Thermal Measurements on Bypass Diodes

Bypass diodes for photovoltaic modules are widely used as protective elements[1]. Common approaches are using axial lead diodes, where the leads are bent[2] and then the parts are assembled into clamp connectors of the junction box. In order to ensure safe operation of such devices, standards (e. g. IEC 61730-2, IEC 61215) are describing a bypass diode test. They provide a formula for estimating the diodes' junction temperature; however, this formula contains two parameters which often are understood wrong, "T_{Case}" and "R_{thCase}". This application note describes first how a diode thermally can be understood, and then how the above parameters have to be used for correctly deriving the junction temperature. The third part gives an advice how to reach as low as possible junction temperatures, for improved lifetime of the devices.

Thermal characteristics of a semiconductor device in plastic package

Whenever a diode is loaded with a certain forward current I_F, there is a forward voltage drop V_F and as a result a power loss:

$$P_V = I_F * V_F \quad (1)$$

This power loss heats up the device junction, and can in extreme case destroy the semiconductor chip. Therefore, manufacturers of semiconductor devices provide in the according data sheet a maximum admissible junction temperature T_j. The direct measurement of T_j is quite complicated and requires special test equipment. For most applications it is however enough accurate to make an estimation based on the **thermal equivalent circuit** shown in Fig. 1.

Well known is the ohmic law: An electrical current I leads to a voltage drop V across a resistor R, which is defined by the relation

$$V = R * I$$

Similarly, a "thermal current" or power loss P_V leads to a temperature drop ΔT at a thermal resistance R_{th}. The according relation is

$$\Delta T = R_{th} * P_V$$

In an axial lead device, the majority of the heat = thermal power P_V is dissipated via the metal leads, having a low thermal resistance **R_{thL} – junction to lead**. Only a very small portion is dissipated via the plastic case, having a quite high thermal resistance (it is isolating!). Therefore, by simply measuring the lead temperature T_L, the junction temperature T_j can be estimated as

$$T_j = T_L + \Delta T_L = T_L + R_{thL} * P_V \quad (2)$$

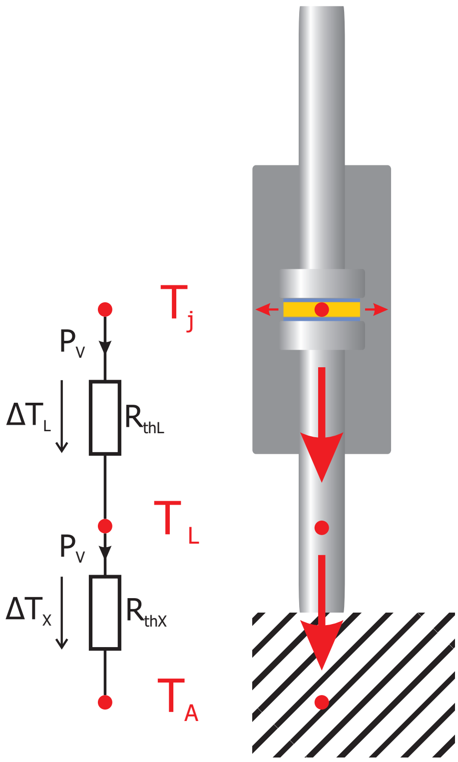

Fig. 1: Thermal model of an axial lead diode

The R_{thL} is given in the device data sheet; at Diotec, this value is measured on the lead at a distance of **3mm** from the plastic case. The device shown in the picture is connected to an infinite heatsink having the temperature T_A (A = Ambient). The thermal resistance R_{thX} contains all the thermal path from the diodes' leads via the clamp connectors and the cables to the ambient air, which is assumed to be constant. It is normally unknown; when T_L is known, R_{thX} can be derived however by the formula

$$R_{thX} = \Delta T_X / P_V = (T_L - T_A) / P_V$$

In the data sheet of Diotec and also of competitors there is another parameter given, the thermal resistance junction to ambient or R_{thA}. This value is indeed measured when the leads are connected in **10mm** distance from the case to again an **infinite** heatsink; it is of mainly theoretical interest however.

At a real diode, of course both leads are connected to a any kind of "heatsink", the values given in the data sheets are considering this fact.

1 Please refer to Diotec's application note "Bypass Diodes for Solarmodules"

2 Please refer to Diotec's application note "How to bend wires of Axial Lead Diodes in a correct way"

In the before mentioned standards, the module short circuit current I_{SC} is applied for one hour to the diode, at an ambient temperature of 75°C. During the test, the junction temperature of the device has to stay below the maximum admissible value. Following above formulas (1) and (2), the standards provide this estimation for junction temperature:

$$T_j = T_{Case} + R_{thCase} * V_F * I_{SC}$$

It should be clear that V_F is the **measured** forward voltage drop across the diode after it has reached a **thermal equilibrium**. I_{SC} is the short circuit current of the photovoltaic module, applied to the diode. More critical however are the terms "T_{Case}" and "R_{thCase}", which are defined in the following.

Correct definition and usage of T_{Case} and R_{thCase}

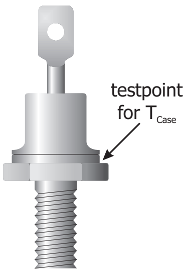

Fig. 2: Diode in full metal case

Former diode packages were fully made of metal, such as the DO-4 package shown in Fig. 2. Therefore, the reference point for the parameter R_{thC} = "thermal resistance junction to case" was set on the edge of the metallic device package or "case". As described earlier, at axial lead diodes the relevant thermal resistance is the one of the leads – R_{thL}, see Fig. 3. The plastic case has got a quite high R_{th}, which is not useful at all. Therefore, at axial lead packages, the temperature of the leads T_L (in the specified distance from case – 3mm at Diotec) has to be used rather than "T_{Case}". Instead of the non-defined "R_{thCase}", the value R_{thL} specified in the data sheet has to be used[1]!

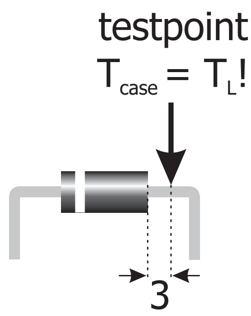

Fig. 3: Axial lead diode with plastic case

How to reduce thermal resistance

From Fig. 1 it is obvious that the junction temperature can be reduced by reducing the values of R_{thL} and R_{thX}. The "X" series of axial lead diodes by Diotec offers drastically reduced values R_{thL}. At the same semiconductor die size, the innovative "X" package outline reduces R_{thL} from 4 K/W down to 2.1 K/W, see Fig. 4 (L = 3mm). Further devices in this package are e. g. the FX2000A or SBX2540 [2].

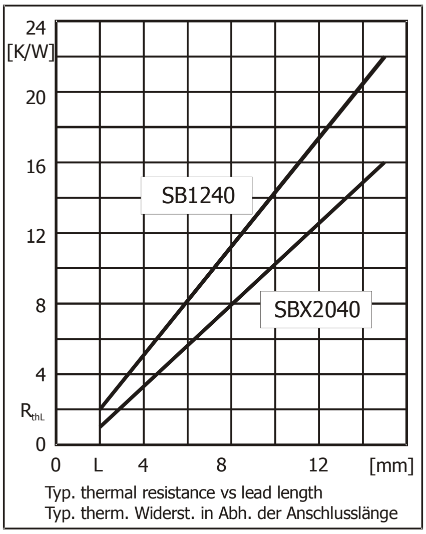

Fig. 4: At the same die size, the "X" package has superior thermal performance [2]

The value R_{thX} is normally the bigger value and as such has got the bigger influence on T_j. The thermal resistance of a lead wire increases almost linearly with its length, see Fig. 4. As a consequence, the length of the leads "L" from device case to the clamp connectors has to be as short as possible, see Fig. 5.

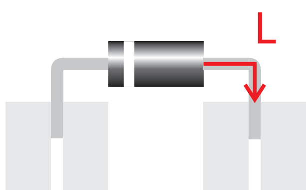

Fig. 5: L has to be as short as possible!

There are further parts of R_{thX} formed by the clamps, the cables and so on. The bigger the cross section of those parts, the lower is their thermal resistance and in consequence R_{thX} and T_j!

1 Some competitors are specifying a value R_{thCase}; its value is however impossible low for a plastic case and therefore more likely the value R_{thL}

2 Data sheets see www.diotec.com

Newer designs of junction boxes use a PCB or a copper lead frame where diodes in power packages, such as TO-220 or D²PAK, are assembled on. The advantage of these package outlines is their tab or flange that allows for direct and tight heat sink connection. Thus the heat can be dissipated much more easy from the semiconductor junction to the case outline. The reference point for "T_{Case}" = T_C and "R_{thCase}" = R_{thC} is shown in Fig. 6. It is again the metal part of the flange and not the plastic case.

Typical part names by Diotec in TO-220 are the FT2000 or SBT18 series, as well as the KT20A120 – Protectifiers® [1]. In D²PAK there are the SK2040YD2 or FR20DAD2. There are also versions of the TO-220 with isolated flange, such as the SBJ1845. Only here the T_C and R_{thC} are specified on the plastic "case" respectively tab at the same position as shown in Fig 6.

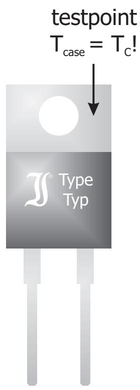

Fig. 6: Power package outline

1 Protectifiers® by Diotec are devices with special reverse overvoltage protection against lightning, ESD etc. Data sheets see www.diotec.com