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SCB IGNITION OF PYROTECHNICS, THERMITES AND INTERMETALLICS

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ABSTRACT

We investigated ignition of pyrotechnics, of metal-fuel/metal-oxide compositions (thermites) and of exothermic alloying compositions (intermetallics) using a semiconductor bridge, SCB. These materials possess unique properties that include high energy density, high combustion temperatures, good thermal stability and low gas production. We demonstrated that these materials could be ignited at low energy levels with an appropriately designed SCB, with proper loading density and with good thermal isolation. Materials tested included Al/CuO, B/$BaCrO_4$, $TiH_{1.65}$/$KClO_4$, Ti/$KClO_4$, Zr/$BaCrO_4$, Zr/CuO, Zr/Fe_2O_3, Zr/$KClO_4$ and 100-mesh Al/Pd. The firing set for our tests was a capacitor discharge unit with charge capacitors ranging from 3 to 20,000 μF at charge voltages from 5 to 50 V. The devices functioned a few milliseconds after onset of the current pulse at input energies as low as 3 mJ. We also report on a thermite torch design.

DISCLAIMER

INTRODUCTION

Most electroexplosive devices contain a small metal bridgewire heated by a current pulse from a firing set operating at voltages from one to several tens of Volts. The exoergic material against the bridge is heated by thermal conduction from the bridgewire and typically ignites a few milliseconds after the onset of the current pulse.

Manufacture of bridgewire devices is often a time consuming, hand process; therefore, alternative methods for ignition, such as metal foils and films and solid state films and elements, have been tested. As with bridgewires, most of the alternative devices also heat the powder by thermal conduction and most have not achieved commercial success.

THE SCB

Sandia's semiconductor bridge (SCB) offers a new method for explosive ignition and has been used for several Sandia programs.[1] Figure 1 depicts the SCB. It is a small, heavily doped, polysilicon volume formed out of a polysilicon-on-silicon wafer. The bridge element itself is 2 μm thick and its length is determined by the spacing of the aluminum lands shown in Figure 1. Nominal bridge resistance is one ohm. The shape of the polysilicon layer and the aluminum lands is determined by computer generated masks. Therefore, we can easily tailor bridge designs to meet a wide variety of needs.

The aluminum lands provide for a very low resistance contact to the underlying doped polysilicon layer. Wires are ultrasonically bonded to the lands permitting a current pulse to flow from land to land through the bridge. This bonding process is a cost effective procedure that produces very strong bonds. In fact, the bonds and wires remain intact after firing for most pyrotechnic compositions.

When a current pulse flows through the SCB, it bursts into a bright plasma discharge that heats the exoergic material by a convective heat transfer process.[2] The physics of this process is very different than the conductive mechanism for bridge wires. This is reflected by the low energies required for SCB ignition (less than 3 mJ and as low as 30 μJ) and the fast function times of the SCB devices. SCB pyrotechnic devices produce an explosive output in less than 50 μs after the onset of the current pulse; this is in contrast to the millisecond response of the same device with a hot wire.[3]

We use many different circuits to fire SCB devices. These include constant current, constant voltage, blasting machines and capacitor discharge units (CDU). In terms of size, simplicity, and cost, the CDU firing set is very effective. A typical firing set is depicted in Figure 2.

Because the substrate provides a very large and reliable heat sink, excellent no-fire levels are obtained even though the all-fire energies are very low. We define no fire as the maximum current that can be applied to the bridge for a specified period of time without ignition, and all fire as the minimum firing energy for reliable ignition. As reported in Ref. 3, the SCB pyrotechnic component (titanium subhydride potassium perchlorate) investigated had an all fire of 2.72 mJ (at -54 C) and a 5 minute no-fire level of 1.39 A (at 74 C) versus the same device with a bridgewire which had an all fire of 32.6 mJ and a no fire of 1.1 A (both measured at ambient). It is important to note that the SCB test conditions in Ref. 3 were more severe than the bridgewire tests. In addition, SCB devices are ESD (electrostatic discharge) and RF (radio frequency) tolerant.[4]

THERMITES & INTERMETALLICS

Thermite mixtures and intermetallic reactants have long been used in pyrotechnic applications. The exothermic reactions between a metal and a metal oxide (thermite) and between metallic elements (intermetallic) are extremely useful sources of energy production, light output, and material synthesis. Advantages of these systems typically include high energy density, high combustion temperature and a wide range of gas production. They generally exhibit high temperature stability, are impact insensitive, and possess insensitive ignition properties. The interesting properties of thermites and intermetallic materials have recently been summarized.[5]

EXPERIMENTAL STUDIES

The purpose of our experimental studies was to determine the conditions under which an SCB could ignite pyrotechnic, thermite and intermetallic materials. For our laboratory experiments, we used the very simple test device shown in Figure 3. This design consisted of an SCB mounted onto a TO-46 transistor header and a charge holder glued onto the header. Powder was poured directly into the charge holder and pressed to the desired density directly onto the SCB. We pressed devices to more than 1.4 MPa (20,000 psi) without damaging the SCB chip or the interconnecting wires. The only requirement for the header for use with an SCB is that the electrical posts be a material that can be ultrasonically welded. We have used many different header designs (ceramic, glass, plastic, phenolic, etc.). The firing set depicted in Figure 2 was used to provide the current pulse to the SCB.

Our studies began with the aluminum and copper oxide thermite composition pressed to a density of 2.3 g/cm^3. Firing conditions to meet specific firing set requirements were reported in a recent conference paper.[6] In those experiments we discovered that the mean all-fire thresholds were significantly influenced by the thermal conductivity of the charge holder. For example, with a brass charge holder and a charge voltage on the firing set capacitor of 50 V, a 30.1 μF capacitor was required. But for a non-conducting fiber-glass-epoxy composite (G10) charge holder the all-fire capacitor was 2.0 μF. In addition, we determined that the CuO morphology affected the function time (interval between start of the firing set current and the output of the device) but did not significantly affect the threshold energy. The SCB bridge was 90 μm long, 270 μm wide and 2 μm thick; typical function times were 1.5 ms.

In contrast to the pressed Al/CuO thermite, we determined that the bulk density material could be ignited over a wide range of firing set capacitances. We selected a firing set operating voltage of 28 V because of the large number of military devices that operate at that voltage. Our experiments with bulk density Al/CuO used the fixture shown in Figure 2 with a brass charge holder. Tests were with a 20,000 µF capacitor (essentially a constant voltage firing source) and with 470, 300 and 45 µF capacitors. All of the devices functioned in less than 2 ms using an SCB bridge 100 µm long, 360 µm wide and 2 µm thick.. The flame produced by the 130 mg of Al/CuO in the TO-46 fixture was several feet long.

Attempts to reduce the firing voltage much below 28 V met with difficulties because of the high thermal conductivity of the Al/CuO and the very short duration (less than 1 µs) of the plasma pulse from the SCB. To sustain the plasma, we added a small inductor in series with the SCB. This increased the plasma pulse to several microseconds. The results are summarized in Table I. With the inductor added to the firing set we obtained ignition of the Al/CuO at voltages as low as 4.5 V using a 1000 µF capacitor. The thermite was pressed to a density of 2.5 g/cm^3 and the charge holder was made from a low-thermal conductivity phenolic tube.

To demonstrate the portability of our system, we built a CDU firing set with two lithium batteries as the power source; the firing pulse was obtained from a 9 V, battery-operated, trigger circuit housed in a small circuit box. The thermite device was loaded with 108 mg of Al/CuO pressed to 2.5 g/cm^3 and placed in a clear plastic cylinder 1.2 m long (48") and 0.3 m in diameter (12"). The device produced a loud report and the cylinder was filled with flame. This mixture produced little smoke and, even in a closed room, produced very little noticeable odor.

We also designed a thermite torch assembled as shown in Figure 4. This device was loaded with 153 mg of Al/CuO and pressed to a density of 2.5 g/cm^3. The firing set was a 20,000 µF CDU charged to 28 V. A graphite plug with a 1.58 mm (0.062") nozzle was inserted into the charge holder onto the output charge. The design of this torch is unique because of the configuration of the thermite charge. Typically, torches use a center-perforated, cylindrical grain. In contrast, our design incorporated a reversed end burning charge (i.e. the thermite is ignited at the header end and burns towards the nozzle). This greatly simplified loading and ignition of the thermite. This unit produce an output flame at least 0.3 m (12") long and drilled through 0.25 mm (0.010") stainless steel shim stock in a few milliseconds.

We also carried out a large number of experiments using a wide variety of pyrotechnics and thermites. These tests are summarized in Table II. Materials tested included: Al/CuO, $B/BaCrO_4$, $TiH_{1.65}/KClO4$, Ti/KCl_{o4}, $Zr/BaCrO_4$, Zr/CuO, Zr/Fe_2O_3 and $Zr/KClO_4$. Input energies for ignition were as low as 3 mJ.

We carried out experiments with one intermetallic compound. The device tested is shown in Figure 5. It consisted of a Riebling (plastic) header epoxied into a steel charge holder, a load of 100 mesh Al/Pd (bulk density), and for some of the tests, a Pyrofuze™ wire inserted into the bulk material held in place by the graphite seal. The firing set was a 20,000 µF CDU charged to

28 V. Ignition of the bulk material was indicated by the sparkling Al/Pd material. The pyrofuze™ wire, approximately 0.3 m long, was consumed in a few milliseconds. The light output from the burning wire was recorded on a videorecorder.

SUMMARY

We demonstrated that an SCB device can ignite a variety of pyrotechnics, thermites and an intermetallic over a wide range of operating conditions. With a CDU firing set, input energies as low as a few millijoules produced an output in less than 2 ms. These materials have many interesting properties for use in energetic devices.

ACKNOWLEDGMENTS

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FIGURES

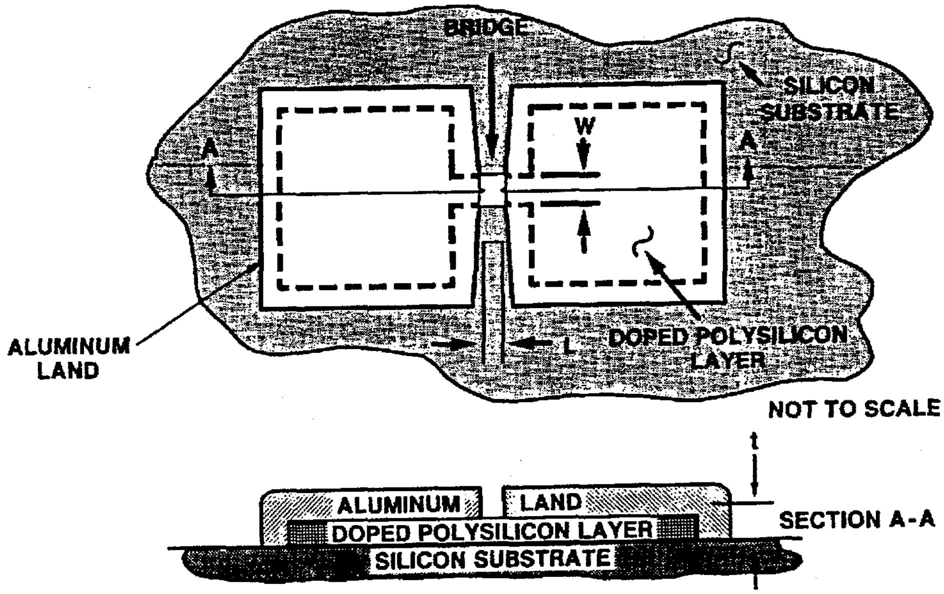

Figure 1. Simplified sketch of a semiconductor bridge (SCB). The bridge is formed out of the heavily doped polysilicon layer enclosed by the dashed lines. Typical bridge dimensions are 270 μm wide (W) by 90μm long (L) by 2 μm thick (t). Electrical leads are attached to the aluminum lands, permitting an applied current pulse to flow from land-to-land through the bridge.

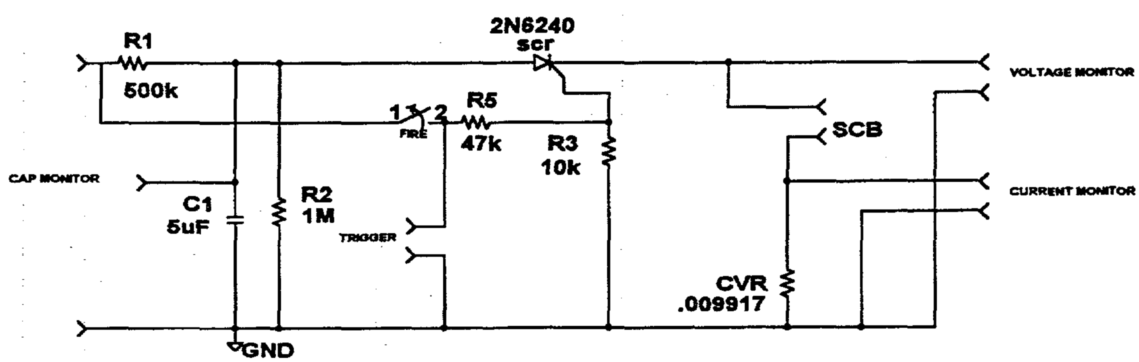

Figure 2. Capacitor discharge unit, CDU, firing set schematic. C1 is the discharge capacitor and is 5 μF in this figure. A 5 V, 10 μs trigger pulse fires the solid state switch which can be the SCR shown or an FET. For diagnostic purposes, the monitors shown are used to capture the voltage and current waveforms and measure the charge voltage.

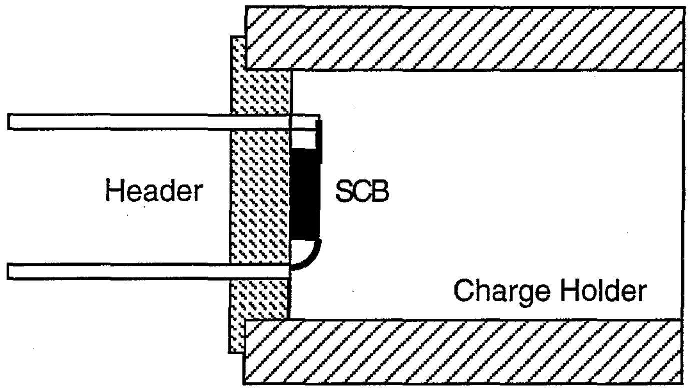

Figure 3. TO-46 transistor base (header) with a charge holder glued in place. The internal diameter of the charge holder is 3.8 mm (0.150") and the internal length is 6.9 mm (0.270"). The outside diameter of the charge holder is 6.4 mm (0.250"). The energetic material is accurately weighed into the charge holder and then pressed onto the SCB to the required density.

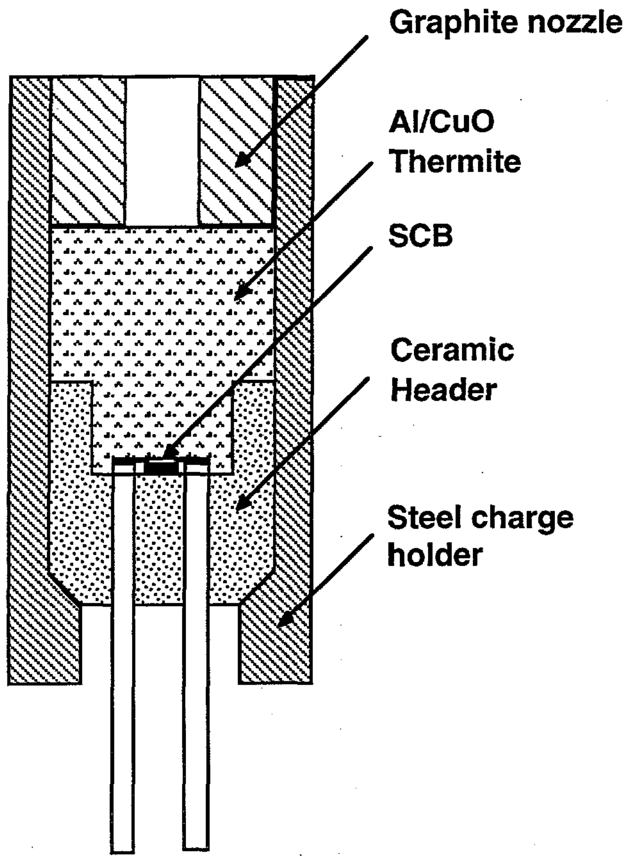

Figure 4. Thermite torch consisting of a ceramic header mounted in a steel charge holder. The thermite is pressed to a density of 2.5 g/cm^3; the graphite plug with a 1.58 mm (0.062") nozzle is inserted into the charge holder onto the output charge.

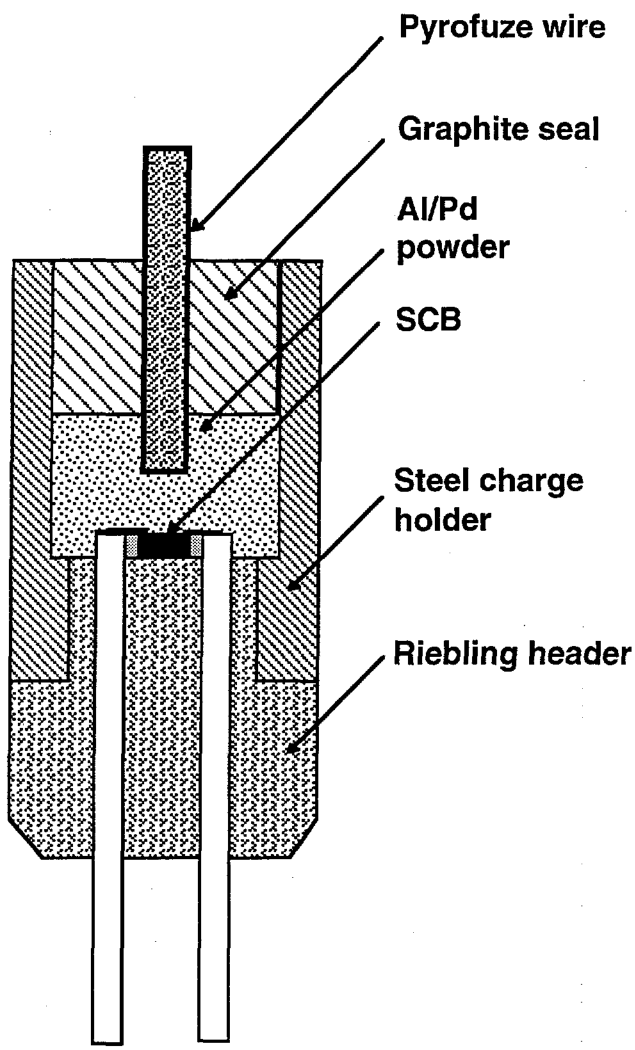

Figure 5. Al/Pd device consists of a Riebling (plastic) header, a load of 100 mesh Al/Pd (density) over the SCB and a pyrofuze fuze wire inserted into the bulk material.

TABLES

Table I. Firing Conditions for 2.5 g/cm^3 Al/CuO, a 1000 μF CDU Firing Set and 28 μH Inductor

Cap Voltage (V)	Delivered Energy (mJ)	Function Time (μs)
4.5	2.0	891
5.0	4.8	763
7.5	11.6	758
15	61.0	645
25	71.0	154

Table II. Energetic Materials List — Tested Ignition Conditions

Material	Firing Set Capacitance (μF)	Firing Set Voltage (V)
B/BaCrO4	20	28
B/BaCrO4	20,000	28
TiH1.65/KClO4	470	28
TiH1.65/KClO4	20,000	5
Ti/KClO4	1,000	7.5
Zr/BaCrO4	20	28
Zr/BaCrO4	20,000	28
Zr/CuO	20,000	28
Zr/Fe2O3	20	28
Zr/Fe2O3	20,000	28
Zr/KClO4	20	28
Zr/KClO4	1,000	7.5
Zr/KClO4	20,000	28

REFERENCES

(1) R. W. Bickes, Jr., M. C. Grubelich, J. A. Merson, J. H. Weinlein, "An Overview of Semiconductor Bridge, SCB, Applications at Sandia National Laboratories," *31st AIAA Joint Propulsion Conference and Exhibit*, San Diego, California (July 10-12, 1995).

(2) D. A. Benson, M. E. Larsen., A. M. Renlund, W. M. Trott and R. W. Bickes, Jr., "Semiconductor Bridge (SCB): A Plasma Generator for the Ignition of Explosives," *Journ. Appl. Phys.* 62(5), 1622-1632 (Sept. 1987).

(3) R. W. Bickes, Jr., S. L. Schlobohm, and D. W. Ewick, ""Semiconductor Bridge (SCB) Studies: I. Comparison of SCB and Hot-Wire Pyrotechnic Actuators," *13th International Pyrotechnics Seminar*, Grand Junction, Colorado (July 11-15, 1988).

(4) R. W. Bickes, Jr., D. Greenway, W. J. Meyer, J. K. Hartman and C. B. McCampbell, "HERO Resistant Semiconductor Bridge Igniter," JANNAF Interagency Propulsion Committee Combustion Meeting, Hampton, Virginia (Oct. 19-23, 1992).

(5) S. H. Fischer and M. C. Grubelich, "A Survey of Combustible Metals, Thermites and Intermetallics for Pyrotechnic Application," *32nd AIAA/ASME/SAE/ASEE Joint Conference and Exhibit*, Lake Buena Vista, Florida, (July 1-3,1996).

(6) R. W. Bickes, Jr., M. C. Grubelich, D. E. Wackerbarth and J. H. Mohler, "A Very Low-Ignition Energy SCB Thermite Igniter," *22nd International Pyrotechnics Seminar*, Fort Collins, Colorado (July 15-19, 1996.)