MicroNote #050

Radiation Hardened Performance of Discrete Semiconductor Products

by:

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Many system designs have required radiation hardness assurance for semiconductor products. In earlier years this primarily dealt with military programs, but has now evolved to numerous communication satellites exposed to radiation belts while orbiting the earth.

The most common form of radiation in space is from solar electromagnetic radiation or total ionizing dose (TID) effects over a period of time. However other radiation can be of concern particularly in small subcomponents of integrated circuits. For example, radiation can include single event effects (SEE) with heavy ions or charged particle strikes. These may produce collected charge at sensitive node regions in ICs that would impact normal operation. Also single-ion induced events within a MOSFET can result in "single-event gate rupture" (SEGR) and failure particularly for DMOS or EPROMs. Logic circuits can also experience single-event upset (SEU), or in other cases single-event latchup (SEL) as a result of a parasitic SCR structure in an IC becoming energized by an ion strike.

Despite these type radiation effects, many discrete semiconductors can be characterized simply by total ionizing dose effects to ensure satellite mission life. This also conveniently offers program managers and circuit designers a quick overview in performance for many discrete products for radiation hardened space system design. Requirements are typically specified in TID levels of 10^3 to 10^6 rads(Si) or 1 krad to 1 Mrad(Si) depending on the satellite orbit and shielding. In those cases where it may also involve nuclear weapon survivability, it can additionally include neutron irradiation and prompt dose rate testing. The latter can determine if prompt ionization current effects are excessive to trigger SCRs or damage sensitive components such as integrated circuits lacking transient protection.

Many of the silicon p-n junction diode products provided by Microsemi with passivated die in hermetic packages are inherently hard for these radiation levels generally observed in satellite applications and military requirements. Much of this insight has been acquired with accumulated data over the last 20+ years. However some diodes as well as other discrete product types deserve caution. These distinctions are further outlined as follows.

Rectifiers are typically observed as radiation hard up to 10^6 or 10^7 rads(Si) and 10^{14} n/cm^2. This performance is dependent on the rectifier breakdown voltage (V_{BR}) as well as pre and post irradiation requirements in application. Forward voltage (V_F) and reverse leakage current (I_R) eventually become excessive beyond these radiation levels, particularly for higher voltage rectifiers beyond a few hundred volts. The "fast" and "ultrafast" rectifiers will have somewhat lesser effect from high radiation with their shorter minority carrier lifetime material characteristics and other epitaxial design features to minimize forward voltage. This may offer further advantage in some *high* radiation applications. All of these rectifier products are available from various Microsemi Divisions including Santa Ana, Scottsdale, Colorado, Lawrence, and Ireland. The following products are also available.

Zeners and Transient Voltage Suppressors are very radiation hard with majority carrier avalanche breakdown voltage regulation. These easily perform up to 10^7 rads(Si) and 10^{14} n/cm^2 for products up to 200 volts. Below 100 volts, they exceed 10^8 rads(Si) and 10^{15} n/cm^2. These are available from the Microsemi Santa Ana, Scottsdale, and Lawrence Divisions.

Schottky rectifiers also operate on a majority carrier principle with very radiation hard performance and are comparable to zeners less than 100 volts described above. These are available from Colorado, Lawrence, Santa Ana, and Scottsdale Microsemi Divisions.

One of the discrete diode products that are not as comparatively hard includes zero-TC reference diodes that specify very small voltage change with temperature for critical circuit references. Minority carrier lifetime killing effects from radiation can notably influence the reference voltage stability, particularly since there are forward biased pn junction(s) in series with a zener for their zero-TC features (see MicroNote 205). These effects require radiation hardened designs for total dose levels 1 x 10^5 rads(Si) or 1 x 10^{11} n/cm^2 or higher. Some programs requiring guardbands may also choose to impose these hardened design selections at lower levels. Many of these reference diode options are available with specific hardened performance features characterized up to 10^6 rads and 10^{14} n/cm^2 and beyond. This includes specific part numbers and data sheets identifying a very radiation hard type with an "RH" prefix. If ordering a 1N829A for example, the very radiation hard design selection would be identified as RH829A in a DO-7 package from the Scottsdale Division. Other similar DO-35 products are also available from both Lawrence and Scottsdale. Many of these example devices have JAN, JANTX, JANTXV qualifications or JANS equivalent screening. A tungsten slug voidless-hard-glass double-slug design is also available from the Microsemi Santa Ana Division.

Microsemi Corporation also provides Silicon Controlled Rectifiers (SCRs). These are not radiation hard beyond 10^5 rads(Si) and 10^{11} n/cm^2 except when specifically designed for that purpose. Examples include the 2N3027 to 2N3032, which are radiation tolerant. Also the GA100, GA101, and GA102 devices are specifically radiation hardened up to 3×10^{14} n/cm^2 and 10^7 rads(Si) or higher depending on parametric requirements. Details on these and other devices are further described in product data sheets from the Microsemi Lawrence Division (previously Microsemi Watertown on some of these examples).

Microsemi Corporation has also been adding or acquiring numerous transistor products including many that are military qualified. Specific radiation hardened type designs are also available from the Microsemi Lawrence Division. Examples include special designs for the 2N2369, and 2N3725 transistors that have recently been demonstrated radiation hard to the demanding Rockwell Peacekeeper Program. Other types such as 2N5153 and 2N5154 are also available that have generic data demonstrating radiation tolerant performance above 10^5 rad(Si) if operated at I_C collector currents within their specified min-max range. When npn or pnp standard discrete transistors are operated at relatively low I_C current values, they deserve caution in current gain or h_{FE} performance where they are not considered as radiation tolerant.

Other investigations in the industry such as reported by A.H Johnston, et al, at JPL, have found npn devices degrade far more than pnp *discrete* transistors. Devices with high collector-base voltage ratings degrade far more than those with low voltage ratings. Also less damage or degradation occurs at high current densities than at low currents. Wide variations in the total dose hardness of discrete transistors can occur with nearly identical geometries from different manufacturers. Very few devices degrade much below 10^4 rads(Si) while most transistors will degrade significantly at levels of approximately 5×10^4 rad(Si) or more. The primary parameter affected by radiation is gain loss. Circuits that are designed to be less critical to gain losses are also less sensitive to radiation affects.

The rapidly growing PIN diode product line at the Microsemi Microwave Products Division in Lowell offers circuit designers efficient means of RF signal switching. These devices operate with very long minority carrier lifetime in their intrinsic or "I" region for overall RF frequency range performance. Lifetime killing effects from radiation will eventually compromise the lower operating frequencies of these diodes. Although little radiation data is available on PIN diodes, it is still anticipated that moderate levels of total dose radiation up to 10^4 to 10^5 rads(Si) can be absorbed without severely impairing RF parametric switching performance, particularly at higher frequencies.

One example PIN diode that has been characterized in radiation response includes the UM9441. It is specified for use as a detector for nuclear and electromagnetic radiation when reverse biased. This includes gamma, electrons, and X-rays of 10^5 to 10^8 rads.

Since PIN diodes are seeing greater use in new RF applications for replacing reed relays (including 1 GHz or more), a further interest in characterizing them in radiation response is anticipated. Microsemi welcomes R&D evaluation opportunities with PIN diodes (or any other product) in radiation environments where overall high reliability is essential.

Other discrete products that Microsemi has recently added to its product line include MOSFETS and photo detectors. These products are also not considered radiation hard without special processing.

Microsemi has been involved for over 25 years in numerous military programs involving radiation hardened product specifications with stringent performance requirements. This also now includes the largest selection of JANS qualified products in the world that have become predominant in satellite programs. With recent design trends, this also includes surface mount packaging options for virtually any product as well as chips for hybrid use. The Microsemi home page at http://www.microsemi.com also has much of this information.