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Application of TVS in electrostatic protection for SCB initiators

***Abstract**. In an effort to avoid damages or unintentional firing of SCB initiators caused by ESD, three types of TVS chips are employed for electrostatic protection in this paper. The parameters and protection principles of TVS chips are analysed, and the appropriate TVS are selected to verify its ability for protecting SCB initiators from ESD. By electrostatic sensitivity experiments, the affection of TVS parameters on the electrostatic-protection- effect is studied, the results show that the A type TVS chips can significantly protect SCB against static electricity, and the TVS chips with lower parasitic resistance and larger parasitic capacitance can enhance the anti-electrostatic capability of SCB initiators.*

***Streszczenie.** W celu uniknięcia zniszczenia przez wypalenie inicjatora SCB sprawdzono trzy rodzaje zabezpieczeń TVS przed wyładowaniem elektrostatycznym. W wyniku eksperymentu stwierdzono że zabezpieczenie typu A chroni urządzenie przed wyładowaniem. (**Zastosowanie układu TVS do elektrostatycznego zabezpieczenia inicjatora SCB**)*

Keywords: initiators; SCB; TVS; anti-electrostatic
Słowa kluczowe: inicjator SCB, wyładowanie elektrostatyczne

Introduction

Semiconductor Bridge (SCB) is a new technology ignition device that is produced by standard integrated circuit processing. The bridge is formed by heavily doped region, and its resistance is decided by doping concentration, bridge size and shape. Depending on different application, it can easily meet different requirements and achieve the best behaviours by adjusting bridge parameters.

Due to the sufficient contact between polysilicon layer and crystalline silicon substrate, the heat generated on SCB by radio frequency (RF) could be conducted easily through substrate, which ensures the safety of electro-explosive devices (EEDs) or initiators under the environmental of static electricity or RF. However, the higher electrostatic or RF energy applied to SCB may also cause unintentional firing or characteristics change for initiators. So the electromagnetic compatibility (EMC) of SCB initiators is more demanding with increasing levels of electromagnetic interference (EMI) both in military and civilian applications.

Many scholars have done lots of research on initiators EMC. According to the research of T. A. Baginski [1], the existence of the distributed capacitance in the chip is able to shunt high-frequency coupling currents. T. L. King [2] used a pin to pin parallel zener diode to protect electro-explosive devices (initiators) against electrostatic discharge (ESD). Zhou Bin [3] used TVS diode for pin-to-shell anti-electrostatic of Initiators. Fei Chen [4] researched on the mechanism of pin-to-pin ESD to SCB initiators, and found that electrostatic affected on SCB mainly by Joule heating. B. M. Tovar [5] studied the surface-connectable SCB chips, and made two back-to-back diodes on the side of the chip by the process of cross-cutting and doping, so those two diodes in parallel with SCB, which means the electrostatic voltage discharges through diodes to protect initiators from the effect of ESD. M. T. Bernardo [6] studied the SCB device with voltage protection function, and on the chip there is a dielectric layer between metal pad and bridge section. Due to its specific breakdown voltage, this dielectric layer could prevent the induced voltage that lowers than the breakdown voltage effecting on SCB. On the contrary, the dielectric breakdown could provide current flown though SCB and get SCB functioned when load voltage is higher than the breakdown voltage of the dielectric layer.

In this paper, we proposes a new element that maybe useful for electrostatic protection of SCB initiators due to its advantages. This element is transient voltage suppressor (TVS), it can withstand high current and with wide-range suitable breakdown voltage. In order to study the anti-electrostatic properties of TVS chips, the avalanche breakdown characteristic is analysed, and the appropriate TVS chip is selected to package with SCB in electrode hosing to form a parallel structure.

1 Theoretical analyses

1.1 Parameters of SCB and TVS chips

A typical SCB is schematically illustrated in Fig. 1. The bridge is formed from the heavily doped H-shaped region enclosed by the dashed lines in the figure, doping element is phosphorus and doping concentration is about 7×10^{19} atoms per cubic centimeter. The thickness (T) of the bridge is determined by that of the polysilicon film deposited onto the silicon dioxide (SiO_2) layer; the width (W) of the bridge is decided from the shape of the doped region; and the length (L) is determined by the gold lands, which provide the means for electrical contact with the underlying polysilicon layer. The size of SCB is 100μm(L)×400μm(W)×2μm(T).

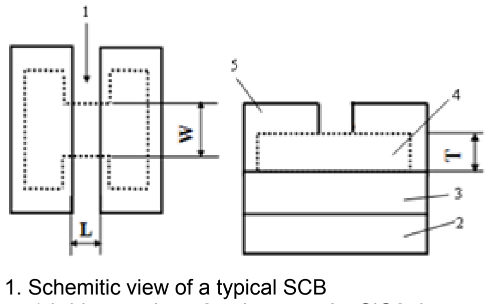


Fig. 1. Schemitic view of a typical SCB
Where:1-bridge region, 2-substrate, 3- SiO2 layer, 4-polysilicon layer, 5-gold landing, L-length, W-width, T-thickness

Considering of the structure and protective parameters requirements of SCB initiators, the SMBJ series TVS chips are used in the SCB ESD experiments. To achieve convenient packaging and without increasing volume of SCB initiators, the TVS chips without packaging are selected. The cross-section view of the TVS chip is shown in Fig.2, and its basic parameters are listed in Table 1.

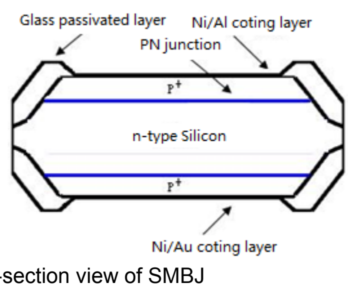


Fig. 2 The cross-section view of SMBJ

Table 1 the basic parameters of SMBJ series TVS chip

Size	Peak power /W	Steady state power /W	Leakage current /μA
2mm×2mm×0.3mm	600	5	<5

The equivalent circuit model of SMBJ series TVS chips under direct-current (DC) is shown in Fig. 3. The circuit is open under the condition that the reverse biased voltage of the SMBJ chips is lower than its breakdown voltage. However, when instantaneous voltage on the chip is higher than its breakdown voltage, the chip avalanches and forms an ultra-low-resistance current path. After the instantaneous pulse, the chip automatically returns to its high resistance state.

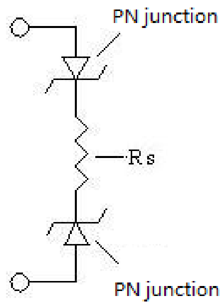


Fig. 3 Equivalent circuit schematics of SMBJ under DC

Under the circumstances of certain TVS chip size, a lower substrate doping concentration leads to a higher chip breakdown voltage, which results in the higher parasitic resistance and the lower PN junction capacitance. The affection of TVS parameters on SCB anti-electrostatic capability will be discussed later by experimental research.

1.2 Protection Principles

TVS chips are in parallel with SCB for electrostatic protection. When the voltage of SCB after series resistance dividing exceeds the breakdown voltage of TVS chip, then TVS forms a low-impedance open current path in nanosecond time, and SCB voltage clamps to a fixed value, so the electrostatic voltage is discharged by TVS chip to protect SCB from ESD. During the experiment, the breakdown voltage and current-path resistance formed from the breakdown of TVS chip both affect its anti-electrostatic capability.

Under the condition of capacitance discharge test, the TVS chips breakdown and shunt current when firing voltage of SCB is higher than TVS breakdown voltage, so the ignition time of SCB is delayed. On the contrary, TVS chips do no harm to the ignition performances of SCB.

2 Experiments and Discussion

2.1 Experimental samples

Three types of TVS chips, called *A*, *B* and *C,* are used for electro-exploding experiments and electrostatic tests. The breakdown voltage of each kind of chip is measured preliminarily in order to ensure the accuracy of the experimental results, which separately are 11.8V-12.3V (*TVS A*), 26.1V-27.5V (*TVS B*) and 88.7V-91.2V (*TVS C*). It must take into account the influence of different parameters of the three TVS chips on each experiment. In electrical explosive experiments, if the breakdown voltage of the chips is too low, it may lead to avalanche breakdown and shunt the firing current, which could possibly result in unreliable firing of SCB. But low breakdown voltage and low parasitic resistance can significantly enhance the anti-electrostatic capability of SCB against high voltage electrostatic.

After the type-selecting and the parameters-testing, stick those three kinds of TVS chips (*TVS A, B and C*) with insulating epoxy to the bottom of the SCB ceramic housing, and connect two electrodes of TVS chip and foot pins in the ceramic housing separately with silver paste. Then TVS and SCB chips form a parallel structure after stoving silver paste. Dip lead styphnate (LTNR) as primary explosive on the surface of SCB chip, where the outer diameter of ceramic housing is 4.7mm.

2.2 Experimental devices

Electrostatic discharge effect can be equivalently seen as the process of a capacitor that is charged to a certain voltage and discharges through a specified resistance between two feet wires of initiators, and ignition voltage or ignition rate is measured under specified conditions. Experimental principle circle is shown in Fig. 4.

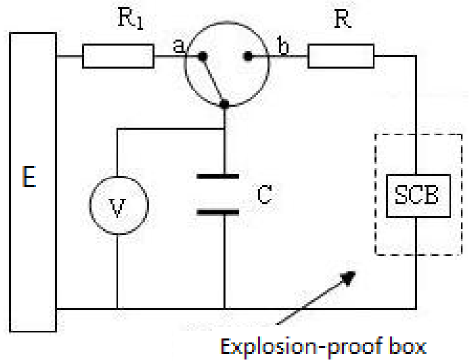


Fig. 4 Electrostatic experiments circle schematics
C- Storage capacitor, R_1- charging resistor, R- discharge resistor, V- electrostatic voltmeter, E-high voltage DC power supply, a b-switch contacts

In the experiment, the storage capacitor was charged through the charging resistor (R_1) by a high voltage DC source, and the voltage across the capacitor can be measured by an electrostatic voltmeter. After charging, the energy in the capacitor discharges to SCB initiators through the discharge resistor (R) by controlling the switch. The JGY-50 III type electrostatic sensitivity test instrument is used in this experiment, which is a tester for static sensitivity tests of explosives or EEDs and designed by 213 Research Institute of China Ordnance; the output voltage of this instrument is 200V to 35kV.

2.3 The experimental results and discussion

In order to verify the anti-electrostatic feasibility of TVS chip used for SCB and obtain the anti-electrostatic laws, the test conditions in U.S. Military Standards [7] are referenced. Two kinds of test conditions are selected, of which one is 500pF capacitor and 500Ω resistor, and the other is 500pF capacitor and 150Ω resistor. The damage conditions of SCB under ESD and the anti-electrostatic effect of TVS chip are researched by the electrostatic tests on SCB with and without LTNR.

2.3.1 The electrostatic tests of SCB without LTNR

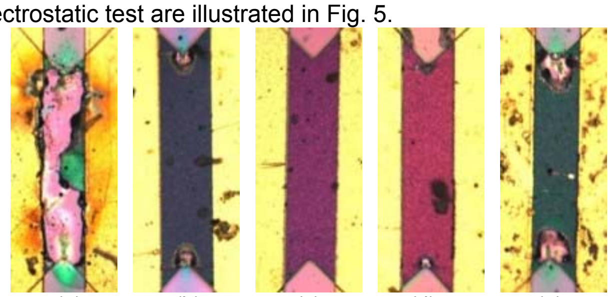
To study the effects of electrostatic conditions on SCB and provide basis for the later tests of SCB with LTNR, the spark-generating situation of SCB under different load voltages are observed and the resistance changes before and after test are recorded.

Experimental conditions: 500pF energy storage capacitor, 150Ω series resistance and adjustable electrostatic voltage. The results are shown in Tab. 2, where R_{be} is the resistance before test and R_{af} is the resistance after test.

Table 2 experimental results under different static voltage at 500 pF and 150 Ω

Type	No.	Voltage /kV	R_{be} /Ω	R_{af} /Ω	Phenomenon
SCB without protection	1	10	1.14	0.98	Spark
	2	10	1.14	1.00	Spark
	3	15	1.05	1.77	Spark
	4	25	1.09	3.21	Spark
SCB in parallel with TVS A	5	15	1.15	1.14	No spark
	6	20	1.14	1.12	No spark
	7	25	1.11	1.08	Spark
	8	25	1.14	1.07	Spark
	9	25	1.13	0.99	Spark
SCB in parallel with TVS B	10	25	1.15	1.40	Spark
	11	15	1.10	1.06	Spark
SCB in parallel with TVS C	12	15	1.15	1.34	Spark
	13	15	1.15	1.64	Spark
	14	15	1.05	1.53	Spark

Some photomicrographs of SCB bridge region after electrostatic test are illustrated in Fig. 5.



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

Fig.5 the damage situation of SCB bridge region under different test conditions

It can be seen from Fig. 5 that the bridge region without protection almost completely melts under the electrostatic test conditions of 25kV, 500pF and 150Ω (see in Fig. 5a). And only the V-type corners vaporize under 10kV electrostatic tests (see in Fig. 5b). However, there is no significant change in bridge region of SCB in parallel with *TVS A* under 20kV electrostatic voltage (Fig. 5c). When the electrostatic voltage is 15 kV, the damage situation of SCB in parallel with *TVS B* reduces significantly compared to the SCB without protection (Fig. 5d), while the bridge region of the SCB in parallel with *TVS C* vaporizes a lot (Fig. 5e), which means the *C* type TVS chip does not show any anti-electrostatic capability.

When series a 150Ω resistance in electrostatic discharge circuit, the electrostatic voltage ranges from 10 kV to 25 kV, and the voltage loaded onto SCB actually is from 67V to 167V. Under this situation, the *TVS A* and *TVS B* chip both can breakdown to form a low-impedance current path, and the resistance is determined by its parasitic resistance. According to Ohm's law, the one that has a lower parasitic resistance can divide more electrostatic current after breakdown, so the *TVS A* demonstrates stronger electrostatic protective capability.

2.3.2 The electrostatic tests of SCB with LTNR

Set the condition of LTNR combustion or explosion as firing standard of SCB initiators in the experiments. The four types samples, which are SCB initiators without protection and SCB initiators protected separately by three types of TVS chip, are tested under the electrostatic experimental conditions of *500pF 5000Ω* and *25kV* that required in the standard of GJB736.11-1990. And the test results are listed in Table 3.

Table 3 Electrostatic test results under 500pF 5000Ω 25kV

Type	Sample quantity	Firing quantity
SCB initiators	5	0
SCB+ *TVS A*	5	0
SCB+ TVS B	5	0
SCB+ TVS C	5	0

It can be easily seen from Tab. 3 that all the SCB initiators are not firing no matter with or without protection, which means SCB initiators have excellent antistatic capability in themselves.

As the above test conditions did not show any difference, the test conditions are changed to 500pF 500Ω (required in MIL-STD-331C). The samples are tested in various voltages, and the results are shown in Table 4.

As it shows in Table 4, all of the SCB initiators without protection fire or explode, and there is no significant protective effect of *TVS B* and *C* type TVS chips. However, the SCB initiators with the protection of *A* type TVS chip did not show any sign of firing under several times test at 25kV or 30kV, where 30kV is the maximum output voltage of experimental equipment. And at the test condition of 25kV, the voltage loaded onto SCB is about 50V, which means the *A* type TVS chip plays a good performance in shunting current.

In order to investigate the breakdown and shunt effects of those three types TVS chips, the series resistance in the electrostatic equipment is adjusted to 150Ω, so the voltage loaded onto SCB increases. The test results under different electrostatic voltages are listed in Table 5.

As it shows in Table 5 that all of the SCB initiators without protection and the SCB initiators in parallel with *TVS C* fire at 11kV electrostatic voltage; parts of the SCB initiators in parallel with *TVS B* fire, and none of the SCB initiators in parallel with *TVS A* fires even at 22kV. It means *TVS A* can effectively improve SCB antistatic capability, while a weak protection effect of *TVS B* and barely any effect of *TVS C* for SCB electrostatic protection. Because of low resistance of SCB, the parasitic resistance will be the most important factor for electrostatic protective capability when static voltage exceeds breakdown voltage of TVS. Therefore, the TVS chip with low breakdown voltage and low parasitic resistance should be chosen for SCB electrostatic protection on the condition of doing no harm to SCB initiators firing performances.

Table. 4 test results under different static voltages at 500 pF 500 Ω

Type	No.	Voltage /kV	R_1 /Ω	R_2 /Ω	Firing	Phenomenon
SCB	1	25	1.04	1.03	1	Burning
	2	25	1.10	1.25	1	Explosion
	3	25	1.10	2.53	1	Explosion
SCB in parallel with TVS A	4	25	1.07	1.06	0	(Continuous test five times)
	5	30	1.07	1.07	0	(Continuous test five times)
	6	30	1.03	1.03	0	(Continuous test five times)
SCB in parallel with TVS B	7	25	1.05	1.06	1	Explosion
	8	25	1.04	1.06	0	
	9	30	1.03	1.15	1	Explosion
SCB in parallel with TVS C	10	25	1.10	1.76	0/1	Firing at fourth test

Note: 0-no fire, 1-fire

Table 5 test results under different static voltages at 500 pF 150 Ω

Type	No.	Voltage/kV	R1 /Ω	R2 /Ω	Firing
SCB Without protection	1	11	1.10	1.07	1
	2	11	1.09	1.02	1
	3	11	1.08	0.98	1
	4	11	1.08	0.99	1
	5	11	1.01	0.60	1
SCB in parallel with TVS A	6	25	1.08	1.00	1
	7	22	1.06	1.00	0
	8	22	1.09	1.01	0
	9	22	1.03	1.00	0
	10	22	1.08	1.05	0
	11	22	1.11	1.08	0
SCB in parallel with TVS B	12	15	1.13	1.11	0
	13	15	1.13	1.04	1
	14	11	1.07	1.06	0
	15	11	1.11	1.09	0
	16	11	1.14	1.06	1
	17	11	1.07	1.07	0
SCB in parallel with TVS C	18	11	1.06	0.98	1
	19	11	1.10	0.69	1

4 Conclusions

In this paper, the impacts of TVS performance parameters on SCB electrostatic protection are studied by electrostatic sensitivity tests and the conclusions are as follows:

(1) SCB itself has a good insensitive characteristic against electrostatic inherently. SCB initiators do not fire under the test conditions of 500pF 5000Ω and 25kV, however, when the resistance is changed to 500Ω or 150Ω, all of the SCB initiators fire.

(2) The photomicrographs of SCB without LTNR after electrostatic test illustrate that *A* type TVS chips can significantly protect SCB against electrostatic.

(3) As SMBJ series TVS chips are used for SCB electrostatic protection, the *A* type TVS chip can improve antistatic capability of SCB significantly due to its low breakdown voltage and low parasitic resistance, while the *TVS B* type has a weak effect and the *C* type TVS barely shows any protective effect. So breakdown voltage and parasitic resistance of TVS chip are the most important factors. The lower the breakdown voltage and the lower the parasitic resistance are, the greater anti-electrostatic capability is.

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