Technical Synopsis

This synopsis presents a brief description of the prototype BetaBattery™ design. The BetaBattery™ was intended to be the micro-power unit source of choice for a variety of defense and medical applications where it is vital that continuous, unattended power be delivered in inaccessible locations for 10-20 years or more.

The BetaBattery™

The BetaBattery™ is a long-life, self-recharging battery with 4 primary components:

1. Charger: Tritiated 3D silicon diodes
2. Storage: Thin-film rechargeable Lithium battery
3. Charging Control Board: Microelectronic circuitry that matches the Charger to the rechargeable battery and maintains fully-charged status
4. Case: NRC-approved hermetically-sealed case for secure containment.

The voltage, current, power, energy, duty cycle, and lifetime characteristics are designed for each specific application. In general, the three key characteristics of the BetaBattery™ are:

- Long life: 10 to 25 years
- Low power: < 5 volts, <900µW
- Small size: coin to standard 9v battery

The long-life, self-recharging feature is the differentiating characteristic of the BetaBattery™.

Figure 1 sketches the basic BetaBattery™ fabrication and assembly procedure.

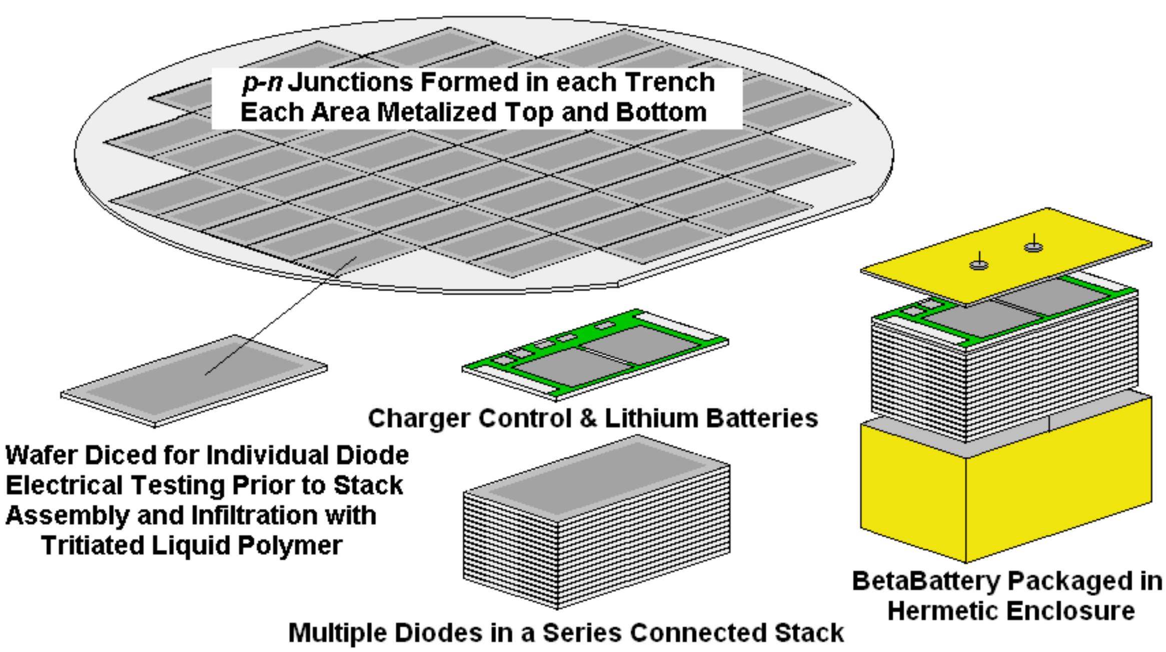

Figure 1. *Prototype BetaBattery™ fabrication and assembly steps.*

Standard photolithography, dopant diffusion and direct electrode deposition processes are done in a semiconductor fabrication facility to produce the 3D diodes. Trenches are formed by deep reactive ion etching (DRIE) followed by the construction of *p-n* junctions on the sidewalls. After dicing the diode chips from the wafer, the complete 3D diode chip stack is assembled and hermetically sealed, excepting the fill tubes, using standard semiconductor welding techniques. The tritiated butyl rubber (TBR) polymer energy source is infiltrated into the stack at an appropriately-licensed radioactive materials handling facility. In the last step, the fill tubes are permanently sealed. At appropriate points during 3D diode fabrication and assembly, electronic measurements are performed to assure the desired performance levels have been achieved. The trench structure for each 3D diode chip and TBR infiltration into the trenches of the stack is illustrated in Figure 2.

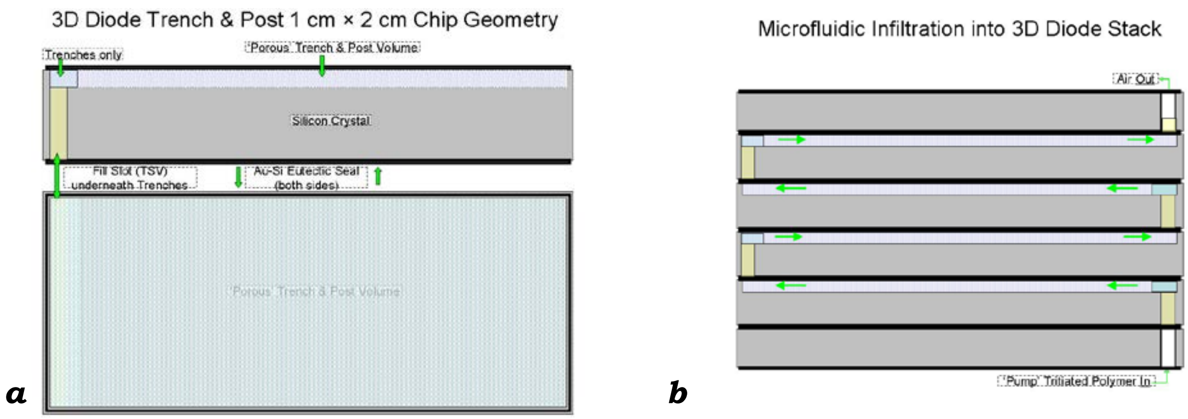

Figure 3. *3D Diode Chip Trench and Stack Design:* ***a*** *Side and top view of 3D diode chip with trench structure.* ***b*** *Side view of 3D diode stack showing flow path of tritiated polymer.*

Inherently Safe Design

It is to be emphasized that the BetaBattery was designed to be inherently safe from the beginning. Tritium only emits low energy electrons which can be stopped by a sheet of paper or a layer of dead skin. The tritiated butyl rubber polymer is biologically inactive and cannot be digested and broken down by normal physiological processes. Thus, once this Tritium energy source is doubly encapsulated inside the 3D diode stack and then inside the hermetic case, there is no external radiation of any kind. The case itself is mechanically strong enough to resist several atmospheres of overpressure. A 'getter' will be incorporated to absorb any Tritium gas that might be evolved. Finally the helium (^3He) resulting from Tritium decay will slowly migrate through the glass-to-metal seals.

The production of the tritiated butyl rubber (TBR) polymer as the energy source for BetaBatt's 3D diode 'charger' stack has been designed with safety in mind. The TBR synthesis procedure constructs the base molecule, $C_4H_3T_5$, without producing unwanted products of mixed hydrogen and tritium isotopes. This capability means that the entire TBR production process will be able to use or recycle the tritium feedstock with the highly desirable benefit of a near-zero waste stream.

Experimental Data and Modeling Results

A selection of experimental data collected from pre-prototype tritiated 3D macroporous silicon diodes and performance estimates from mathematical modeling performed at the University of Texas at Arlington are shown in Figure 3. These 3D diodes performed at lower efficiencies than expected apparently due to excessive charge trapping and a non-optimum *p-n* junction profile. The diode modeling effort was launched to determine the appropriate material and device parameters to maximize the betavoltaic energy conversion response. The yellow line connects the measured photovoltaic power values for two illumination conditions, namely, a solar photon flux of 100 mW/cm^2 (AM1.0) and 'dim room' light which corresponded to a photon flux of ~0.10 mW/cm^2 or AM1.0/1000. The dark blue line shows the mathematical model estimates of both photovoltaic and betavoltaic power. The betavoltaic energy sources are Tritium (T_2) gas, tritiated beta carotene (TBC), and tritiated butyl rubber (TBR).

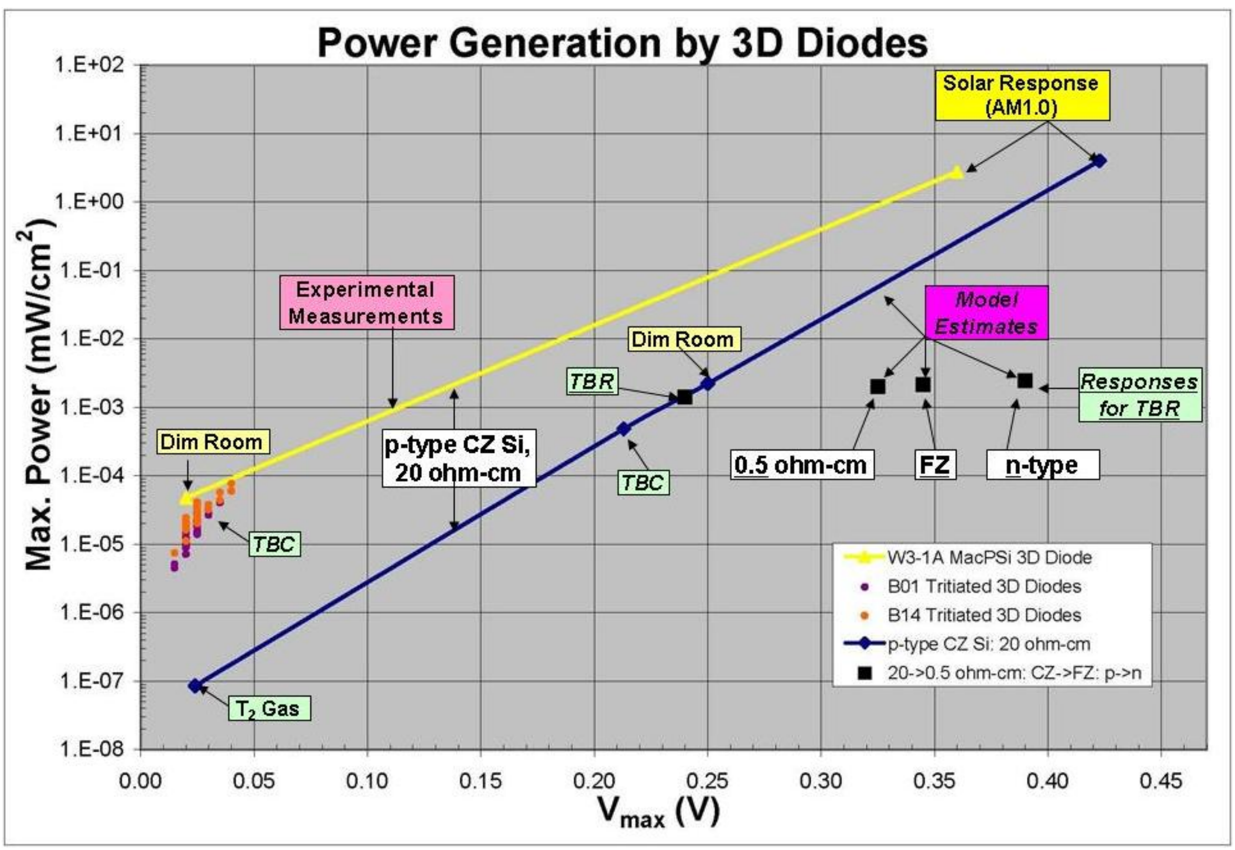

Figure 3. *Comparison of 3D diode power outputs per unit chip area for experimental measurements (yellow line, orange and purple points) with estimates from the mathematical model (dark blue line and black squares) per unit diode area. These results were approximately calibrated to the incident solar flux. The inset Table gives additional technical information and identifiers.*