A RF-Insensitive Electro-Explosive Device with 500 V Standoff Capability

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Abstract—The description and characterization of a monolithic solid-state electro-explosive (EED) device is presented. The structure has demonstrated the ability to standoff a 500 V potential for a sustained period of time (24 hrs) with no adverse effects. This unique standoff capability ensures the device remains unaffected by exposure to harsh Electro-Magnetic Interference (EMI) environments. Test results substantiating the standoff capability (EMI insensitivity) and the firing threshold of the device are presented.

Index Terms—initiator, high voltage standoff, EMI insensitive

I. Introduction

Electro-explosive devices are required to meet a variety of safety criteria based upon the anticipated operating environment. One such criteria is contained in MIL-STD-1316D which states that an initiator for an electrically fired non-interrupted (i.e., in-line) explosive train shall not be capable of being actuated by any electrical potential of less than 500 V [1].

Historically, an exploding foil initiator (EFI) or exploding bridgewire (EBW) has met this criterion. However, both these devices are generally utilized with an insensitive high-explosive and produce a substantial shock output. In certain applications (i.e., a rocket motor igniter) it is desirable to initiate a pyrotechnic compound and not an explosive. A wide variety of structures have been described in the literature which are capable of this function. These structures often utilize laminates of reactive materials or nano-energetic compounds combined with advanced ignition structures [2]–[11].

It would be advantageous in a number of applications, which utilize a high-voltage capacitor discharge unit (CDU), for an EED to standoff 500 V indefinitely and not actuate or fail. It would also be advantageous for the initiator to directly ignite a thermally sensitive pyrotechnic compound such as boron potassium nitrate ($BKNO_3$). A top view photograph of such a device is illustrated in Figure 1, with a pictorial representation shown in Figure 2. The chip size is approximately 1 mm by 1 mm. A detailed process fabrication schedule is listed in [12].

Chips were attached to standard TO-3 headers. Gold wire bonds (1 mil) were used to connect the chips to the header pins. Non-conductive epoxy was utilized to passivate the chips and wire bonds.

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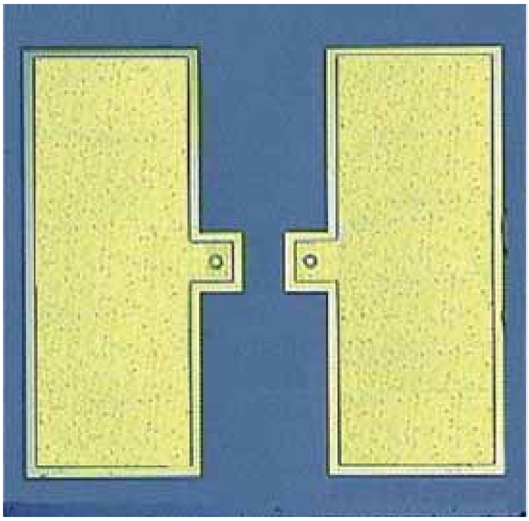

Fig. 1. Top view Photograph of Device.

A metal sleeve was welded onto the base of the header. The cylindrical volume was next filled with fine grain boron potassium nitrate (BKNO3) and consolidated at 15 kpsi. A metal cap was then welded over the sleeve to form a hermetic seal. A pictorial representation of a packaged device is illustrated in Figure 3.

II. Theory of Operation

A schematic representation of a device is shown in Figure 4. The structure essentially consists of two pn junctions, which have been designed to breakdown at potentials exceeding 500 V. These junctions are represented as diodes. The small parasitic interconnect resistance of the aluminum contacts and silicon substrate are represented by R_C. Operation of the device is straightforward.

A voltage potential, which is applied between the pins, will result in one diode being forward biased and the other being reverse biased. As long as the magnitude of the potential is less than the breakdown voltage (V_{BV}) of the reverse biased junction no current will flow through the part. Hence, no power can be coupled to the part from the power supply for potentials less than the breakdown voltage (V_{BV}).

Forward and reverse biased pn junctions have a capacitance associated with mobile charge being stored on opposite sides of the metallurgical junction. At RF frequencies the back to back pn junctions appear as two small value (typically 2-10pF) series connected capacitors. A small resistance (R_C) is connected between them. R_C accounts for the resistance associated with the silicon substrate (typically a small fraction of an ohm). A

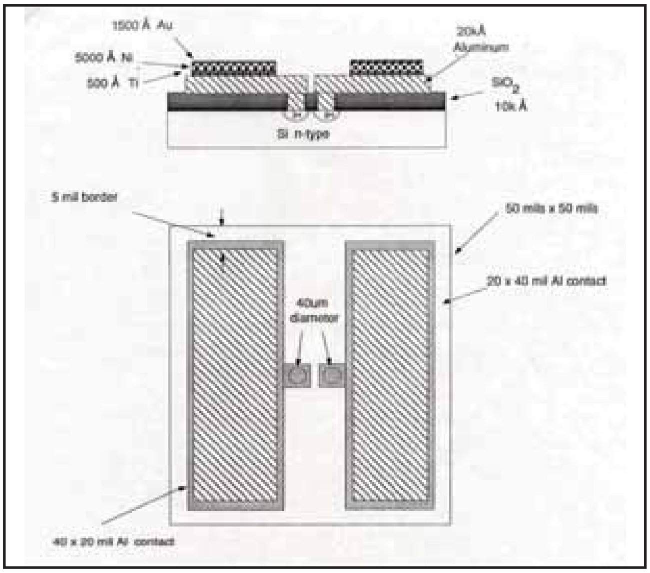

Fig. 2. Pictorial representation of the device.

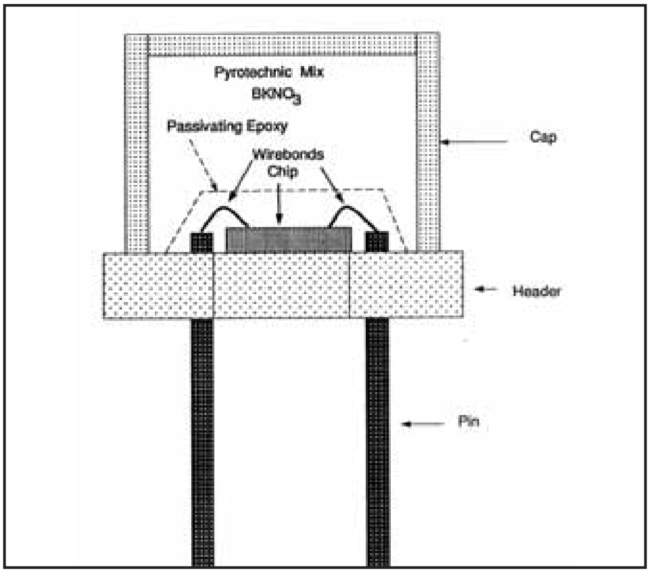

Fig. 3. A pictorial representation of a packaged device.

more complete description of the RF characteristics and EMI insensitivity of the integrated pn junctions was previously discussed in [13]–[14].

Any RF signal coupled to the leads of the device is essentially presented with a purely capacitive, reactive load, for any value voltage below V_{BV}, irrespective of signal frequency. The voltage measured across the input leads and current flowing through the series connected pn junctions is essentially always 90 degrees out of phase. Hence, the power coupled to the structure is purely imaginary, except for the negligible Joule heating of the silicon substrate resistor R_C.

A simple test to verify this phenomenon is to plug the leads directly into a standard 110 VAC power outlet. No deleterious effects were ever observed. All parts plugged into a conventional outlet were then fired. The parts functioned normally with no observed irregularities. This capability fulfills a Mil-Standard requirement (MIL-STD-1316D) which is presently unachievable by other initiators.

Any signal coupled to the device, of any frequency, which is below the breakdown voltage of 500 V does not heat the pn junctions. Hence, the device is insensitive to any frequency signal with peak amplitude less than 500 V. This standoff capability provides extreme EMI insensitivity.

A number of parts were placed in a curve tracer to empirically determine the current-voltage characteristics of the devices. A typical trace is shown in Figure 5. It is noted that a potential of approximately 540–560 V was required to drive the reverse biased pn junction into breakdown. To further substantiate the standoff capability, parts were connected to the output of a high-voltage DC power supply.

A potential of 500 VDC was applied across the terminals of the part. The device was kept at this potential for at least 30 minutes and then the leads were reversed to stress the other pn junction on the chip. No parts that were observed to have a breakdown voltage in excess of 500 V on the curve tracer were in anyway affected by the sustained bias of the

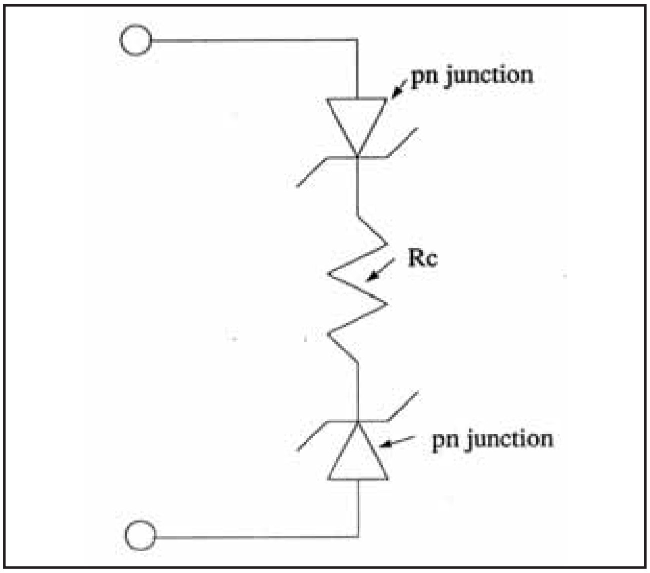

Fig. 4. Schematic representation of completed device.

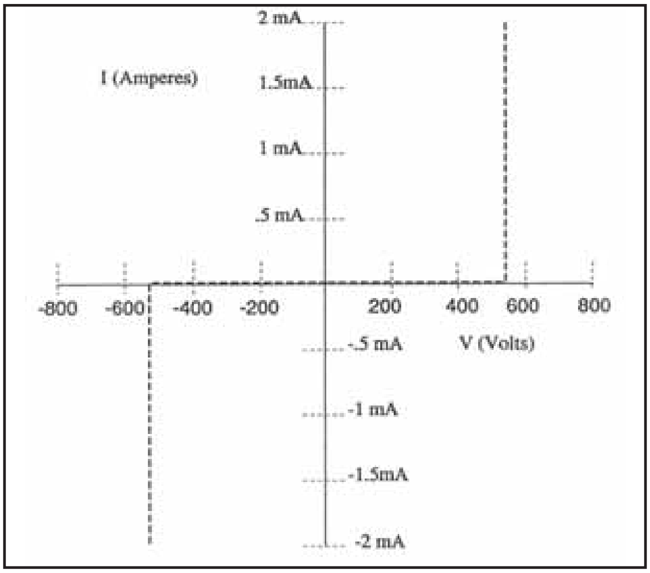

Fig. 5. Typical curve trace of device.

Fig. 6. Silicon pn junction during vaporization.

Fig. 7. Photograph of a fired device.

500 VDC potential. A number of parts were also stressed at 500 VDC for 24 hours with no effect.

III. Firing Characteristics

Firing of the device is achieved by applying a potential which exceeds the breakdown voltage (V_{BV}) of the reverse biased junction, such that a sustained current I (t) will flow through the device. The product of V_{BV} and I (t) is the power which is dissipated in the reverse biased pn junction. The absorbed power quickly heats the junction until it undergoes a phase transition from solid into a very high conductivity region of plasma. An example of a pn junction operating in this mode is illustrated in Figure 6 [15].

The utilization of a fire set with low inductance and resistance optimizes power being coupled to the junction during firing. A photograph of a typical fired part is illustrated in Figure 7.

It is evident that considerable silicon has evaporated from the center of the chip where the diodes were located. It is also interesting to note that the 1 mil-diameter gold wire bonds evaporated in the plasma in addition to the junction areas on the chip. Since an exploding bridge wire has been extensively studied it may be possible to construct a detonator by pressing a suitable high explosive around the gold wire and the surface of the chip. The hot plasma that forms by exploding the gold wire and chip surface may be capable of initiating a high explosive in a manner analogous to an exploding bridge wire (EBW).

A schematic of the firing circuit is illustrated in Figure 8. The circuit consists of a high voltage power supply which is adjustable to produce an output voltage from 0 V to 1 kV. This potential is used to charge a .1 μF capacitor through a 1 MΩ series resistor. A 5.0 MΩ bleed resistor was included which was electrically connected in parallel with the firing capacitor. A triggered spark gap was utilized to discharge the capacitor through the part. Simple metal clip leads were used to connect to the leads of the part. The series inductance and resistance of the fire set were measured in the conventional manner from the ringing down of the shorted fire set. The inductance was measured as 272 ηH and the resistance was 255 mΩ.

The test firing of several dozen parts yielded a mean firing voltage of 800 V with a corresponding sigma of 8 V. The current and voltage of a typical firing (1 kV) is portrayed in Figure 9. The peak current was approximately 250 Amperes. The peak voltage measured across the leads was approximately 850 V. The entire time period for the capacitor to discharge was approximately 1 μsec.

Several dozen parts were also fired at 1 kV. The voltage was always sufficient to ignite the powder charge. The emphasis of this effort was to demonstrate that a monolithic device could be fabricated which could standoff the required voltage (500 V) listed in MIL-STD-1313D and directly initiate $BKNO_3$.

The breakdown voltage of this device can be varied to either a higher or lower value by selectively varying the background doping of the substrate, implant dose, drive-in time and diam-

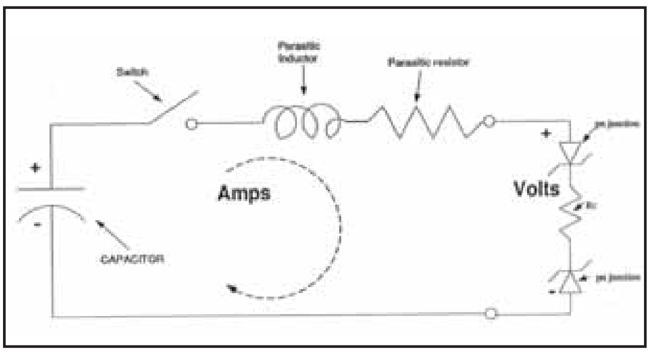

Fig. 8. Typical Firing Circuit.

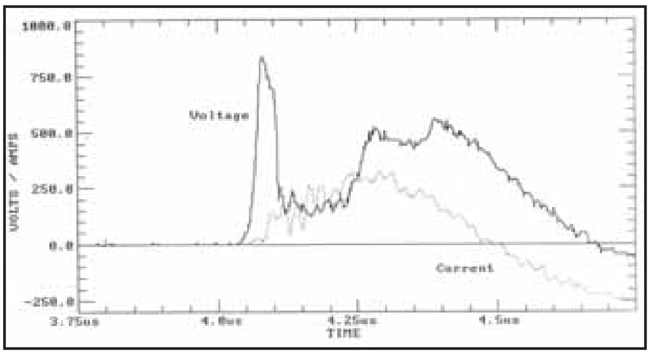

Fig. 9. Current and voltage of a typical firing.

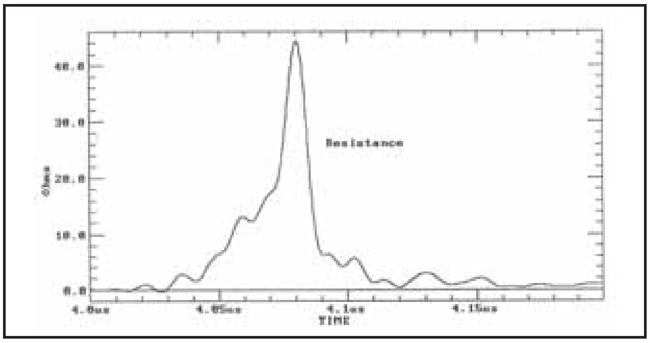

Fig. 10. Ratio of voltage to current for typical firing.

eter of the two pn junctions [16]–[17]. A plot of the ratio of voltage to current is illustrated in Figure 10.

Conclusion

A monolithic electro-explosive device has been demonstrated which is capable of standing off a potential of 500 V for extended periods of time. The device is simple, easy to fabricate, mechanically robust, and capable of directly igniting a common pyrotechnic compound ($BKNO_3$). Successful functioning of the device was accomplished using a capacitor driven discharge. The effort represents the first semiconductor igniter to standoff large voltages independent of external electrical filtering circuitry. Future efforts will be directed at studying the plasma created by functioning of the device via optical spectroscopy.

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