Research paper

Effect of semiconductor bridge shape and size on the ignition process in Al/CuO energetic initiator

Xiaowei Fan*, Jupeng Liu**, Yong Li***, Bin Zhou*†, and Jun Wang*

*School of Chemical Engineering, Nanjing University of Science and Technology, Nanjing 210094, CHINA
Phone: +86−18061601916
†Corresponding author: zhoubinnust@126.com

**North Special Energy Group Co., LTD, Xi'an 710061, CHINA

***Institute of Chemical Materials, China Academy of Engineering Physics, Mianyang 621900, CHINA

Received: August 14, 2017 Accepted: March 14, 2018

Abstract

In order to explore the effect of semiconductor bridge shape and size on the performance of Al/CuO energetic initiators, two shapes and two sizes of bridges were designed and studied during capacitor discharge. The results show that there is a delay between the V-angle and other parts of the V-shaped bridge. Both V-shaped and miniaturization designs were capable to accelerate the process and reduce the required function energy. However, when initiating explosive was coated on the initiators, the ignition time of explosive on initiators with V angles but different sizes is quite close .

Keywords:semiconductor bridges, energetic initiator, bridge shape, Al/CuO films

1. Introduction

Semiconductor bridges (SCBs) are important devices that are often used to ignite explosions. It is paramount that they meet high safety and reliability standards while requiring little energy to operate[1]. SCBs are increasingly uses in military and commercial applications. Unfortunately, the ignition process becomes less reliable when insensitive explosives need to be used or there is a gap between the SCB chips and explosives where high output energy is needed[2]. This limitation represents a serious limitation for the practical application of SCBs.

An energetic initiator consists of plated nano-energetic multilayer films (nEMFs) on a polysilicon bridge[3] to improve the SCB ignition performance. A self-propagating exothermic reaction takes place in nEMFs, where a large amount of heat is released after triggering through external heat or other types of energetic stimulation[4), 5)]. Among these nEMFs systems, Al/CuO films have been studied predominantly in recent years for its easily being ignited and high exothermic reaction[6)−9)].

Some research has been done on traditional polysilicon SCB chips with different bridge shapes and sizes. It was found that a V-shaped bridge design can reduce both input energy and function time. The design is most effective if a 90° angle is used[10]. Both function time and energy consumption decrease when the length-width ratio increases[11]. It is also known that a large bridge requires more energy to melt[12]. However, there are no studies focusing on the effect of shape and size in energetic initiators.

In this paper, Al/CuO energetic initiators with two different shapes (V shape and rectangle) and two different sizes of bridges were used to study how bridge shapes and sizes affect the ignition. When there was no explosive, the product condition was recorded, and voltage and current curves were plotted to find any changes. When an explosive was deposited, some tests were done to compare feature time, energy, and ignition time.

2. Experimental

2.1 Fabrication of the bridge

To explore the effect of bridge shapes and sizes, bridges with two different shapes and two sizes were designed and tested. These shapes are shown in Figure 1 and the parameters for each bridge are shown in Table 1.

The Al/CuO energetic initiators is shown in Figure 2.

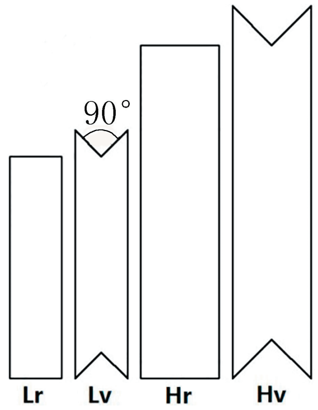

Figure 1 Shapes of four different energetic bridges.

Table 1 Parameters for the investigated bridges.

Sample	Shapes	Wide [μm]	Length [μm]	Length-Width ratio	Thickness [μm]
Lr	rectangle	350	100	3.5	2
Lv	V-shape	400	100	4	2
Hr	rectangle	500	143	3.5	2
Hv	V-shape	572	143	4	2

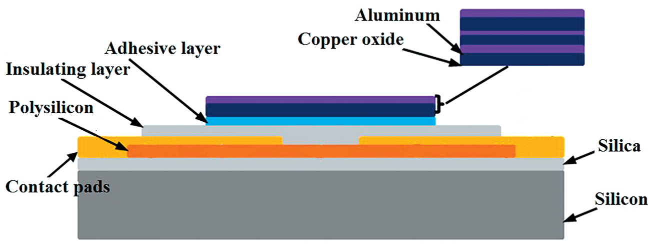

Figure 2 Structure of an energetic Al/CuO-SCB.

An insulating layer was deposited on a conventional polysilicon bridge to prevent the electric current from passing through the Al/CuO layers and modify the ignition properties. Using an adhesive layer, a stack of Al and CuO films was plated on top of the insulating layer by depositing layers of copper oxide and aluminum.

We placed the Al/CuO energetic initiators into ceramic plugs (ϕ 6.1 mm) with foot wires. This was done using the following procedure: The chips were pasted in the notch using epoxy. The foot wires were connected with contact pads using bonding wire and ultrasonic bonding technology. Some conductive adhesive was used to cover and protect the wires.

2.2 Test setup

The booting energy is supplied by a capacitor discharge unit (CDU) with a resolution of 0.1V. The voltage and current variations during operation were recorded using an oscilloscope. A synchronous triggering device ensured the ultra-high-speed camera operates correctly to record the firing process of the initiator. The phototube received an optical signal and sends a reversal signal if the initiators are active. A circuit diagram of the test setup is shown in Figure 3.

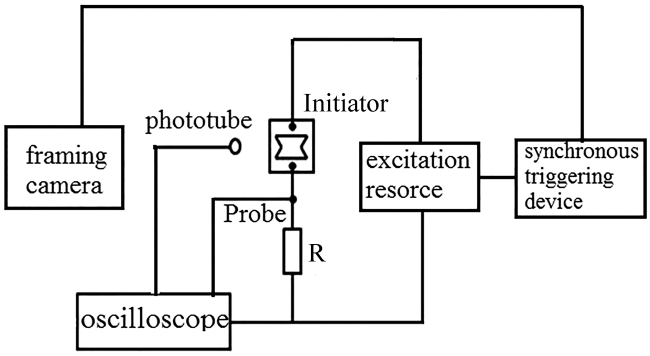

Figure 3 Circuit diagram of the test setup.

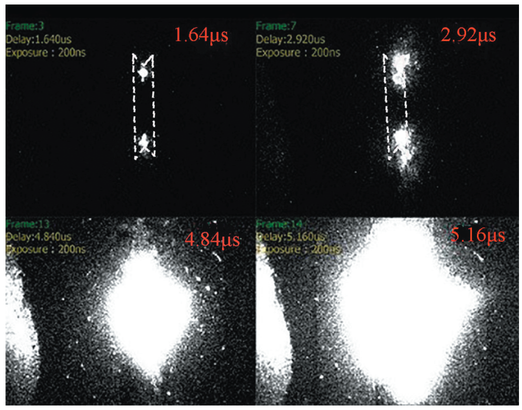

Figure 4 The transformation process in the Lv initiator for 47 μF 30V discharge.

3. Result and discussion

The transformation of a Lv initiator for a 47 μF 30V CDU discharge was recorded by an ultra-high-speed camera and is shown in Figure 4. In the figure, the shape of the bridge is marked by white dotted lines. Filming time is shown at the upper right corner. Melting begins at the two V-angles of polysilicon bridge (1.64 μs) first before proceeding to other parts (2.92 μs). After the bridge had melted completely it began to gasify (4.84 μs). It then produced a bright plasma-discharge to detonate the Al/CuO film (5.16 μs). The burning process of Al/CuO film could last more than 100 μs.

The transformation process in a Lr initiator during a 47 μF 30V CDU discharge is shown in Figure 5. The process begins at one of the angles of polysilicon bridge (at the bottom right corner in the figure) at 5.16 μs and continues along the right-angle sides (5.48 μs). The bridge film bursts into a plasma before detonating the thermite film (5.80 μs).

The difference between the two types of bridges are the electric current clusters at the V-shaped corners. This produces a higher joule heat-generating rate, which generates a higher temperature and a more pronounced thermal gradient. The V-angle become active earlier than other parts. The current is distributed evenly at the rectangle-shaped bridge with no variation near the edges of the bridge. The bridges operate starting from the edge where the thermal gradient is higher.

Data for Lv and Lr initiators during a 47 μF 30 V discharge are shown in Figure 6. Note that the first voltage peak of Lv separates into two sections. Because ultra-high-speed photography reveals that the V-shaped

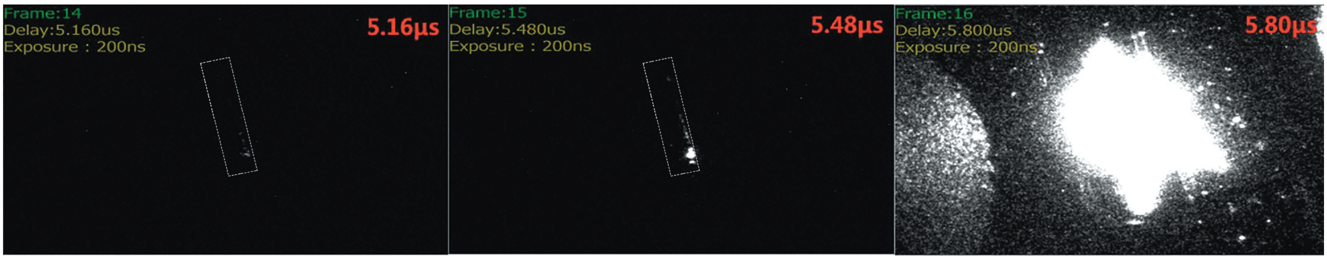

Figure 5 The transformation process in the Lr initiator for 47 μF 30V discharge.

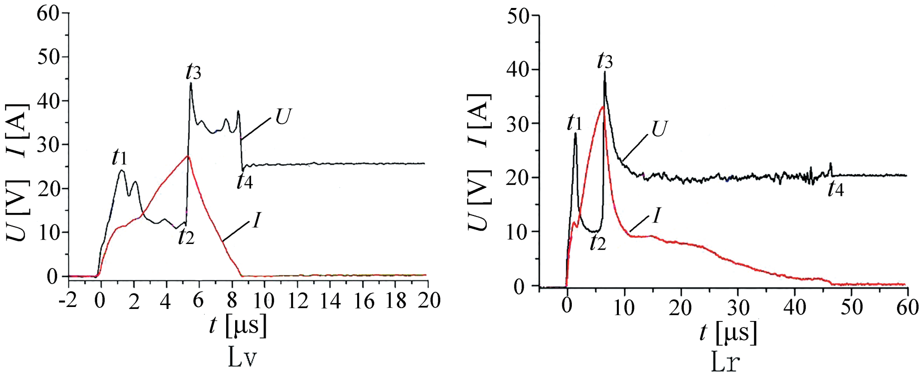

Figure 6 Electrical characteristics of the Lv and Lr initiators for 47 μF 30V discharge.

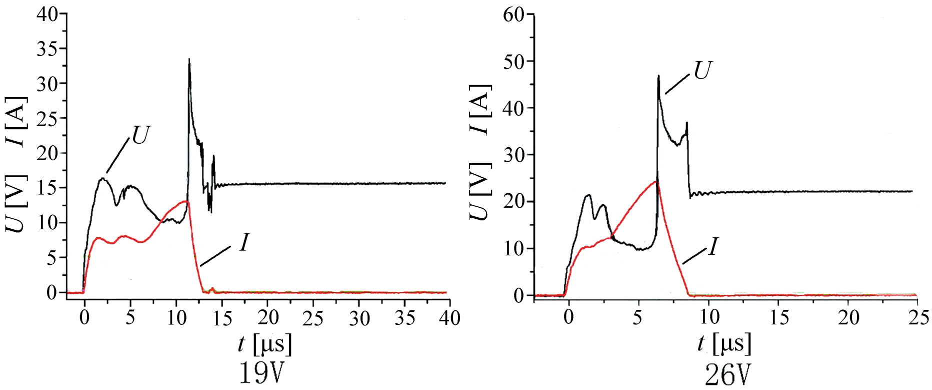

Figure 7 Electrical characteristics of the Lv initiators for 19V and 26V discharge.

angle functions faster, we think it is the function delay for different regions that produces separated peaks.

Another two tests of Lv initiators during a 47 μF capacitor charged to 19 V and 26 V, respectively, were performed to see whether the observed separation of peaks is a special case. The obtained curves are shown in Figure 7. The separation of peaks becomes more pronounced with decreasing CDU voltage, which confirms our conclusion.

In practical application, initiating explosive is coated on the initiator to detonate subsequent charge. Tests were performed to measure the feature time and homologous integral energy of four kinds of initiators with lead styphnate (LTNR) coated. The firing set for a 47 μF tantalum capacitor charged to 22 V. The results are shown in Figure 8. The values in the curve are the average value of several samples.

t_1, t_2, t_3, and t_4 are intrinsic excitation time, melting time, explosion time, and function time, obtained from the electrical characteristics; t_{fire} is the ignition time of LTNR getting from the phototube; E_1, E_2, E_3 and E_4 are the integral energies corresponding to feature time.

Note that the ignition feature time increase with increasing size, as well as the integral energy; and the time and homologous integral energy of the V-type bridges is smaller than that of the rectangle type bridge with identical size.

The feature time and homologous integral energy of the Hv initiators are larger than that of Lr and Lv, while the ignition time of the Hv initiator is at 26.3 μs. This is a much earlier time than for Lr (36.1 μs) and Hr (39.1 μs), and close to Lv (26.6 μs). This is because the V-angle of the Hv bridge activates first and the explosion product is capable to ignite the LTNR. Although the bridge was not fully activated, LTNR ignited.

4. Conclusion

From the ultra-high-speed photography we find that the V-angle of V-shaped bridges functions before other parts do, and rectangle-shaped bridges become active starting from one of the right angles. Due to the activation interval of the V-type bridge, the first peak of the voltage curve divides into two peaks during CDU discharge.

With LTNR coated, the increasing size increases both

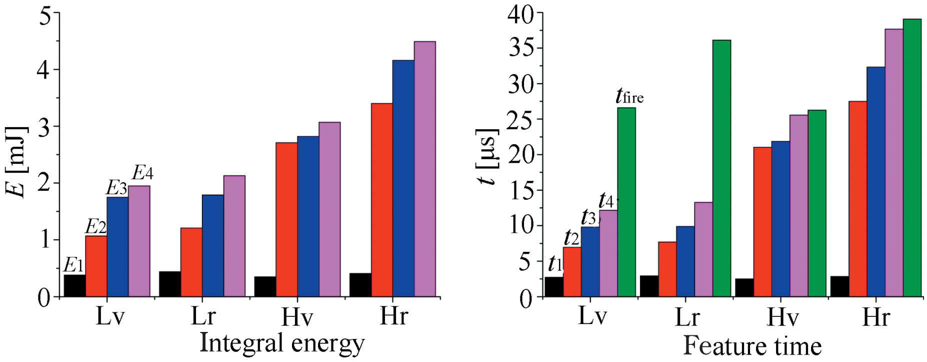

Figure 8 Feature time and energy of energetic initiators for 47 μF22V discharge.

the feature time and energy. The Hv initiator is unusual for its longer feature time but similar ignition time with Lv initiator due to the earlier function of the V angle.

In conclusion, we found that V-shaped bridges can accelerate functioning and reduce energy consumption. Feature time and homologous energy are also positively correlated with bridge size.

References

1) R. W. Bickes and C. Alfred, US Patent 4708060 (1987).
2) T. A. Baginski, T. S. Parker, and D. W. M. Fahey, EP Patent 1315941 (2006).
3) P. Zhu, R. Shen, Y. Ye, S. Fu, and D. Li, J. Appl. Phys., 113, 184505 (2013).
4) A. S. Rogachev and A. S. Mukasyan, Combust. Explos. Shock Waves, 46, 243–266 (2010).
5) A. S. Shteinberg, J. Therm. Anal. Calorim., 106, 39–46 (2011).
6) M. Petrantoni, C. Rossi, L. Salvagnac, V. Conedera, A. Esteve, C. Tenailleau, P. Alphonse, and Y. J. Chabal, J. Appl. Phys., 108, 084323 (2010).
7) X. Zhou, R. Shen, Y. Ye, P. Zhu, Y. Hu, and L. Wu, J. Appl. Phys., 110, 094505 (2011).
8) K. Zhang, C. Rossi, and G. A. Rodriguez, Appl. Phys. Lett., 91, 113–117(2007).
9) K. Zhang, C. Rossi, M. Petrantoni, and N. Mauran, J. Microelectromech. Syst., 17, 832–836 (2008).
10) B. Zhou, Z. Qin, and G. Mao, Chin. J. Energ. Mater., 17, 349 – 352(2009). (in Chinese).
11) B. Zhou, Z. Qin, and G. Mao. J. Nanjing Univ. Sci. Technol., 33, 235–237 (2009). (in Chinese).
12) M. Liu and X. Zhang, J. Ballist., 22, 70–74 (2010). (in Chinese).