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A NEW TECHNIQUE FOR HARDENING OPTICALLY-TRIGGERED THYRISTORS

R. F. Carson, R. C. Hughes, H. T. Weaver,
T. M. Brennan, and B. E. Hammons

Sandia National Laboratories, PO Box 5800, Albuquerque, NM 87185

ABSTRACT

Optically-triggered thyristors are hardened to high X-ray dose rates by the addition of a monolithically integrated compensating photodetector. Tests of discrete device arrangements show radiation-induced switching is completely inhibited up to 1.4 x 10^9 rad (Si)/sec.

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SUMMARY

Purpose of This Work

A design technique with potential for unlimited dose-rate hardening of optically-triggered thyristor switches has been implemented in silicon (Si) and gallium arsenide (GaAs) devices.

Optically-triggered thyristors represent a class of switches that allow fast, reliable, noise-immune operation over a wide range of electrical currents. Consequently, these switches find a wide variety of applications. GaAs thyristors show immunity to switching or latch-up in the presence of high ionizing radiation dose rates [1]. Their designs, however, generally require trade-offs between hardness and operating voltage. As a result, there remains the need for a high-voltage, ultra-hard optically-triggered thyristor. Here, we address this need by demonstrating a hardening technique that involves the use of a compensating element with the thyristor.

Significant Results

In this work we describe: (1) the basic hardening concept, (2) experimental data on x ray-induced switching using discrete silicon devices in a compensation arrangement, (3) design and performance of a monolithic GaAs hardened switch. These results document a very large improvement in tolerance to radiation dose rate.

Our hardening technique is shown schematically in Fig. 1. It employs a photodetector (a photodiode or phototransistor) as a gate-turn-off element for an optically-triggered thyristor. This compensating element is shielded from the optical trigger signal and only becomes active in a radiation environment. When hit with radiation, both the switch and the compensator uniformly absorb photons. This provides a negative "turn-off" photocurrent at the gate of the thyristor. The turn-off signal increases with the level of radiation dose-rate and provides self-regulating feedback against radiation-induced photocurrents generated in the thyristor.

Using this technique, design parameters such as device thickness no longer strongly influence radiation dose-rate tolerance. Thus, there is no trade-off between radiation tolerance and operating voltage. This allows the design of an extremely light-sensitive high-voltage thyristor that is immune to switching by high radiation dose rates.

We first tested the compensation concept, using a discrete silicon thyristor and photodiode, as in Fig. 1A. The thyristor was a three-terminal, 100 V device (Unitrode GA200), exposed to a 3 ns radiation burst from a Febetron 706 x-ray pulser. Results appear in Fig. 2. 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 voltage combinations that will cause switching. With the gate of the device floating, switching occurred along the lower line of Fig. 2, indicating that the device is soft above 4 x 10^9 Rad(Si)/sec at applied voltages greater than $\approx$ 5 V. Various negative currents were applied to the gate of the thyristor during testing. We found that as little as -1.0 μA into the gate would inhibit switching up to our maximum obtainable values of 100 V and 1 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 Fig. 1A. When it was biased at -10 V through 50 Ω, switching was again inhibited up to 100 V and 1 x 10^9 Rad(si)/sec as in Fig. 2. Finally, the biased photodiode was shielded with lead so it would not produce photocurrent during the radiation pulse. In this configuration, only the negative leakage current ($\approx$ 1 nA) flowed from the gate of the thyristor. It then switched along the upper curve in Fig. 2 so that dose rates above 7 x 10^8 Rad(Si)/sec switched at applied voltages greater than 20 V. These experimental results show that our compensation technique effectively inhibits radiation-induced switching in thyristors.

The pair of devices used in Fig. 1 can be monolithically integrated on a substrate for simplicity, reliability, and dose-rate uniformity. Integration is most easily accomplished in the GaAs epitaxial device structure of Fig. 3. This implements the circuit of Figure 1B, where a phototransistor is the compensating element. A top view appears in the inset of Fig. 4, where the center device is forward biased to be the optically-triggered thyristor and the outer ring is reverse-biased to act as the compensating photodetector.

The breakover voltage level without illumination is a function of depletion width, avalanche effects, and the regenerative gain present in the n-p-n-p structure. To first order, the blocking layer must be low-doped to prevent avalanche breakdown at higher voltages. The layer thickness must then be large to prevent the punch-through breakdown condition [1]. When the thickness is increased to accommodate a larger voltage, the radiation tolerance drops for uncompensated devices. Because the induced photocurrent in the compensating transistor of Fig. 3 increases with blocking layer thickness, the thyristor will be compensated, even when the blocking layer is thick. Thus, the integrated design can be hardened without limits on operating voltage.

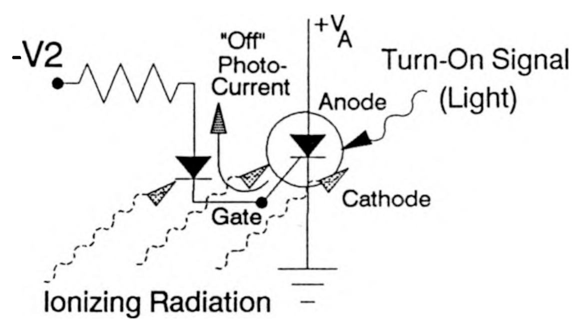
We performed tests on the integrated structure where light impinged on both devices. The results, shown in Figure 4, confirm the compensation mechanism described in Figure 1. Here, the voltage-current curve was traced in a current-controlled mode (a) without light, (b) with light only on the thyristor, and (c) with light impinged on both devices. The curve in part (c) shows that even though photocurrent is generated within the device, the compensator disrupts the gain of the regenerative switching mechanism in the thyristor. This keeps the device from switching up to 36 Volts. Additional design and construction details will be presented for the integrated device, along with pulsed x-ray test results.

Impact of This Work

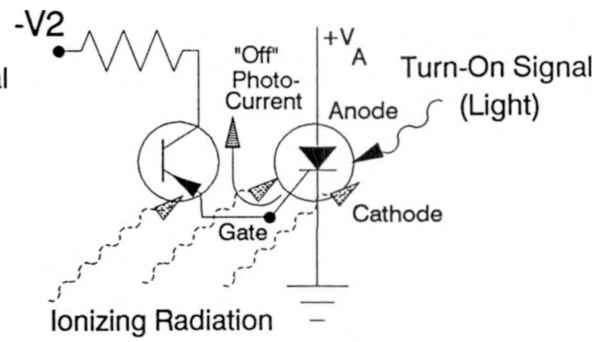
This work presents a technique to harden thyristor structures against radiation-induced latch-up. A properly designed structure will prevent latching at very high dose rates, even for long pulses, since it provides a proportional compensating photocurrent for the duration of the radiation pulse. The use of this technique will also allow thyristors to be designed to high voltage levels without compromising radiation tolerance.

References

1. R. F. Carson, et. al. "Radiation Response of Optically-Triggered GaAs Thyristors," Paper PF-1 presented at IEEE NSREC, 1989 and to appear in IEEE Trans. on Nuclear Science, (December, 1989).



A. With a compensating photodiode.



B. With a compensating phototransistor.

Figure 1. Radiation-compensated thyristor schematic diagrams. Compensating elements provide greatly increased tolerance to radiation-induced switching.

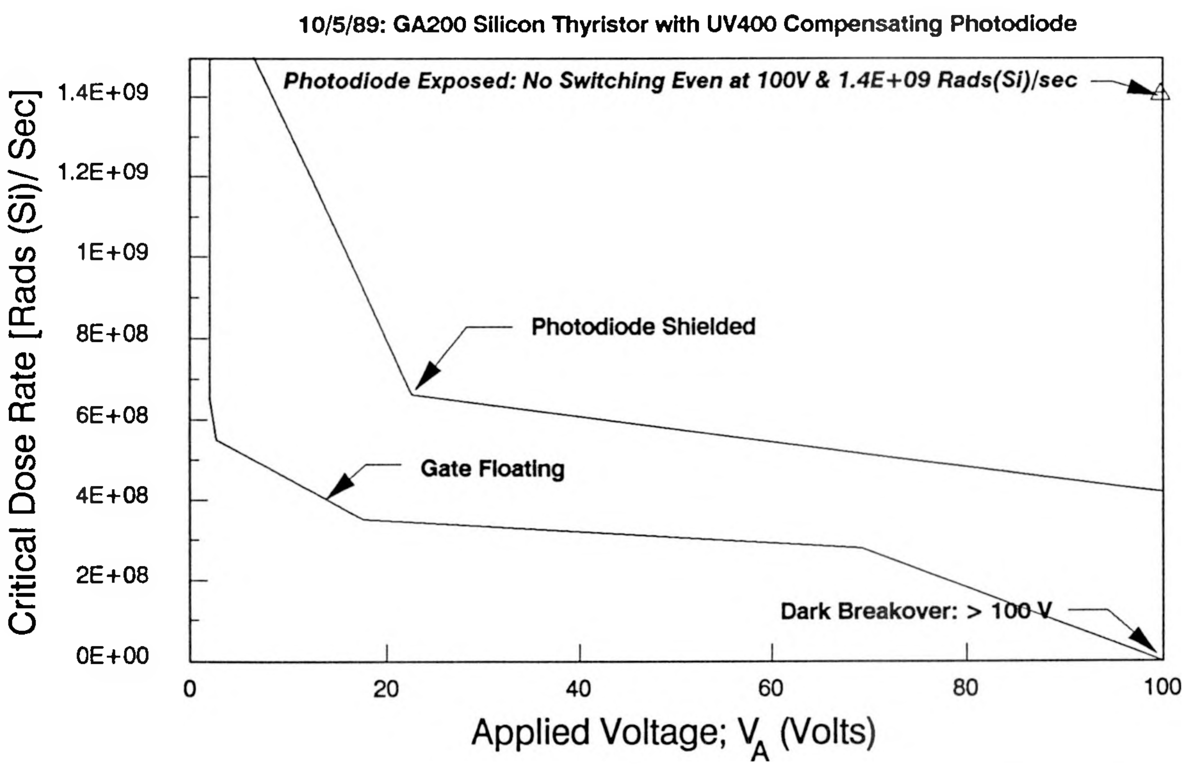
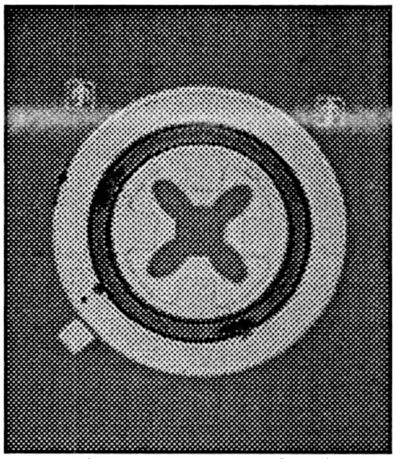
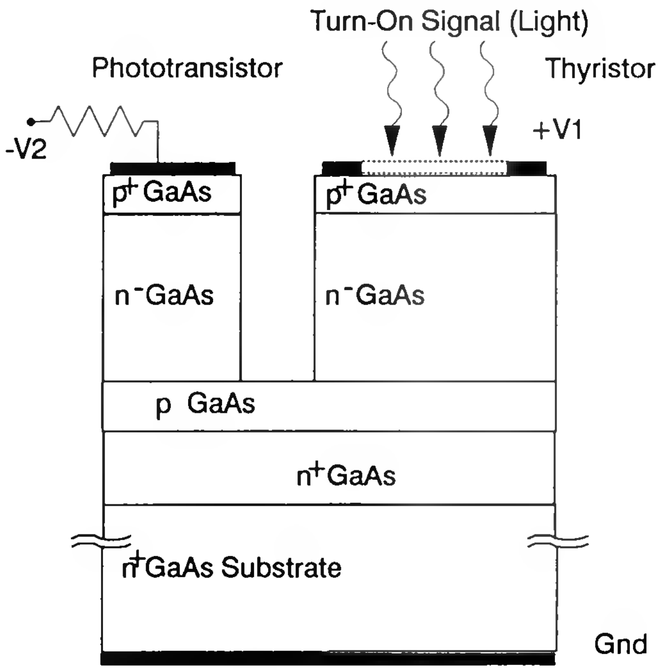


Figure 2. Radiation test results for a silicon thyristor with and without a discrete compensating photodiode, biased at -10 V. Note that we could not switch the device with the compensation in place, even at 100V and 1.4×10^9 Rads(Si)/sec.



Top View: center device is the thyristor and the outer ring is the compensator.



Cross Section

Figure 3. Monolithic implementation of the compensated thyristor in GaAs material.

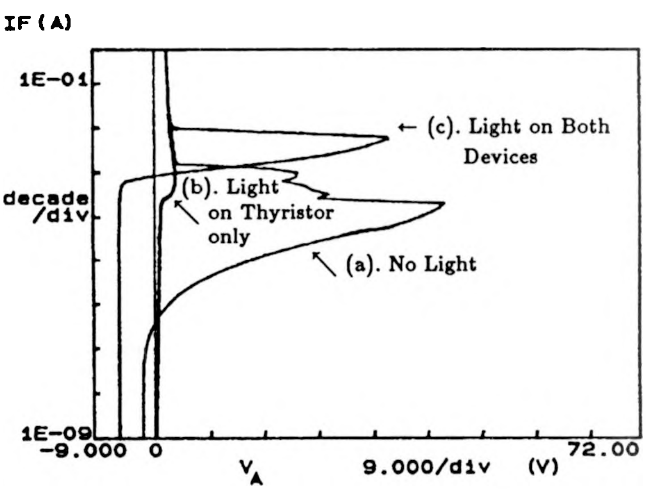


Figure 4. Current-voltage curves demonstrate the compensation mechanism in an integrated GaAs device. When photons impinge on both devices (c), photocurrent is generated but breakover voltage does not drop. In curve (b), light strikes only the thyristor, and there is no voltage hold-off because the compensator is inactive. Curve (a) shows the breakover voltage without light on either device.