Reliability of Bypass-Diodes in Photovoltaic Junction Boxes

Diotec Semiconductor

The cost of Solar energy is a hotly discussed topic. To calculate the cost of energy produced by Photovoltaic panels one needs to depreciate the value of these panels over a number of years. A typical value would be 25 years. As such manufacturers of these panels need to give a warranty period and are interested in the long term reliability of their product.

Attached to the panels are the so-called Photovoltaic Junction Boxes (PV Boxes), necessary when shading occurs on the panels. These PV boxes usually contain 3 rectifiers in series. The rectifiers can be manufactured using either standard Silicon Technology or Schottky technology. Millions of rectifiers are consumed every year by the solar industry. The rectifiers always see either current or voltage when there is daylight. Over a time period of 25 years, this accumulates into a lot of device hours. As a result there are a lot of questions about the reliability of the rectifiers.

The problem in discussing reliability is that most semiconductor manufacturers give FIT data (Failure in Time – number of failures in 10^9 device hours) based upon HTRB testing (High Temperature Reverse Bias). They use the Arrhenius equation to determine FIT data at T_A = 85°C. The problem with this method is that reliability of a PV Box is determined by what happens during shading, not by what happens when the diodes are reversed biased.

In normal operation, the rectifiers are reversed biased. The standard tests by TÜV/UL/etc assume worst case temperatures of 85°C. In general there are 3 rectifiers in series, and a Schottky diode would see around 15V worst case. Such Schottky diode sees minimal stress and it is impossible to fail a Schottky diode this way. In the normal operation during the lifetime of the PV Box, the T_A will be much lower.
HTRB testing looks for contamination and passivation defects. The acceleration factor in a PV Box is minimal and should not be considered as a significant factor to produce reliability problems. Also typically HTRB test are performed at a voltage that is twice as high as the PV Box working voltage. This significantly increases the acceleration factors and the actual performance will be better than that predicted by FIT data.

The real reliability of a PV Box however is determined by what happens during the shading process when the Rectifiers conduct the full current. Here the T_j of the rectifier is typically anywhere between 130°C and 190°C. How often shading occurs is not very well known in the industry and not a lot of statistical data are available. It can be quite insignificant in purpose build large “Solar Fields” by energy providers. It can happen very often when installed on a roof of a private house with a chimney.
The PV Box with the best reliability is the PV Box where the rectifiers have the lowest T_j when conducting the full current. This can be achieved with the right combination of a good rectifier and a good thermal design by the manufacturer.
The failure modes would be more related to soldering or metallization defects – which are not linked to HTRB testing.
Another factor that determines the reliability of a system is how well the materials of the PV Box are matched. A different coefficient of thermal expansion between the various materials surrounding the rectifier and the rectifier itself will add stress to the design. This also only becomes visible when the module is shaded.

The discussion and clarifications about the trade-offs and reliability of various designs is only needed for PV Boxes that use Schottky technology. In thin film PV Boxes that require voltages of 800V, 1000V or even 1200V, standard Silicon technology is used. Leakage current and HTRB performance of the rectifier become completely irrelevant when discussion the reliability of the PV Box. Here T_j during shading is the only factor.

Several technologies exist to manufacture Schottky rectifiers. The V_F of a Schottky is essentially determined by the combination of the barrier height of the metal used, the EPI spec used and Breakdown voltage and the Die size (cost)
The Low Barrier Height, Low Temperature (LT) based products have a very low typical V_F but a high I_R or leakage current. Their maximum temperature for AC operation is 125°C. They can be ideal for portable equipment.
The High Temperature (HT) based products have a very high V_F and a very low I_R. They are specified up to 175°C for AC operation and they actually are aimed at the automotive market where some applications work with an ambient temperature of 125°C.
Diotec uses the standard barrier material for the Schottky diodes for the PV market. They have a 150°C rating for AC operation and 200°C for DC operation. They are the best compromise from a reliability and cost perspective.

In the area of the 125°C materials, the leakage current is quite high and will impact the efficiency of the system in standby. Also when pushing these products over 150°C in DC operation, the leakage losses may become unsustainable.
The 175°C Barrier materials add extra costs for no reliability benefits. Given the same die size as the 150°C material, the T_j will be significantly higher at e. g. 8A because the V_F will be higher. An increase of T_j by 10°C during shading will reduce the lifetime of the box by roughly 50% - as per the Arrhenius rule. This is what really matters. So-called reliability improvements based upon higher acceleration factors and 175°C HTRB tests are not relevant in this application!
The standard 150°C barrier material is indeed the best compromise. The worst case T_j of 200°C during DC operation in forward direction can be accepted, as moulding compound changes only take place over 200°C. Obviously designers are encouraged to keep the T_j as low as possible to maximize reliability. This can be achieved by improving the total thermal resistance of the PV Box – adding a heat sink, use diodes in TO-220 package - and buying the correct die size / Schottky.

Diotec Semiconductor has produced well over 200 million rectifiers that are currently in the field in PV panels. The products based on standard 150°C barrier materials always passed TÜV/UL/etc tests (in dozens of boxes). At correctly made designs, it is not possible to produce thermal runaway in normal circumstances. The products produce minimal field failures.
Our reliability estimates reflect our experience of our products in the field. FIT data based upon HTRB testing do not meaningfully reflect the actual reliability of rectifiers in real PV Box applications.

Diotec manufacturers a wide range of products. The 12A axial Schottky is one of the most common products. However 15A axial products with larger die are also available. These larger die can further reduce the power dissipation during shading tests and reduce the junction temperature of the rectifier. This improves the reliability.
Another improvement would be the SBX series of axial rectifiers with improved R_{thL} (on request). The reduction of thermal resistance reduces the junction temperature and improves the reliability.
For Surface Mount Assembly, Diotec manufacturers 18A and 20A single rectifiers with a good V_F rating. Single die have advantages over so-called centre tap Rectifiers. Centre tap

rectifiers share the current between 2 parallel die. The die are however never 100% matched and this can lead to unbalanced current sharing.

If one looks at a Pareto analysis of field/production failures of rectifiers one sees that the main root causes are:

- Lightning
- Dust Lines, Dirt and Bird Droppings
- Excessive ESD during testing / handling
- Voltage spikes (law of induction V=L*di/dt) caused during installation (uncovered modules under sunlight) and improper testing at customers

Diotec has products aimed at solving the problems caused by Lightning/ESD/voltage spikes. Contact Diotec for the so-called Protectifiers® series of bypass diodes – aimed and tested specifically for those problems.
Diotec can support manufacturers on handling and potential testing of rectifiers in their production to avoid problems.

Diotec Semiconductor

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