

ECE 340: The diode equation

day10

1. The Shockley diode equation

$$i_D = I_S \left[\exp\left(\frac{v_D}{n \cdot V_T}\right) - 1 \right] \quad (1)$$

Very often (see [day09 diode-equation](#)), we ignore the “-1” and use the approximation

$$i_D = I_S \exp\left(\frac{v_D}{n \cdot V_T}\right) \quad (2)$$

i_D current through the diode

I_S scale current or (reverse-bias) saturation current

v_D voltage across the diode

n ideality factor or emission coefficient. =1 for an “ideal” diode and is 1 to 2 for a real device.

2. Temperature dependence

Temperature has a large effect on the value of I_S , go back in the notes to see how it is affected by geometry, doping, material, and temperature.

[hw09](#) deals with this mathematically.

There are two *rules of thumb* for a *pn* junction’s temperature dependence:

- For a constant current: v_D changes by about $-2 \text{ mV} / ^\circ\text{C}$.
- For a constant voltage: i_D doubles every $10 ^\circ\text{C}$ increase.

2.1. 1N4148 datasheet

See this temperature dependence in the datasheet for the 1N4148

[diode_1N4148_Vishay.pdf](#)

- Fig. 1 shows v_D vs. temperature
- Fig. 2 shows i_D vs. v_D

Vishay’s datasheet also has good information about maximum temperatures and power dissipation (remember: $v_D \times i_D$ is power absorbed).

Heat transfer for ECEs

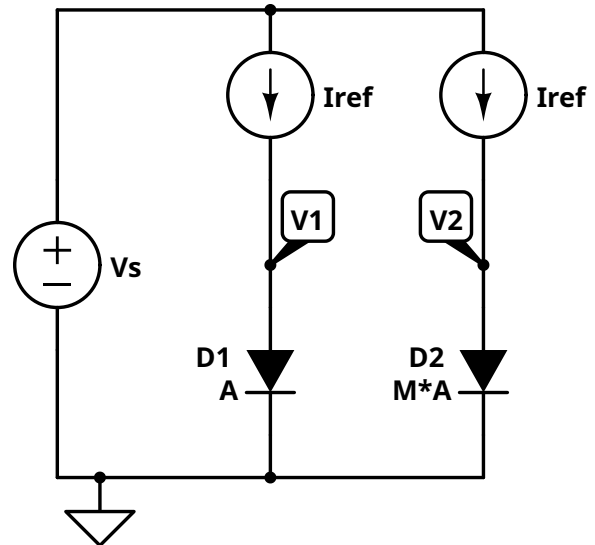
But that datasheet curiously lists **two** maximum power dissipation numbers (440 mW vs. 500 mW). [day10_thermal-tutorial.pdf](#) gives a brief tutorial on how to use *thermal resistance* to predict temperatures from power dissipation numbers and explains why the datasheet quotes two numbers..

3. First application circuit

The first (interesting!) circuit we can make with a diode once we know the Shockley equation is a *proportional to absolute temperature* (PTAT) circuit.

Have two *pn* junctions that are held to the same temperature but the second has a junction **area** **M** times larger. Glue the packages together, or, better yet, fabricate them on the same piece of silicon somehow.

- Force the same current through both diodes.
- Measure the voltage across each diode.



The difference between these voltages is:

$$v_1 - v_2 = \frac{k_B T}{q} \ln(M) \quad (3)$$

Notice that this has nothing to do with:

- doping
- absolute size of the junction (just the size ratio)
- diffusion or mobility constants

Just the temperature scaled by three well-known constants!

4. Ultra doping

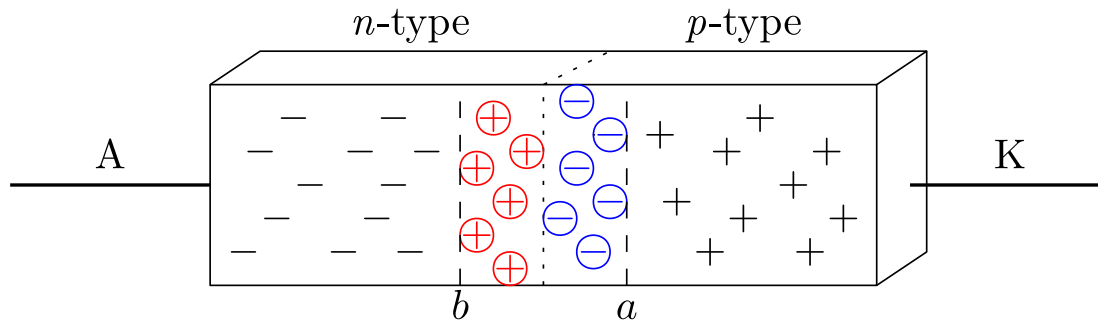


Figure 1. *pn junction*

Consider a *pn* junction and dope the *p* side heavier.

...

Further increase N_A on the *p* side.

...

Keep doping more and more.

...

We know that:

- increasing the doping makes the (non-depletion, “outer”) region more conductive.

If the doping is obscenely large, this region will be conductive ... perhaps like a *metal*.

- → Can you just replace the *p* side with a metal?

Yes! This is called a Schottky diode.

5. Reverse-bias until something breaks

If you reverse bias a pn junction and keep increasing the amount of reverse voltage, current will suddenly begin to flow.

Normally, the built-in and applied E-fields add and oppose current flow, but there are two phenomena that come into play.

- Zener breakdown
- Avalanche breakdown