APPENDIX - F

PIN DIODE RADIATION DETECTORS

NOTES

THE SILICON PIN DIODE RADIATION DETECTORS: UM9441 & UM9442

INTRODUCTION

Silicon PIN diodes have been used as detectors of nuclear radiation for many years [1]. They are more efficient detectors than pn - junctions, and offer good sensitivity to various forms of radiation. They are not restricted to use at low temperature operation but are effective detectors across the entire operating temperature range of -55 ^{o}C to +150 ^{o}C. The PIN diode detects radiation by generating a transient photo current during the time that the radiation pulse is absorbed by the diode's I-layer.

MECHANISM BY WHICH SILICON PIN DIODES DETECT RADIATION

A detailed discussion of the various effects nuclear radiation can have on semiconductor materials is clearly beyond the scope of this brief article. We are concerned here with the mechanism by which a PIN diode detects certain forms of nuclear radiation.

In a heuristic sense, nuclear radiation is the effluence from a nuclear radiation source that consists of energy in the form of particles or waves. The waves are represented as photons or quanta of radiant energy. A radiation detector may be exposed to neutrons (particles), gamma rays, X-rays, or other radiation energy. The radiation can vary in energy density, wavelength, and duration.

When semiconductor material is exposed to nuclear radiation, the energy quanta (Er) is absorbed by the elements of the lattice structure if Er equal to or greater than the band gap energy (Eg) of the material. A hole-electron pair is generated for each quantum absorbed. For Silicon, Eg=1.1eV, which corresponds to a photon of 1.1 micron wavelength [1,2]. Lower energy quanta (or longer wavelengths) are either transmitted through the material or interact with free electrons or lattice site atoms, increasing their steady-state energies.

The predominant reactions of high energy quanta with Silicon are inelastic collisions with electrons and elastic collisions with lattice site atoms. In the former case, the electrons absorb sufficient energy (1.1 eV) to transit from the valence band to the conduction band, creating a pair of carriers (transient effect) that will survive for a time referred to as the recombination time or minority carrier lifetime. Bulk recombination time is typically several microseconds in Silicon PIN diodes. If Er > Eg, secondary ionization effects can occur. If Er is sufficiently large (> 15 eV), lattice site reaction can eject silicon atoms from their equilibrium sites creating permanent damage to the lattice . The presence of these defects after exposure to nuclear radiation adds to the number of carrier recombination sites within the lattice and permanently decreases the minority carrier lifetime of the device. Lifetime can be reduced by as much as a factor of 10, depending on the resistivity of the Silicon and the intensity of the radiation. The device can still function as a radiation detector because lifetime is not a significant parameter when the PIN diode is fully reverse biased.

SILICON PIN DIODES

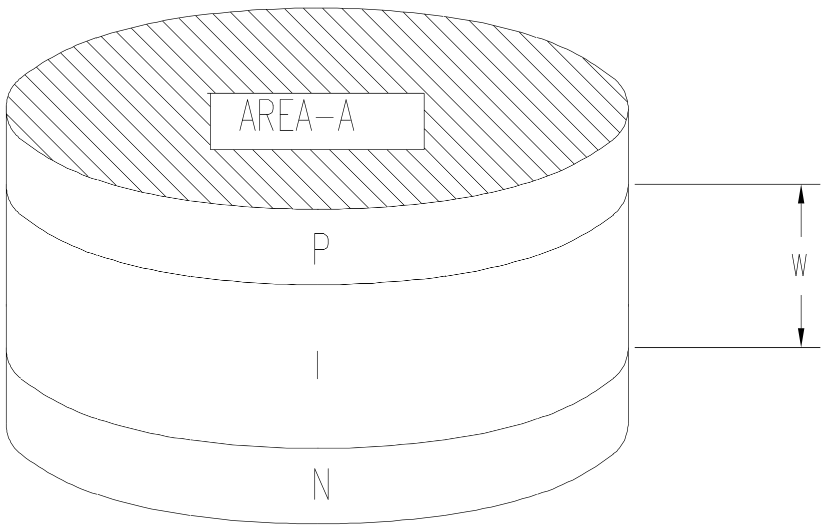


Figure F.1. PIN Diode Chip Structure

Figure F.1 shows the PIN diode chip structure. The high resistivity intrinsic layer is sandwiched between N+ and P+ layers. The PIN diode detects the presence of radiation by the mechanism discussed above. During gamma and/or X-ray irradiation, electron - hole pairs are generated in the silicon.

The PIN diode is reverse biased so that the entire I-layer is swept out (depleted of free carriers). This reverse bias creates an electric force field across the I-layer so that the electrons are swept to the P+ layer and the holes, to the N+ layer. This flow of carriers in response to a pulse of radiation, constitutes a photocurrent that can be measured. To maximize this photocurrent, the I-region must be as large as possible.

In summary, the PIN diode structure possesses the following advantages over pn-junction devices:

Detector Sensitivity (mA of photocurrent per Rad) and photocurrent measurement accuracy are enhanced by the PIN diode structure.

Lot to lot reproducibility of PIN Diode Radiation Detector characteristics is greatly enhanced by Microsemi's PIN diode structure that uses high resistivity Silicon I-layer material.

THE ROLE OF DEVICE PACKAGING

Microsemi PIN Diode Radiation Detectors are available in a glass axial leaded UM9441 and in the TO-39 UM9442. Device packaging also plays a role in the overall performance of a radiation detector. In practice, not all of the radiation pulse is absorbed by the semiconductor material. Some of the radiation is absorbed by the package and other components of the structure. These materials generally emit a spectrum of secondary energies and particles that can be absorbed in the semiconductor material and this gives rise to a photocurrent enhancement effect. The enhancement effect for a particular package can be determined theoretically [1] but is usually determined empirically in practice.

THE UM9441 & UM9442 RADIATION DETECTOR

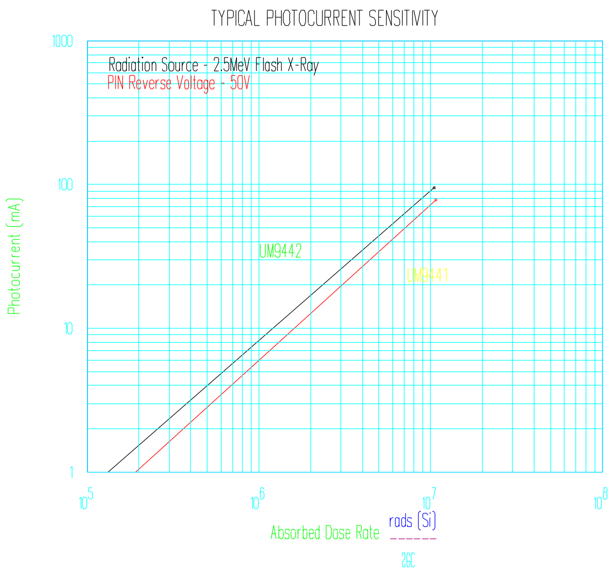
Microsemi Silicon PIN diodes are efficient detectors of nuclear and electromagnetic radiation, including gamma radiation, electrons, and X-rays. The Microsemi UM9441 & UM9442 series utilize high resistivity Silicon and are designed to have uniform area mesa structures to define the active volume of the detectors. Their current sensitivity is proportional to only the I-region volume and is independent of the device temperature as long as the reverse bias voltage exceeds the saturation voltage.

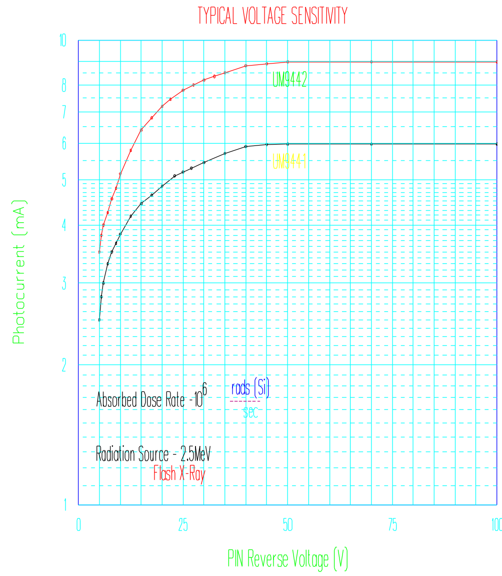
This diode structure minimizes the effects of permanent damage caused by neutrons and other high energy radiation and therefore can withstand high radiation levels. Experiments on UM9441 radiation detectors show that these devices exhibit no degradation in gamma radiation sensitivity when exposed to a total dose of 10 x E 14 neutrons/ cm^2 or a 1 MeV equivalent.

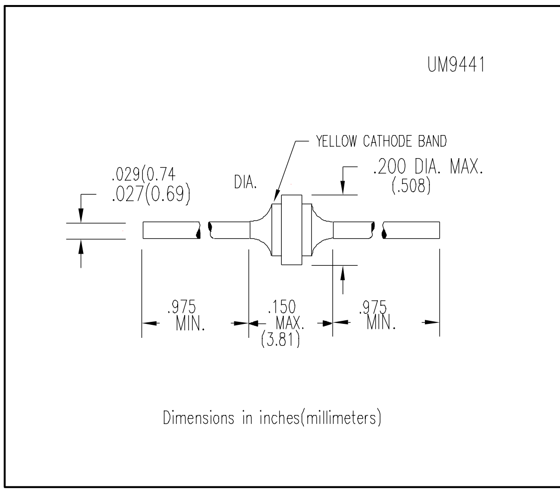
The UM9441 is an axially leaded device constructed by metalurgically bonding the PIN chip between two molybdenum refractory pins that are typically 0.125 inches in diameter and 0.050 inches long. Hyper-pure glass is then fused over this bond to form a voidless seal. Leads are then brazed to the ends of the molybdenum pins. This results in a high reliability HERMETIC package that uses materials that are so well matched thermally, that the UM9441 can withstand temperature shock or cycling from -196 C to + 300 C.
The UM9441 & UM9442 series of radiation detectors can be obtained with compliance to full military high reliability testing. Usually, these devices are procured to a customer's specification control drawing. However, they can be procured as catalog devices with Microsemi's HR2 level screening.

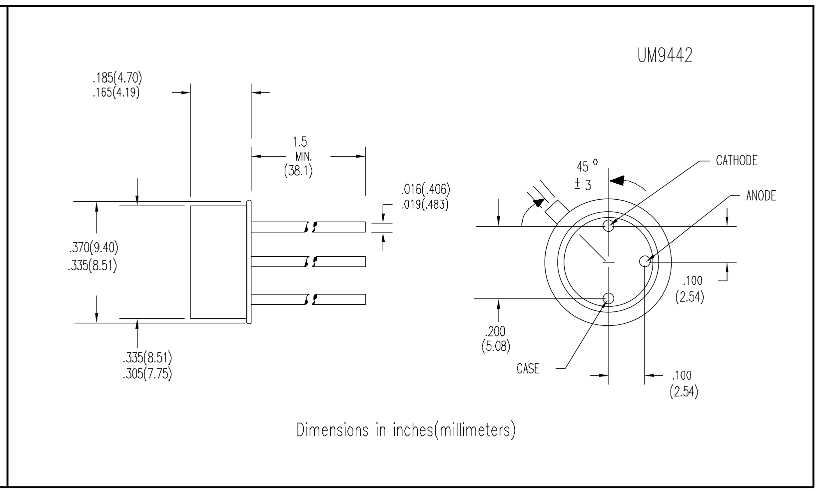
ELECTRICAL SPECIFICATIONS (at 25°C)

Test	UM9441			UM9442			Units	Test Conditions
	Min	Typ	Max	Min	Typ	Max		
Photocurrent	4.0	6.0		6.0	9.0		mA	V_R = 50V $10^6 \frac{rads(Si)}{sec.}$
Photocurrent Rise Time (10%-90%)		10			10		ns	2.5 MeV Flash X-Ray Ion Physics Corp. FX-25
Capacitance		10	15		15	20	pF	F = 1 MHz V = 50V
Reverse Current			1.0			1.0	µA	V_R = 50V
Minority Carrier Lifetime	2.0			2.0			µs	I_f = 10mA









Figures and features are from UM9441 & UM9442 data sheet

APPLICATION	**RECOMMENDED PIN DIODE TYPE**
RADIATION DETECTORS	UM9441, UM9442 CUSTOM DEVICES