Introduction To SCHOTTKY Rectifier and Application Guidelines

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Why SCHOTTKY?

For Silicon devices, the forward voltage drop of the pn-junction rectifier can not be reduced below about 0.8 volts even if the device is not required to block higher reverse voltage. In the case of the output rectifiers used in power supplies for computers and telecommunications, this voltage drop is a large fraction of the output voltage of 5V or less. This results in a loss in the power supply efficiency by 20% - 30%. For Schottky barrier rectifier they can exhibit a very low forward voltage drop leading a smaller conduction loss than that of pn-junction rectifier, and switching speeds approaching zero-time. This combination hence makes Schottky barrier rectifiers ideal for the output stages of switching power supplies.

Schottky diodes

Presently the breakdown voltage of the Silicon Schottky diode cannot be reliably made larger than 200V. However, the drawback of the Silicon Schottky rectifier can be addressed by fabricating the devices by using other semiconductor materials, such as gallium arsenide and silicon carbide.

Schottky diodes have positive and negative sides. They are shown below.

Advantage:
- Switching speed faster than a comparable pn-junction diode
- Very low forward voltage drop (VF)
- Having much less voltage overshoot during device turn-on than comparable pn-junction diodes

Disadvantage:
- Limited high-temperature operation
- High leakage
- Limited breakdown voltage range for Silicon Schottky diode

Switching Characteristics

A Schottky diode turns on and turns off faster than a comparable pn-junction diode. The basic reason is that Schottky diodes are majority-carrier devices and have no stored minority carriers that must be injected into the device during turn-on and pulled out during turn-off.

Trade-off

The four most important application characteristics of a Schottky are:
- forward voltage drop
- reverse leakage current

- reverse blocking voltage
- maximum junction temperature

Generally for a given application the basic hallmarks of any Schottky process are its maximum rated junction temperature, Tjmax and the maximum recurrent peak reverse voltage, VRM. These two basic hallmarks are set by the process, then determine the best trade-off between the forward voltage and the leakage current.

A decrease of the forward voltage increases the efficiency of the converter but increase at the same time the leakage, and the maximum operating temperature Tjmax decreases.

Choice of the Schottky

For using the Schottky diodes well the designers need to realize the impact of the choice of Schottky on circuit operating performance and heat sink requirements in their particular application.

These guidelines will be discussed following.

(1) Operating temperature margin

The maximum operating junction temperature of Schottky diode must be less than the maximum rating of junction temperature in data sheet to keep a safe junction-temperature margin from thermal runaway. For example, as using an axial lead Schottky the recommendation to circuit designer is to obey the data sheet condition of manufacturer.

(2) Heat sink thermal resistance

If designers want to minimize the energy losses of an electrical system by increasing the physical size of the heat sink disproportionately with decreasing thermal resistance, the efficiency would simultaneously be degraded.

For instance, in a situation where reverse losses are low and conduction losses predominate, if increasing the heat sink size (beyond that required for a safe design) will increase the losses because conduction losses increase with decreasing temperature.

(3) Increasing the die size

Using larger die is a direct way to reduce the forward voltage drop and forward current, and hence has lower conduction losses. However, the larger die will introduce a larger reverse leakage current leading larger reverse losses.

Computing the net result of energy loss of Schottky rectifier it is still lower and a smaller heat sink can therefore be requested.

(4) Option of Tjmax class

The choosing of a suitable Schottky often varies with the different applications. As minimization of total energy losses, and a relatively low heat sink temperature are more attractive to designers than minimization of the size of heat sink, a lower Tjmax class Schottky may be the better choice. If minimization of heat sink size is more important than minimization of energy losses, than a higher Tjmax class Schotty will generally be the better choice.

(5) Heat sink temperature

A situation worth to mention for designers is whether there are other components to be mounted on the heat sink with the Schottky diodes.

Higher Tjmax class Schottkys allow a higher heat sink temperature; this temperature might be too high for the other components on the same heat sink.

A suggestion to designers is to use a separate heat sink for the components.

(6) High ambient temperature

As ambient temperature increase, choosing a Schottky with a higher rated Tjmax will help reduce the heat sink size.

(7) Selecting the right voltage class

Within a given Tjmax class, lowest losses and smallest heat sink will usually be obtained by selecting the Schottky from the lowest voltage class that is compatible within the circuit voltage.

A lower voltage class Schotty has lower forward voltage drop and lower conduction losses. Reverse leakage losses of a lower voltage Schottky will be somewhat higher. But generally total losses will be lower and heat sink size smaller for the Schottky with the lowest voltage class compatible with the circuit operating voltage.

Power dissipation vs. thermal resistance

The thermal resistance required of the heat sink, for a given power supply output current, can be significantly influenced by the choice of the Schotty type, as well as by the choice of converter circuit.

As the operating power dissipation in a Schotty increases, the required heat sink thermal resistance decrease, because the increasing internal temperature rise allows less available temperature rise for the heat sink. This explains the trade-off relationship between Schottky power dissipation and the required heat sink thermal resistance.

Mounting torque

To screw-mounted devices a mechanical damage might be caused by an over-application of torque, while under-application might fail to achieve the proper thermal leading a highvalues of thermal resistance.

Switching Performance of Super-Fast Diode

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Introduction

Super-fast diode becomes more and more important as the operating frequency of AC/DC-converters, inverters, DC choppers and switch mode power supplies tends to increase to achieve more compact circuit lay-outs and reduced noise levels.

In Taiwan Semiconductor's product series , supper fast rectifier hand forward currents from 1A to 30A, block voltages up to 600V , and exhibit fast reverse recovery of 35nS, using Silicon Pin rectifier technology.

The Pin structure (P+/N/N+) is one of the most common topology for power circuit application because the base width thickness can be tailored to optimize the frequency response. The structure allows discrete semiconductor manufacturers to offer the widest range of performances and characteristics, such as blocking voltage capability, forward voltage drop and switching speed, by controlling the following key parameters:

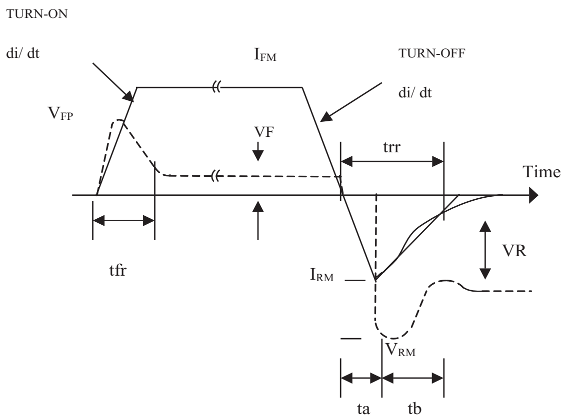
- Die Size
- Die Thickness
- Base width
- Doping Level
- Recombination Lifetime Control

Switch behavior

The switching of die has two types:

- Either switching from the non-conducting to the conducting state: "turn on"
- Or switching from the conducting to non-conducting state: "turn off "

Figure 1. Both typical tern-on and turn-off waveforms of diode.



I_{FM} = maximum forward current
I_{RM} = maximum reverse recovery current
V_{RM} = maximum reverse voltage
VF = continuous forward current
VR = continuous reverse voltage
V_{FP} = maximum forward recovery voltage
tfr = forward recovery time
ta = storage time
tb = reverse current decay time
trr = reverse recovery time

The switch of an super-fast diode is illustrated as the figure 1. When the diode is turned on with a high di/dt , there is a voltage overshoot (VFP) across the diode, which decreases progressively during a given time tfr. When diode is switched from its conduction state to non-conducting state, the evacuation of charges stored during the forward current flow produces phenomenon of reverse recovery for a certain period of time (trr). At the end of the period denoted as ta, the diode impedance begins to rise, allowing reverse current to decay. During the tb interval the nature of decay will depend on the impurity profile of the diode, the test or circuit electrical conditions, and the loop inductance.

If the waveform decays smoothly in a somewhat exponential manner, as shown by the waveform of figure 2-(a), the diode is said to exhibit " soft recovery." If the waveform exhibits a rapid change in slope, as shown in 2-(b), 2-(c), and 2-(d) the recovery is described as abrupt. The abrupt recovery often produces circuit ringing, which causes EMI problems in electronic equipment. A frequent way to avoid abrupt recovery is by adding snubbers to the circuit.

Figure 2-a. Soft- recovery

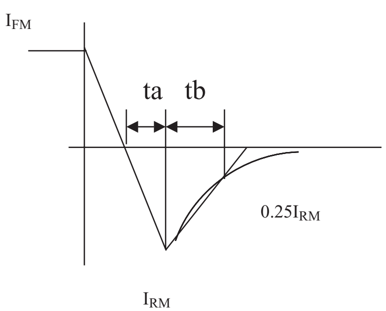


Figure 2-b. Abrupt recovery and Figure 2-c Abrupt recovery

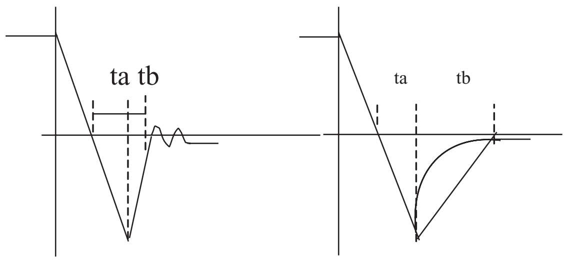
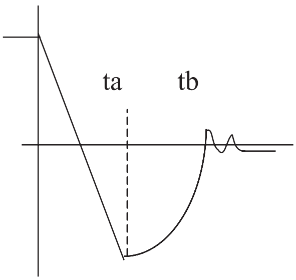


Figure 2-d Abrupt recovery



Lifetime control

Under thermal equilibrium conditions, a continuous balance between the generation and recombination of the electron-hole pairs occurs in semiconductors. Any creation of excess carriers by an external stimulus will disturb this equilibrium. Upon removal of the external excitations, the excess carrier density decays and the carrier concentration returned to the equilibrium value. The lifetime is a measure of the duration of this recovery.

Two fundamental processing methods have been developed to control lifetime (and consequently trr) in power device.

- Using thermal diffusion of gold or platinum
- Bombarding the silicon wafer with high energy particles

Taiwan Semiconductor used the method of diffusion gold or platinum into silicon for the processing of super-fast recovery diode series.

Why gold or platinum?

The recombination level introduced by gold diffusion is different from that by platinum diffusion. The superior conduction characteristics are observed in gold-doped devices. For example, for equal forward voltage, Au-doped device will have faster switching time than Pt-doped device. However, the leakage current of platinum doped devices will be much lower than for gold-doped devices.

Since gold-doped devices created a larger leakage current (especially the high temperature leakage current is significantly high.) so the parasitic heating of the gold-doped rectifier occurs highly than platinum doped rectifier. A continuous heating will cause thermal run away finally. But the gold- doped devices will introduce a softer recovery waveform than platinum.

From the trade-off comparison the circuit designer has to be careful on choosing the device that will be expected to use on the different application.

Diode design/ selection

The optimum choice for a given application depends on the power losses generated by the diode. The power losses come from two different phases. One is reverse switching loss. The other one is forward conduction loss. Here, the switching loss is proportional to the maximum reverse recovery current, IRM of diode. The conduction loss is proportional to forward voltage, VF.

For example, increasing the speed of a rectifier will decrease the IRM and then a smaller switching loss was obtained. While the VF value of diode will get an increment, and therefore the conduction loss become larger. For a diode the compromise VF-IRM has to be made to reduce the total looses.

What Is A Silicon Transient Voltage Suppressor?

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Introduction

The silicon transient voltage suppressors (TVS's) are clamping devices that can limit the voltage spikes by avalanche breakdown. It is a component worked in a reverse mode in electronic system.

In an electric circuit when the transient spike with voltage drop higher than the clamping voltage of TVS device, and with energy content less than the power of TVS device, the TVS begins conducting effectively and clamp the transient spike to a safe level at which it will not damage the load we expected to protect. Such safe level is within the range between minimum and maximum breakdown voltages of TVS device. As the voltage drop of signal bellows its clamping voltage, the device will restore to the non-conducting mode. The function is illustrated in figure 1.

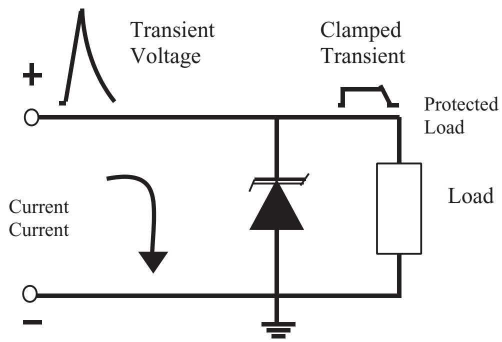


Fig. 1 The transient current is diverted to ground through TVS; the voltage seen by the protected load is limited to the clamping voltage level of the TVS, then the clamped voltage ramp down to normal operating voltage of TVS device.

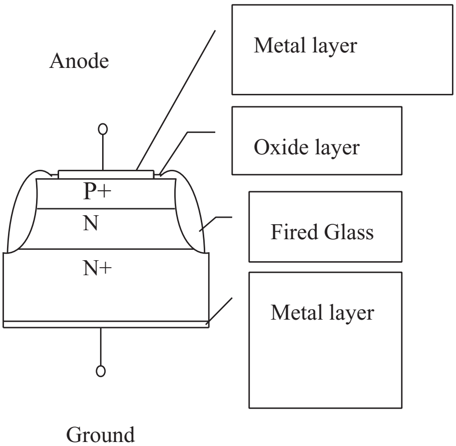
Source of Transients

General speaking, transients have two sources. One is in electric circuits, resulting from the sudden release of previously stored energy. Such transient might be voluntary and created in the circuit due to inductive switching, commutation voltage spikes, etc. Next might be created outside the circuit and then coupled into it. These can be caused by lighting strikes, electrostatic charge, or substation problems. These transients are difficult to identify and measure by the circuit designer.

Silicon TVS diodes

All TVS devices use glass passivated die with mesa structure in Taiwan Semiconductor. The operation temperature can be at 175^{O}C for axial lead package, and 150^{O}C for surface mount package, individually. The chip configuration (P+/N/N+) of unidirectional TVS will be shown below.

Fig. 2 Cross section of chip for unidirectional TVS



The p-n junction diode is a unidirectional device. For use on AC signal lines, bi-directional devices are available which are based upon stacking two diodes back to back. Most manufactures use monolithic NPN and PNP structures. The center region is made relatively wide compared to a base of transistor to minimize the transistor action which can cause increased leakage current.

TSC's Silicon TVS diodes were designed with a wide spectrum of power rating from 400 watts to 1500 watts for 10 / 1000 us waveform. They have a surge suppressor function.

The Zener diode in a circuit (power supply) plays a role of regulator. Most Zeners handle less than their rated power during normal applications and are designed to operate with lower power compared to TVS diode.

Taiwan Semiconductor's TVS products exhibit several advantages including:

1. Superior clamping characteristics
2. Very low leakage below breakdown voltage
3. Sub-nano second turn-on times
4. No wear out mechanism (within device energy limits)
5. Fail "short" with overstress
6. Be available as unidirectional and bi-directional

Taiwan Semiconductor's TVS products are the preferable option for your transient suppression needs that can not satisfy you.

Electrical characteristics of TVS diodes

The major electrical parameters contain operating voltage, reverse breakdown voltage, maximum peak pulse current, peak clamping voltage, peak pulse power, and leakage current. The typical I-V characteristic curve for a unidirectional transient suppressor is shown in Figure 3. Although the curve shown is for a unidirectional TVS, the same parameters also use for a bi-directional part.

1. The normal operating or working voltage is usually called the reverse standoff voltage or working standoff voltage (Vwm) in specification data sheets. At the standoff voltage the TVS device only has leakage, but is not in conductive modulation.

2. The reverse breakdown voltage (Vbr) is specified at a bias level at which the device begins to conduct avalanche mode.

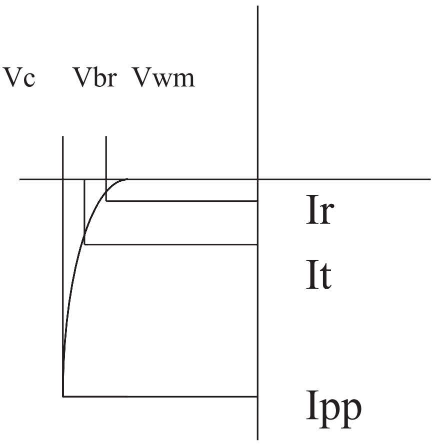
3. Peak pulse current (IPPM) is the maximum upper limit at which the device is expected to survive. We can measure the peak pulse power dissipated by the product of the clamping voltage (Vc) multiplied by the peak pulse current conducted through the device.

4. Clamping voltage (Vc) is specified only at the maximum limit on data sheets. The transient spike voltage drop can be clipped to a voltage level acceptable for safe operating condition by the clamping function of TVS diode.

5. Peak pulse power (Ppp) is the instantaneous power dissipated at the rated pulse condition. Common peak pulse power rating are 500W, 600W, and 1500W for 10/1000 us waveform. As the pulse width decreases, the peak power capability increases in a logarithmic relationship.

6. Leakage current (Ir) is the reverse current measured at the working voltage.

Fig. 3 Unidirectional TVS characteristic curve.



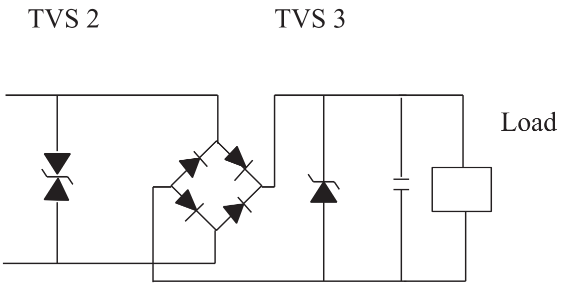
Package classification

The package of TVS has both axial lead and surface mount. The axial leaded components are available in peak pulse power ratings of 400W, 500W, 600W, and 1.5KW. Surface mount devices are available in ratings of 300W, 600W, and 1.5KW.

Example of using TVS diodes in circuit

TVS parts can be used in a circuit with various degrees of protection. For a typical linear power supply we may find the different TVS diodes providing different protection of the load or the electrical components that we expected to protect.

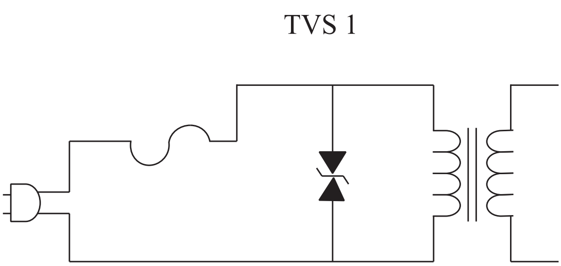
Fig 4. TVS 1provides the maximum protection to the transformer.



Transient Voltage Suppressors 1 shown in figure 4 provides a maximum protection. However, we do not recommend to use the TVS diode here, unless we can know the electric circuit impedance and the magnitude of surge rushed into the circuit. Otherwise the TVS diode is easy to be destroyed by voltage surge.

When transients produced by interrupting the transformer magnetizing current, these transients might destroy a rectifier diode or filter capacitor shown in figure 5 if a low impedance discharge path is not provided.

Fig. 5 The bi-directional TVS before bridge rectifier provides an excellent protection to the bridge rectifier.



So if we can place a bi-directional TVS part (TVS2) before bridge rectifier it may provide excellent protection of circuit.

TVS3 provides the load with complete protection. In almost every application, the unidirectional transient suppression device is placed in parallel with the load, since the main purpose of the circuit is to clamp the voltage appearing across the load. In figure 3, and figure 4 if only TVS3 is in use, the bridge rectifier then is unprotected and would require a higher voltage and current rating to prevent failure by transients.

Selection of a correct TVS

Several elements shown below are essential to how to choose a correct TVS diodes expected to be used in your application circuits.

1. Determine where the maximum DC or continuous operating voltage of your electrical circuit is. Use the TVS diode with standoff voltage higher than operating voltage.

2. Select TVS diode without its working standoff voltage (VWM) less than the circuit operation voltage. Since if the standoff voltage is chosen to have a lower rating, the TVS device may go into avalanche.

3. Determine the transient conditions of the circuit. Define the wave shape or transient source and the pulse duration. Choose a TVS device that can dissipate the non-repetitive or repetitive peak pulse power.

4. Select a TVS with a maximum clamping voltage (Vc) less than the voltage that can cause circuit damage.

End-Use application

TVS are available for operating with various voltage ranging. They are used in applications including automotive, computer, consumer, industrial, lighting ballast, power supply, and telecom system.