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Effect of V-type Angle and Hole of Semiconductor Bridge on Electro-explosive Performance

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Abstract: Fourteen kinds of SCBs with V-type angle and hole were designed, and the electro-explosive performances including the function time, energy required were investigated with firing by capacitor discharge circuit. The plasma firing mechanism of SCB was analyzed. Results indicate that the function time and the energy required decrease significantly for SCB firing with the V-type angle on the SCB decreasing, while the holes have a little effect on the explosive performance of SCB.

Key words: applied chemistry; igniting device; semiconductor bridge; function time; firing energy required

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1 Introduction

The Semiconductor bridge (SCB) igniting device is a new means for ignition using a heavily doped polysilicon bridge[1]. Subjected to a low-energy current pulse, the bridge bursts into a plasma which causes rapid ignition of the explosive material pressed against the bridge. The SCB devices require significantly less energy than the hot-wire component. However, to meet the requirement on the miniaturized igniting device, reducing the firing energy of the SCB further is necessary. The critical firing energy of the SCB is an important index for the SCB igniting device. It is thus very important to reduce the critical firing energy and the voltage, which may help to achieve ingenious, miniaturized and intelligent igniting devices. The critical firing energy of the SCB igniting device is mainly related to the characteristics of explosive and the geometrical parameters of the SCB. When the same explosive is used, the effect on function time and firing energy of the SCB igniting device is mainly due to its structure[2-3], including the length, width, thickness and geometry etc. C. B. McCampbell discussed the energy required for SCBs with different bridge areas. The results showed that the ignition energy was a function of bridge areas. The smaller the bridge area was, the lower ignition energy was required[4]. Zhu Feng-chun analyzed theoretically the affection of bridge geometry including V-angle on critical firing energy[2]. In this paper, the affections of V-type angles and holes on the electro-explosive performance of SCB were investigated.

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2 Design of SCB Chip

The micro-convection firing mechanism is used to explain the firing of the SCB. When voltage pulse is applied on SCB for a few microseconds duration, heat is generated internally by passing current which in turn changes the electrical features of the bridge. The bridge begins to melt into molten silicon channels which produce a weakly ionized vapor of silicon above the bridge. Melting and vaporization of the bridge are a consequence of Joule heating and the inverse skin effect produced by an uneven high current density distribution. As the pulse continues, the entire silicon bridge region between the aluminum lands is vaporized and bursts into a hot plasma (4100 K ~ 6000 K) that ignites the explosive material pressed against the SCB devices[5-6].

The bridge geometry influences the current density distribution on the bridge, and a higher current density region has a higher temperature. If the bridge is designed with angles and holes, that can make the current density higher on the angles and holes region. The temperature of bridge rises when the current flows through it. The regions near angles and holes have higher temperature than others do, and may produce plasma firstly. That will contribute to the reduction of the function time and firing energy.

Based on this point, 14 kinds of SCBs($D_1 - D_{14}$) with different geometry were designed including different cutting angles, holes aperture and the hole amounts(see Table 1).

The difference among D_1, D_2 and D_3 was the angles. That was same among D_4, D_5 and D_6, but height among them was bigger than D_1, D_2 and D_3. The aperture of the holes in the center of SCB was different among D_7, D_8 and D_9. The difference among D_{11}, D_{12}, D_{13} and D_{14} was the numbers of angles and holes. 14 kinds prototypes of SCBs were presented in Fig. 1.

Semiconductor bridge chip D_8 was shown in Fig. 2 as an example. The width (W) is determined by the shape of the doped silicon region. The length (L) of the bridge is determined by the two metal lands. The length for SCB sample was 100 μm, and the width was 400 μm .

The SCB was packaged with a ceramic header. The chips were stuck on the flute with epoxy resin between the pins of ceramics-plug, and the aluminum wires were bonded to the lands and the posts of an explosive header that supported the SCB chip.

Table 1 Parameters of 14 kinds of SCBs

SCB type	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9	D_{10}	D_{11}	D_{12}	D_{13}	D_{14}
d/μm	10	10	10	20	20	20	20	20	20	30	20	20	20	20
α/(°)	60	90	120	120	90	60	90	90	90	90	90	90	90	90
m	1	1	1	1	1	1	1	1	1	1	1	3	2	2
φ	/	/	/	/	/	/	8.2	10	12	/	10	10	10	10
n	/	/	/	/	/	/	1	1	1	/	2	1	1	2

Note: d is the angle height, α is the angle degree, m is the amount of angle, φ is the aperture and n is the amount of aperture.

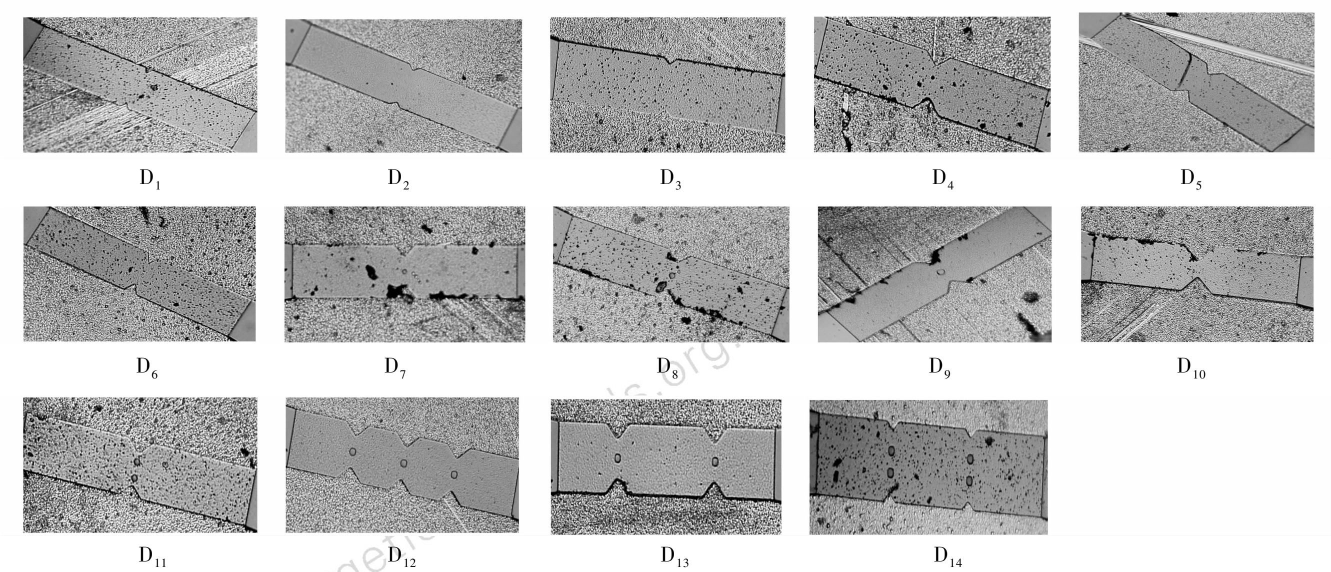

Fig. 1 The geometry of 14 kinds of SCBs

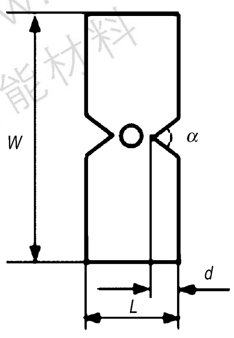

Fig. 2 Sketch map of SCB chip D_8

3 Experimental

In experimental the capacitive discharge was adopted as the SCB firing mode to acquire electrical parameters of the SCB. Experimental circuit was shown in Fig. 3. The test system included a capacitance, constant-voltage source, digital oscilloscope etc. The tantalum capacitance was used as battery charging capacitance. Leakage current of tantalum capacitance is very small, and its internal resistance is small and the discharging is fast, which meets the firing requirements of SCB ignition device. In the ignition process, the fluctuant curve following time of voltage and current on both SCB sides was recorded by digital oscilloscope. Function time of the devices was obtained by measuring the time interval between the start of the firing pulse and the light output corresponding to the time that SCB plasma produced[7]. The energy requirement of SCB ignition came from the integral of power with time. The typical voltage and current curves were shown in Fig. 4.

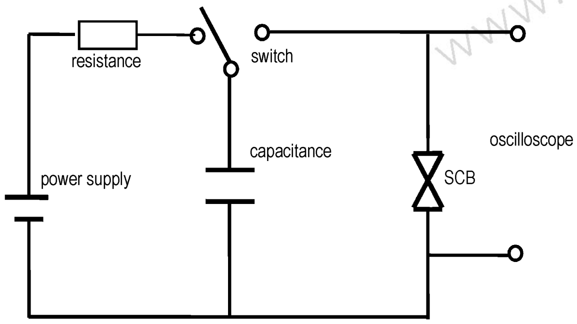

Fig. 3　Diagram of the firing and testing circuit

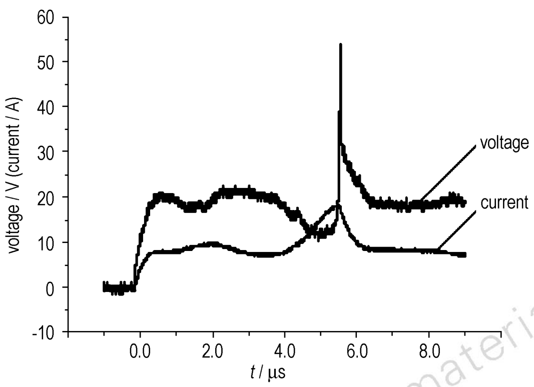

Fig. 4　Curves of voltage and current of SCB

4　Results and discussion

It is well known that both the function time and required of firing energy are important parameters of SCB. Under the uniform capacitor and voltage, the performances of the SCB with different figures were measured. In case of 22 μF tantalum capacitor and 50 V charging voltage, the function time and the energy required of 14 kinds of SCBs measured and listed in Table 2.

The performances of SCBs with different angles, holes and hole numbers were compared in Table 3 – 5 at 22 μF and 50 V.

Table 2　Function time and the firing energy required under the condition of 22 μF, 50 V

type	amount of experiment	function time / μs	σ_t / μs	energy required of SCB firing / mJ	σ_E / mJ
D_1	5	2.73	0.10	1.89	0.05
D_2	5	2.53	0.05	1.65	0.05
D_3	5	2.64	0.07	1.75	0.03
D_4	5	2.59	0.06	1.70	0.04
D_5	5	2.55	0.08	1.68	0.03
D_6	5	2.71	0.06	1.81	0.07
D_7	5	2.61	0.12	1.75	0.09
D_8	5	2.65	0.04	1.78	0.02
D_9	5	2.60	0.06	1.75	0.04
D_{10}	5	2.34	0.03	1.63	0.05
D_{11}	5	2.63	0.06	1.85	0.05
D_{12}	5	1.95	0.04	1.33	0.03
D_{13}	5	2.16	0.02	1.52	0.05
D_{14}	5	2.41	0.04	1.59	0.04

Note: σ_t is the standard deviation of function time, σ_E is the standard deviation of energy required SCB firing.

In Table 3, when the "V" font angle of both sides of SCB is 90°, the function time of SCB and the energy required are smaller than those of 60° and 120° angles. The effects of holes and apertures on the firing performance were shown in Table 4. Obviously, with a certain number of angles, the aperture of the holes have little effect on the function time and the energy required. But the function time and the firing energy required obviously decrease with the increase of the number of angles, indicating the angle has more affection on explosive performance of SCBs than the holes. Furthermore, the number of angles is more effective than the amount of holes in SCB on the function time of SCB and the energy required (see in Table 5).

Based on the results, the function time and the energy required decrease with the increase of the height and number of angles. The reason is likely to be that the resistance in the angle region is small, and the current through the region is thus large. In the region, temperature rises rapidly and the velocity of gasification forming the plasma is also fast. As a result, while the angle is deeper and the number of angles is more, the function time and the energy required decrease significantly.

Table 3 Effect of angle height and angle of SCB on explosive performance

α/(°)	d/μm		
	10	20	30
60	D_1(2.73,1.89)	D_6(2.71,1.81)	
90	D_2(2.53,1.65)	D_5(2.55,1.68)	D_{10}(2.34,1.63)
120	D_3(2.64,1.75)	D_4(2.59,1.70)	

Note: the left data in the brackets are the function times, μs;
the right data are the energies required of SCB firing, mJ.

Table 4 Effect of the amount of the angle and the aperture of the hole on explosive performance

φ	m		
	1	2	3
0	D_5(2.55,1.68)		
8.2	D_7(2.61,1.75)		
10	D_8(2.65,1.78)	D_{13}(2.16,1.52)	D_{12}(1.95,1.33)
12	D_9(2.60,1.75)		

Table 5 Effect of the amount of the angle and the amount of the hole on explosive performance

N	m		
	1	2	3
1	D_8(2.65,1.78)	D_{13}(2.16,1.52)	D_{12}(1.95,1.33)
2	D_9(2.63,1.85)	D_{14}(2.41,1.59)	

5 Conclusions

The SCBs with different geometry were fabricated and measured. The conclusions were as below:

(1) The function time and the firing energy required for the SCB with the angle of 90° in the middle of the bridge are smaller than those with 60° and 120° angles.

(2) Increasing the angle height reduces the function time and the firing energy required.

(3) The function time of SCB and the firing energy required obviously decrease with increase of the number of angles, which is more effective than the amount of holes on SCB.

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半导体桥上尖角、圆孔对其电爆性能的影响

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摘要: 设计了 14 种带有尖角和圆孔的半导体桥,研究了在电容放电发火条件下尖角、圆孔对其发火时间、发火所消耗的能量等性能参数的影响规律,并从半导体桥的作用机理方面对实验结果进行了分析。结果表明,SCB 上 V 型尖角使得 SCB 发火时间和发火所消耗的能量明显降低,而圆孔对 SCB 发火性能影响不明显。

关键词: 应用化学; 火工品; 半导体桥; 发火时间; 发火消耗能量
中图分类号: TJ450.2; TN402; O69 **文献标识码:** A