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OPTICALLY-TRIGGERED HARDENED THYRISTORS FOR FIRING SET CIRCUITS

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ABSTRACT

Silicon thyristors, directly triggered by light, are used to switch pulsed currents in firing set circuits. They are hardened to transient ionizing radiation by the addition of a reverse-biased compensating photodiode connected to the gate of the thyristor. Tests of these compensated devices show radiation-induced switching is completely inhibited in excess of 1.4×10^9 rad (Si)/sec.

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SUMMARY

Purpose of This Work

An optically-triggered silicon thyristor for high pulsed-current (firing set) applications has been hardened to unwanted triggering due to transient ionizing radiation by the use of a compensating photodiode. Thyristors can achieve fast switching for high peak values of pulsed current. Optical triggering is particularly useful in firing set applications, because the trigger circuit can be electrically isolated in a Faraday cage that only requires non-conductive optical fiber inputs for control. This reduces the possibility of inadvertent introduction of electrical energy and allows for an extra margin of safety in firing set trigger design. Thyristors, however, are susceptible to switching or latch-up in the presence of high ionizing radiation dose rates[1]. As a result, a high-voltage, radiation-hardened optically-triggered thyristor is needed for military firing set applications. We are developing thyristors that are hardened to transient radiation by the use of a compensating photodiode. The compensating device is reverse-biased, and is connected to the gate of the thyristor. Both devices are packaged together to form a radiation-hardened, optically-triggered switch.

Significant Results

Here we describe the basic hardening concept, its application to discrete silicon thyristors, the design of the hardened switch, and experimental data on radiation-induced switching. These results document a large improvement in tolerance to radiation dose rate.

The hardening technique for the optically-triggered thyristor is shown in the schematic of Figure 1. The compensating photodiode acts as a gate-turn-off element for the optically-triggered thyristor. This compensating element is shielded from the optical trigger signal and is only activated in a radiation environment. When hit with a pulse of radiation, both the thyristor and the photodiode uniformly absorb the high-energy photons. This produces a negative photocurrent at the gate of the thyristor, which then functions as a gate turn-off device. The turn-off signal increases with the level of radiation dose-rate and provides self-regulating feedback against switching by the radiation-induced photocurrents generated within the thyristor.

Since the thyristor is optically triggered, its gate is available for use with the radiation compensator. This concept separates our compensating technique from balanced or "dark diode" circuits. If the gate of the thyristor was required for both triggering and compensation elements, then those input elements would have to be balanced.[2] Here, the turn-off current at the gate of the thyristor must only be sufficient to keep it from turning on. Thus, the thyristor and photodiode do not have to be balanced in their radiation characteristics.

Figure 2 shows an implementation of the optically-triggered, radiation-compensated thyristor in a typical firing set circuit. Note the use of a double voltage divider, which allows the thyristor and photodiode to be biased with a single-polarity power supply. When the thyristor is triggered by the incoming light pulse, it discharges the capacitor, which induces a pulse of current on the transformer. The corresponding voltage pulse (V_{trig}) at the transformer secondary then triggers the high-voltage sprytron switch, which fires a detonator. Previously used circumvention techniques have included a shunting path for the capacitor discharge.[2] Recharging of the capacitor, however, can take a large amount of time, due to the series resistors used in the voltage divider. The use of a compensated thyristor represents an improvement over shunting techniques, since the capacitor is not discharged during a transient radiation pulse.

We tested the compensation concept using a discrete silicon thyristor and photodiode in the arrangement of Figure 1. The thyristor was a three-terminal, 100 V device (Unitrode GA201), connected to an EG&G UV-040 photodiode (40 square mil active region). The devices were exposed to 3 ns radiation pulses from a Febetron 706 x-ray pulser using a tantalum target. Peak spectral response was between 100 and 300 keV. Experimental results appear in Figure 3. Here, the critical radiation dose rate (required for switching) is plotted as a function of applied voltage (V_A). The area above and to the right of each threshold line represents dose rate and applied voltage combinations that will cause switching. With the gate of the device floating, switching occurred along the lower line of Figure 3, indicating that the device is soft above 4 x 10^8 Rad(Si)/sec at applied voltages greater than ≈ 5 V. Various negative currents were then applied directly to the gate of the thyristor during testing. We found that compensation currents of only -1.0 μA into the gate would inhibit switching up to our maximum obtainable values of 100 V and 1.4 x 10^9 Rad(Si)/sec. Next, an EG&G UV-040 silicon photodiode was connected to the gate of the thyristor in the configuration of Figure 1. When it was biased through 50 Ω at -10 V, switching was again inhibited up to 100 V and 1.4 x 10^9 Rad(si)/sec as in Figure 3. Finally, the biased photodiode was shielded with 0.75 inches of lead so it would not produce large photocurrent during the radiation pulse. In this configuration, any negative photocurrents were on the same order as the leakage current (≈ 1 nA) that flowed from the gate of the thyristor. Switching then occured along the upper curve in Figure 3 so that dose rates above 7 x 10^8 Rad(Si)/sec caused triggering at applied voltages greater than 20 V. These experimental results show that our compensation technique effectively inhibits radiation-induced switching in thyristors. Compensation can be easily applied to existing silicon devices.

An important property of the radiation-compensated thyristor is its ability to be triggered easily by light, while being resistant to triggering by radiation. This can be described as discrimination between light and radiation. As demonstrated above, small (1 μA) negative leakage currents at the gate of the thyristor can cause the radiation-induced switching to cease. If this leakage affects the optical switching, then unacceptable jitter may occur.
Optically-induced switching was verified using a circuit similar to that of Figure 2. In this test configuration, the transformer was removed such that the thyristor discharged a 0.47 uF capacitor. Discharge currents were monitored with a pulse current transformer probe. The thyristor was first tested with the compensator removed. The optical fiber from the semiconductor diode laser was positioned to produce an 80 mil diameter spot of light on the 80 mil x 80 mil thyristor chip. Incident optical powers as low as 3.5 mW in a 200 ns pulse triggered the thyristor, though switching delays as high as 200 ns were associated with the low-power optical switching. Between 80 mW and 365 mW peak power, switching delays were essentially circuit-limited at 50 ns. The laser input currents associated with these

optical powers ranged from .15 to 1 A. This further illustrates the advantages of optical triggering, as high currents were easily controlled with a very low energy triggering stimulus.

Laser triggering was again tested at 80 mW, but a reverse-biased photodiode was connected to the gate of the thyristor. Various levels of continuous light were focused onto the photodiode to simulate the effects of constant-current leakage. The results appear in Figure 4. Note here that switching delays are approximately constant at 120 ns up to 6 μA of reverse leakage. At 2mA, the delay is only increased to 180 ns. This increase was much less at high values of input laser power. Since compensating photodiodes would not be expected to leak more than a few μA, the compensation technique does not cause reduced trigger performance. In fact, the increase in photodiode leakage at higher temperatures can be used to stabilize the voltage blocking characteristics of the thyristor.

The pair of devices used in Figure 1 can be packaged as a single optically-triggered radiation-compensated component. This is accomplished as in Figure 5, where the two devices are mounted on the base of a TO-5 package. The thyristor is placed such that its anode is against the gold-plated top surface of the insulator spacer. Contact is made from this layer to an insulated package lead by a 1 x 20 mil gold ribbon. The cathode is connected to the other insulated lead by four aluminum wire bonds, each 1 mil in diameter. Large-area or multiple wires (or ribbons) are required for the thyristor to handle the high pulsed current associated with firing set circuits. This arrangement also allows the thyristor anode and cathode to be placed at raised potentials with respect to ground, as in Figure 2. The photodiode can then be reverse biased by mounting it directly on the TO5 package (as in Figure 5), or on another insulator connected to a pin, which is then connected to ground by a resistor. The photodiode cathode is directly connected to the gate of the thyristor by a 1 mil wire. To complete the package, the photodiode will be shielded from light by an opaque coating, and a windowed cap added to allow optical fiber access to the thyristor.

In order to qualitatively simulate the limits of the radiation compensation technique, the thyristor and photodiode of Figure 4 were tested with laser pulses of various durations with several values of photodiode bias. Light was focused onto both devices and peak powers were well above switching threshold. The result of this experiment was that at high powers a negative current on the thyristor gate was required even after the laser pulse had ceased. This need for compensation past the time of the stimulus is due to the long transit times associated with thyristor switching. The time constant of the compensator circuit must then be large to extend the limits of radiation tolerance. In addition, longer pulse lengths (above 100 ns) require greater compensation currents for longer periods of time to keep the thyristor from switching. This is an expected result, since the pulse lengths were all well below the expected carrier lifetime in the silicon thyristor. These limitations will be investigated, using radiation sources that can provide longer pulse durations. In addition, the effect of neutrons on the compensation technique will also be determined.

Impact of This Work

We have presented a technique to harden optically-triggered thyristors against radiation-induced latch-up. The advantages of optical triggering are especially apparent, as the optical trigger allows the gate terminal to be used for radiation compensation. The compensation technique is also attractive when compared to shunted circumvent circuits, since the use of this component in a firing set circuit will prevent radiation-induced capacitor discharge. Circuit recovery time associated with capacitor charging is then improved. These features make the radiation compensation of optically-triggered thyristors particularly well suited to firing set applications, and the technique can be used on a variety of circuits that require high current switching in transient radiation environments.

References

1. R. F. Carson, R. C. Hughes, T. E. Zipperian, H. T. Weaver, T. M. Brennan, B. E. Hammons, and J. F. Klem, "Radiation Response of Optically-Triggered GaAs Thyristors," *IEEE Trans. on Nuclear Science*, vol. 36, pp. 2147-2154 (1989).

2. J. H. Stitchman, "Thyristor Switching of Capacitor Discharge Firing Units," From Report LA-7244C, "Second Annual Joint Y-Unit Steering Committee / Livermore Firing Set Committee Firing Systems Conference"(U), Los Alamos, NM, p.162 (1978).

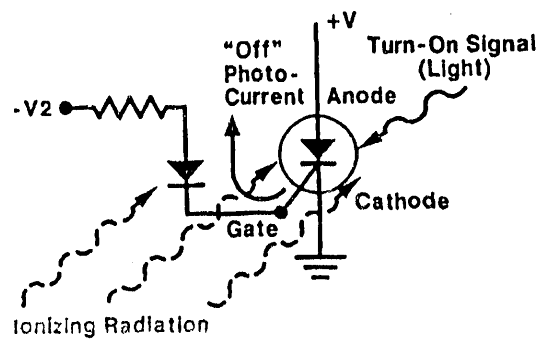

Figure 1. Radiation-compensated thyristor schematic diagram. The compensating photodiode provides greatly increased tolerance to radiation-induced switching.

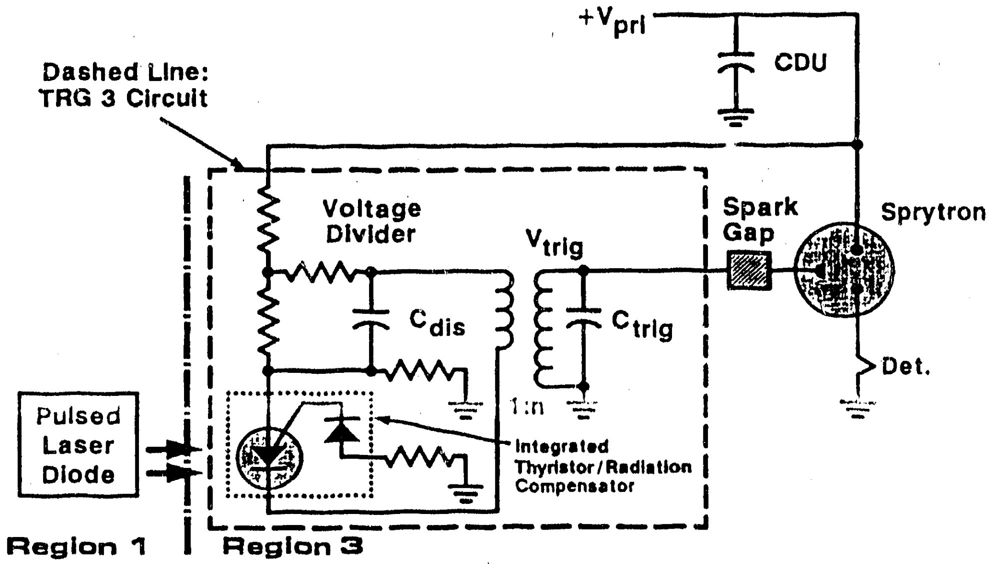

Figure 2 Use of the radiation-compensated thyristor in a single polarity firing set circuit.

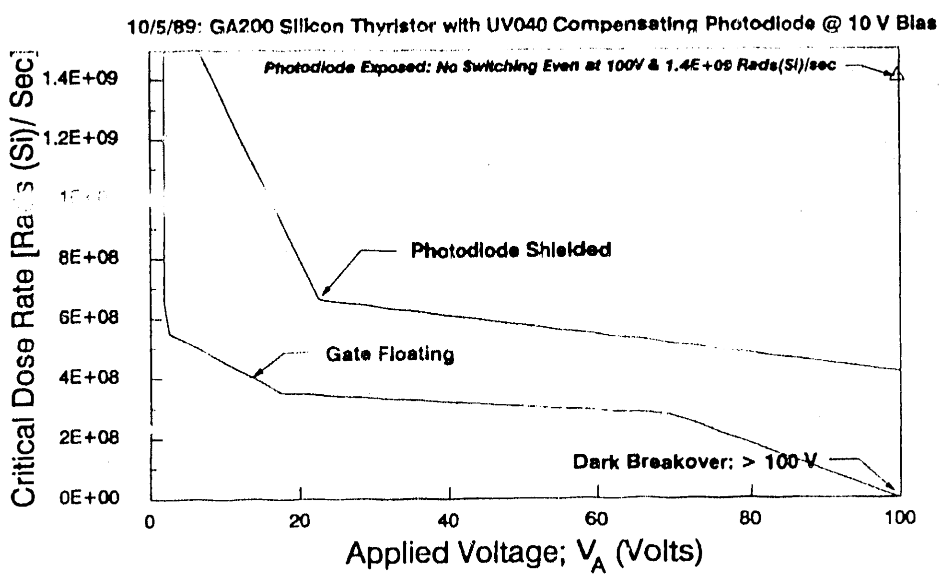

Figure 3. Radiation tolerance of the compensated thyristor to high dose rate, 3 ns pulses from a Febetron X-Ray pulser.

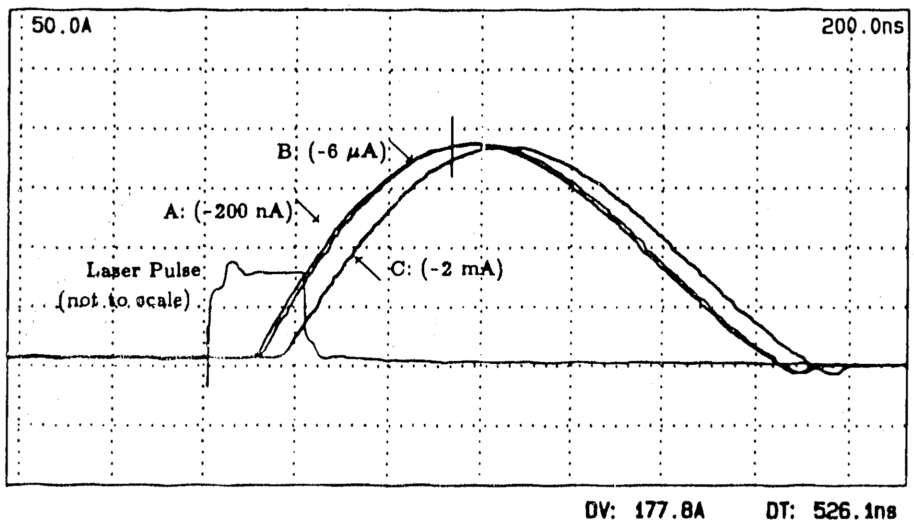

Figure 4 Time versus current trace of capacitor switching. Scales are 50 A/div (vertical) and 200 ns/div (horizontal). Various photodiode reverse leakage currents were simulated as follows: A = -200 nA B = -6 μA C = -2 mA.

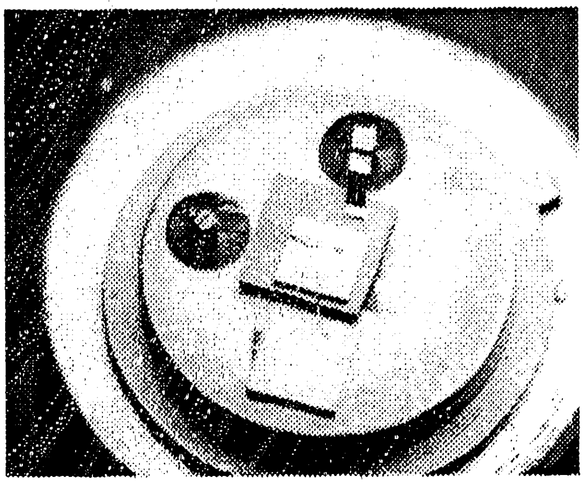

Figure 5 The optically triggered thyristor and radiation-compensating photodiode in a TO5 package.

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