Research paper

Research on mechanism of energetic igniter under constant current excitation

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Abstract

The process of action and energy conversion mechanism of Al/CuO-SCB (Semiconductor Bridge) energetic igniter under constant excitation was analyzed by experiments. The results showed that the heat generated by the polysilicon film would continuously transfer to the upper Al/CuO composite film when the polysilicon film was given a low amplitude and long pulse width current. The heat generated by the polysilicon film can promote the chemical reaction of Al/CuO film and the polysilicon film would get a heat feedback from the chemical reaction which accelerates the function of Al/CuO-SCB energetic igniter.

Keywords: energetic ignite, energy conversion mechanism, semiconductor bridge

1. Introduction

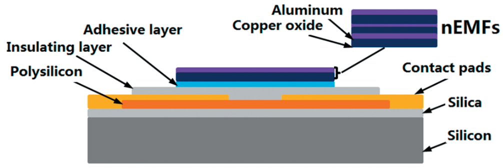
Compared to the existing bridge wire initiators, SCB (Semiconductor Bridge) gradually reflected its large-scale application due to its high no-fire level and low initiation energy. SCB initiator can meet the requirements both in security and reliability[1]. However, limited by the excitation energy and quality of the bridge district, the SCB may fail to function when ignite insensitive igniting powder or there exists a gap between semiconductor bridge and igniting powder[2]. So energetic igniter is designed to improve the output energy of SCB initiator. The energetic igniter designed to solve SCB output performance is a new igniter which is fabricated on the basis of the polycrystalline silicon ignition chip deposited multilayer energetic nano-materials composite film by sputtering technology[3]. Energetic nano-materials composite film is an energetic material with new structure. It is fabricated by two or more reactive materials which is deposited with a certain thickness, periodic and alternating process. It could start self-sustaining chemical reaction and release a large amount of heat by outside stimulations such as heat or electricity[4),5]. Therefore, the exothermic chemical reaction of composite film improved the output performance of igniter. After plenty of experiments, researchers study the exploding progress, variety of electric characteristic parameters and ignition performance on energetic igniter under capacitance discharge excitation, the results showed that the output performance has been improved significantly after added Al/CuO composite film compared to polysilicon igniter[6]. However, the process of action and energy conversion mechanism between polysilicon film and Al/CuO composite film under constant excitation have not been reported in public. Therefore, the process of action and energy conversion mechanism of energetic igniter under constant excitation is researched by experiment in the paper.

2. Experiment

2.1 Sample and setup

Polysilicon ignition chip and energetic igniter chip designed is shown in Figure 1. Based on the polysilicon ignition chip, a layer of insulation is covered above the bridge district and electrode layer to prevent the input current flowing through the Al/CuO composite film which may affect the process of energy conversion on polycrystalline silicon thin film and copper oxide and aluminum are also deposited alternately. The insulating

a. Polysilicon igniter chip



b. Energetic igniter chip

Figure 1 Schematic of igniter chip.

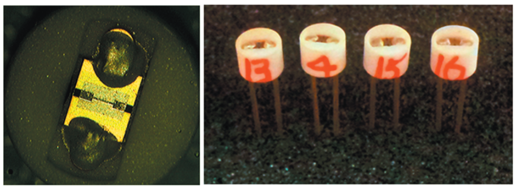


Figure 2 Appearance of completed package device.

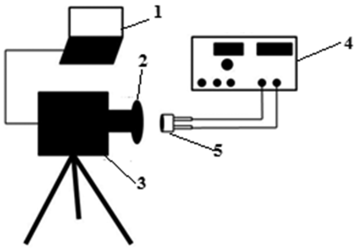


Figure 3 Schematic diagram of temperature measuring experimental setup.
1-Processor, 2-Llens, 3-Infrared microscopic thermographer, 4-Constant current source, 5-SCB initiator

layer can limit the current to flow between polysilicon and electrode only and prevent the heat transfer to some extent to ensure that there is no influence on the safety of igniter when the composite film is added.

The ignition chips (polysilicon ignition chip and energetic igniter chip) is packaged into ceramic plug equipped with pins and the external diameter of ceramic plug is 6.1 mm. Packaging process is presented roughly as follows: The chip is placed into ceramic plug recess with the epoxy resin, then connect the chip electrode with the ceramic plug pins by bonding wires after curing in the oven and cover the bonding wires with conductive plastic. The appearance of the completed package is shown in Figure 2.

The samples were tested in 5 min constant current of 1 A, 1.1 A and 1.3 A provided by constant current source (ALG-HL-15A) excitation. The infrared thermal imager (A 40-M) display was used for recording the infrared radiation energy density distribution in real-time and the temperature calculated through ThermaCAM Researcher software in the computer while provide 5 min constant current to SCB igniter. A schematic diagram of experimental setup is shown in Figure 3.

2.2 Experimental phenomenon and results

2.2.1 The polysilicon igniter

The surface change progress under constant current excitation of polycrystalline silicon film was analyzed before examining the action progress of composite film. Figure 4 is the infrared thermogram of polysilicon ignition chip on the condition of 1.1A -5 min. The electrode on the left side of bridge has changed at 186 s. The region of variation has been further expanded at 194 s and the electrode of another side began rippling to other regions. The bridge district was covered by melting metal electrode at 202 s and bridge district was completely covered at 266 s.

Micrographs of chip surface and resistance change before and after the experiment are shown in Figure 5 and Table 1. Ignition chip surface was almost unchanged shown in Figure 5 (b) and the resistance increased slightly from 1.08 Ω to 1.12 Ω after 1A -5 min. The trace of metal melting appeared on the electrodes on both sides of bridge which is shown in Figure 5 (c) and resistance was reduced from 1.10 Ω to 0.374 Ω after 1.1A -5 min. Electrode portion on chip surface was damaged seriously and there was no visually recognizable damage on the bridge which is shown in Figure 5 (d) but the resistance was reduced from 1.07 Ω to 0.138 Ω after 1.3A -5 min. The damaged area of the electrode portion was growing and the resistance of

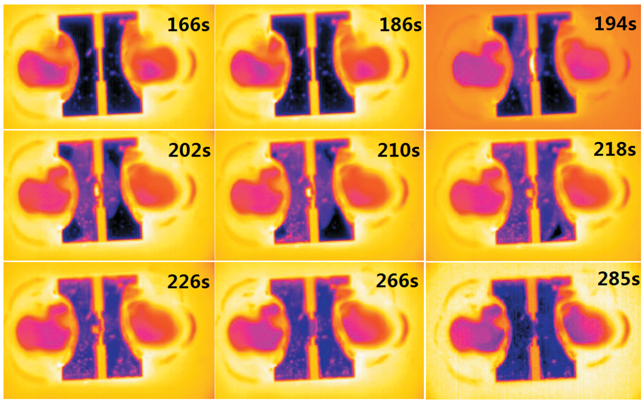


Figure 4 Infrared thermal image of polysilicon ignition chip.

Table 1 Experimental condition and resistance change.

Samples	constant current [A]	Resistance before experiment [Ω]	Resistance after experiment [Ω]
Polysilicon igniter	1.0	1.08	1.12
	1.1	1.10	0.374
	1.3	1.07	0.138
Energetic igniter	1.0	1.06	1.12
	1.3	1.08	1.28k

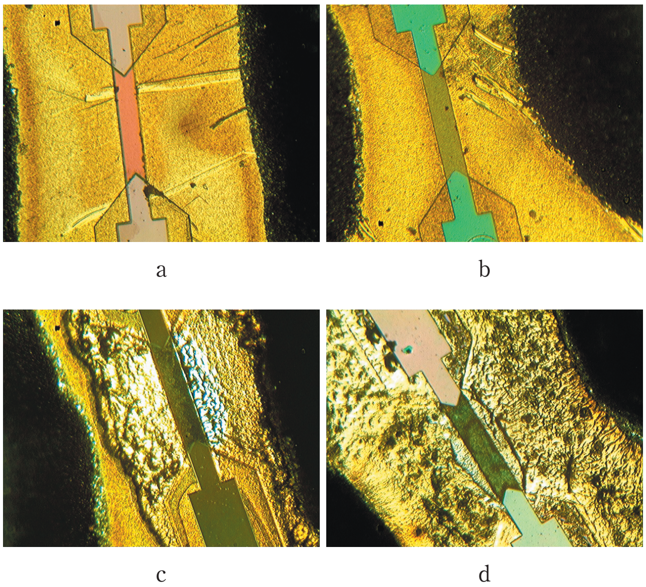


Figure 5 Micrograph of chip surface before and after the experiment.
a. before the experiment
b. after 1A -5 min experiment
c. after 1.1A -5 min experiment
d. after 1.3A -5 min experiment

chip was getting lower as the excitation current increased. This indicates that the polysilicon has reached its intrinsic temperature (800 K) but has not been fused.

2.2.2 Energetic ignition

The time profile of Infrared Thermogram of energetic ignition chip under 1.3A -5 min is shown in Figure 6. The shape of polysilicon bridge was visible and its thermal image had passed through composite film at 74 s. The right-side electrode of composite film corrugated at 80 s. Electrodes on both sides of composite film changed and the area of composite film above polysilicon area becomes larger at 98 s. The change on composite film was impelled to all the film in arcuate way which was obviously seen at 125 s and expanded to the whole composite film at 128 s. Cracks appeared on composite film at 147 s and the temperature decreased at 171 s.

Micrographs of chip surface and resistance change before and after the experiment are shown in Figure 7 and Table 1. There was no significant change on chip surface which is shown in Figure 7 (b) and the resistance increased slightly from 1.06 Ω to 1.12 Ω after 1A -5 min.

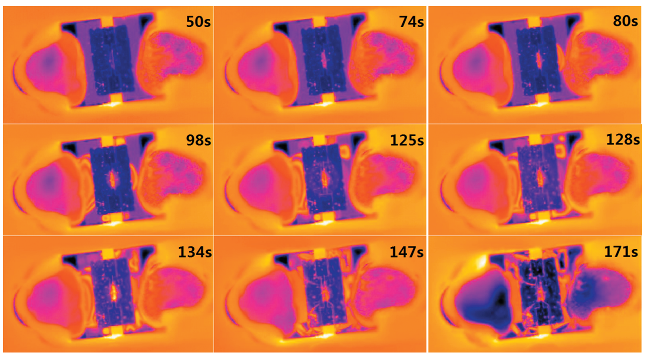


Figure 6 Infrared thermography of energetic ignition chip.

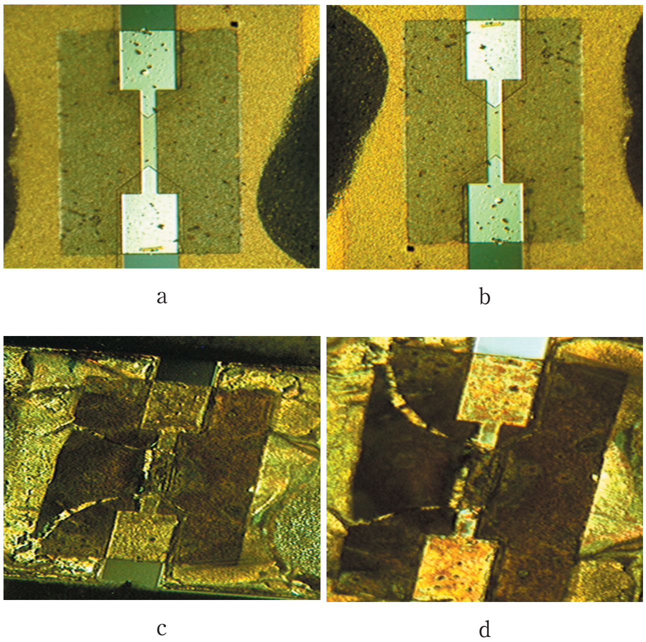


Figure 7 Micrograph of chip surface before and after the experiment.
a. before the experiment
b. after 1 A -5 min experiment
c. the whole chip after 1.3 A -5 min experiment
d. partial enlarged drawing

The color of the composite film was changed from metallic gray into black-yellow and the left part was broken into 3 pieces and there were obvious traces of ablation on composite film which is shown in Figure 7 (c), (d) after 1.3A -5 min. The resistance increased from 1.08 Ω to 1.28 kΩ. This indicated that the polysilicon has been fused.

3. Analysis and discuss

According to the experiment above: the poly-silicon film (melting point 1680 K) can continuously generate heat accumulation because of Joule effect when applied a lower amplitude and longer pulse width current. A part of heat makes its temperature higher and another part was dissipated through the electrode, matrix, ceramic plugs and so on. The continuous thermal conduction could reach the melting point (gold 1330 K) of electrode material. The melt flowed into poly-silicon bridge which broken the balance between heat generation and dissipation. When

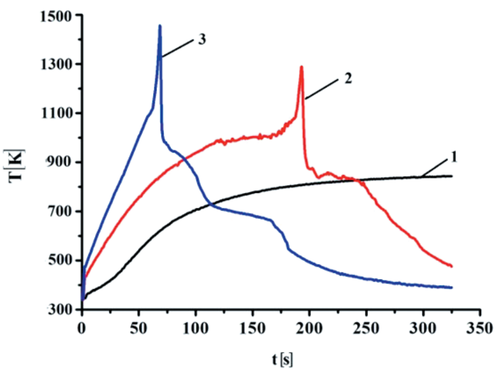


Figure 8 Temperature curve of polysilicon chip surface under 5 min constant current.
1- 1.0 A constant current, 2- 1.1 A constant current,
3- 1.3 A constant current

the most of bridge was covered by the melt, the resistance decreased rapidly and the heating rate was lower than the rate of heat loss that result in the temperature of bridge film decreased which is shown in Figure 8.

However, under the same excitation energy (1.3A -5 min), one part of composite film above the poly-silicon area was obviously ablated and the other part of composite film above the electrode was broken. According to the resistance change before and after the experiment, the polysilicon bridge has been melted or vaporized. It is indicated that there is other heat to prompt the further action for polysilicon bridge in addition to its own Joule heat binding of the action progress of polysilicon ignition chip.

It is difficult to obtain the mechanism of energy conversion and process of action between polysilicon bridge and Al/CuO composite film by experiment. The analysis found that it is similar to the progress and energy conversion mechanism of igniting powder ignited by polysilicon.

The whole progress and energy conversion mechanism of energetic igniter can be explained by theory in report SAND97-8246 which investigated the heat feedback between polysilicon bridge film and igniting powder[7].

Since there is no reason to believe that the loss mechanisms remember the initial voltage that the SCB sees, the most straightforward approach is to assume that the loss is a function of the instantaneous voltage at the SCB leads. This suggests that the SCB energy budget might be described by the following equation :

$$dE_{SCB}/dt = VI\left[1 - A_L f_L(V)\right] + \left[\dot{E}_{SCB}\right]_{TF} \qquad (1)$$

Where, E_{SCB} is transient energy and V is transient voltage of SCB, I is transient current, A_L is for adjusting the magnitude of the heat loss coefficient, $f_L(V)$ is transient voltage function on SCB, $\left[\dot{E}_{SCB}\right]_{TF}$ is the energy that pharmacy thermal feedback. When the function time of SCB is longer than 1 ms, the mechanism meets the thermal feedback model.

Thermal energy feedback is chemical reaction heat of energetic igniter and expressed as :

$$dE_{SCB}/dt = VI\left[1 - A_L f_L(V)\right] + \left[\dot{E}_{Al/CuO}\right]_{TF} \qquad (2)$$

$$\left[\dot{E}_{Al/CuO}\right]_{TF} = QK_0 \exp(-E_a/R_c T) \qquad (3)$$

Where, Q is a chemical reaction heat, K_0 is the frequency factor, E is the activation energy, and Rc is the gas constant.

In addition to its own warming and heat loss, the heat generated by the poly-silicon film will be transferred to the upper Al/CuO composite film. The chemical reaction begins to occur in Al/CuO composite film when it reached the reaction temperature (800 K) with continuous heating. The reaction was spread in the form of wave front from the center to the surroundings. At the same time, the polycrystalline silicon film get thermal feedback from chemical reaction heat which made it melt or even vaporize.

It is indicated that the heat feedback is enough to melt the bridge and the resistance reached kilohms compared with the phenomenon that the resistance of the polysilicon ignition chip without Al/CuO composite film after 1.3A -5 min was obviously reduced.

In summary, energy conversion mechanism between the composite film and the polysilicon bridge film consists of initial thermal conduction and thermal feedback after the reaction on composite film when energetic igniter is applied a lower amplitude and longer pulse width current. Therefore, under the condition of a lower amplitude and longer pulse width current, heat source when energetic igniter is ignited mainly include : Joule heat on polysilicon film and chemical reaction heat on Al/CuO composite film under the excitation conditions.

4. Conclusions

This paper investigated the mechanism of energetic igniter which was manufactured by depositing multiple layers of Al/CuO nano-energetic materials composite films based on the mature polysilicon semiconductor bridge and aims to solve the problem of output capability.

The 5 min constant current excitation experiments were carried on the igniter equipped with polysilicon chip and energetic chip, thermography on chip surface and the change of resistance and micrograph was measured, the results showed that there is other heat source to prompt further action on polysilicon film except Joule heat generated by its own. The action progress and energy conversion mechanism between polysilicon bridge film and Al/CuO composite film were analyzed, and the result was that energy conversion mechanism between the composite film and the polysilicon bridge film consisted of thermal conduction in initial phase and thermal feedback after the reaction on composite film when energetic igniter was exposed to lower amplitude and longer pulse width energy.

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