한국추진공학회 2007년도 추계학술대회 논문집 pp.252~255 2007 KSPE Fall Conference

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이 융 조

Devlopment of Smart Pyrotechnic Igniter

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ABSTRACT

Recently military industrial company, utilizing company funded R&D and goverment and industry contracts, has developed ACTS/DACS technology. This technology can be utilized to rapidly steer "smart" bullets, "smart" rounds, tactical missile, cruise missile and kill vehicles for both endo- and exoatmospheric applications. The ACTS/DACS typically consists of a Smart Bus Controller(SCB), a proprietary network firing bus, Smart Pyrotechnic Devices(SPD), rocket motors, and a structure. The SCB communicates with the SPDs over the propretary network firing bus. Each rocket motor contains an SPD which provides rocket motor ignition. Firing energy is stored locally in the SPD so surge currents do not occur in the system as rocket motors are fired. This approach allows multiple, truly simultaneous firings without the need for large, dedicated batteries. Each SPD also functions as a network tranceiver and high reliability fir set all in the space of a single-sided 10 millimeter diameter circuit. The present work develops a new means for igniting explosive materials. The volume of semiconductor bridge (SCB) is over 30 times smaller than a conventional hot wire. We believe that the present work has a potential for development of a new igniter such as smart pyrotechnic device.

초 록

최근에 선진국에서 아주 빠른 시간(마이크로 초)에 작동이 되고, 크기가 소형이면서, 많은 케이블과 커넥터를 사용하지 않는 Smart Bus Controller(SCB) 기법을 이용한 초소형/초고속(스마트) 점화기술에 집중적인 연구를 진행하고 있는 실정이다. 이와 같은 점화기술은 기존의 점화장치에서 사용하던 케이블과 커넥터 공간을 최소화 할 수 있게 MEMS 기법을 이용하여 케이블과 커넥터 장치를 설계 제작하였고, 저 용량/저 전류에서 작동할 수 있는 플라즈마를 이용한 초고속 착화장치를 사용하여 전류와 전압(배터리) 크기와 용량도 많이 감소시킬 수 있다. 스마트 파이로테크닉스 점화장치 개발에는 간결한 회로 점화통제장치 설계 및 제작, 빠른 점화작동시간을 가능하게 하는 플라즈마형 초고속 착화장치 설계 및 특성연구가 필요하다. 본 연구에서는 플라즈마형 초고속 착화장치의 특성연구에 대해 기술하였다.

Key Words: Smart Pyrotechnic Igniter(스마트 파이로테크닉 점화장치), Semiconductor Bridge Initator (반도체브리지형 착화장치), Late Time Discharge(늦은 방전반응), Smart Bus Controller(스마트 네트워크 조절정치)

1. Smart Pyrotechnic Igniter

The increased attractiveness and demand for affordable, precesion guided weapons has resulted in a need for noval, low-cost concept for rapid in-flight maneuvering of vehicle systems. One such concept called an attitude control thruster system[1] (ACTS) or divert and attitude control thruster[1] (DACS) utilizes an array of single shot, high thrust, fast action time, implusive rocket motors mounted orthogonal to the vehicle flight axis. Because this attitude control concept requires an array of hundreds of rocket motors, novel solutions for packing, commanding and fabrication the ACTS/DACS are required. Thru-nozzle ignition using miniature Smart Energetics Architecture (SEA) network mortor igniters eliminates the need for heavey, through-bulkhead type igniters and associated bulky cabling. The ACTS/DACS typically consists of a Smart Bus a proprietary network firing bus, Smart Pyrotechnic Devices (SPDs), rocket motors, and a structure. Each rocket motor contains an SPD, Fig. 1, which provides rocket motor ignition. Firing energy is stored locally in the SPDs so surge currents do not occur in the system as rocket motors are fired. This approach allows multiple, truly simultaneous firings without the need for large, dedicated batteries. Each SPD also functions as a network tranceiver and high reliability fir set all in the space of a single-sided 10 millimeter diameter circuit card.

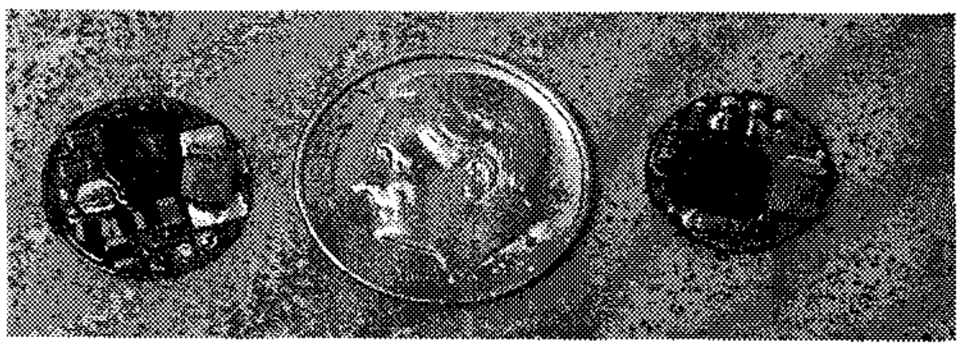

Fig. 1 Smart Pyrotechnic Device (SPD)

In general, a SEA based designe has several advantages over conventional designs, which use a central firing unit and one wire pair per thruster. The advantages include battery size/weight (since the system battery does not need to directly provide the firing current), minimized wiring and connectors, and Bulit-in-Test (BIT) capability which provides real time motor and system status of health.

Due to the cartridge-loaded design approach allowed by an innovative through-nozzle ignition concept, parts count is minimized and a separate bulkhead-style igniter is not required. The rocket motor design shown in Fig. 2 features a motor case, welded nozzle plug, and SPD igniter. The SPD igniter is installed into a counter-bore in the nozzle, and following motor ignition, is ejected from the nozzle.

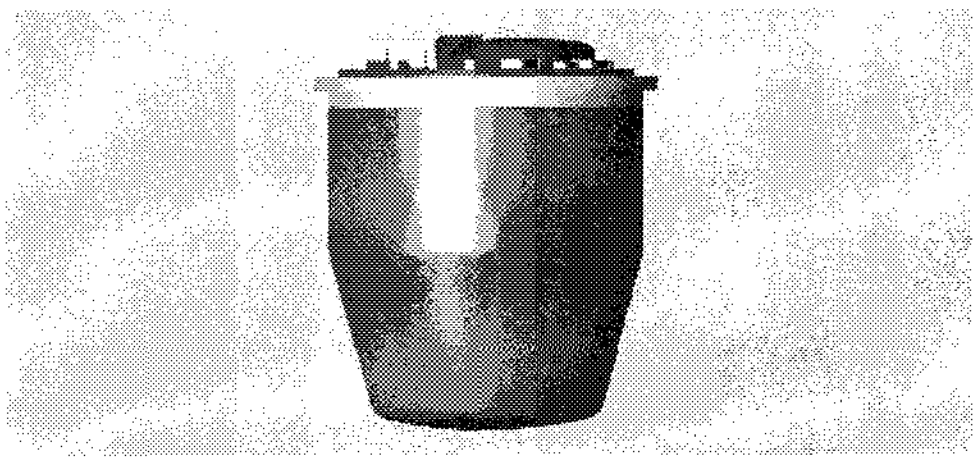

Fig. 2 Smart Rocket Motor

Due to the large of ACTS/DACS applications and requirements, performance capabilities have been tested and demonstrated over a wide operational and envirmental spectrum as indicated in Table 1.

Table 1. Demonstrated ACTS/DACS capabilities

Parameter	Value
Delivered Impulse	0.0005 N-s to 100 N-s
Thrust	5 N to 6500 N
Motor burn time	100 μsec to 20 msec
Impulse repeatability	Within 2%
Ignition delay, (command to 10% thrust)	10 μsec to 500 μsec
Operational temperature range	-40C to +80C
Operational acceleration	10,000 Gs
System power	3 Watt

Delivered impluse from motor to motor is very repeatable as is required in most ACTS/DACS applications. Ignition dealys for rocket motors are typically much less than 1 mmillisecond and are very repeatable for a

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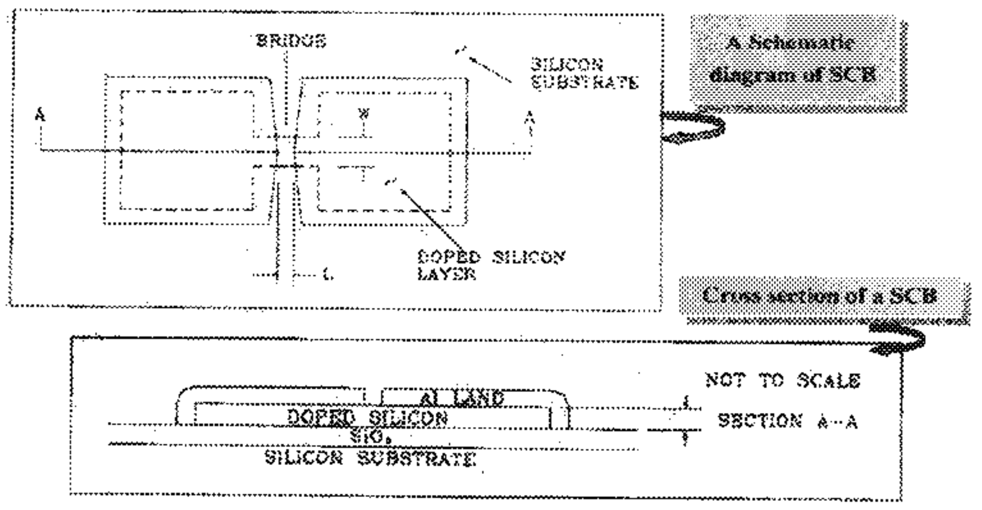
given rocket motor size and configuration.

A high speed video hot-fire sequence of a typical attitude control thruster in the ballistic pendulum is shown that ignition occurs within 200 microseconds, the plume is fully established prior to 1.3 milliseconds and the motor is extinguished at approximately 5 milliseconds. Notice the well formed mach diamonds visible in the seconf and third frames.

2. Semiconductor Bridge Igniter

Most electro explosive devices (EED) are initiated with a metallic bridgewire that is electrically heated as a firing current passes through the bridgewire. Typically, a 3 to 5 amperes current is passed through the wire heating it to approximately 900K, the hot-wire conductively heats the powder pressed against it, igniting the powder and producing a slow burn or deflagration in the powder column. For these hot-wire devices a usable explosive output is usually not obtained until several milliseconds after the current pulse is applied[2,3]. Hot-wires are used in igniters, actuators, matches, squibs and detonators. If the device is exposed to potentially hazardous electromagnetic radiation that could heat the bridge inadvertently, then the bridgewire's thermal and electrical impedance can be lowered so more electrical current is required to initiate the explosive materials.



A sketch of a semiconductor bridge(SCB). The bridge is formed out of the heavily doped poly-silicon layer enclosed by the dashed lines. Typical bridge dimensions are 40㎛ long(L), 80㎛ wide(W) by 1㎛ thick(t)

The use of silicon as a substitute for the metallic bridgewire presents several potential advantages and additional design challenges. Silicon is different from metal bridgewires, when heated electrically, silicon forms a high temperature plasma which becomes very conductive and rapidly converts the electrical energy into heat. When a small silicon bridge is heated electrically and a voltage applied across the device, a plasma is formed in a few microseconds which reaches temperatures greater than 2000 K, while metal wires can also be exploded into a plasma, as used in exploding bridgewire detonators, this require high voltage (800-2000V) and hundreds of amperes of current. The same plasma effect can be created with a silicon bridge at low voltage and 10-20 amperes of current pulse. Silicon is also an efficient conductor of heat, this effect can be used to design bridge with low thermal impedance, thus improving safety.

The present work develops a new means for igniting explosive materials. The volume of semiconductor bridge (SCB) is over 30 times smaller than a conventional hot wire. We believe that the present work has a potential for development of a new igniter such as smart pyrotechnic device.

Semiconductor bridge is formed out of the heavily doped silicon area enclosed by the dashed lines. The width of the bridge, w, is determined by the width of the narrow silicon region connecting the large silicon pads, and the length of the bridge, L, is defined by the spacing of the overlaid aluminum land. Typical bridge dimensions for a one-ohm device are 40㎛ long, 80㎛ wide and 1㎛ thick on a square chip; the aluminum lands are approximately 1㎛ thick. The lands provide a means for electrical connection to the bridge. Polysilicon-on-silicon (POLY) has been used for processing SCBs.

When a DC square pulse with the rising time of less than a few hundred nano second and the duration of more than several micro seconds is applied to the conventional SCB one can identify two distinct peaks of voltage as a function of time. It has been observed that the occurrence of the second peak and the LTD is influenced by the rising time. When the rising time of the pulse is longer than several micro second, no LTD has been observed. The second peak of voltage in time scale is relatively sharp but not always appear in the present cases.

By comparing the voltage vs. time data with the ultra high speed camera image which enables one to see the magnified view of the bridge at every micro seconds, we may explain intuitively the voltage characteristics as followings: In stage 1 the electrical resistance of the bridge increases according to the application of a DC square pulse and reaches a maximum which is supposed to be equal to the low-voltage resistance of the bridge. The voltage decreases according to the reduction of the dynamic impedance of the bridge in the stage. This discharge process is similar to the avalanche breakdown in the case of the pn-junction or conventional solid-state plasma processing. In the ultra high speed camera image used we could see that the bridge starts to melt from the edges and it develops into the middle of the bridge in this stage. The resistance of the bridge is reduced accordingly which is due to the fact that the resistivity of the liquid state of the semiconductor is an order of magnitude smaller than that of the solid state. However, in the present experiments the voltage value at the end of the stage 2 is not 10 times smaller than the maximum voltage V_{max} at the end of the stage 1, but it is only about a half or a third of V_{max}. The reason of the elevated dynamic impedance at the end of the stage 2 may be due to the facts that the bridge partially remains as solid state, or some part of the bridge sublimates to the vapor state[4,5].

At the end of the breakdown some of the ions are vaporized upon further heating and liquid portion which enables the current to flow with relatively low impedance is diminished. When most of the bridge is vaporized the dynamic impedance increases suddenly at the end of stage 3, then the plasma discharge will occur as the applied square pulse meets the appropriate condition. According to the report[6], one of the required conditions for the LTD is the current for a given cross sectional area of the bridge.

In the final stage, the plasma discharge process happens and it lasts until the end of the pulse. It is believed that the heated plasma is produced during the LTD which is capable of thermally igniting granular explosives[7]. The interpretation of the dynamic impedance of the heated plasma is little known up to date.

3. Conclusion

It has been demonstrated that one can generate a plasma discharge from SCB in order to ignite the explosive materials. Through the development of the SCB it was demonstrated that SCB will function as an initiator of the igniting system which works with low input energy and fast functioning time. Furthermore it is highly safe device and the replacement for variety of electro explosive device. In conclusion, we believe that SCB may have many smart pyrotechnic applications.

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