Problem Solving Packet

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I am presenting the following PAR's (Problem-Action-Result) as a Consultant to show the depth and breadth of my technical knowledge, exposure and experience. These were all actual projects I completed.

1) Rad-Hard needs Rad-Hard Testing

Problem: An ever-increasing interest in Rad-Hard transistors exposed the facts that not only didn't we have a way to do gamma radiation testing on Bipolar Junction Transistors (BJT), but the DSCC Government individual component "slash sheets" specifications had no provisions either for this test nor for evaluating end points to determine pass or fail.

Action: Working with a local University Radiation Lab, I established monthly and then annual contracts to gain access to their ^{60}Cobalt gamma radiation "cave". I designed and built universal test boards to begin testing to see how our products fared. My next step was to design and build a complete temperature and humidity controlled control room adjacent to the "cave". I brought in automatic testers (Lorlin, Tesec) and connected data lines so results could be sent immediately to the factory across town. I designed an eye-popping radiation report format in Excel that stored, performed all the calculations necessary and presented detail plots of all the critical parameters versus a family of radiation exposure curves. All radiation certifications were included in the package. Working closely with Wafer Fab, I promoted design improvements that would cast a wider and wider net full of radiation hardened BJT product.

Result: We were the first company to offer Rad-Hard BJT products qualified to Mil-Prf-19500 specifications described in DLA Slash Sheets whose templates I had designed. We were especially pleased to find that Rad-Hard transistors sold for much more money than ordinary Military Grade transistors. Our products were soon flying and orbiting and I made many, many presentations at numerous radiation forums and aerospace customers promoting this line.

2) Too Many Part Numbers

Problem: With over 4000 Mil-Prf-19500 QPL part numbers and myriads of associated data and documents, it was nearly impossible for both myself and others in Sales to quickly perform a parametric search and access the corresponding military drawings. What was needed was a magic key or "QPL Engine".

Action: I created what I called the "QPL Engine" and gave it the ability to quickly search and select part number candidates in real-time while a customer was on the line. Beside a searchable and sortable parametric listing for each part number, supplemental information such as package volume and settings for PIND, Fine Leak, terminal plating thickness, package outlines and outline dimensions were at one's fingertips. In addition, I provided hot links to the related and dated DLA slash-sheet documents right out of the Government's own DLA resources. Alternately the QPL Engine could evoke DLA's own internal search engine to find newly proposed slash sheet drafts not yet dated.

Result: When customers called me for product and parametric information, almost instantly I could provide the answer plus send the customer a hot-link to the document in question all of which were provided by the QPL Engine. New-hires and new sales staff now were able to get up-to-speed very quickly well-armed with this handy resource of information. Beyond that, I began to offer the QPL Engine to many customers. Nothing makes a customer happier than being turned into an instant "expert".

3) ELDRS the “Hot Tip” and “FatBoy”

Problem: The Space community was learning a new reality in space. Radiation exposure at low dose rates can sometimes be much more deadly that high dose rate radiation. Extra Low Dose Rate Susceptibility (ELDRS) became an imperative for successful radiation testing for medium orbit, high orbit and deep space travel near other planets and moons. If you didn’t have ELDRS test data on your product, you just couldn’t sell them anymore.

Action: I approached our local University Radiation Lab and they were helpful in getting us started but there was a very big new problem. ELDRS testing could take months so all your dangerous high voltage power supplies had to be left set up and exposed during the entire time (often for weeks or even months). Also, the long exposure times cost a small fortune in University lab time, plus, we had very limited flexibility in package types we could use in a world where package types could greatly influence the results in the ELDR radiation field.

My solution was to have constructed a low dose rate ^{60}Cobalt gamma irradiator which I nicknamed “FatBoy” because it weighed 6000 pounds and is, well, fat. Meanwhile, there was a contention over whether the dose rate should be 10mRad/s as being done in the USA or 100mRad/s as was frequently being in Europe. The latter, of course, took only 10% as long to test.

My solution was to have my “FatBoy” built with dual hemispheres where one hemisphere was 10mRad/s and the other hemisphere was 100mRad/s. The biggest innovation, however, was the power distribution network which I designed completely from the ground up. This included all the PCB board designs, chassis boxes, distribution wall panel boxes, automatic safety alarm with automatic disconnect. I could finally allow any production operator to both program and safely connect the voltage biases using individual low-cost voltage program cards that also served as the high voltage interlock switch when plugged into a simple programmable power bias box.

One thing that turned out to be very handy was that I made the cards reversible so polarity could be switched in an instant. Also, each box had its own home-made DVM with the voltage range being automatically switchable to 20V, 200V or to 2000V by the card with complete safety. The programming card voltage setting could be read from across the room and was easily comparable to the DVM display so anyone entering the secure irradiation room could instantly tell if all bias conditions were healthy.

“FatBoy” itself was equipped with 12 plug-in boards each with 4 individual channels leading out to 48 individual program boxes and accompanying program cards. Production now finally was given complete control over all ELDRS irradiation testing armed with a bevy of socket boards that I built which could accommodate nearly every transistor (BJT or MOSFET) as well as most diodes. For the “icing on the cake” I wrote special Excel software that gave production complete control over all exposures and times plus schedule aids to make sure all runs started and ended during the work week. Even the ^{60}Cobalt gamma source was monitored by this software and taken into account. The software even provides for manual tuning of specific dose rates for each test board for special applications. Last, the software could print out a certificate that confirmed all dates and times as well as records of exposure, test board and socket numbers, voltages and configuration. Of course, the total status could be monitored by anyone from their own desk.

Result: We were finally in the ELDRS game. Since there were now competitors also doing ELDRS, “FatBoy” was helping us stay in the game which was becoming very heated indeed. As I write this, DLA is planning on creating a new JANS series that absolutely requires ELDRS on every part number and likely on every lot. Even though the final dose rate has not been locked down, the flexibility of “FatBoy” to customize voltage and dose rate should easily keep up with the changing field.

4) The Shanghai Project

Problem: A lucrative contract to sell a diversity of semiconductor technologies to China was in jeopardy because one technology, the alloy micro zener, was not working and the Chinese delegation was due the following week for training and transfer of processes.

Action: Answering a plea for help from the team leader for this contract, I studied the problem and contacted key resources, then determined where the process had gone wrong and began ordering materials. We had the wrong wafers, the wrong crystal orientation and the wrong alloy boat and furnace profile. Calling in some favors I obtained the necessary wafers to quickly make replacements. The material needed to make the alloy boat arrived the day before the delegation did and the new alloy process worked perfectly the very first time. Long into that night I put together the training program with process and graphic illustrations. I trained the delegation the next day on all aspects of aluminum alloying as if we had always known how to do it.

Result: We enjoyed over $2,000,000 revenue from this venture and the Chinese delegation went home pleased.

5) This Transistor Won’t Hunt

Problem: An important power transistor was plagued with low yields to BVceo. With a prime spec at 80 volts and no customer buying the 70-volt bin fallout, the consistent distribution of around just 75 volts was not well received by either production nor by our customers.

Action: I wrote a transistor simulation computer model that mapped transistor voltage sustaining fields under base narrowing conditions. I then wrote an optimizer for the model that would automatically seek out the best design. Running all night, the model predicted a BVceo of 110 volts for the new design. I ordered the appropriate crystal amid the skepticism of my colleagues and a production lot was started.

Result: The production lot closed with an average BVceo of 110 volts without sacrifice of high current gain or reverse energy and the entire backlog was filled from the single order of crystal. The 70-volt fallout bin never saw another part.

6) Small Signal--Big Trouble

Problem: Waferfab production of 2N2222A and 2N2907A was mired in missed targets, broad h_{FE} distributions and burn-in failures. Low current gain “droop” added to the problems. Offshore assembly build allocations of 40,000 per month could not be met and distributors were in a panic.

Action: My computer simulation models provided better sheet targets and base-emitter depths. No more hit and miss. Introducing C-V plotting and SPC coupled with TCA cleaning, passivation became stable for burn-in. Last, introduction of solid source dopants reduced wide sheet resistance swings.

Result: Wafer production opened up wide. The 2N2222A went so well that die inventories for life-of-program were being accumulated at over 100,000 per month. The 2N2907A, requiring the most changes, ramped up to similar success soon afterwards.

7) The Matrix

Problem: The company had over 6700 part numbers and a maze of chip, substrate, preform and package combinations. New sales people were intimidated by the plethora of products and the product makeup secrets were locked in the minds of people who had left recently.

Action: I employed the assistance of document control and accounting and created a series of matrices covering all of the chips, packages, and part numbers. Information included key parameters, vendors, industry equivalent and even component costs. This information was put into a series of Excel "engines" I developed that served as automatic search and organizers for the data. Sales and key internal people received copies (some information restricted depending on who was getting it). Each matrix had its own built-in "help" resources.

Result: New customer engineering quote review cycle time was reduced from 1-2 weeks to 1-2 days. Error rates went from 1-in-5 to essentially nil. Most important, the information was documented so that future generations would be spared the steep learning curve.

8) No More Gold

Problem: Gold prices were going through the roof and semiconductor prices were falling through the cellar. The days of gold-silicon die attach at low cost were over. As the Engineering Manager, I had to do something fast without compromising the quality of the thermal bond or shear strength of the die. I also needed to be mindful of the sensitivity that ultrasonic wire bonding had to the system used to bond the die to the header.

Action: Working closely with R&D and the rest of engineering, we introduced the use of Pb5In2.5Ag alloy clad nickel-molybdenum disks. This was probably the first use of this alloy in the country. We had requested 4 different PbInAg blends from the vendor. The first and preferred blend worked so well that we never needed to try the other 3 and history was made.

Result: No more gold, either on the die, in the preforms or on the package. Savings were $1 per transistor or well over $70,000 per year.

9) The Implant

Problem: A hybrid circuit manufactured for an implantable defibrillator was in trouble because purchased rectifier chips were failing leakage during temperature cycle.

Action: I formed a team with QA, hybrid design engineering and process engineering. I performed a detailed failure analysis of both the good and the failed chips. SEM, SRP and junction stains were performed first. I approved of the chip diffusion profile and passivation so that wasn't the problem. Since the chips were wire bonded, I evaluated our wire bond process and found that it was excellent so that wasn't the problem. Finally, a detailed analysis of the chip surface with the metal removed revealed that the vendor was not using polished wafers—bad news for wire bond operations. The vendor was unwilling to change so I searched and replaced them with another vendor who promptly sent new qualifying chips.

Result: The new vendor qualified and the old vendor was replaced. Our customer approved of the change. The 10% to 30% module fallout (at $1,000 per module) attributed solely to diode failure essentially dropped to zero.

10) The Space Bridge

Problem: A prominent Space Systems Manufacturer faced a satellite launch program shutdown when a key, non-redundant component (high voltage rectifier bridge) supplied by a sole source vendor was found to be failing at a 50% rate while just in storage. They had no alternate source and were desperate.

Action: I took a 3-pronged parallel tactic.

1) I computer modeled the individual glass rectifiers in the bridge, researched the best source and ordered the epitaxial material to minimize the lead time issue. A new dopant scheme never used before was required. I wrote all appropriate travelers and processes.

2) Using the customer's package outline, I did a thermal heat and stress analysis to select appropriate materials and metal base design. Working with another engineer, I selected the appropriate fill epoxy and ordered these items.

3) I designed the glass diode package, die bonding profile and seal profiles.

Dummy prototypes were run to confirm the braze and seal cycles. I wrote all appropriate processes.

Result: My company was the first ever to pass full space qualification for this component. I met all design deadlines and there were no interruptions in the customer's space launch program. The customer even went as far as to fly out from the West Coast and show us videos of their successful launches. This brought over $100,000 business to my company and prepared us for other space-related markets. It also gave us a new product line.

11) The Nickel Moved

Problem: Consolidating two buildings into one, an already trouble-plagued electroless nickel silicon plating line needed to be reduced in floor space from its initial 1200 sq. ft. I was asked to get it under 600 sq. ft. if at all possible and, by the way, would I please fix the die failure problem attributed to the nickel adhesion failures as well.

Action: My team consisted of the production supervisor and myself. I computer-drafted a tight, efficient plating line with a multi-functional plating sink as the anchor. My drawings went to a local plastics house and a single low-cost 8-foot-long sink with multiple compartments, pump, filter and temperature controlled wells returned. I also changed the nickel metal chemistry to address the die-bonding problem which I had determined was caused by boron embrittlement during die braze. I calculated all the reactions and devised a chemical replenishment scheme that would keep the baths at peak efficiency. Last, I added gold flash capability to the sink, temperature controlled, of course, to prolong the shelf life of the final plated wafer.

Result: The final floor space was now only 120 ft. sq., well under the 600 sq. ft. target. It was esthetically pleasing to behold and went a long way to impress our customers that toured the line. Due to the replenishment scheme and the more compact tank sizes, chemical usage was dropped to 1/5 the previous use rate. This cut nickel waste disposal from $13,000 per year to $2,600 per year. Purchased chemicals were also reduced by a similar factor. The line's capacity was never exceeded and the reliability problem was fixed as well.

12) Zener Target

Problem: Zener target voltage distributions of +/-15% were considered normal. Occasional lots missed target so far that they were scrapped. However, gone were the days of selling a part number for every 5% voltage increment. Our market was now in specific niches and missed targets only added to useless no-value inventory. Also, a large inventory of raw wafers specified for voltages that were no longer selling represented a considerable amount of cash that was unavailable.

Action: I found a number of things wrong. 1) The dopant source, which was spray applied, was not consistent in dosage from wafer to wafer. I changed over to a paper source. 2) The wafer resistivity probe, an eddy induction model, was not repeatable. Since the budget was minimal, I built a reliable 4-point probe. 3) The silicon wafer surface finish varied from vendor to vendor and from lot to lot. I tightened the procurement specs and performed a pre-etch on each wafer to make them all behave the same. 4) Last but most important, I developed a computer model for the following: The diffusion process, the reverse field mapping, the integrated ionization rates, the zener forward characteristics, junction capacitance and TVS clamp voltage.

Result: Zener voltage distributions tightened to +/-3% and, even then, this distribution was limited in part by how tight production was willing to group the starting wafers. I converted my zener targeting model into an Excel VisualBASIC model, turned it over to production and trained them to target their own lots. Because of the model accuracy, previously unusable wafers became usable using diffusion times offered by the new model. Production needed only to stay within the min/max diffusion depth target that I gave them. Wafer starts were reduced to about 33% and the unusable wafer inventory was eventually consumed.

13) The Tin Crystal Grew

Problem: A small crystal of tin breaking off in a satellite and resulting in a cascade system failure high in orbit brought about the sudden end of using economical tin plating for electronic components. Our company was in a scramble because tin plating was all we had.

Action: I, along with industry colleagues, negotiated with the government for a compromise. Tin with 2% minimum lead doping was proven to not have crystal growing problems and was acceptable to all. I contacted my chemical vendor and evaluated several plating chemistries. I used new chemicals, doped anodes and daily production bath monitoring to bring the final plating bath system on line. I had to re-design the plating barrels for better performance because tin-lead baths are more current density sensitive. I wrote a computer model for the entire plating process which spanned barrel high-low loading ratios of 10-to-1 and tolerated the use of filler media when appropriate.

Result: The new bath went on line running within the targeted 3% to 5% lead content. The computer model allowed production to plate a very wide variety of package types and barrel loading quantities. Using the replenishment schemes, plating tank life was extended from 6 months to 1 year. Plating rework was reduced by an approximate factor of 10. Total offline time was held to approximately 2 weeks. The beauty of it all was that production was now enabled to run the line reducing their dependence upon constant engineering supervision.

14) The Slug Had Stripes

Problem: The glass double-slug zener line had been purchased from Hoffman and was very problematic. The glass package's mechanical, hermetic and electrical failures threatened the key business account I was managing. The original engineers were gone and no help could be offered.

Action: I was invited to fix the problem by the plant manager. My assembled team varied as the project progressed but always had representatives from production, facilities, QA and R&D. I determined that the moly-silver-glass seal had limitations and set out to achieve a moly-oxide-glass seal. The final design had silver ends for brazing and a green oxide sealing surface on the inner side under the glass sleeve. Since stress analysis dictated that the silver had to crown the ends of the slug, the green oxide appeared as a stripe around the middle of the slug. Sealing and strength were excellent with lead wires always breaking before the glass during pull test. The glass actually fused to the slug's sides. Since no vendor knew how to make this slug, I designed and directed the set up of the entire production area within our plant and the stripped double-slug diode became a reality. It was necessary for me to re-design the vacuum sealing boats and re-map heat and current flow over the DAP graphite tooling to achieve a maximum 5C temperature spread over the boat.

Result: All mechanical problems with the double-slug zeners stopped and I received a patent on the slug. I went on to develop a standard and a platinum rectifier series spanning 150V to 1600V in this package as well. I received a patent for the platinum silica spin-on dopant that I developed. Another patent was received for the phosphorous spin-on glazing used for the rectifier anode contact. The company gained a silicon nitride passivation technology and I later expanded the line into larger packages and offered many lead-wire combinations and branched out into potted power assemblies as well. (See 3844029, *High Power Double Slug Package*)

15) The ThermalRating Model for DLA

Problem: Thermal derating curves in many Mil-Prf-19500 slash sheets were often inaccurate or altogether missing. Adding to this, it often was impossible to determine if a device was even stable and free from thermal-runaway over the entire intended operating temperature range with the selected mounting method.

Action: I created the ThermalRating Model with which DLA finally had tools to create derating curves while the Model simultaneously monitored for thermal runaway conditions. ThermalRating also allowed the User to simulate HTRB (DC, Pulse, Half-Sine, etc.) on zeners, rectifiers, transistors and MOSFET devices, or, the reverse leakage component during power burn-in on most devices. In deference to Space applications, this model was applicable up to Tj=275C. Included utilities also allowed the User to switch from built-in default constants and calculate their own constants based on a few specific measured values. While not specifically designed for Silicon Carbide or other non-silicon semiconductors, the utilities should allow anyone to calculate the necessary constants to estimate performance on SiC or GaN just the same.

Result: I was finally out of the loop of creating Derating Curves for slash sheets, plus, I was able to enable DLA to work more-or-less independent of constant vendor inputs. Many current DLA derating curves have been updated with ThermalRating. I released the model to JEDEC public domain so that everyone else could predict how safe their HTRB would be or how stable their part would be with the final chosen system heat sinking design. (See JEDEC *Ralph E. McCullough Technical Contributor of the Year Award, 2004)*

16) The Skin-Deep Hot Carrier Killer "Repeller"

Problem: Zener diodes used as Transient Voltage Suppressors (TVS) successfully passing all HTRB Space requirements were now falling short of a new requirement for powered reverse avalanche burn-in. While the lower voltage zeners fared well, voltages at 100V and higher degraded out of spec and the product line was in jeopardy.

Action: I ruled out mobile ion contaminants because of the excellent success with HTRB for the very same parts. Since the failure mode was proportional to the intensity of the voltage field and fared worse as the avalanche voltage increased, the problem was pinned on high energy Hot Carriers. Hot Carriers (fast electron Majority Carriers traveling up to 1E7 cm/s) were colliding with the silicon-glassivation interface and trapping themselves just "under the skin". This was confirmed with numerous experiments and was tied to the silicon self-diffusion activation temperature. The parts could be made to "heal" and become normal again. Classic solutions such as positive bevel mesa structures were not possible since material inventory was fixed to negative bevel construction and time was running out. Since the company had zero sophisticated equipment, such as ion implanters or high resolution photo aligners, I created a self-aligning filtered charge-counter-doping treatment after first designing and building the company's first ever doped AP-CVD glass deposition system. Sure there were commercial versions available but time and money were of the essence here. Since the "filter" required a thin thermal oxide but all furnaces available were far too "dirty" with background boron and phosphorous, it was necessary to create an extremely low temperature oxidation process without the luxury of high pressure steam or special gasses.

Result: By creating a skin-deep "no-hot-carriers-allowed" zone just under the passivation, hot carriers screaming toward the junction-glassivation interface were slowed down and de-energized to nearly a halt and, basically, became neutralized. Now finally, hard-avalanche power operation of zener diodes was available to the humble poor semiconductor manufacturer (us).

17) Centrifugal Powdered Glass Coating System with Peroxide Force Field

Problem: An early glassivation process employed suspending finely ground powdered glass in a high dielectric constant liquid such as propanol. This "magnified" the electric field around each ground-glass-particle and helped keep these individual particles from settling or clumping because of the built-in mutually repelling electric fields. The idea was to pour a small amount of this glass suspension liquid over the top of any substrate and then use a centrifuge to drive the glass particles down and out of suspension onto the silicon surface. Sounds simple but, in fact, the glass particles greatly enjoyed remaining in suspension so the convention of the day was to "poison" the propanol's strong dielectric properties with large amounts of acetone which itself had poor dielectric properties. Well, that sort of worked but the glass ended up as a thick "mud" on the wafer surface which was very easy to disturb while decanting the excess alcohol-acetone-glass solution. Not always a very pretty sight.

Action: My solution was to forget the acetone and add a very small trace of hydrogen peroxide solution just prior to centrifuge which, to the eye, seemed to change nothing. The glass continued to remain in suspension until the centrifuge was employed. The peroxide, you see, further expanded the radius of the electric field around each particle still keeping it nicely in suspension. However, now the centrifuge pushed these particles together so closely that the individual particle electric fields began to overlap, encompass each other and "snap" around each other forming a single mutually attracting field. This made for a continuous and stable coating

Result: I patented the process but this was such a boon to the ground-glass industry that they immediately started copying it and even publishing it in their own application notes. This ended up being my gift to the industry but, happily, it was also the end of all our glassivation problems for many years. (See 4039702, *Method for Settling a Glass Suspension Using Preferential Polar Adsorption*)