Application Notes

Sinterglass Diodes Connected in Series for Increased Reverse Voltage

The use of several sinterglass diodes connected in series is necessary where the voltage rating of a single sinterglass diode is too low, or where special requirements such as very low switching losses requires the implementation of several low-loss ultra fast sinterglass diodes. In these cases sinterglass diodes connected in series are used for high voltage applications, e.g. TV Monitor or Automotive and in switching applications such as PFC-Boost-Converters, SMPS or other applications where low losses and high voltages are necessary.

According to the text book it is usually necessary to ensure symmetrical conditions for each sinterglass diode. This is normally done with resistors for static conditions and with capacitors for dynamic conditions, see Figure 1. Circuit Diagram, which illustrates the situation for two sinterglass diodes.

These configurations cause an increase in power dissipation and increase costs because of the larger number of parts. If you want to avoid this by simply connecting sinterglass diodes in series without resistors and capacitors for symmetrical conditions then the following applies.

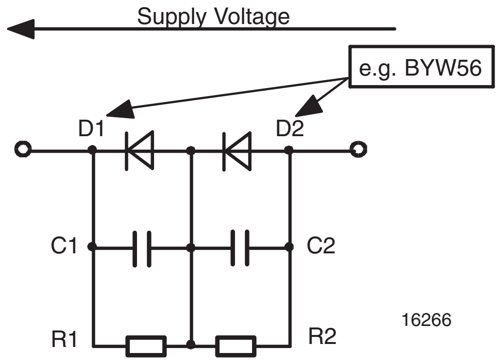

Figure 1. Circuit Diagram

Static Conditions without Resistors for Symmetry

For static conditions the important parameters are the reverse characteristics, especially the reverse breakdown-voltage. Applying a certain supply voltage will result in a certain reverse current, IRsum, through both sinterglass diodes, at which the sum of the reverse voltage across each sinterglass diode is equal to the applied supply voltage.

In principle there are three different cases (the drawings below are exaggerated for better understanding).

Similar sinterglass diodes with sufficient reverse breakdown-voltage

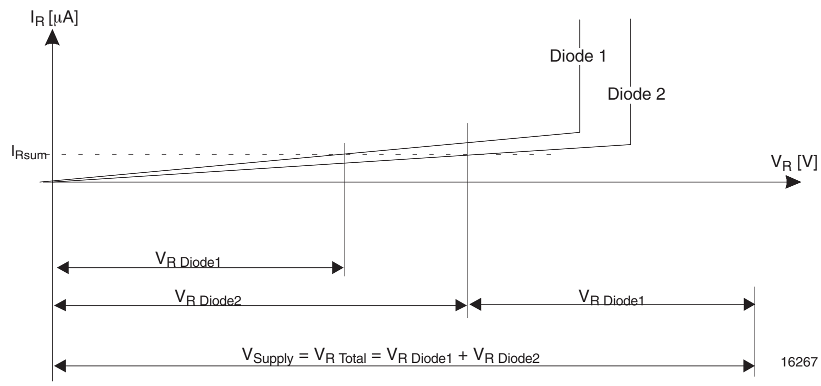

Figure 2. Static conditions for similar sinterglass diodes with sufficient V_R

For sinterglass diodes with similar and sufficient reverse characteristics the resulting reverse voltage across sinterglass diode 1 and sinterglass diode 2, $V_{R\ Diode\ 1}$ and $V_{R\ Diode\ 2}$ is well below the breakdown-voltage. Therefore the resulting leakage current of this configuration will be very low and no problems will occur, even if there are small overvoltage spikes on the supply. This is a practicable solution, but one needs sinterglass diodes with a breakdown-voltage which is much higher than half of the supply voltage (for 2 sinterglass diodes) if the sinterglass diodes are not avalanche safe!

Similar sinterglass diodes with insufficient reverse breakdown-voltage

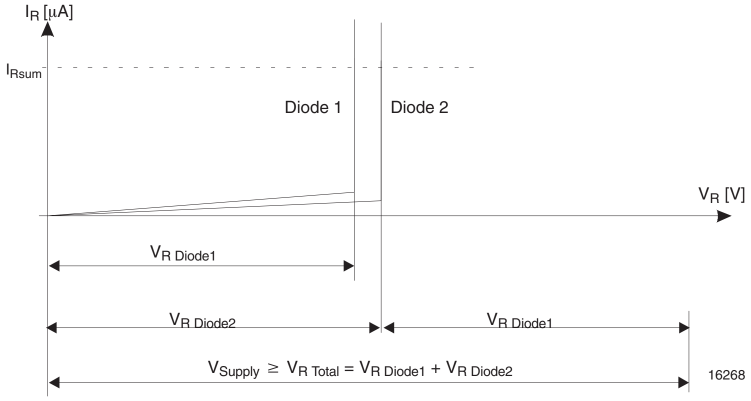

Figure 3. Static conditions for similar sinterglass diodes with insufficient VR

For sinterglass diodes with similar and insufficient reverse characteristics the resulting reverse voltage across sinterglass diode 1 and sinterglass diode 2, $V_{R\ Diode\ 1}$ and $V_{R\ Diode\ 2}$ is the breakdown-voltage. Both sinterglass diodes will be in the reverse avalanche mode - and they must be able to withstand it!

Normally the whole configuration will behave like a Zener-Diode because the sum of the breakdown-voltages of both sinterglass diodes is less than the applied supply voltage, with a very high reverse current mainly limited by the power supply and not the sinterglass diode. If by chance the sum of the breakdown-voltages is exactly the supply voltage, the reverse leakage current will be mainly limited by the sinterglass diode reverse characteristics. Because the reverse characteristics depend on the junction temperature the sum of the breakdown-voltages will change with the temperature too and the configuration will behave like a Zener-Diode again.

So this is not really a practicable solution.

Sinterglass diode with different reverse breakdown-voltages

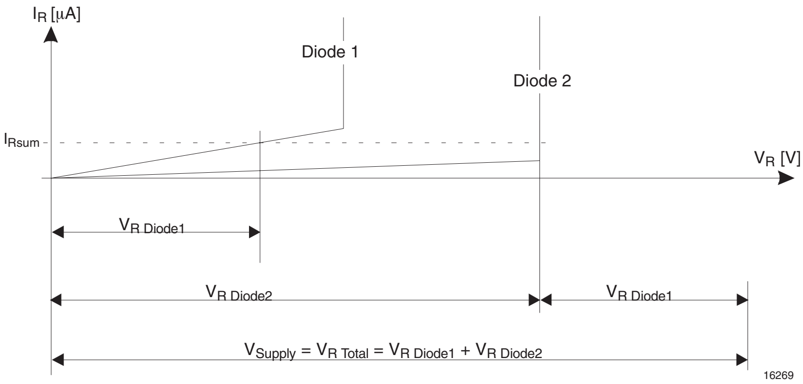

Figure 4. Static conditions for different sinterglass diodes

For sinterglass diodes with different reverse characteristics, the resulting reverse voltage for one sinterglass diode, the better one, sinterglass diode 2 in

Figure 4. Static conditions for different sinterglass diodes, is in the area of the breakdown-voltage ($V_{RDiode2}$) and for the other, sinterglass diode 1, below the breakdown-voltage ($V_{R\ Diode\ 1}$).

Because of the variations in the manufacturing processes for semiconductors it can always happen that within one certain type there will be sinterglass diodes with different reverse characteristics as mentioned above.

If sinterglass diode 2 is able to withstand this reverse avalanche energy, it is a practicable solution even if there are some overvoltage spikes. And there is no need for a large safety factor of the reverse breakdown-voltage if the sinterglass diodes are avalanche safe!

Dynamic Conditions without Capacitors for Symmetry

Switching sinterglass diodes, which are connected in series without capacitors, from a certain forward condition, e.g. 1A forward current, to a certain reverse condition, e.g. 1000V reverse voltage, will generate an avalanche pulse in the faster sinterglass diode. It is similar to a chain, there the weak part will break first, here the faster sinterglass diode will be off first.

The reverse recovery characteristics are the important parameters for dynamic conditions, not only for sinterglass diodes in switch mode power supply with frequencies of kHz to MHz, but also for sinterglass diodes used for the rectification of the mains with 50 or 60Hz.

As already noted, due to variations in the manufacturing process there will be differences in the characteristics of the semiconductors. For better understanding of what is happening with each sinterglass diode, we carried out measurements with two different ultrafast sinterglass diodes connected in series without other components in parallel. The difference between the reverse recovery times is the same as can happen within one type due to the variations of the processes. For slower sinterglass diodes it will be similar.

sinterglass diode 1: (e.g. BYT53G)
reverse recovery time t_{rr} =45ns
(I_F = 0.5A / I_R = 1.0A / i_r = 0.25A)
reverse breakdown-voltage
$V_{(BR)R}$ = 500V

sinterglass diode 2: (e.g. SF4007)
reverse recovery time t_{rr} =60ns
(I_F = 0.5A / I_R = 1.0A / i_r = 0.25A)
reverse breakdown-voltage
$V_{(BR)R}$ = 1200V

Dynamic conditions with low reverse voltage

Figure 5. Dynamic conditions with low VR shows the dynamic characteristics with low reverse voltage, approx. 50V, and constant current, using the test circuit for measuring the reverse recovery time trr according to JEDEC with a forward current I_F = 500mA , a reverse current I_R = 1A and measuring at 250mA (for further explanations see the application-note "Test Circuit for the Reverse Recovery Time t_{rr} ")

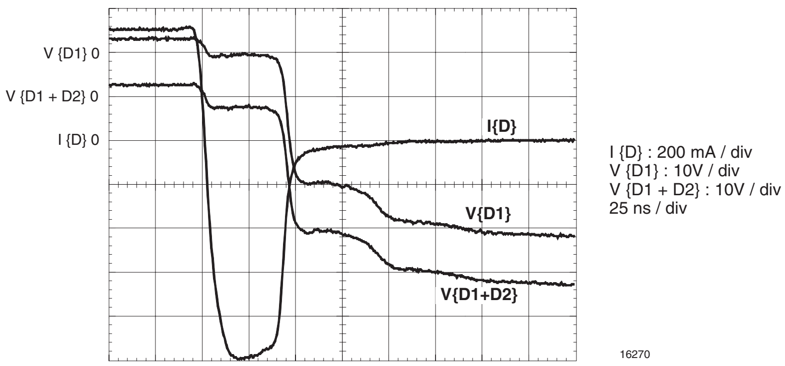

Figure 5. Dynamic conditions with low VR

One can see the current through both sinterglass diodes I{D}, the voltage across sinterglass diode 1, V{D1} and the total voltage across both sinterglass diodes, V{D1+D2}.

As expected, the switching time of the series connection is the same as the switching time of the faster sinterglass diode, D1, with trr = 45ns. At the beginning the total reverse voltage is applied to the faster one (D1), V{D1} 9 V{D1+D2}, see Figure 5. Dynamic conditions with low VR. The stored charge of sinterglass diode 1 is less than the charge stored in sinterglass diode 2, the slower one. Because the same current is passing through both sinterglass diodes, the charge stored in sinterglass diode 1 is reduced faster and sinterglass diode 1 will be in the reverse mode with a small reverse current before all the charge stored in sinterglass diode 2 is reduced. The reduction of the remaining charge in sinterglass diode 2 is achieved by the low leakage current of sinterglass diode 1, which will take a long time depending on the difference between the charges in the sinterglass diodes.

Although the above explanations are more or less of theoretical interest because of the low applied reverse voltage, it is important to understand the mechanism. In real life situations, with high reverse voltage, the reason for switching the sinterglass diodes in series becomes apparent when we consider the next step.

Dynamic conditions with high supply voltage

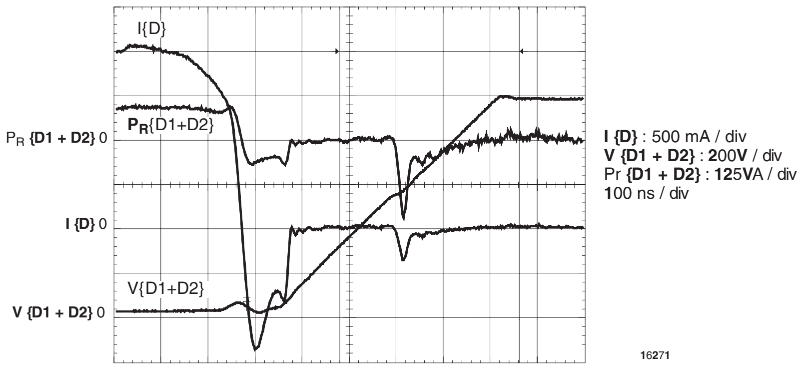

Figure 6. Dynamic conditions with high VR

Figure 6. Dynamic conditions with high VR shows the dynamic characteristics with high reverse voltage, approx. 1000V, and constant current (forward current I_F = 2A and a reverse current I_R = 1A).

Again one can see the current through both sinterglass diodes I{D}, the total voltage across both sinterglass diodes connected in series, V{D1+D2} and the total energy of both sinterglass diodes P_R{D1+D2}.

Understanding the mechanism, as explained in 2.1, we know that the stored charge is reduced faster in the faster sinterglass diode, sinterglass diode 1, therefore this sinterglass diode is in the reverse mode first, sinterglass diode 2 is still not in the reverse mode.

The total reverse voltage increases with a certain slope due to the inductive load. After approx. 250ns the voltage across the sinterglass diodes is the breakdown-voltage of sinterglass diode 1. At this moment sinterglass diode 1 goes into the reverse avalanche mode with a short current peak, approx. 350mA for 40ns and a breakdown-voltage of approx. 550V (at 350mA). But this means an avalanche pulse of approx. 8µWs, which the sinterglass diode must be able to survive!

Due to the avalanche current peak of sinterglass diode 1 the stored charge in sinterglass diode 2 is reduced and this sinterglass diode will be in the reverse mode too. After this the total reverse voltage across both sinterglass diodes can rise further, up to the maximum supply voltage of approx. 1000V. When the final reverse voltage of both sinterglass diodes is reached, the static conditions as described above apply.

Depending on the difference of the reverse recovery characteristics (stored charge) the current peak and the duration of the avalanche pulse will be different.

It is very important to the losses generated consider by the short avalanche pulse in the example mentioned above, see Figure 6. Dynamic conditions with high VR. Each time switching from forward to reverse takes place, this will result in an avalanche energy of approx. 8µWs. If the frequency of this application is 100kHz, the power loss due to the avalanche pulse is 800mW! This can result in a temperature increase of approx. 80°C for a sinterglass diode in the SOD57 package such as the BYV26 or BYV27. The real reverse loss due to the avalanche of the better sinterglass diode is given through the circuit and must definitely be taken into account when calculating the total loss of the parts!

Summary

For static conditions the important parameter is the reverse characteristic. A certain supply voltage results in a certain reverse current at which the sum of the reverse voltages of all the sinterglass diodes is equal to the applied supply voltage. If the safety factor for the reverse breakdown-voltage for each sinterglass diode is low (e.g. 10%), it can happen that the best sinterglass diode (best reverse characteristics, high breakdown-voltage and low leakage current) will be in the avalanche mode all the time.

For dynamic conditions the important parameter is the switching characteristic. Switching from forward to reverse conditions will result in a short avalanche pulse in the fastest sinterglass diode, because this sinterglass diode is already in the reverse mode with reverse voltage and the other not, i.e. there is still some charge stored in the slower one.

Sinterglass diodes can be connected in series without external components for symmetrical conditions if these sinterglass diodes are able to withstand the avalanche energy and the resulting junction temperature is below the maximum guaranteed temperature .

VISHAY offers a wide range of sinterglass diodes with a special construction of the junction to be avalanche safe. In addition, they are 100% tested with the guaranteed avalanche energy. For more details please refer to the datasheets.