SAND95-0968C

AIAA 95-2549

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**31st AIAA/ASME/SAE/ASEE
Joint Propulsion Conference and Exhibit
July 10-12, 1995/San Diego, CA**

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Conf-950720--5

AN OVERVIEW OF SEMICONDUCTOR BRIDGE, SCB, APPLICATIONS AT SANDIA NATIONAL LABORATORIES

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Abstract

The semiconductor bridge, SCB, developed by Sandia National Laboratories is a maturing technology now being used in several applications by Sandia customers. Most applications arose because of a need at the system level to provide explosive assemblies that were light weight, small volume, low cost and required small quantities of electrical energy to function — for the purposes of this paper we define an explosive assembly to mean the combination of the firing set and an explosive component. As a result, and because conventional firing systems could not meet the stringent size, weight and energy requirements of our customers, we designed and are investigating SCB applications that range from devices for Sandia applications to igniters for fireworks. We present in this paper an overview of SCB technology with specific examples of the systems designed for our customers to meet modern requirements that sophisticated explosive systems must satisfy in today's market environments.

Introduction

A large number of electroexplosive devices contain a small metal bridgewire heated by a current pulse from a firing set with nominal output voltages ranging from one to several tens of Volts. Heat transport is by means of thermal conduction from the bridgewire to the exoergic material next to the wire, producing an explosive output typically measured in milliseconds after the onset of the current pulse. No-fire (the maximum current that can be applied to the bridgewire for a period of time without causing ignition) and all-fire (the minimum current level required for reliable ignition) current levels are often strongly dependent upon the exoergic material and the physical construction of the explosive device. In addition, because the manufacture of many bridgewire devices is often a tedious, time consuming and inexact process, investigators have looked at alternative methods for ignition including metal foils and films and solid state films and elements. Many of those devices also heat the exoergic material by thermalconduction and most have not achieved significant commercial success.

One of the first semiconductor devices proposed was the solid state initiator (SSI) patented by L. E. Hollander in 1968[1]. He used "off the shelf" grade silicon materials (approximately 0.2 Ω-cm resistivity) to produce 50 Ω devices designed for 28-V firing sets and measured function times of less than 20 ms. (Function time is the interval between the start of the firing pulse and the explosive output of the component.) A more recent invention by Baginski[2] describes a junction diode device that is resistant to radio frequency environments. That device is presently under development.

The Sandia semiconductor bridge, SCB, has three forms and was patented in 1987[3] and 1990[4]. Devices incorporating the 1987 art have been incorporated into Sandia, Department of Defense (DoD) and commercial systems. In addition, Sandia and University of New Mexico technology transfer programs successfully created a small business in New Mexico (SCB Technologies Inc.) in 1989 for the production of SCB "chips." SCB Technologies was acquired by Ensign-Bickford Industries, March 1995.

The 1987 patent describes the device shown in Fig. 1. It consists of a small doped polysilicon (or silicon) volume formed on a silicon (or sapphire) substrate. The length of the bridge is determined by the spacing of the aluminum lands seen in the figure. The lands provide a low ohmic contact to the underlying doped layer. Wires ultrasonically bonded to the lands permit a current pulse to flow from land to land through the bridge; the ultrasonic process produces very strong bonds and is a cost effective procedure. The doped layer is typically 2 µm thick; bridges are nominally 100 µm long and 380 µm wide. Bridge resistance at ambient conditions is 1 Ω; however, the bridge dimensions can be easily altered to produce other resistances. The 1990 patent eliminated the doping process by depositing a tungsten layer over the (undoped) silicon layer. Device operation is the same as the doped device due to the formation of tungsten silicide which acts as the dopant.

Passage of current through the SCB causes it to burst into a bright plasma discharge that heats the exoergic material pressed against the bridge by a convective process that is both rapid and efficient. Consequently, SCB devices operate at very low energies (typically less than 5 mJ and as low as 30 µJ) and function very quickly producing an explosive output in less than 50 µs for pyrotechnic devices. But despite the low energy for ignition, the substrate provides a very large and reliable heat sink for excellent no-fire levels; in addition, the devices are ESD (electrostatic discharge and RF (radio frequency) tolerant.

Department of Energy (DOE) Systems

Aerospace Devices

At the 1992 International Pyrotechnics Seminar[5] we described a study that compared a standard Sandia bridgewire actuator with the same device retrofitted with an SCB. We reported that the SCB units had an all-fire input energy of 2.7 mJ at -54 C versus 32.6 mJ at ambient for the conventional device. In addition, the no-fire level for the SCB device was 1.2 A at 74 C versus 1.0 A for the bridgewire design at ambient. The results prompted Sandia's Aerospace Systems Center to ask us to design two SCB-ignited gas generators for flight applications for one of its programs. Of particular interest to the Aerospace Center were the low energy requirements of the SCB igniter and the replacement of a heavy mechanical system with a light-weight explosive assembly. Both SCB assemblies flown provided significant savings in weight and volume both in terms of the explosive device itself and also because of the compact and low mass firing set that was designed for these applications.

The requirement for the first gas generator system was to design a payload ejection system that was beyond the physical capabilities of mechanical spring powered systems. The gas generator consisted of retrofitting an existing Sandia hot wire actuator with an SCB. The new SCB actuator contained THKP (titanium sub-hydride potassium perchlorate, $TiH_{1.65}/KClO_4$). The gas output from this device was used to drive a piston that ejected a payload from a flight vehicle. The requirement for the second device was to generate a sufficient quantity of gas at a controlled rate to perform mechanical work in order to erect a structure. In this case the previously mentioned actuator was used as an igniter to light a composite propellant gas generator. Once again, due to mass and volume limitations of the overall system, existing (non-SCB) electro-explosive technology could not be employed. The SCB devices were flight approved and flown successfully in 1994.

Other SCB Devices

The Sandia Transportation Systems Center had need for several explosive devices assembled into a single volume. Here the electrical system size requirements were critical and the firing set size needed for conventional bridgewire devices did not meet this customer's needs. The two SCB devices developed (actuator/igniter and a detonator) are described by Sanchez and Tarbell[6] in this meeting. A prototype firing set used for laboratory tests is shown in Fig. 2 and forms the basis for the firing system for this application. This single firing set is used for both the detonator and the actuator/igniter obviating the need for two separate firing systems.

A dual mix device was developed to satisfy the requirement of a component that could act as an actuator (gas generator) as well as an igniter (hot particle producer). THKP and a thermite (CuO/Al) were used in this device. 50 mg of THKP were pressed against the SCB; 200 mg of CuO/Al thermite were pressed on top of the THKP. Upon application of the firing signal, the SCB ignites the THKP which in turn ignites and ejects the high density thermite composition. The THKP produces a fast, high-pressure gas pulse (150 kpsi in a zero volume system) capable of performing mechanical work through the expansion of the hot, high-pressure gas. The thermite produces a long thermal pulse via the formation of copper in the vapor, liquid and solid states. This hot copper is an excellent igniter for the high ignition energy requirements of composite propellants. The Transportation Systems Center was able to replace numerous specialized bridgewire igniter and actuator components using several exoergic materials with one SCB component, thereby reducing cost as well as meeting stringent safety specifications. Additionally, the SCB allowed for the firing set volume specifications to be met.

The Sandia California Weapon Development Center requested the design of a detonator that meets both strict volume and supply voltage requirements. The SCB detonator was a conventional Sandia design that used the explosive CP (2-(5-cyanotetrazolato) pentaammine Cobalt III perchlorate). The key to this system was the firing set shown in Fig. 3. The voltage doubling circuit permitted the use of a small volume capacitor and a compact firing set.

Advanced Studies

SCB Slapper

We have been working on the development of an SCB slapper detonator for the last two years. This device is similar in design to other SCB devices but has a flyer material coated over the bridge region (see Fig. 4). When the SCB functions, the plasma discharge propels the flyer material into a secondary explosive such as HNS (hexanitrostilbene) or PETN (pentaerythritol tetranitrate). The flyer impact on the secondary explosive causes a prompt shock initiation. Several different bridge dimensions and thicknesses have been studied, along with three different flyer materials. Currently, polyimide is being used as the flyer material because it is amenable to photoprocessing. We hope that this device can one day replace exploding foil initiators (EFI's). We expect the cost per unit will be at least an order of magnitude less than EFI's because of the manufacturing techniques employed. In addition, we believe energy requirements will be significantly lower because the bridge and flyer can be tailored to any dimensions, allowing for optimization not possible with EFI's.

Mil. Std. 1316D Detonators

We evaluated several insensitive explosives defined by Mil. Std. 1316D for possible detonator applications with SCB's. In addition, high density PETN was also investigated. These materials all required a run-up to detonation from the impulse received from the SCB. The run-up may be considered as a deflagration-to-detonation transition (DDT) process. The firing sets for these experiments operated at voltages up to 3.5 kV. We used a Type 3-2 SCB (100 μm long x 380 μm wide x 2 μm thick bridge). The test plan included heavy confinement fixtures to determine feasibility (VISAR was used to verify detonation when dent depths were inconclusive), and we also looked at reduced confinement (shorter length and smaller diameter explosive columns) in potentially useful cases. VISAR (Velocity Interferometry System for Any Reflector) is a well known technique for determining velocities in explosive systems[7].

The powders studied included Comp A-5 (1.5% stearic acid and 98.5% RDX, which is hexahydro-1,3,5-trinitro-s-triazine), PBXN-5 (5% Viton A and 95% HMX, which is octohydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine), HNS IV, PBX 9407 (94% RDX and 6% Exon 461) and PETN. The results are summarized in Table I.

As verified by VISAR, DDT of Comp A-5 with a density of 1.7 g/cc was demonstrated using heavy confinement. Explosive column diameters of 0.375" and 0.250" and column lengths of 4" were used. The charge volume contained approximately 12 g of the explosive. Several voltages ranging from 500 to 3,500 V with a 1 μF capacitor resulted in successful DDT. Using a 35 V, 20 μF CDU, we were unable to achieve ignition of the explosive. When the confinement around the Comp A-5 was lost due to yield of the metal casing, DDT was not achieved. Attempts with PBXN-5 (1.83 g/cc), HNS IV (1.6 g/cc) and PBX 9407 (1.8 g/cc) all proved unsuccessful; all were carried out in heavy confinement fixtures. In addition, experiments with PETN at densities ranging from 1.2 g/cc to 1.67 g/cc proved very successful. This led to our development of PETN devices for Department of Defense (DoD) applications.

The above experiments demonstrated that a DDT detonator using an SCB can be built with a Mil Std. 1316D approved explosive. The intent, however, of the fuzing standard is to avoid situations where DDT can be a potential safety problem. This points the difficulty of specifying system safety based solely on an explosive powder characteristic. Individual components must be characterized in their complete full-up configuration and individual systems should receive the same level of review. Qualification of whole systems and components should demonstrate safety.

Department of Defense (DoD) Systems

We incorporated the results from our Mil. Std. 1316D studies in the design of a PETN detonator for a DoD application. Our detonator contained a 1" long column of PETN pressed at a density of 1.67 g/cc against an SCB. The powder column was 0.235" diameter and the stainless steel housing was 0.5" diameter. The 0.12 μF CDU firing set converted a 12 V d.c. input to a 700 V, 1 μs long voltage pulse that fired the SCB. The detonator functioned approximately 65 μs after the onset of the 700 V pulse producing an output capable of directly initiating the next assembly; no booster pellet was needed.

We studied the RF vulnerability of SCB devices designed by SCB Technologies, Inc. for use in the Navy Phalanx program[8] and in DoD cartridge actuated devices. We injected RF power directly into these devices. The units withstood power levels of 5 watts at 10 MHz and 15 Watts at 450 MHz for 5 minutes without damage to the devices. We are also studying the use of SCB devices in sonobuoy applications.

Commercial Systems

We presently have a Cooperative Research and Development Agreement (CRADA) with Buena Vista Distributors (a wholly owned subsidiary of Walt Disney World) for the use of SCB devices in pyrotechnic displays. The low energy of the SCB and the small size of the firing sets make this technology of potential interest for more sophisticated fireworks displays. With support from the National Machine Tool Partnership, we assisted Thiokol/Elkton in their design of the actuator for the Conax-Florida Universal Water Activated Release System (UWARS). This device is housed in the buckle connecting the pilot's harness to the parachute and will release the parachute upon entry into sea water. Conax-Florida was able to design a significantly smaller device utilizing the SCB as opposed to conventional bridgewire components. We recently studied the RF vulnerability of the Halliburton RED™ oil well perforator. This product was announced in April 1995 and is claimed to be operable in severe electromagnetic environments caused by powerful communication equipment and welding operations.

Summary and Conclusions

We have used the SCB for several applications for system requirements that could not have been met using conventional electroexplosive (i.e. bridgewire or metal foil) devices. The low energy inputs of the SCB coupled with its excellent no-fire safety and use of insensitive materials permitted the development of successful designs for our customers' applications. We point out however that the mere use of so-called insensitive materials does not in itself guarantee device safety; our Mil. Std. 1316D studies revealed that a properly designed system configuration can produce outputs not anticipated by the Mil. Std. We also want to stress the need to look at overall applications and not merely the individual components.

Acknowledgment

This work was supported by the United States Department of Energy under Contract DE-AC04-94AL85000.

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TABLE I. Powder Combinations in Insensitive Explosive Characterization

Explosive	Density	Detonation
Comp A-5	1.7	Yes
PBXN-5	1.83	No
HNS IV	1.6	No
PBX 9407	1.8	No
PETN	1.2, 1.4, 1.67	Yes

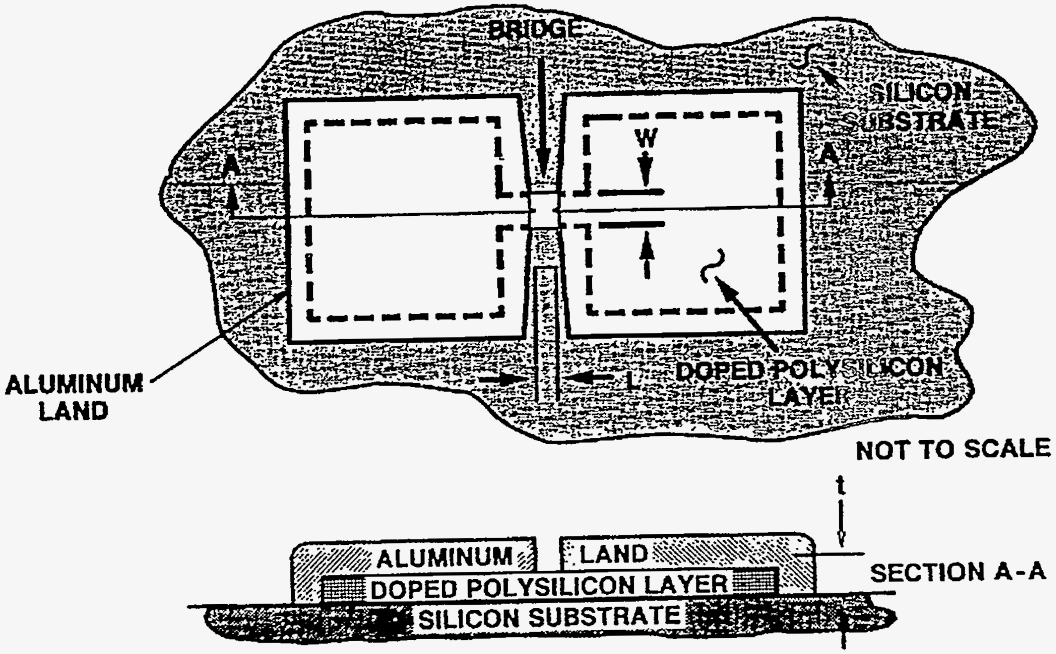

Figure 1. Simplified sketch of a silicon SCB. The bridge is formed out of the heavily doped polysilicon layer enclosed by the dashed lines. The overlying aluminum lands define the bridge length and provide a low ohmic contact to the polysilicon layer. Wires are bonded to the lands to permit current flow from land to land through the bridge.

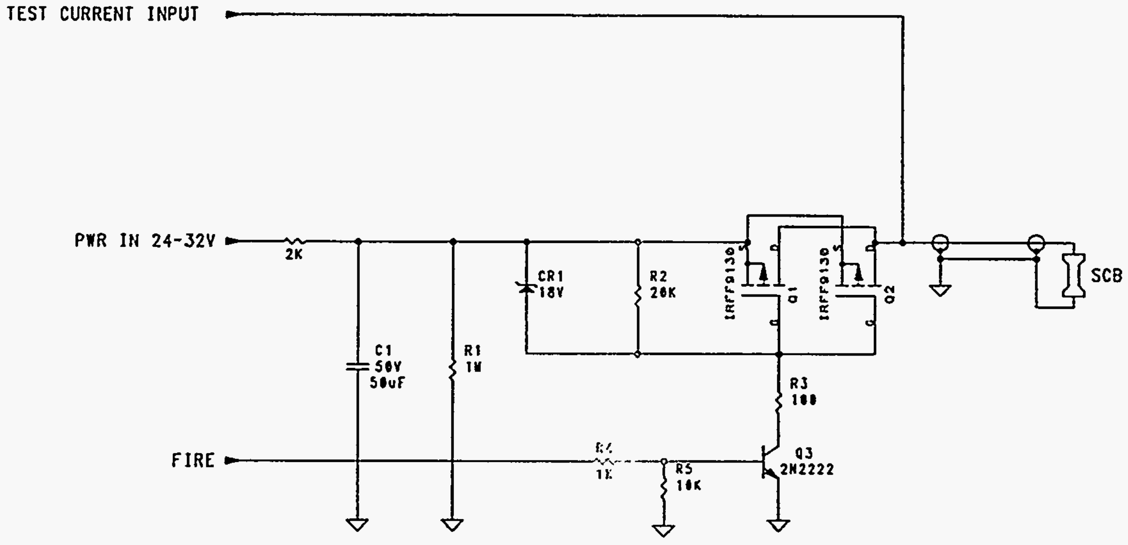

Figure 2. Wiring schematic for a capacitor discharge (CDU) firing set; C_1 is the charge capacitor. Two FET switches in parallel provide for a lower on resistance. High side switching is employed in order that the explosive device is at ground. R_1 is a current bleed for safety.

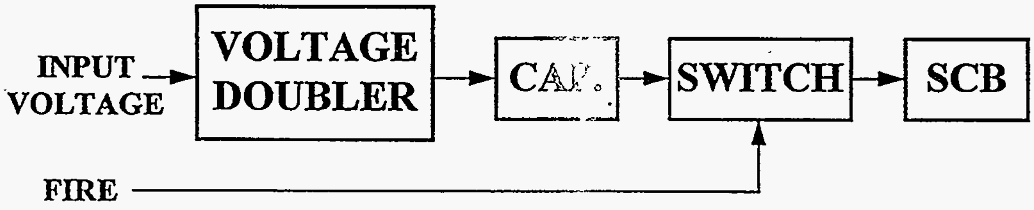

Figure 3. Small firing set size was needed for this application; consequently, the CDU charge capacitor needed to be a small value. Therefore, to get the energy output to the desired level a voltage doubler was used which allowed us to build the firing set in the volume available.

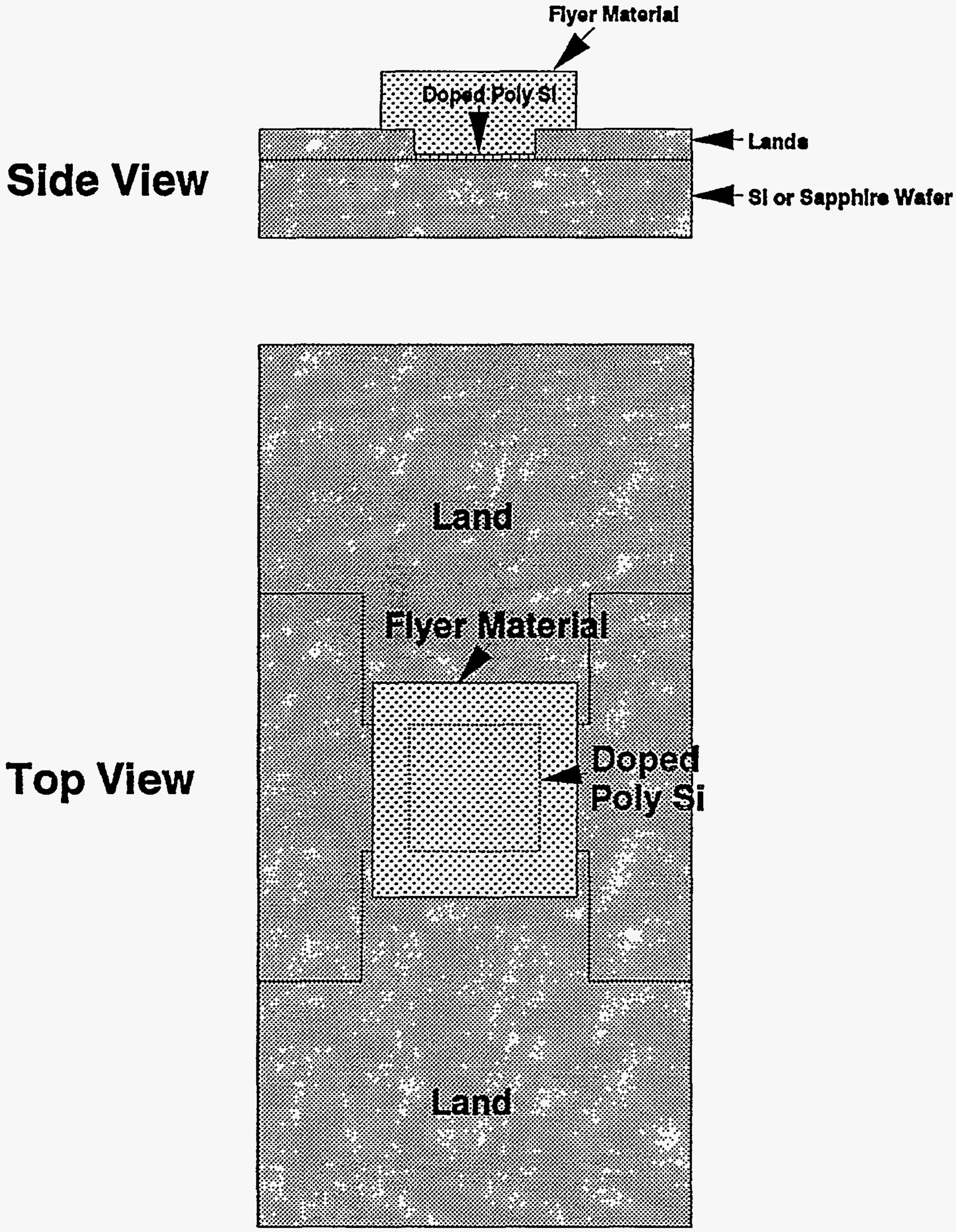

Figure 4. The basic layout of an SCB Slapper chip. A silicon or sapphire wafer with a doped polysilicon layer is etched to the pattern as shown. The remaining doped polysilicon forms the bridge region shown in the center of the top view. The lands, shown on both sides of the doped polysilicon are formed from aluminum, gold, or copper. Finally, the flyer material is shown over the doped polysilicon and part of the lands.