells is that the metal plate of the positive electrode (Al) shorts to the anode material. Vast amount of charge transfer concentrated in a tiny locality in such short circuit condition would cause very rapid temperature rise and the ignition of a fire. The risk of a fire is depending on the heat generated in a localized tiny spot rather than the current magnitude of a short circuit, according to the experts of electrochemistry.



Such ISC condition could be caused by :

- Burrs on the aluminum plate
- Impurity particles in the coating of the positive electrode
- Burrs on the welding point of the positive tab
- Irregularity of the insulation tape pasted on the tab
- Excessive external pressure onto the cell edges

# 1. Analysis of major causes to the explosion of LIB cells

## 1.2 Why the regular IR and Hi-Pot tests can not detect battery jelly-roll insulation abnormality completely?

It sounds unreasonable, but easy to explain: **There is not short-circuited yet when you test it!**

There are a few misconception in general insulation test on the LIB Jelly roll: Ex.,

- It is OK as long as there is no "short-circuit" condition, thus very low voltage is applied to the DUT during the insulation test.
- Insulation NG means insulation resistance is low, thus employing regular IR (Insulation Resistance) meter for such tests.
- As long as the leakage current is lower than the limit-value in Hi-Pot/IR test, the insulation is good. People tend to ignore the risk of existing burrs may still causes potential ISC in the future, even temporal healing has occurred by those electrical flashovers during the test.

There is no solid shell or enclosure for the LIB pouch cell until they are formed a module/pack. Hence it is not easy to find those insulation problem during the insulation test if they are not pressed. But, even cylindrical and cubic can cells, fire accident occurs during the production process and after sold (means they passed the jelly-roll Hi-Pot/IR testing .

# 1. Analysis of major causes to the explosion of LIB cells

## 1.2 Why the regular IR and Hi-Pot tests can not detect battery jelly-roll insulation abnormality completely?

Even without externally excessive force or poor BMS design, LIB may get burned or exploded during the regular charge/discharge cycles. Root cause of this problem is that **the anode (-) material inflates during the charging process. Moreover, it will keep inflating as the charging process repeat again and again !**

# 1. Analysis of major causes to the explosion of LIB cells

## 1.2 Why the regular IR and Hi-Pot tests can not detect battery jelly-roll insulation abnormality completely?

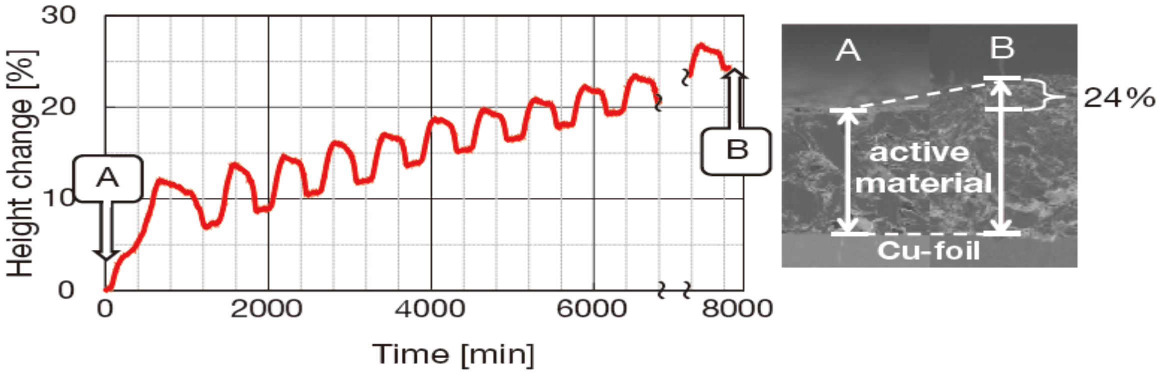



Figure 1-2: Changes of the thickness of the graphite material on the negative electrode of LIB during repetitive charging/discharging cycles. (According to the report no. 134 2015/1 from Furukawa Electric)

From figure 1-2, after around 10 charging/discharging cycles, the graphite material on the negative electrode could inflate up to 24% more of its original thickness. It is stated in the same report that: after the same number of charging/discharging cycles, the silicon material on the same negative electrode would increase by even 110% more than the original. This can explain why the LIB still get burned after even being sold to the end customers.

# 1. Analysis of major causes to the explosion of LIB cells

## 1.2 Why the regular IR and Hi-Pot tests can not detect battery jelly-roll insulation abnormality completely?

1. The correct insulation test for the LIB dry cells should be to test **if the distance between the two electrodes is enough.** Assume a 20μm (separator thickness) cell with IR around 20GΩ, then a 5μm one still with a vey high resistance at around 5GΩ. It is difficult to accurately measure such a high resistance on a high capacitance (> uF) of a normal automotive LIB dry cells. Meanwhile, battery cell manufacturer generally test IR at a lower voltage, obviously, just very few of them decide the test voltage from the consideration of "distance" inspection.

$$E = V/d$$

$$E_{max} = V_{max}/d$$

(Air in normal humidity: Emax ~ 3kV/mm; plastic is about 30 times of this; separator should be between them)

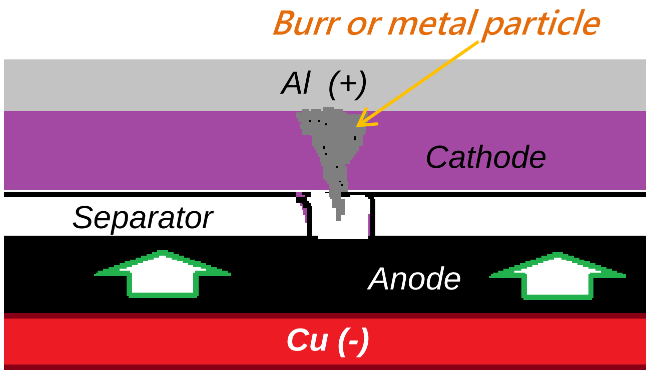
# 1. Analysis of major causes to the explosion of LIB cells

## 1.2 Why the regular IR and Hi-Pot tests can not detect battery jelly-roll insulation abnormality completely?

2. The inflation of anode material while charging is not a news for battery talents, but most of them trust separator. The current technology demands thinner and thinner separators inside the cells (from the main trend of 25um thickness nowadays all the way down to 5um in the future), while, at the same time, the thickness of anode material increases. This would lead to more serious compression on the separator, and hence more defects of possible micro ISC conditions. Consequently, some users exclude the suppliers of LIB simply because the suppliers use too thin separators.

# 1. Analysis of major causes to the explosion of LIB cells

## 1.2 Why the regular IR and Hi-Pot tests can not detect battery jelly-roll insulation abnormality completely?



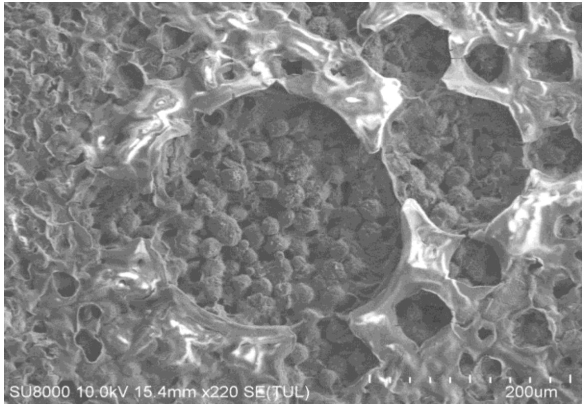

3. A more serious problem which is not known by most people: During a regular IR/Hi-Pot test on the dry cell of LIB, electrical discharge may happen on the burrs or metal impurities on the positive Al plate, and causes a melted hole in the separator, the electrical discharge may further cause the burrs shrunk so it won't be able to create the path for flashover anymore.

   The result is this defective DUT passes most of the WV and IR tests. However, the melted hole and the burr is still there and is a big hazard to the safety. It could cause fire in the field if the anode material touch the burrs in further charging processes.

   (1) Since the plastic material of the melted hole was contracted already during the WV /IR test. Some original protection mechanisms of the separator do not work anymore.

## 1.2 Why the regular IR and Hi-Pot tests can not detect battery jelly-roll insulation abnormality completely?

(2) Chroma has joint-research programs on the dry cells of LIB with local universities in Taiwan. In a recent study by the faculty of a university, we discovered that there are partial “fast-charge” phenomenon observed on the locality of the melted hole, which means there are spots with lithium metal accumulation on the anode material near the melted holes. This phenomenon further poses a bad effect on the quality and reduced life expectancy of the LIB cells.




(Pictures of the phenomenon and effects mentioned above is in next page)

# 1. Analysis of major causes to the explosion of LIB cells

## 1.2 Why the regular IR and Hi-Pot tests can not detect battery jelly-roll insulation abnormality completely?

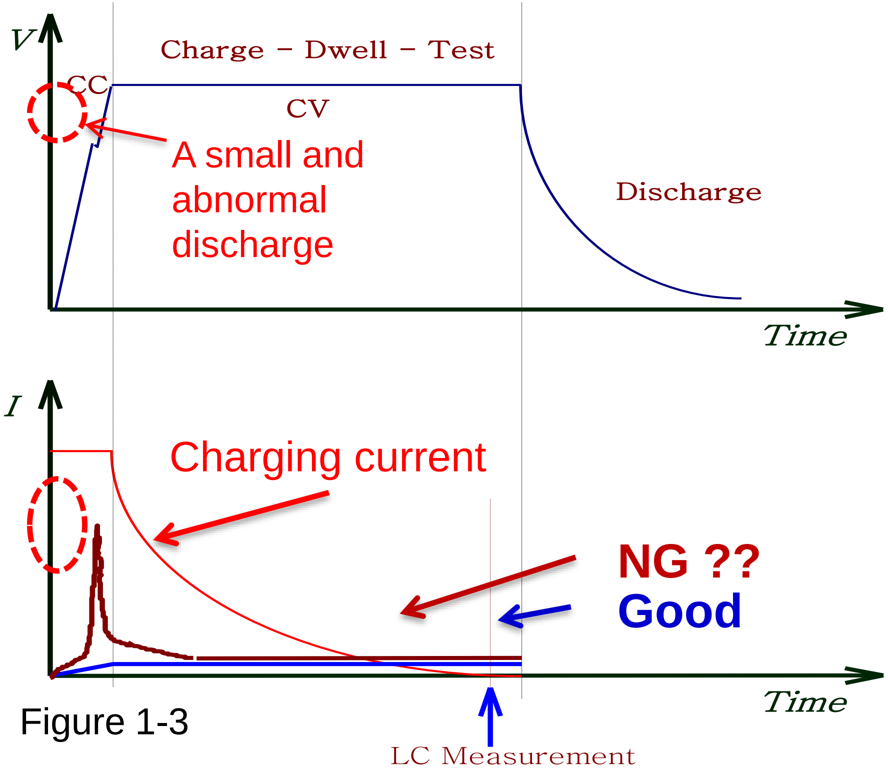



Figure 1-3

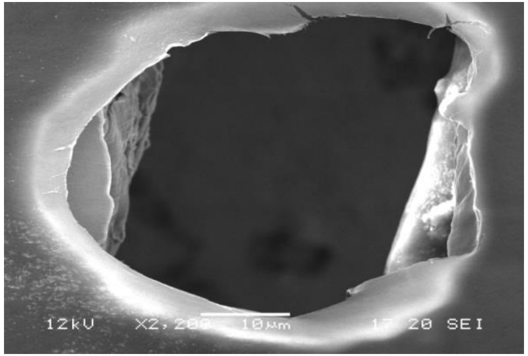



Figure1-3 The melted hole caused by a electrical discharge during the regular IR or WV test because of a shorter distance between electrodes. However this defective DUT can easily pass the general regular WV/IR tests and goes to the end users.

# 1. Analysis of major causes to the explosion of LIB cells

## 1.3 Why the LIB cells still explode after passing all the in-house safety tests and go to the end-users.

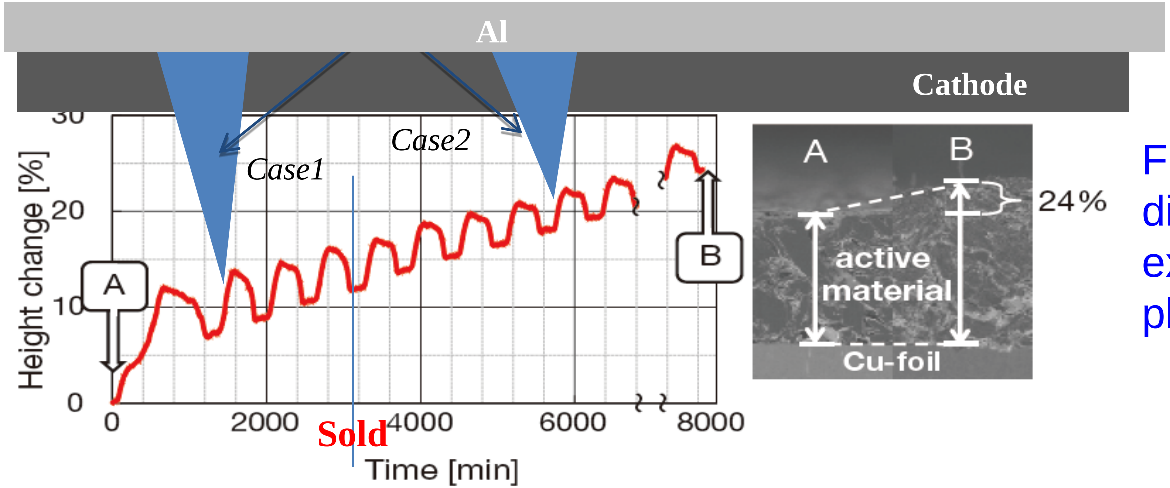



Figure 1-4 Two burrs with different height(length) extruded out from the *Al* plate

From Figure 1-4, case 1 will cause fire on the 2nd time of charging, while case 2 will not cause fire in house, and unfortunately, it causes fire after shipping to the customers. If these burr defects were not detected in the state of dry cell, it will not be detected by general “Rest” method (ΔV) because the distance between electrodes will NOT change while resting.

# 2. Techniques of electrical inspection

## 2.1 The correct way of doing insulation test for the dry cells

From figure 1-3, it is not enough to just measure end leakage current in the WV/IR test. Flashover detection is a must for this issue, the entire testing duration is closely monitored for flashover detection.

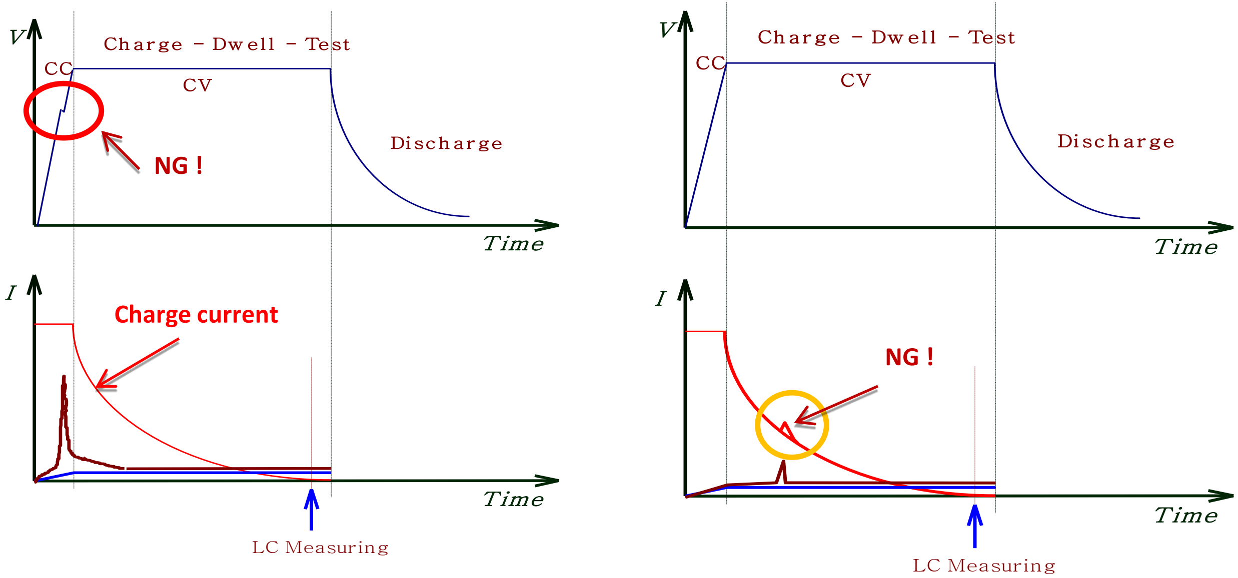



Figure 2-1 Flashover detection is a must for the entire testing duration

Flashover detection for the entire process plus the leakage current monitoring is a sounder test methodology for this issue. Furthermore, the test voltage selection (in according to the thickness of the separator, anode material conditions) and the applying clamping force on the pouch cells while doing this test are also very important.

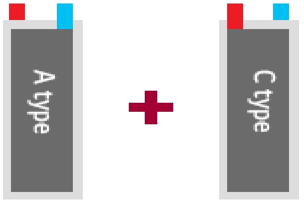
# Chroma 11210 Battery Cell Insulation Tester


- Test voltage **~ 1KV**
- Programmable charging current: **0~50mA**
- High speed measurement: **20mS~**
- Contact check **(pre-test, post-test or both)**
- Fully automatic tests (charging-dwell-measure-discharge) **(LC/IR test executed simultaneously with PD detection) .**
- PD detection in the entire process[PD Option: **Level** and **Number** of each occurrence]
- PD analyzer function[PD Analyzer option : **Waveform recording and analysis**]

# 3. Chroma Test Solutions

## 3.3 Where to use? (take a pouch cell as an example)

### *Lamination*



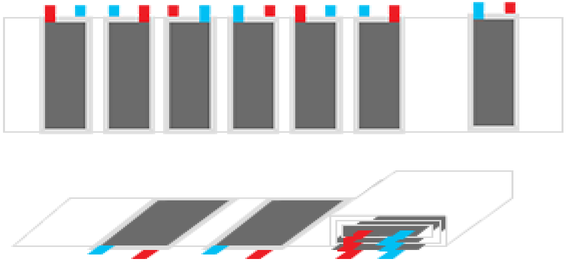

Bi-cell Lamination

** Test voltage and test time only for reference**

*Test V: 20~300V*
*Test time: 0.05~0.2s*

**Use multiple instruments to do the insulation tests**

### *Folding*



Bi-cell folding

*Test V: 70~500V*
*Test time: 0.3~2s*

**Some will do the insulation test again after tab-welding**

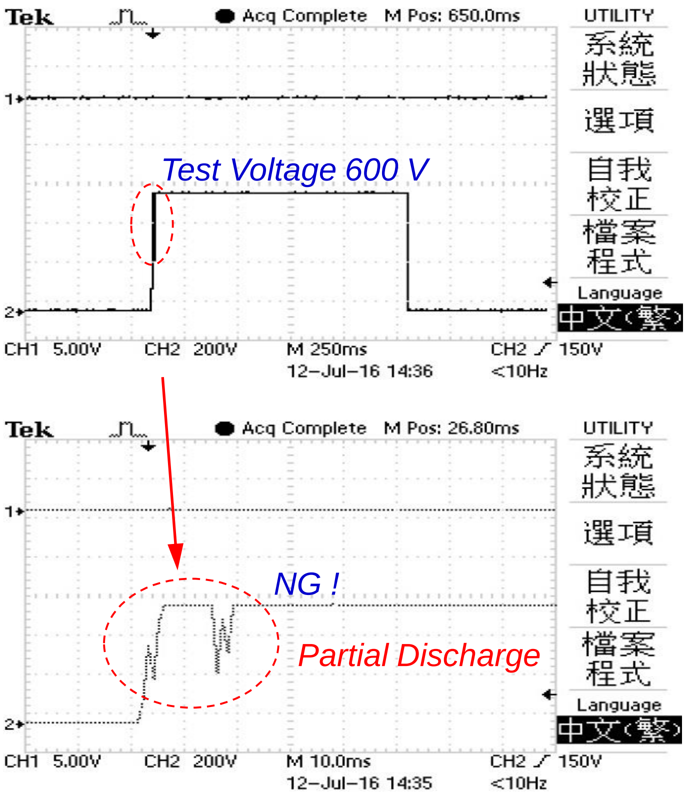
### *Package*

**Seal in aluminum film case**

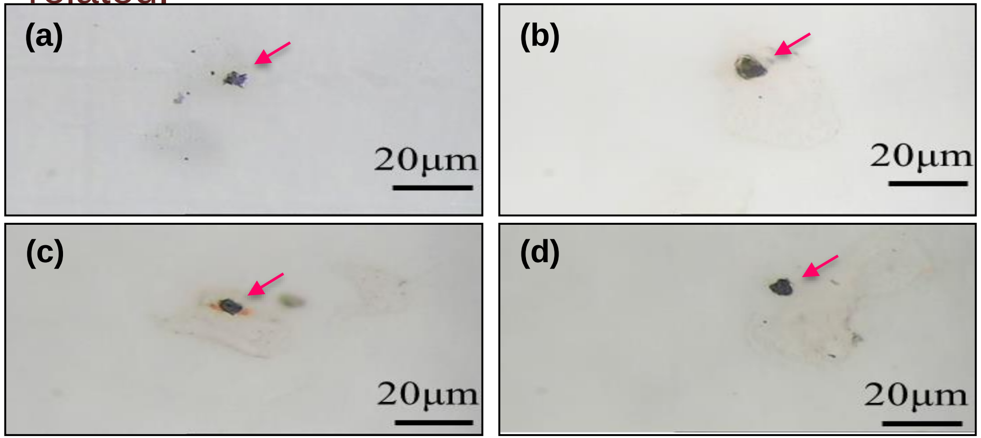
*Test V: 200~1000V*
*Test time: 2s~*
*Test between electrode and case*

**Insulation test is also carried out between electrodes and metal case. (after electrolyte injection)**

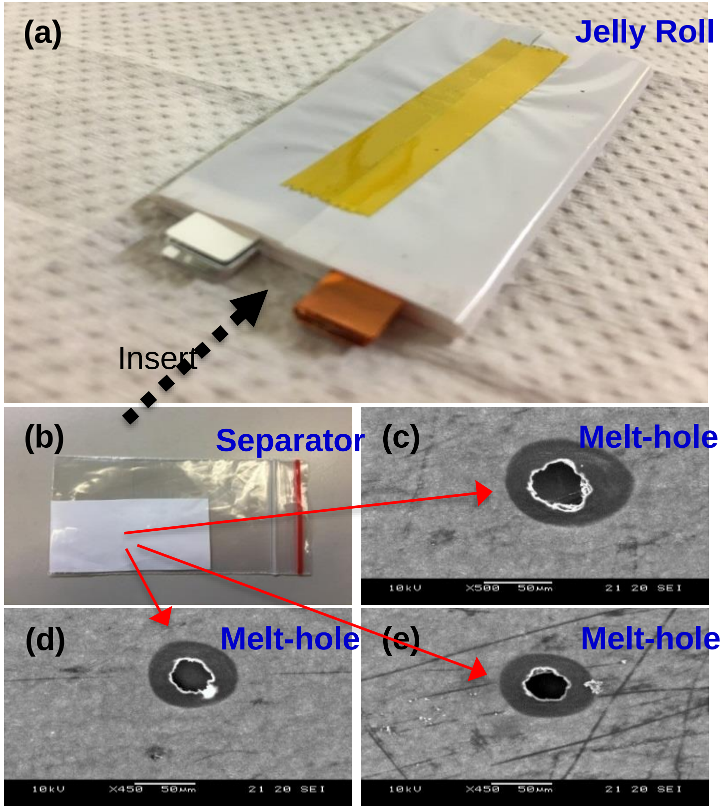
## Verification (1): Correlation between PD (flashover) and the melted holes




Analysis on the test voltage waveform and the surface of the separator. Through SEM photos, we confirm that PD did cause melted holes on the separator. The number of the holes and the number of PD is very closely related.



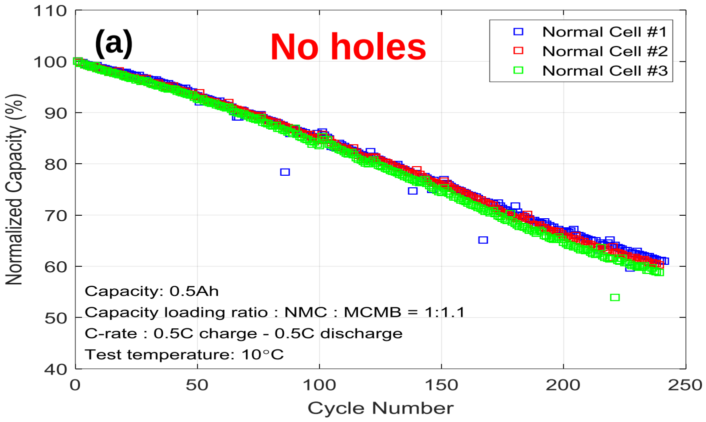
## Verification (2): Influence of the separator with melted holes to the LIB cell.

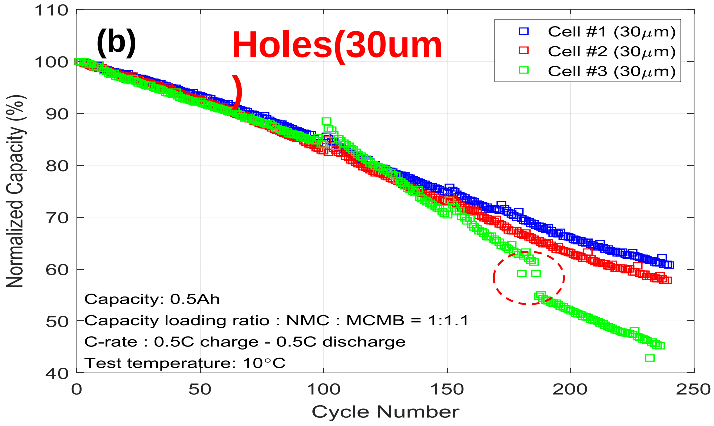


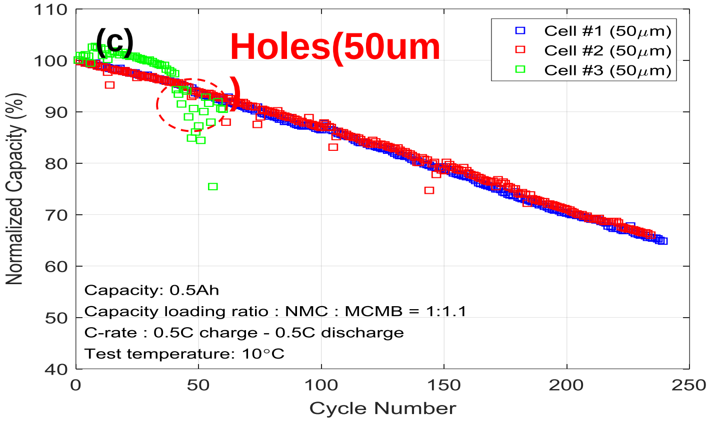

### Experiment :

Making holes on the separator intentionally by laser cutting, then make a LIB cell with this separator. Run through charge/discharge cycles and verify the performance of this LIB. Analyze and study the result.

# 4. Chroma research



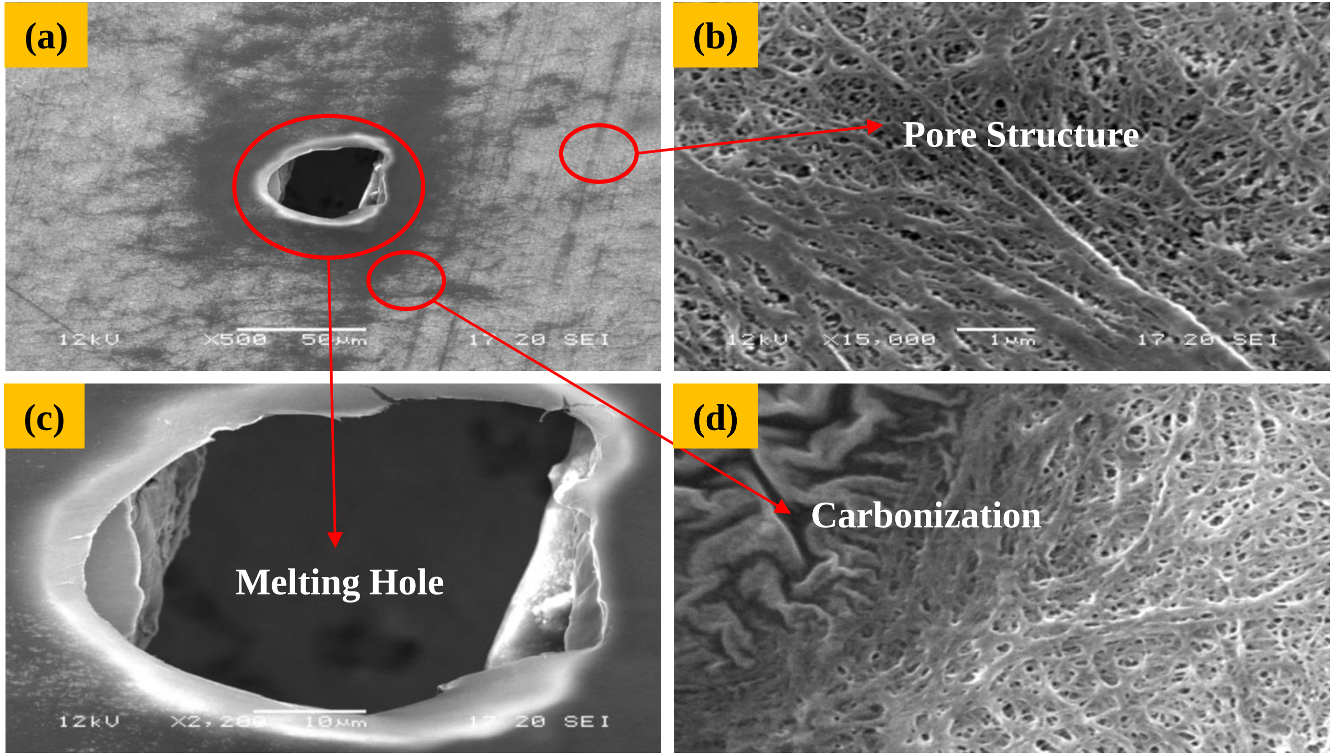



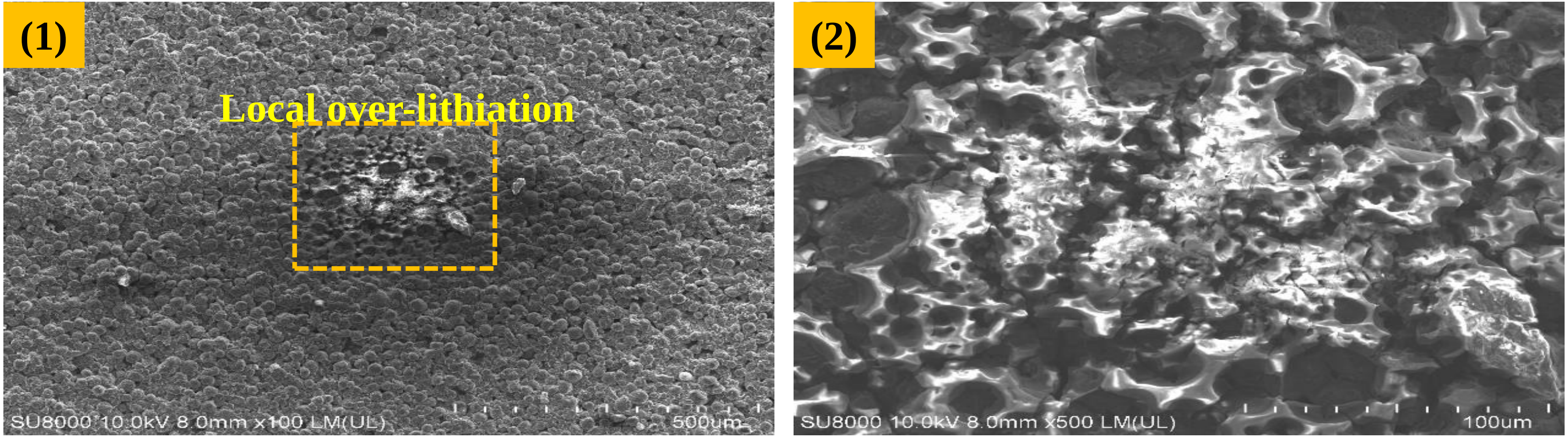

Analyze the changes of those capacities vs. the size of the holes. We observed the dramatic drop of the capacity in some specimen.

## Local Defects on Separator Induced by Flashover

There are black spots or defects due to burning or carbonization can be found on the separator of the jelly rolls when partial discharge being detected during Hi-Pot/IR test.



# 4. Chroma research


White deposits were found with SEM

# 5. Technical Notes

## 5.1 Why a regular Hi-pot machine not suitable for the battery insulation test

1. No PD/flashover detection function during the test
2. Very small DC charging current (Q = It = CV ; t = C V/I)

   E.g. 1Ah~0.1uF ➔ 20Ah @ 1kV …… needs 400mS @ 5mA
3. The DC output from a regular Hi-Pot tester is not a real DC power source. Easily to cause over-charging, negative leakage current (risky to capture a false good), and unstable readings for large cell insulation test .

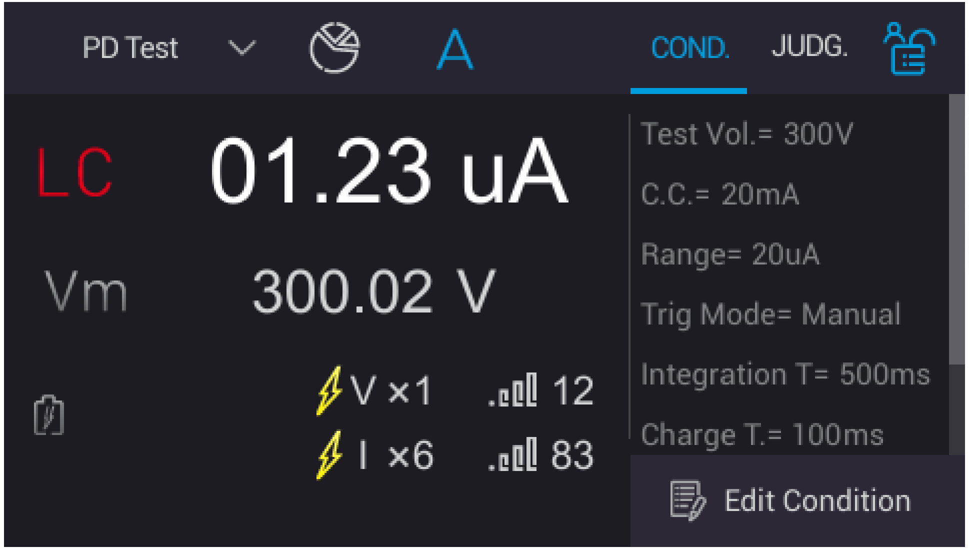
# 5. Technical Notes

## 5.2 Why waveform logging is needed?

Some of the defects (burrs) will be shrunk and cut off due to the strong energy from flashover. The flashover phenomenon may not be reproduced on the same DUT again. This will affect the QA follow-up procedures. To trace back the original failure phenomenon, waveform logging is necessary.

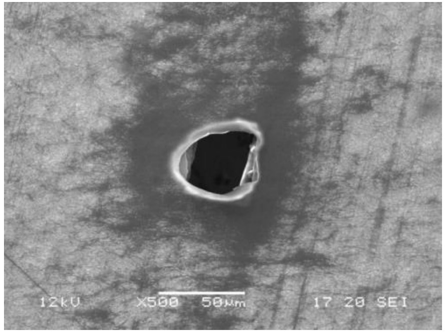
# 6. PD function demo and customer daily-check

## 6.1 11210 display



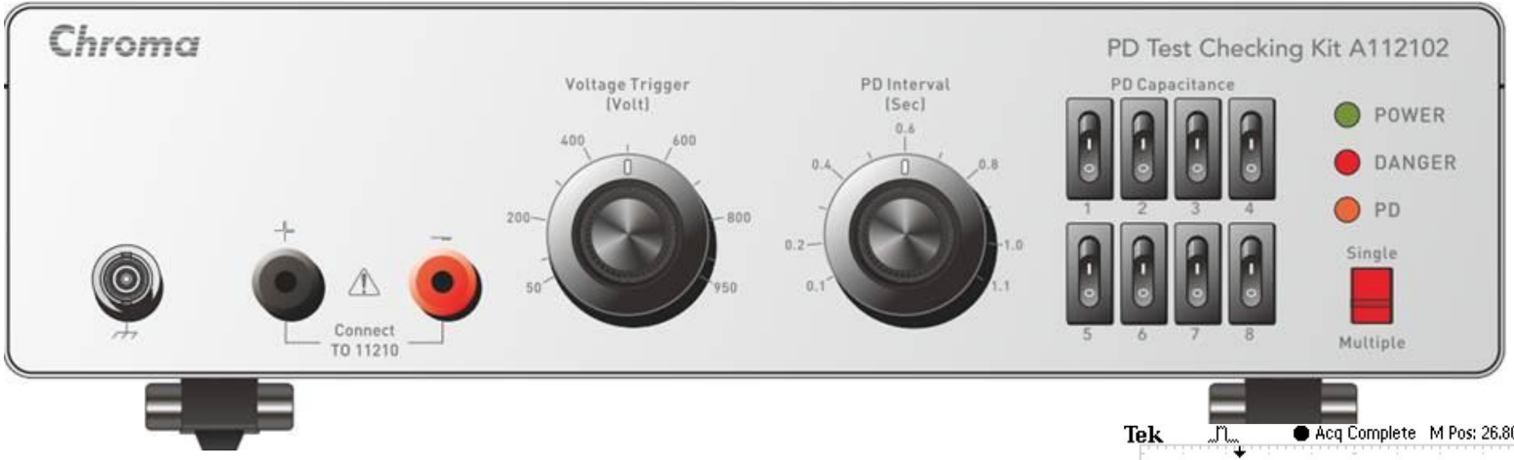

PDV times and level display
PDI times and level display


[11210 overview]



# 6. PD function demo and customer daily-check

## 6.2 PD Test Checking Kit Front Panel



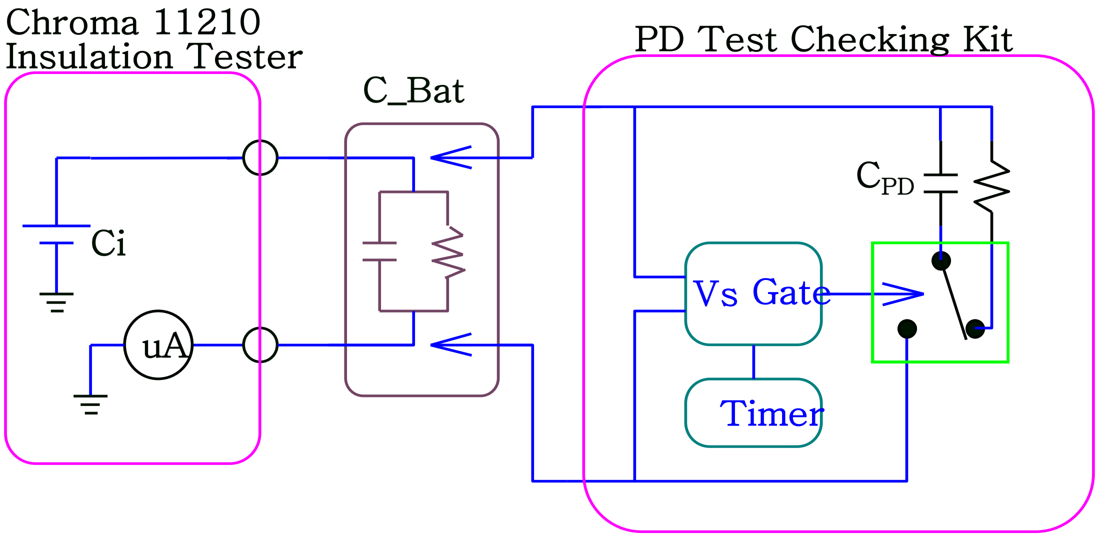

Voltage Trigger : PD ignition voltage level setting in CC charge

PD Interval time : Active when Single/Multi SW is switched to “Multi”

PD Capacitance : Select PD “Energy” or “Charge Capacity”

# 6. PD function demo and customer daily-check

## 6.2 PD Test Checking Kit Circuit Design




PD energy ~ ½ $C_{PD}Vs^2$;
Vs: trigger voltage level

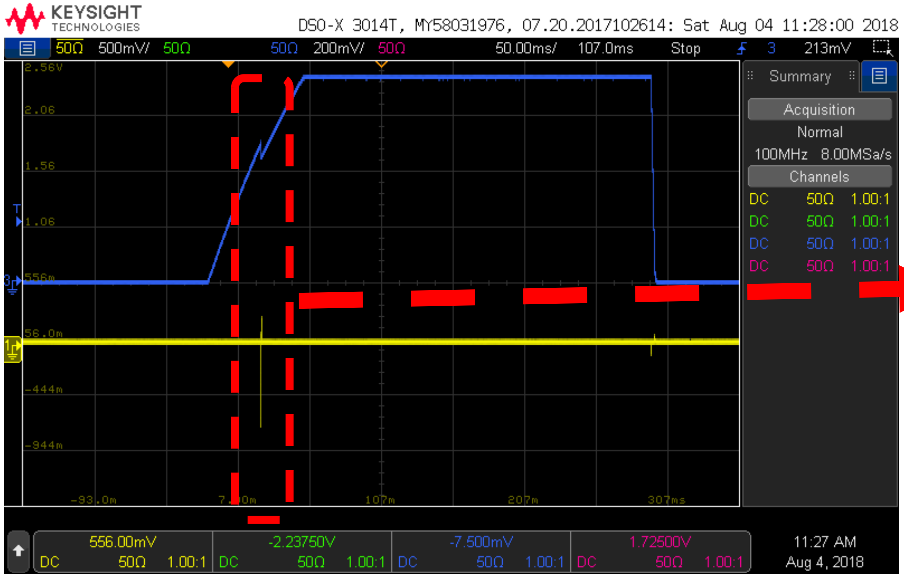
PD charge ~ $C_{PD}Vs$

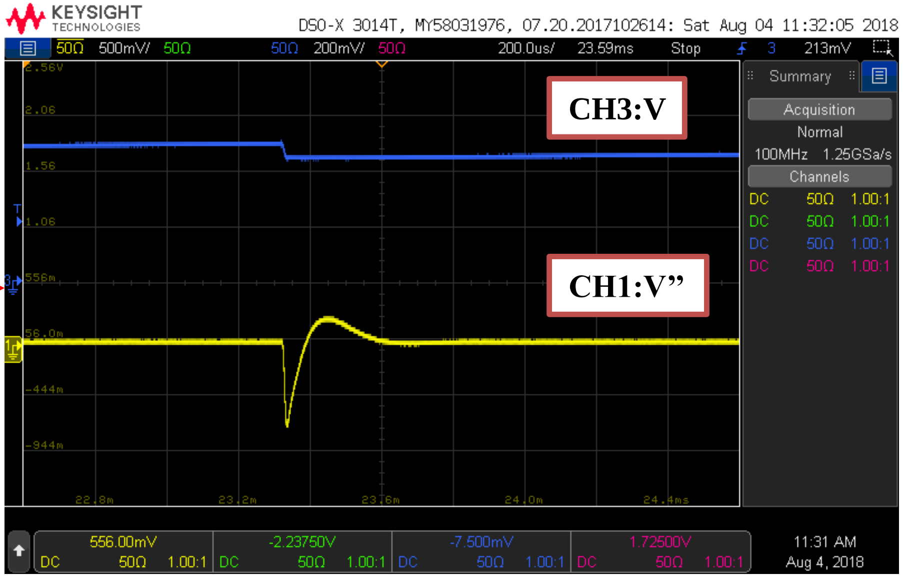
➔ Higher $C_{PD}$ selection gets higher PD level reading
➔ Higher Vs setting gets higher PD level reading

# 6. PD function demo and customer daily-check

Chroma

## VPD Checking




| PD Cecking Table | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PD Mode | A112102 | | | | 11210 | | | | | | |
| | Setting | | | | Setting | | | | | Test Result | |
| | PD CAP. | MODE | Vtriger | PD Interval | Test Voltage | Charge Current | Charge Time | Dwell Time | Test Time | Times | Level |
| VPD | 8 | Single | 200V | 0.1s | 500V | 1mA | 200ms | 50ms | 50ms | | |
| Others Setting(11210) | | | | | | PD Compare Setting(11210) | | | | | |
| 1.LC range setting(11210):20uA | | | | | | VPD | VPD level | VPD times | CPD | VPD level | VPD times |
| 2.Trigger mode(11210):Manual | | | | | | ON | 1 | 1 | ON | 5 | 1 |

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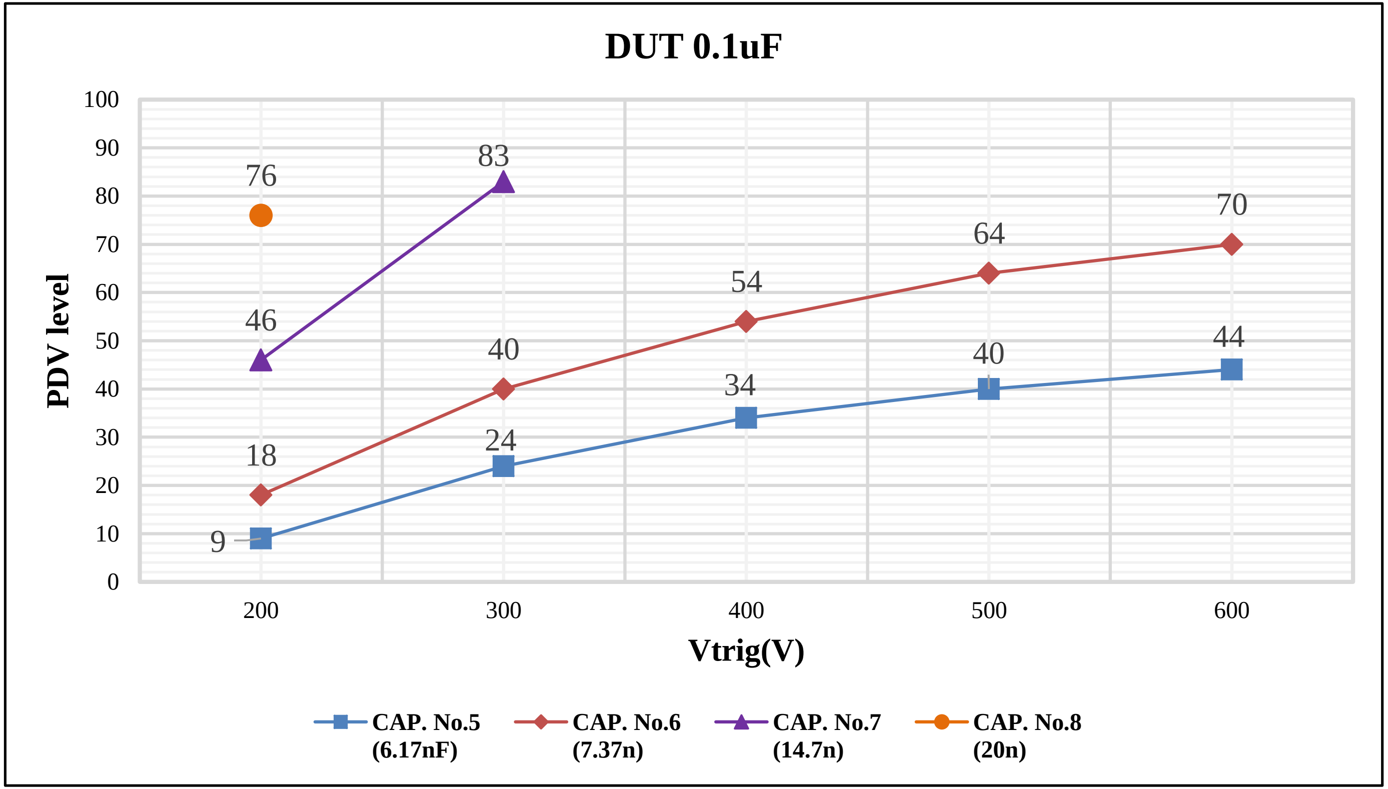


Thank You !