The Noise of Avalanche Breakdown Diodes

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Avalanche Breakdown by Ionization

You can imagine the reverse-biased p-n-junction of a diode as a plate capacitor with an applied voltage between both plates. The size of the plates correlates with the size of the active area of the diode, and the distance of the plates is equal to the width of the depletion zone. This depletion zone should isolate perfectly, so that no current is possible. However, due to the thermal jitter of the silicon crystal, which the diode is made of, single electrons at the border of the depletion zone can be punched into the depletion region, or weakly bound electrons in the depletion region can be released. Due to the existing electric field (voltage per distance) these free electrons are immediately accelerated to the cathode side. Similar to an apple falling to the ground with rising speed in the gravity field of the earth, the free electrons are “falling” with increasing speed along the electric field to the cathode until a collision with a bound electron slows them down again.

At a certain electric field strength, such a free electron can become so fast that its kinetic energy is high enough to punch another bound electron off. After this collision or impact ionization, two electrons are free fall ready to ionize more electrons, and so on. This is the start of the avalanche breakdown.

NO AVALANCHE BREAKDOWN WITHOUT LEAKAGE CURRENT

The presence of a sufficient reverse voltage to generate the critical electric field strength is just one of two preconditions to start an avalanche breakdown. The second precondition is the presence of free electrons that can be measured as a so-called reverse or leakage current. For example, a leakage current of 1.6 pA = 1.6 x 10^{-12} A correlates with an electron flow rate of 10^7 electrons per second. This means that statistically, an impact ionization can happen every 100 ns. However, since not every collision generates a free electron, the average time between two impact ionizations will be even longer.

THE NOISE

According to the description above, the ionization probability for an avalanche breakdown is proportional to the leakage current. The higher the leakage current, the higher the probability of starting an avalanche breakdown. However, between two impact ionizations, the applied rising reverse voltage can rise above the breakdown voltage of the diode. It needs the next impact ionization to break the applied voltage down to the avalanche breakdown level. If the applied voltage source delivers sufficient current, such as 1 mA or higher, the impact ionization can keep itself running by continuous impact ionization. But if the source current is too low - such as 100 µA or lower - the abrupt breakdown drops the applied voltage below the avalanche breakdown level, so that the avalanche stops again. Now it needs some time to charge the diode and line capacitance with the low source current up to the avalanche breakdown voltage level before another electron can trigger an avalanche breakdown event. This perpetual on- and off-switching of the avalanche causes the “noise of the avalanche breakdown.”

As the leakage current rises with the temperature, the noise decreases accordingly. Light can also release free electrons, called photo-current, in the depletion region of the diode so that the noise level becomes lower. Thus the noise in avalanche breakdown is maximal at low temperatures and a dark ambient.

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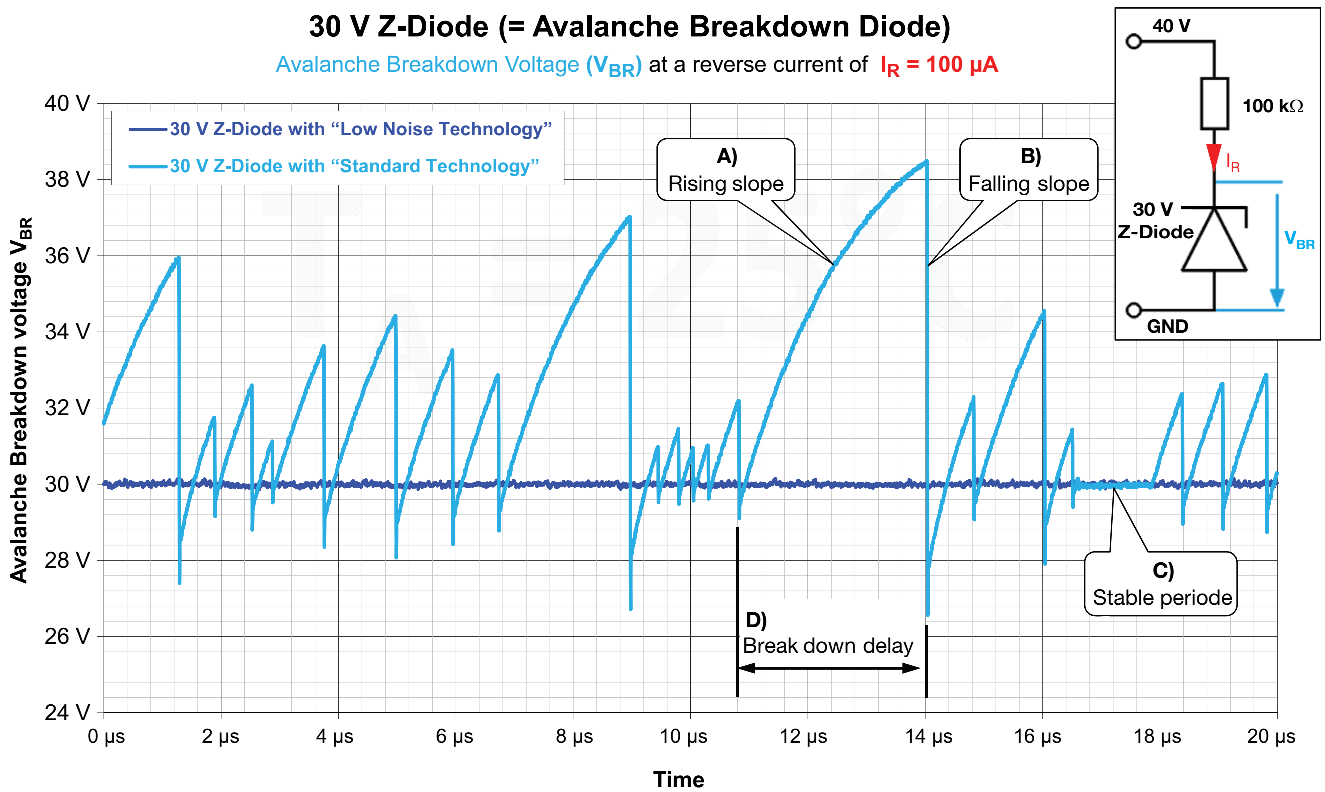

Fig. 1 - Breakdown voltage of one Z-Diode with and one without "Low Noise Technology"

Notes

Fig. 1 shows the breakdown voltage of two Z-diodes with a breakdown voltage of 30 V measured at a reverse current of 100 µA. One was made with a standard technology with very low leakage current, the other with the "Low Noise Technology". While the Z-diode, made with the low noise technology, has a flat and constant voltage, the voltage of the other diode is very unstable.

A) While the voltage is rising the diode is blocked. The voltage curve is defined by the changing of the diode- and line capacitance over the series resistor.

B) In the moment when one free electron in the depletion region triggers an avalanche, the voltage drops suddenly down below the breakdown voltage of 30 V so that the avalanche immediately stops again.

C) Sometimes the voltage can be kept stable for a short periode of time before the avalanche stops and the voltage rise again.

D) The break down delay is a statistical process at which the time between two breakdown events cannot be forcasted. But the average break down delay time correlates with the leakage current of the Z-diode: the higher the leakage current the shorter the break down delay time.

NEW Z-DIODE GENERATION WITH IMPROVED NOISE PERFORMANCE

The new generation of Z-diodes in the SMF-, BZD27-, BZG03-, BZG04-, BZG05-, PLZ-, and VTVS-series takes this behavior into account. With a moderately increased leakage current (I_R ~10 nA), the probability of an impact ionization is clearly increased and the noise reduced accordingly. This offers the user a more stable breakdown voltage at low currents (below ~ 1 mA) and a faster breakdown of fast-rising reverse voltages.

Any questions or hints to this topic?
Let us know by sending an e-mail to: Diodes@vishay.com