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Research on the Mechanism of Pin-to-Pin ESD to SCB Initiators

***Abstract**. By ESD experiment, SEM-EDXA and firing experiment, the electrostatic-response characteristic of SCB was studied and the electrical explosion performance after ESD was measured. Results show that surface-damage of bridge is not obviously visible when lower than 25kV, but part of samples coated with explosive fire; the V-type angles start to be damaged at 25kV. After ESD, the function time and firing energy required decrease significantly. 25kV is the critical damage-voltage of the bridge. When less than 25kV, the electrical energy can only make the polysilicon melting and at 25kV, the temperature reaches the boiling point of silicon to generate plasma.*

***Streszczenie.** Analizowano odpowiedź elektrostatyczną i parametry inicjatora eksplozji. Uszkodzenia mostka są nie zawsze widoczne jeśli napięcie jest poniżej 25 kV. Dlatego stwierdzono że napięcie 25 kV jest krytyczne, poniżej powoduje topienie polisilikonu, ale powyżej skutkuje tworzeniem się plazmy. (**Badania mechanizmu wyładowania elektrostatycznego w inicjatorach półprzewodnikowych SCB**)*

Keywords: initiator; semiconductor bridge; electrostatic discharge; SEM-EDXA
Słowa kluczowe: wyładowanie elektrostatyczne ESB, inicjator wyładowania.

Introduction

The safety of energetic materials is a research hotspot in recent years. Many scholars are devoting themselves to studying the appropriate description of the response in the complex electromagnetic conditions. The initiating explosive devices are the most sensitive components in weapons and ammunition. Therefore, because of the electrostatic, electric explosive devices(EED) are often failure or accidental detonation in use. And the human-body electrostatic is the most important, frequent and dangerous factor in the electrostatic hazards of EED.

Semiconductor bridge (SCB) initiator is a transducer. Under the effect of high electrical energy, the power transforms into thermal power. Then the doped polysilicon layer vaporises and generates high temperature plasma which heats the explosive. Ultimately, when the temperature reaches ignition temperature, the explosive detonates[1]. As the representative of modern advanced initiators, SCB initiators have low-firing energy, short-function time and high-reliability characteristics[2].

But as a kind of EED, SCB still can be affected by the electrostatic energy between the pin-to-pin or pin-to-case. The electrostatic can cause the change of the performance. The pin-to-case electrostatic mainly generates electrostatic spark and then the spark ignites the explosive to accidentally ignite initiators or change the electrical explosion property. In practice, we can design ESD(electrostatic discharge) channel between the pin and case[3] or connect ESD devices(such as zener diode, solid discharge tube, transient voltage suppressor[4-6]) to protect SCB from the pin-to-case electrostatic.

Recently, more and more attention has been paid to the pin-to-pin electrostatic hazards of SCB. GJB5309.14-2004 requires that EED can not get firing in the condition of 500pF±25pF capacitor discharge, 5000Ω±250Ω series resistance and 25kV±0.5kV pin-to-pin voltage. However, at present, the mechanism of pin-to-pin electrostatic hazards to SCB initiators has not been sufficiently researched and the response property of SCB under ESD has not been clearly studied either.

In this paper, we tested the initiators in the pin-to-pin ESD experiment. Then by SEM-EDXA and firing experiment, we studied the mechanism of ESD and the electrical explosion performance of SCB after ESD. It can provide principle basis for selecting the appropriate method of electrostatic protection in practical application.m.

1 Theoretical Principle

Electrostatic is a kind of electric charge in a relatively steady state. When the objects which have different electrostatic potentials are close to or directly contact with each other, it can result in charge transfer. Accordingly, we define it as electrostatic discharge which is expressed as ESD for short[7]. Though the quantity of static electricity is by no means large, the electrostatic voltage is very high. In practice, the human body electrostatic voltage can reach several thousand volts or even tens of thousands of volts.

GJB5309.14-2004 used 500pF capacitor, 5000Ω series resistance and charged 25kV voltage to simulate the condition of human body ESD[8]. The experimental schematic diagram was shown in Figure 1.

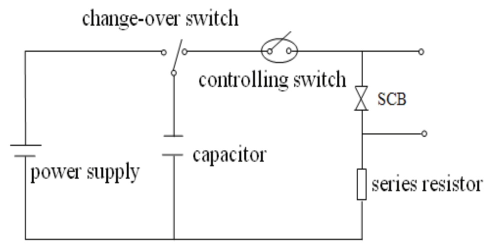


Fig. 1. Schematic diagram of ESD experiment

SCB have already possessed better performance of anti-electrostatic, so it can meet the demand of GJB. In order to increase the ESD energy that acted on SCB, this paper used 10000pF capacitor instead of 500pF capacitor. Meanwhile, we connected the 5000Ω series resistance and changed the charging voltage of capacitor to study the mechanism of human body ESD to SCB.

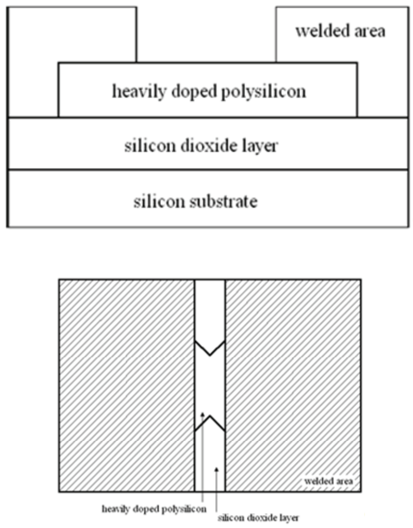


Fig. 2. Structure charts of SCB chip

2 Experiment

2.1 Experimental Sample

The sample used in experiment was a typical SCB initiator and the doping element of the chip is phosphorus. As shown in Figure 2, there was a silicon dioxide isolation layer above the silicon substrate. On top of the isolation layer, there was a heavily doped polysilicon layer whose dopant concentration was about 7×10^{19} atoms per cubic centimeter and the resistance was about 1Ω. The bridge had two V-type angles and the size was 380μm(width) × 80μm(length) × 2μm(thickness). The bridge chip was stuck into the ceramic plug with epoxy resin. The external diameter of ceramic plug was 4.7mm and the height was 4.5mm. Then, the aluminum wires were bonded on the welded area by ultrasonic waves.

2.2 ESD Experiment

2.2.1 Principle of ESD experiment

In the ESD experiment, JGY-50 electrostatic sensitivity instrument was used to test the SCB initiators. Experimental conditions: ambient temperature was 20□, relative humidity was less than 45%, capacitor was 10000pF and series resistor was 5000Ω. The circuit was connected according to the route in Figure 1.

During the experiment, the change-over switch was on the side of power supply at first. Adjust the knob and make the voltage meet the demand of experiment. Right now, the capacitor was charged by power supply. After charging, the switch was quickly converted to the other side. The circuit of power supply, change-over switch and capacitor disconnected while the capacitor, controlling switch, SCB initiator and series resistor composed a discharge circuit.

2.2.2 Results and analysis of ESD experiment

Lead styphnate(LTNR) is a single-component primary explosive and its ignition capacity is lower than the other primary explosive. The SCB chip was coated with LTNR and its electrostatic sensitivity was measured. Electrostatic voltage raised from 23kV to 30kV and ten samples were tested at each voltage level. The resistance of each sample was measured and written down before and after ESD experiment. The result was shown in Table 1.

Table 1. The result of ESD experiment

electrostatic voltage[kV]	amount of sample	amount of firing sample
23	10	2
24	10	6
25	10	7
26	10	9
27	10	9
28	10	10
29	10	10
30	10	10

The result of resistance measurement before and after ESD showed that the varied resistance of the no-fire samples was no more than 0.1Ω. Moreover, the resistance of some samples increased and some decreased. Therefore, we considered that the resistance of the no-fire samples had no significant change.

As shown in Table 1, the electrostatic energy could cause the SCB initiators with explosive accidental detonation. With the increase of the electrostatic voltage, the amount of the firing initiators is also increased. When the electrostatic voltage is higher than 28kV, SCB initiators surely fire.

As shown in Figure 3, the bridge areas of SCBs without explosive were photographed before ESD. Electrostatic voltage was loaded also from 23kV to 30kV. Then, the bridge areas were photographed again after ESD experiment. The diagrams were listed in Figure 4.

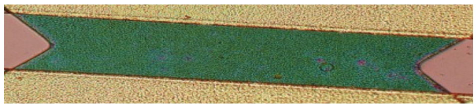
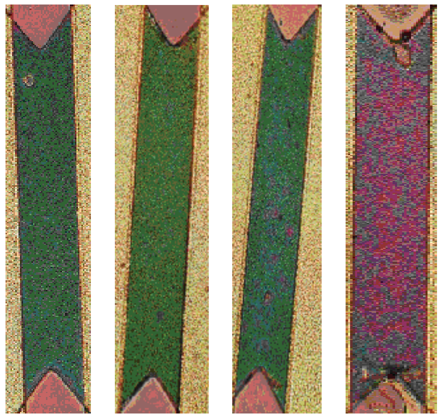
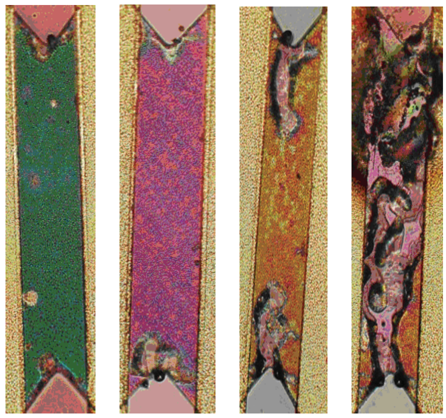


Fig.3. Diagram of SCB bridge area before ESD experiment



(a) (b) (c) (d)



(e) (f) (g) (h)

(a)-23kV, (b)-24kV, (c)-25kV, (d)-26kV, (e)-27kV, (f)-28kV, (g)-29kV, (h)-30kV

Fig. 4. Diagrams of SCB bridge area after ESD experiment

As shown in the pictures above, the shape of bridge area has little change when the electrostatic voltage is low (such as 23kV, 24kV, 25kV). But when the electrostatic voltage is higher than 26kV, the bridge vaporised at sharp corners. And with the increase of the voltage, the vaporised area of bridge angles enlarges. When the electrostatic voltage achieves 30kV, most of the bridge area vaporised and two samples directly explode in the experiment.

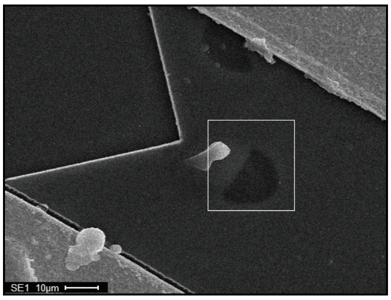
This shows that 25kV is the critical damage-voltage of the bridge.When the electrostatic voltage is less than 25kV, the polysilicon only melts and the melting silicon releases heat on the surface of explosive. Then part of SCB initiators accidentally fire. While the electrostatic voltage exceeds 25kV, the generated temperature can reach the boiling point of silicon to generate plasma. Finally, it causes the accidental ignition of the explosive.

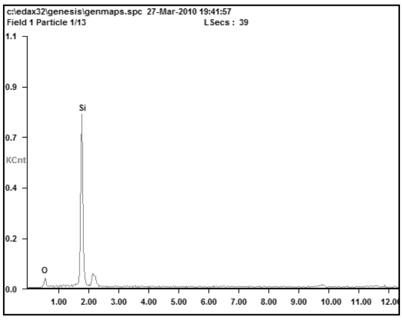
From the result of resistance measurement before and after ESD experiment, we find that the varied resistance of electrode plugs is very small when the loading voltage is less than 28kV and the resistance of samples all increases more than 20% while the voltage is 29kV, 30kV.

2.3 SEM-EDXA

To judge that whether the electrostatic generated plasma at 25kV electrostatic, the damaged bridge area under 25kV electrostatic was observed by SEM-EDXA after

ESD experiment and the elemental composition of this damaged area was analysed. The result was shown in Figure 5.





Element	Wt%	At%
O K	23.95	35.60
SiK	76.05	64.40

Fig. !

From the result, the sharp corners of SCB are damaged and the damaged area is composed by oxygen and silicon elements. The quality percentage of oxygen is 23.95% while the atomic percentage is 35.60%. According to the structure chart of SCB chip(Figure 2), the oxygen roots in silicon dioxide which is under the heavily doped polysilicon layer. It indicates that the loop current generates Joule heating when the electrostatic energy passes though SCB.

(1) $$Q = \int I^2 R dt$$

where: Q – absorbent energy of SCB, R – resistance of SCB, I – current, t – acting time of electrostatic.

Joule heating generates high temperature at the two angles.

(2) $$\Delta t = \frac{Q_f}{mc}$$

where: Q_f – actually received energy of the bridge, $\triangle t$ – value of temperature rising, c – specific heat capacity of SCB, m – mass.

When the temperature is higher than the boiling point of the polysilicon, the polysilicon vaporises and the silicon dioxide layer below exposes. At 25kV, the electrostatic can make the bridge generate plasma and damage the initiator.

2.4 Capacitor Discharge Firing Experiment

The model of capacitor discharge was used in the firing experiment. The experimental schematic diagram was shown in Figure 6. Test system includes energy storage capacitor, constant voltage power supply, digital oscilloscope and so on. In the experiment, the capacitor was charged at first. And then the change-over switch was converted to make up the circuit. So, the voltage was applied to SCB.

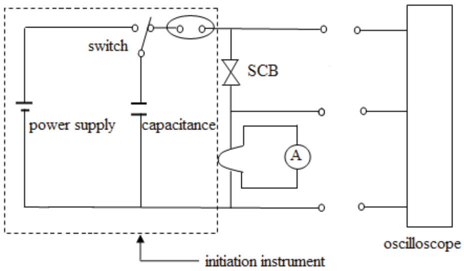


Fig.6. Schematic diagram of the capacitor discharge circuit

The initiators coated with primary explosive were all fired when the electrostatic voltage was higher than 28kV. Therefore, the samples used in this experiment were the SCB electrode plug after ESD experiment and they were not coated with explosive before. The 47μF tantalum capacitor was selected to be the energy storage capacitor and the samples were measured under 22V voltage. Ten samples were tested at each condition and the experimental result was shown in Table 2.

Table 2 The result of firing experiment after ESD experiment

state of sample	average function time[μs]	average firing energy of SCB[mJ]
SCB without ESD	5.50	0.965
SCB after 23 kV ESD	4.87	0.945
SCB after 24 kV ESD	4.93	0.929
SCB after 25 kV ESD	4.98	0.949
SCB after 26 kV ESD	4.43	0.881
SCB after 27 kV ESD	5.07	0.952
SCB after 28 kV ESD	4.68	0.867
SCB after 29 kV ESD	4.51	0.728
SCB after 30 kV ESD	4.17	0.658

Note: the total input energy $E = \frac{1}{2}CU^2 = 11.4mJ$ 。

As can be seen from Table 2, after ESD experiment, the function time and firing energy required of SCB samples are all reduced. According to the result of t test, we find that the function time of SCBs after ESD has significant change than the contrast samples. So after ESD, no matter whether or not the SCBs are damaged to generate plasma, the firing sensitivity of SCBs increases and the safety decreases.

3 Conclusions

(1) The change of bridge area after ESD experiment visually indicates that electrostatic energy can damage SCB and V-type angles are damaged firstly. When coated with explosive, SCB initiators can be accidentally ignited by ESD to result in serious harm.

(2) After SEM-EDXA, we find that the electrostatic affected SCB mainly by Joule heating. When the electrostatic voltage is less than 25kV, the polysilicon is heated to melt. Because of the heat conduction, part of SCB initiators fire or the sensitivity increases. While the electrostatic voltage exceeds 25kV, the electrostatic energy generates high temperature on the surface of the bridge and the silicon bridge directly vaporises to generate plasma.

(3) In the firing experiment, the function time and firing energy required of SCBs after ESD experiment are all obviously reduced. So after ESD experiment, the firing sensitivity of SCB increases and the safety decreases.

REFERENCES

[1] ZHU Fen-chun, QIN Zhi-chun, CHEN Xi-wu, Analyses on semiconductor bridge design, Explosive Materials, 33(2004), No. 2, 22-25

[2] ZHU Fen-chun, XU Zhen-xiang, CHEN Xi-wu, Progress on the semiconductor bridge initiator, Acta Armamentarii, 24(2003), No. 1, 106-110
[3] CHEN Fei, ZHOU Bin, QIN Zhi-chun, Anti-electrostatic and anti-RF technology of semiconductor bridge explosive devices, Explosive Materials, 39(2010), No. 3, 28-32
[4] Keith Haman, Carroll B. McCampbell, Zener diode for Protection of semiconductor explosive bridge, USP51779248(1993)
[5] Monk.David B, Inflator initiator with zener diode electrostatic discharge protection, USP5672841(1997)
[6] Thomas A. Baglnski, Novel electroexplosive device inoorporating a reactive laminated metallic bridge, Journal of Propulsion and Power, 17(2001), No. 1,184-189
[7] LIU Shang-he, ZHOU Wan-zhen, Modeling of electrostatic discharge electromagnetism impulse theory and the development of the study of function mechanism, Journal of Hebei University of Science and Technology, 26(2005), No. 2, 87-91
[8] GJB5309.14-2004 Standard for ESD experiment, Beijing: Commission on science, technology and industry for national defense(2004)

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