Fast Recovery Epitaxial Diodes (FRED)
Characteristics - Applications - Examples

Rüdiger Bürkel, Thomas Schneider

During the last 10 years, power supply topology has undergone a basic change. Power supplies of all kinds are now constructed so that heavy and bulky 50/60 Hz mains transformers are no longer necessary. These transformers represented the major part of volume and weight of a traditional power supply. Today they have been replaced with smaller and lighter transfomers, whose core materials now consist of sintered ferrites instead of iron laminations and which can operate up to 250 kHz. For the same power rating, high frequency operation significantly reduces the weight and volume of the transformer. This development has been significantly influenced by new, fast switching power transistors, such as MOSFETS or IGBTs, working at high blocking voltages (V_{CES} > 600 V).

However, nearly all topologies equipped with these transistors also need ultrafast diodes to conduct the reactive load current and to rectify the AC output when DC voltage is required. The switching behavior of these diodes must be tailored to match the switching charcteristics of the transistors.

This is not only true for switch mode power supplies but also for inverter circuits. For these inverters, manufacturers have chosen PWM frequencies of about 8 kHz to create a smooth sinoidial waveform of the output current or have used a PWM frequency above 20 kHz in order to operate above the audible level.

[1] MOSFET = **M**etal **O**xide **S**emiconductor **F**ield **E**ffect **T**ransistor
[2] IGBT = **I**nsulated **G**ate **B**ipolar **T**ransistor

Apart from the characteristics of the transitor switches, the on-state and dynamic characteristics of the free wheeling diodes have a significant impact on the power loss, the efficiency and the degree of safety in operation of the whole equipment. They also play a decisive role when it comes to increasing the efficiency of a SMPS and to reduce the losses of an inverter, which clearly mandates that ultrafast diodes be used. The ultrafast diodes described here embrace all characteristics of modern epitaxial diodes, such as soft recovery, low reverse recovery current I_{RM} with short reverse recovery times.

Technologies

The abbreviation FRED (**F**ast **R**ecovery **E**pitaxial **D**iodes) stands for a series of ultrafast diodes, which have gained wide acceptance during the last few years.

There exist several methods to control the switching characteristics of diodes and each leads to a different interdependency of forward voltage drop V_F, blocking voltage V_{RRM} and t_{rr} values. It is these interdependencies (or compromises) that differeniate the ultrafast diodes available on the market today. Fig.1 shows a qualitative relationship of forward voltage V_F and reverse recovery time t_{rr}. The most important parameters for the turn-on and turn-off behavior of a diode (Fig. 2) V_{FR}, V_F, t_{fr} and I_{RM}, t_{rr} will be influenced by different manufacturing processes. But as shown in Fig. 1, each technology must come up with a its own compromise between forward voltage and recovery time to obtain a device that will operate satisatisfac-torily.

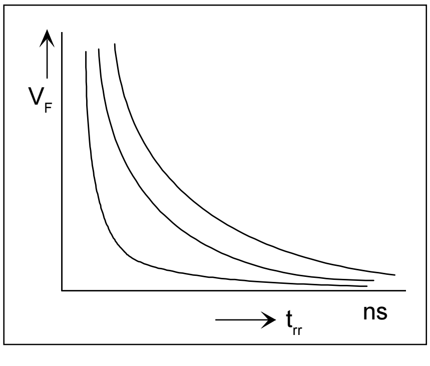


Fig. 1 Qualitative V_F - t_{rr} correlation to show this compromise for various FRED technologies

Figure 2 shows a typical switching cycle for the diode. During forward conduction, the resistivity of the n- epitaxial layer (see Fig. 4) is decreased by excess minority charges (in this case holes) being stored there. When this forward current is commutated to another switch, the diode cannot regain its reverse blocking capability until this excess stored charge is removed, which can only be done by recombination of the stored holes with the background electrons or by reverse current flow through the diode. Since the ideal diode has zero reverse recovery

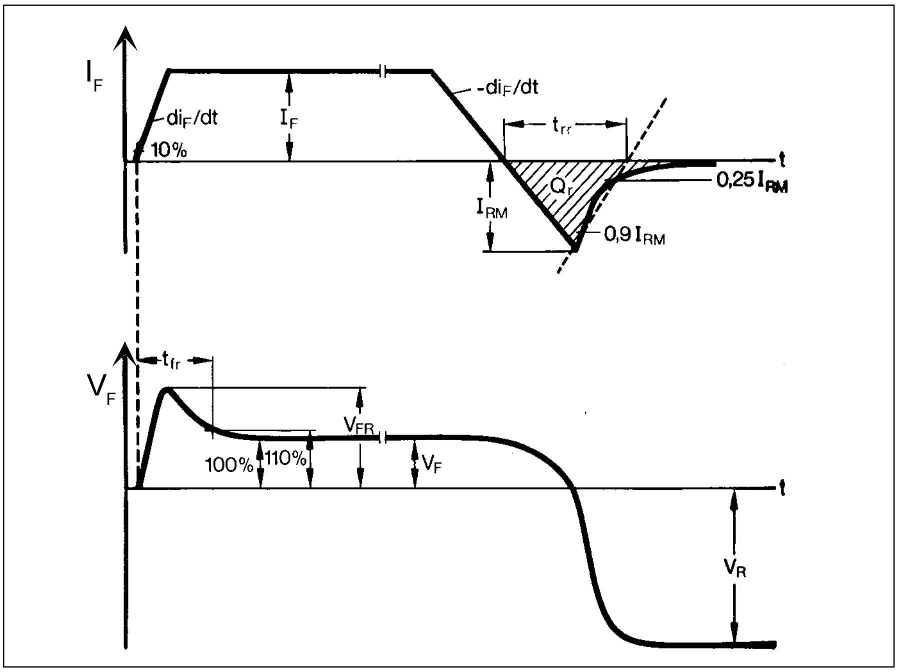


Fig. 2 Typical switching I/V waveforms for a FRED diode

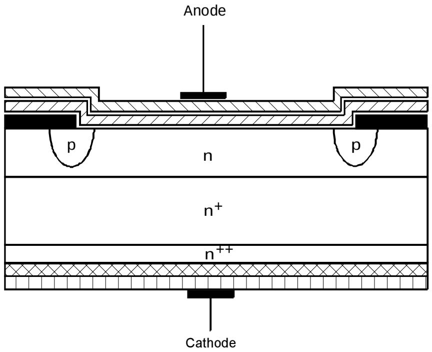


Fig. 3 Cross-sectional view of a Schotty diode

current, the recombination of stored charge must be accelerated, which is done by the introduction of recombination centers into the n- epitaxial layer. Of course, the end result will be that the stored charge both recombines and is swept out by reverse current, resulting in a short negative current pulse, called reverse recovery current. As the reverse recovery current reaches its maximun (I_{RM}), areas free of carriers develop at the pn-junction, which can then start to block voltage. The ensuing decrease of the recovery current is essentially determined by the actual distribution of the remaining carriers in the n-region. The decrease of the recovery current (di_R/dt) versus time is of special importance, because it determines the peak voltage and dv/dt transients that will occur. This will be discussed in more detail below.

As already mentioned, recombination centers are created within the diode to decrease reverse recovery current. The Schottky diode, whose cross-section is shown in Fig. 3, is a majority carrier diode, which can be switched very quickly, similar to a MOSFET. The observed reverse current is due to the charging of the metal barrier-silicon capacitance, which is independent of temperature. Up to now, Schottky diodes have only been used for applications with low reverse voltages (typically less than 60 V). However, newer types with higher blocking voltages up to 300 V and more are already available.

For applications requiring ultrafast diodes with blocking voltages in excess of 300 V, bipolar pn-junction FREDs are the only answer.

Characteristics

The most important processes to speed up the turn-off behavior of a bipolar diode are gold or platinum doping and electron irradiation. In the case of ultrafast diodes, the n-layer that supports the reverse voltage, should be made as thin as possible to minimize the forward voltage drop as well as the stored charge in the pn-junction. To obtain a wafer thickness that allows a good mechanical handling of the wafers, the epitaxial technology is the most favorable choice. This technology makes use of a relatively thick n+ doped wafer substrate for mechanical strength, on which a thin, monocrystal n-layer (the so-called epitaxial layer), is grown. The epi-layer thickness and resistivity are adjusted according to the desired blocking voltage capability.

The passivation of the pn-junction uses planar technology, which is similar to the manufacturing process of transistors. Guard rings reduce the electric field strength to prevent voltage break-down and the surface is glass-coated to ensure blocking voltage stability. To improve the turn-off behavior, either gold or platinum atoms can be diffused interstitially into the epilayer and these atoms act as trapping sites, in which the excess holes can recombine with electrons. Recombination centers can also be created by electron irradiation, which displaces silicon atoms from their normal cyrstalline lattice sites. Very high temperatures will allow the displaced silicon atoms to vibrate back into the lattice structure. Therefore, the irradiation is often followed by an annealing process to anneal out the low

Planar epitaxial diode, DWEP...

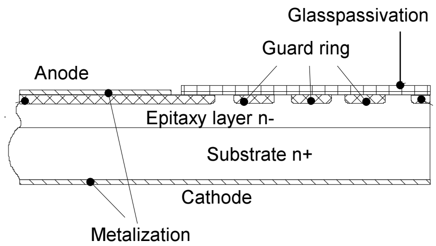


Fig. 4 Cross-sectional view of a FRED junction diode with planar passivation

temperature sensitive portion of the crystal disturbances. If the process parameters, irradiation energy and annealing temperature are properly chosen, the switching characteristic will remain stable. Table 1 shows all the essential characteristics of ultrafast diodes by process technologies.

Of course, any manufacturing process for ultrafast diodes has advantages as well as disadvantages. FRED diodes, using gold doping to control minority carrier lifetime, represent an excellent compromise between forward voltage, low peak reverse recovery currents with soft recovery. These diodes are characterized by a soft recovery behavior from -40°C to +150°C, showing even at very high $-di_F/dt$ (> 800 A/µs) no tendency to “snap-off.” The higher leakage current of the gold doped diode is, in compari-son to the platin doped or irradiated diode, the only disadvantage. However in most applications, the power loss caused by the leakage current is small in comparison to forward current and reverse recovery losses (Fig. 5) [1].

Table 1 Comparative advantages of ultrafast diodes by process technologies

Gold Doped	Platinum Doped	Electron Irradiation	Schottky Diodes
Soft reverse recovery	Tendency to snapp-off	Tendency to snapp-off	Much better turn-off than gold
Good V_F - t_{rr} trade-off, very short t_{rr} with much higher V_F	Good V_F - t_{rr} trade-off at nearly the same V_F as gold; higher I_{RM} for same t_{rr} than gold	V_F - t_{rr} trade-off not as good as Pt or Au doping; clearly longer t_{rr}	Very small I_{RM}, low V_F at low V_R
High I_R at high temperatures (100°C)	Low I_R	Low I_R	Very high I_R, even at room temperature, relatively low V_R

Free Wheeling Diodes

These diodes are mainly used as free wheeling diodes, connected in parallel to fast switching transistors working with an inductive load such as e.g. inductors in a boost or buck converter, transformers and motors. The majority of these circuits is controlled by pulse width modulation working at a fixed frequency. Forced by the inductive load, the current must continue to flow via a free wheeling circuit. In case the transistor is turned-on, the free wheeling path must be blocked to prevent a short circuit. The typical interaction between the power transistor and the free wheeling diode is described in the following example.

Fig. 6 shows the simplified circuit of a buck converter. This circuit provides an output voltage V_{out} which is lower than the supply voltage V_{in}. Fig. 7 shows the control signals of T1 and the voltage and current waveforms of T1 and D1. The conducting and blocking phases of the two active elements T1 and D1 can be devided as follows:

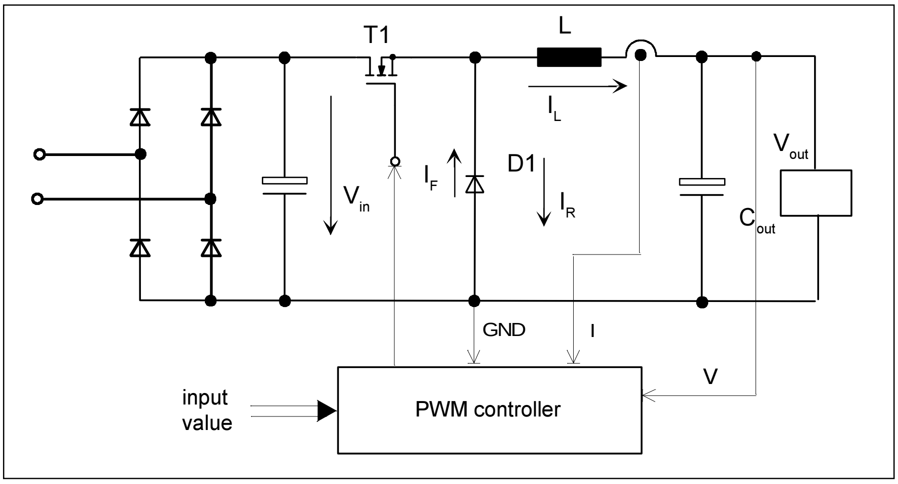


Fig. 6 Buck-converter circuit diagram

The switching action of Diode D1 is characterized by four important phases:

A. the diode blocks while T1 is in the on-state,

B. the transition from blocking to conducting mode: turn-on,

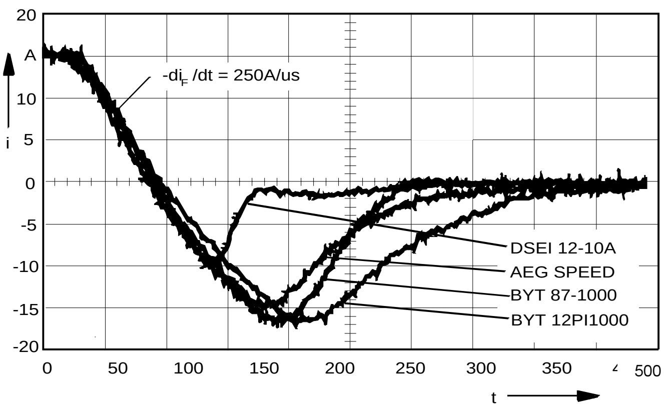


Fig. 5 Comparison of reverse recovery currents for several different FREDs [1]

At a certain time t_0 the controller switches on T1. The series circuit of L and C_{out} is connected to the supply voltage V_{in} and makes the current I_L increase linearly. This current is deter-mined by the inductor L and the output voltage V_{out}. After a certain time, fixed by the controller, T1 is switched off again. In the discontinuous mode of operation, the energy stored in L ($W = 0.5 \cdot L \cdot I_L^2$) is transferred via the free wheeling path into the capacitor C_{out}.

At a certain time t_2, T1 is switched on again and the whole precedure is repeated.

C. the diode conducts forward current while T1 is blocked,

D. the transition from conducting to blocking mode: turn-off.

A. Blocking Mode

While the MOSFET T1 is conducting, the supply voltage V_{in} appears as reverse voltage at diode D1. As with all semiconductors, a low current in the diode flows from the cathode to the anode (leakage current I_R). The leak-age current depends on the blocking voltage cabability, on the temperature of the diode chip and, above all, on the technology of the diode. Together with the applied reverse voltage the reverse power loss is:

$$P_{SP} = V_{in} \cdot I_R$$

B. Turn-On

With the transistor T1 switched off, the current I_L in the inductor must keep on flowing. The voltage across the diode drops down and the diode takes over the current of the inductor. The current rise time in D1 equals the current fall time in T1. The volume charge formed in the pn-junction of the diode during the blocking phase is flooded by carriers causing a change of resistance of the pn-junction during current rise time. This turn-on of the diode is accompanied by a short overvoltage in forward direction which depends on the chip temperature, on the $-di_F/dt$ and again on the chip technology.

Compared to the blocking voltage, the overvoltage is very low (< 50 V) and for most applications, it is not important to the operation of the diode (waveform D1 in Fig. 7). However, this dynamic turn-on voltage of the diode does add to the peak voltage that appears across the transistor T1 and adds to its turn-off losses.

The overvoltage V_{FR} determines the turn-on losses of the diode. These turn-on losses increase linearly with the switching frequency.

C. On-State

Once the turn-on phase is over, the diode conducts the forward current I_F. There is a forward voltage drop V_F due to the threshold voltage of the pn-junction and the resistance of the semi-conductor. This voltage drop depends, as already mentioned, on the chip temperature, the forward current I_F and the process technology.

To indicate the forward voltage drop at various currents and, consequently, to calculate the on-state losses, the parameters V_{T0} and r_T often appear in datasheets.

A simplified model for the forward voltage drop shown in Fig. 8 is:

$V_F = r_T \cdot I_F + V_{T0}$

The on-state power dissipation can then be calculated accordingly:

$P_D = V_{T0} \cdot I_F + r_T \cdot I_F^2$

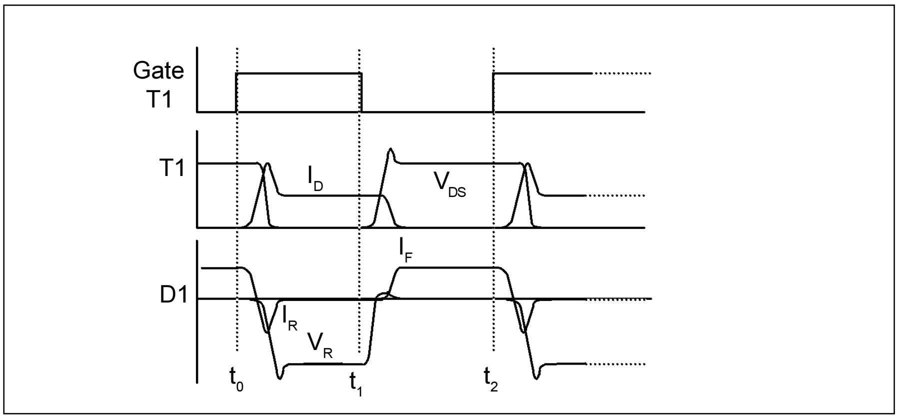


Fig. 7 Transistor gate signals, current and voltage waveforms along with the diode current and voltage waveforms for one switching cycle of the buck-converter shown in Fig. 6

The calculated losses, however, are only approximate values, as V_{T0} and r_T depend a great deal on the temperature and are only given for a certain temperature (T_{VJM}). Since this temperature can differ from the actual operating temperature, the calculated losses are only valid for the given temperature.

D. Turn-Off

Apart from the on-state characteristic, the turn-off behavior is considered to be the most important parameter in determining the suitability of the diode for a high frequency application. If the current I_F is commutated to the transistor, it decreases linearly with the di/dt at which the transistor turns on the current. In the case of power MOSFETs and IGBTs, -di_F/dt values of more than 1000 A/µs can easily be reached. As mentioned before, the carriers which have flooded the pn-junction during the on-state phase must be removed before the diode can start to block reverse voltage.

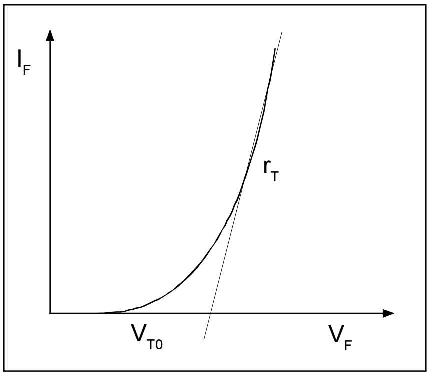


Fig. 8 Typical forward voltage drop V_F versus current its model, $V_{T0} + I_F \cdot r_T$

What results is the reverse recovery current I_R, whose waveform depends on the chip temperature, the forward current I_F, the -di_F/dt and the technology.

Fig. 9 shows how the reverse recovery current depends on the chip temperature of a gold doped (9a) and a platinum doped (9b) epitaxial diode of the same forward characteristic.

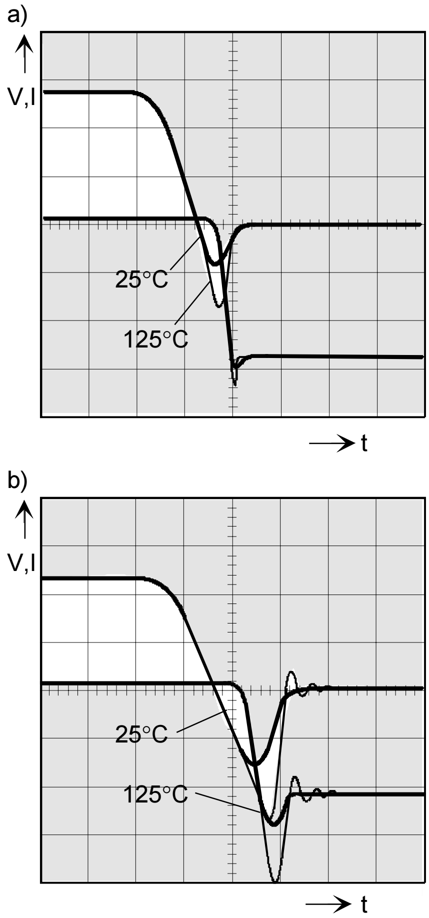


Fig. 9 Reverse recovery current and voltage for two FRED diodes at T_{VJ} = 25°C und 125°C
a) gold-doped diode
b) platinum-doped diode

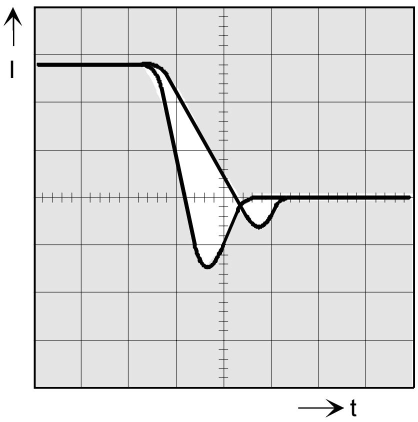
The difference between the two technologies is really striking, if one compares the recovery behavior at various -di_F/dt and at the same temperature.

Whereas, in the case of platinum, the decrease of the recovery current speeds up (Fig. 10b), the gold diodes with controlled minority carrier reduction keep their soft recovery behavior, even at high $-di_F/dt$ values (Fig. 10a).

The faster the decrease of the recovery current (the diode gets "snappy"), the higher the overvoltage caused by the stray inductances of the circuit lay-out. If the maximum voltage reaches the maximum blocking voltage of the transistor, snubbers must be used to guarantee the safety in operation of the equipment. Furthermore, much too high dv/dt values cause EMI/RFI problems, which complicate the shielding, if certain RFI limits have to be kept.

The reverse recovery current flowing in the diode does not only determine the turn-off losses of the diode but also adds to the turn-on losses of the transistor, which now carries the diode current.

a)



b)

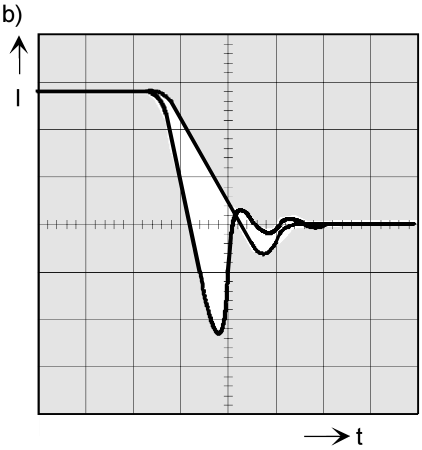


Fig. 10 Reverse recovery currents for different $-di_F/dt$ at T_J = 125°C
a) gold-doped diode
b) platinum-doped diode

The reverse recovery current must be added to the current in the inductor and the turn-on time extended by some portion of trr (Fig. 11a and b).

Figures 11a and 11b emphasize the significance of a low peak recovery current accompanied by soft recovery behavior. In the first place, the soft recovery behavior of the gold doped diodes entails a small overvoltage and a low reverse recovery current. Therefore the diode is marked by low turn-off losses. Secondly, the low reverse recovery current leads to essentially reduced turn-on losses in the transistor. Thus, the choice of the diodes decisively influences the power losses in both devices.

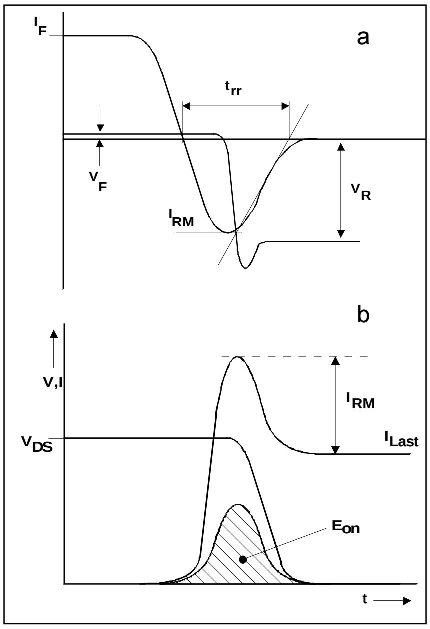


Fig. 11a Reverse recovery waveforms for a free-wheeling diode
Fig. 11b Transistor current and voltage waveforms showing the impact of reverse recovery current as it commu-tates off the free-wheeling diode

Example

The following example illustrates how to calculate the power losses of the free wheeling diode D1 in a buck-converter (Fig. 5). The epitaxial diode, type DSEI 30-10 A, is described in the slightly shortened datasheet (page D1-16), where one can also find the respective data to calculate the power losses.

Operating conditions of the buck-converter:

DC-link voltage V_{in}	600 V
Current fall time of MOSFET t_f	60 ns
Output voltage V_{out}	300 V
Switching frequency f_t	50 kHz
Inductor current I_L	15 A
Duty cycle of MOSFET d	0.5
Max. junction temperature T_{VJ}	125°C

A. Maximum Blocking Losses

From datasheet page 11: I_{Rmax} = 7 mA at T_{VJ} = 125°C, V_R = 800 V

$P_{SP} = V_{in} \cdot I_{Rmax} \cdot d = 600\ V \cdot 7\ mA \cdot 0.5$

$\mathbf{P_{SP} = 2.1\ W}$

B. Turn-on Losses

The calculation of the actual turn-on losses is much more difficult than the calculation of the blocking losses or on-state losses. There is no static operation, the current and the voltage of the diode are functions of time and can only be calculated approximately by using exponential and hyberbolic equations.

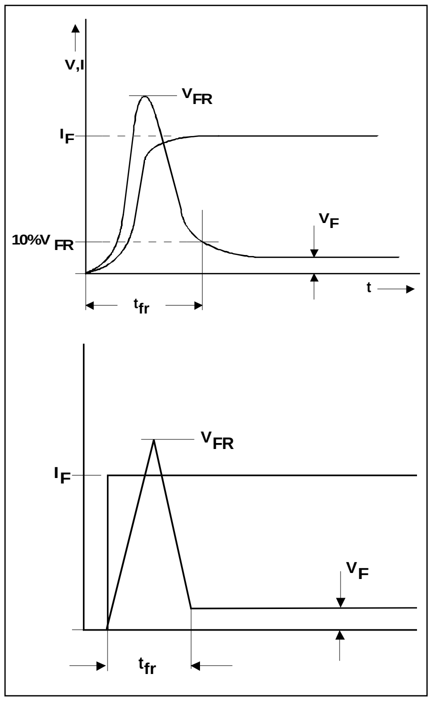


Fig. 12 Actual diode turn-on V/I waveforms and their linearized approximations to simplify turn-on power loss calculations

To estimate the diode turn-on losses, the turn-on waveform is given in a simplified form in Fig. 12. This simplification is conservative, i.e. the actual turn-on losses are smaller than the calculated ones, and makes it possible to do the calculation using the datasheet values.

The current rise time is determined by the turn-off time of the MOSFET and the load current:

$di_F/dt = I_F/t_f = 15\ A/60\ ns = 250\ A/\mu s$

The diagram in Fig. 6 of the datasheet shows the turn-on recovery time t_{fr} and the turn-on overvoltage V_{FR} for a $-di_F/dt = 250\ A/\mu s$: $V_{FR} = 31.5\ V$
$t_{fr} = 360\ ns$

To calculate the turn-on energy, the current I_F, which is assumed to be constant, is multiplied by the triangle waveform of the overvoltage V_{FR} and by the time t_{fr}:

$E_{on} = I_F \cdot V_{FR} \cdot t_{fr} \cdot 0.5 =$

$E_{on} = 15\ A \cdot 31.5\ V \cdot 360\ ns \cdot 0.5 =$

$E_{on} = 85\ \mu J$

The turn-on power losses can be calculated by multiplying the pulse energy E_{on} by the switching frequency:

$P_{on} = E_{on} \cdot f_t = 85\ \mu J \cdot 50\ kHz =$

$\mathbf{P_{on} = 4.3\ W}$

C. On-State Losses

The on-state forward voltage at $I_F = 15\ A$ and $T_{VJ} = 125°C$ is shown in the diagram in Fig. 1, page 12. The on-state forward voltage at 15 A is given by the V_F curve for $T_{VJ} = 100°C$: $V_F = 1.77\ V$

Thus the following on-state losses can be calculated:

$P_D = V_F \cdot I_F \cdot d = 1.77\ V \cdot 15\ A \cdot 0.5 =$

$\mathbf{P_D = 13.3\ W}$

If one calculates the on-state losses using the formula
$P_D \approx (V_{T0} \cdot I_F + r_T \cdot I_F^2)\ (1\text{-}d)$, one gets a smaller value:
$V_{T0} = 1.5\ V$ and $r_T = 12.5\ m\Omega$
$P_D \approx 1.5\ V \cdot 15\ A \cdot 0.5 + 12.5\ m\Omega \cdot 15\ A^2 \cdot 0.5^2$

$\mathbf{P_D \approx 12\ W}$

D. Turn-off Losses

Similar to the turn-on losses, the turn-off losses can only be calculated approximately using the datasheet values. Once again, the waveforms of the voltage and of the current are simplified (Fig.13).

If one assumes the same di_F/dt as given during switch-on, the diagrams of Fig. 3 and Fig. 5 of the datasheet show: $I_{RM} = 15\ A$, $t_{rr} = 100\ ns$. These data are valid for $T_{VJ} = 100°C$ and must be multiplied by a factor adjusting these data for $T_{VJ} = 125°C$. This factor K_f is given in the diagram of Fig. 4 of the datasheet. For $T_{VJ} = 125°C$ the data for I_{RM} are to be multiplied by 1.1. This simplified calculation of the turn-off behavior results in a turn-off energy of:

$E_{off} = I_{RM} \cdot K_f \cdot V_R \cdot t_{rr}/2 \cdot 0.5$

$E_{off} = 15\ A \cdot 1.1 \cdot 600\ V \cdot 50\ ns \cdot 0.5 =$

$E_{off} = 248\ \mu J$

The multiplication by the switching frequency results in a turn-off power loss:

$P_{off} = E_{off} \cdot f_t = 248\ \mu J \cdot 50\ kHz$

$\mathbf{P_{off} = 12.5\ W}$

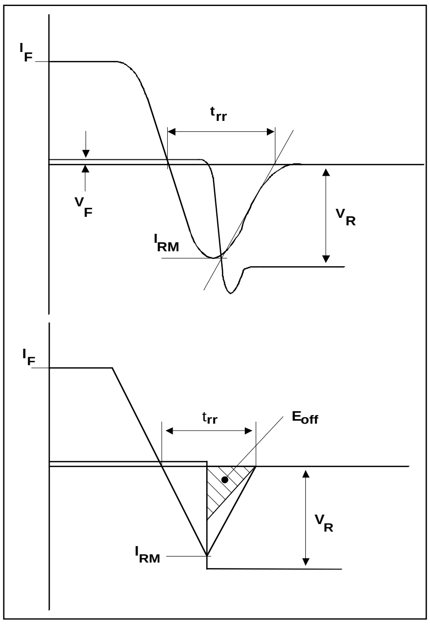


Fig. 13 Actual diode reverse recovery I/V waveforms and their linearized approximations

The total losses of the diode in the buck-converter are:

$P_{tot} = P_{SP} + P_{on} + P_D + P_{off}$

$P_{tot} = 2.1\ W + 4.3\ W + 13.3\ W + 12.4\ W$

$\mathbf{P_{tot} = 32.1\ W}$

Using the thermal resistance $R_{thJC} = 0.9\ K/W$, which is shown in the data-sheet, the chip temperature is 29°C above the case temperature. Assuming a thermal resistance of $R_{thCK} = 0.25\ K/W$ and a chip temperature of less than 125°C, the maximum heatsink temperature may not exceed 88°C:

$T_{Kmax} = T_{VJM} - (R_{thJC} + R_{thCK}) \cdot P_{tot}$

$T_{Kmax} = 125°C - (0.9+0.25)\ K/W \cdot 32.1\ W =$

$T_{Kmax} = 88°C$

While this application used a buck-converter circuit as an example, the same approximations and calculations can be used for the boost-converter.

Further Applications

Rectifier Diodes

Ultrafast epitaxial diodes are used as rectifier diodes but only if the switching frequency is higher than 1 kHz and the blocking voltage exceeds 200 V. These conditions are very common in switch-mode power supplies delivering output voltages of more than 200 V, because there are no Schottky barrier diodes with the required blocking voltage capability (Fig. 14). Switch-mode power supplies generally operate with a PWM controller. Therefore the mode of operation of the epi-diode used as rectifier is very similar to that of the free wheeling diode. As the current and voltage waveforms are rectangular, the calculation of the power losses can be carried out as described in the case of the free wheeling diode.

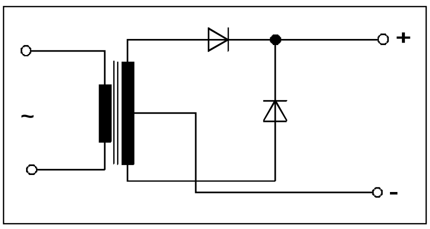


Fig. 14 Center-tapped DC output circuit with common-cathode diode connection

Snubber Diodes

"Snubber" circuits are used to protect power semiconductors from being destroyed by short overvoltage spikes. The di/dt values of more than 1000 A/µs, which can be reached with transistors (MOSFETs or IGBTs), cause overvoltages due to the parasitic stray inductances of the circuit wiring.

The equation V = L • di/dt underlines how high these overvoltages can be, even at very low stray inductances. For example, for the the case of a -di/dt of 1000 A/µs during switch-off with a stray inductance of 100 nH, the computed voltage spike is:

V = 100 nH • 1000 A/µs = 100 V

This 100 V spike, which will be added to the DC bus voltage, will require the use of a higher voltage MOSFET or IGBT. These devices not only cost more but the efficiency of the circuit will decrease due to their higher switching losses. Snubber circuits can limit the generated overvoltage transferring the energy stored in the stray inductances to a capacitor. Apart from its capaci-tance, the turn-on behavior of the diode determines the remaining overvoltage.

The diagram in Fig. 6 of the datasheet illustrates the forward recovery voltage V_{FR}, which can be expected, and the forward recovery time t_{fr} for various di/dt values.

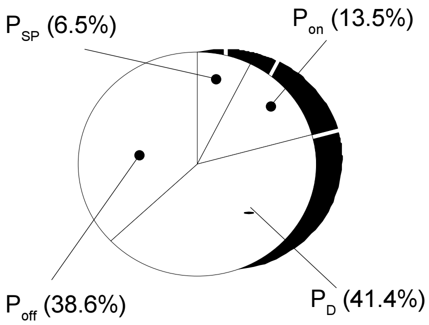


Fig. 15 Comparative losses for the free-wheeling diode in the buck-converter example

Summary

As depicted in detail, ultrafast diodes can have different characteristics depending on the manufacturing process. These characteristics should be considered to make best use of them in the various applications.
If standard FREDs in an existing circuit are replaced by DSEI diodes, the power losses of both the diode and the transistor can thus be reduced. The soft recovery behavior of all DSEI diodes also prevents the transistor from being overloaded by too high a dv/dt or overvoltage spike and also reduces EMI/RFI.

The market for ultrafast diodes is constantly expanding. Apart from their standard application as free wheeling diode in inverters, these diodes are also more and more used in snubber circuits and in rectifier circuits in switch-mode power supplies.

All FRED diodes delivered by IXYS are characterized by very low reverse recovery currents, even at high $-di_F/dt$. Simultaneaously, they show a soft decrease of the reverse recovery current, thus avoiding inductive overvoltages with very high dv/dt. These overvoltages could cause a malfunction or even the destruction of the active switching device, eg. a MOSFET, an IGBT or bipolar transistor.

The given example of the buck-converter shows, that when choosing an ultrafast diode, all operating modes taken together must be considered and not only the individual parameters.

The losses of the diode in the buck-converter can be divided as illustrated in Fig. 15. The on-state and turn-off losses make up 80 % of the total losses of the diode. The determining factors of these losses are:
$P_D \sim V_F$
$P_{off} \sim t_{rr}, I_{RM}$
IXYS offers ultrafast diodes (FRED = **F**ast **R**ecovery **E**pitaxial **D**iodes) in the TO-220, TO-247 and SOT-227B packa-ges. These diodes are available with blocking voltages from 400 to 1200 V. Furthermore, IXYS provides FRED modules in various topologies up to 300 A and 1200 V (table 2, page 10).

FRED Modules

The FRED modules type MEO, MEE, MEA and MEK (Fig. 16) are an extension of the discrete DSEI to higher current while sharing the same diode characteristics mentioned before. They can be applied in all circuits with MOSFETs, IGBTs or bipolar Darlingtons, working at switching frequencies of more than about 1 kHz.

If the paralleling of several discrete diodes or miniBLOCs is necessary, these modules represent a possible alternative to minimize the assembly time and the size of the final equipment. Generally the FRED modules can be used as free wheeling diodes for high current IGBTs or for bipolar Darlingtons and as fast rectifiers in power supplies and welding equipments. What follows is a series of applications showing the use of FRED modules.

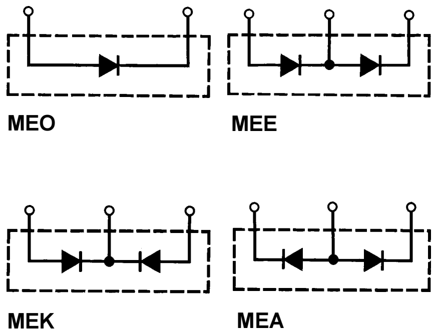


Fig. 16 Circuit diagrams for the available FRED modules

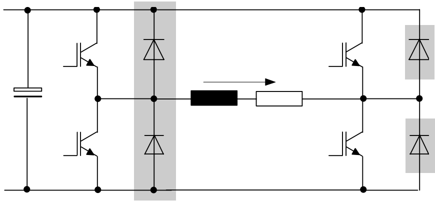


Fig. 17 MEE type or MEO type

A. Application as free wheeling diode in one or three phase inverters for drive and UPS systems, working with PWM controlling and switching frequen-cies in the kHz range (Fig. 17)

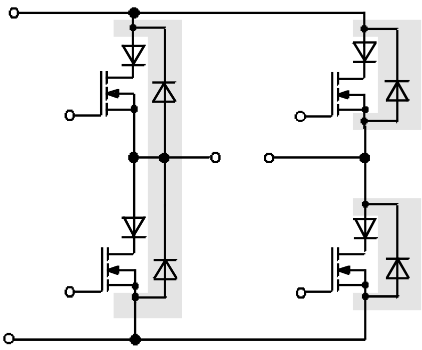


Fig. 18a MEE type or MEO type

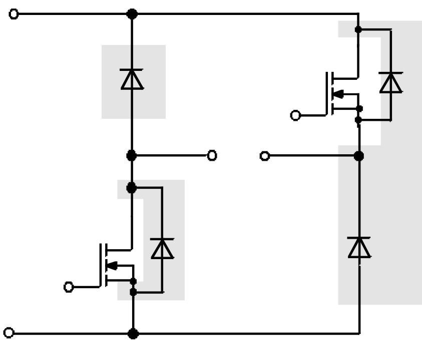


Fig. 18b MEO type or MEE type

B. Application as free wheeling diode in switch-mode power supplies and servo drives
a. symmetrical full bridge with MOSFETs and Schottky blocking di-odes (Fig. 18a)
b. assymmetrical full bridge with MOSFETs for forward converters and DC motor drives (Fig. 18b)

C. Application as rectifier in power supplies and welding equipments

Half-wave rectifier (Fig. 19a). Depend-ing on the load current, several MEO modules can be paralleled.

Common cathode topology (Fig. 19b). Depending on the load current, several MEK modules can be paralleled.

Common anode topology (Fig. 19c). Depending on the load current, several MEA modules can be paralleled.

Full bridge rectifier (Fig.19 d). Depend-ing on the load current, either MEE or MEO modules can be paralleled.

Full bridge rectifer for higher output voltages (Fig. 19e). Here both diodes in the MEE module are connected in series to obtain a higher/blocking voltage.

For all FRED modules the continuous DC current I_{FAVM} is given at a heatsink temperature of T_S = 65°C and a junction temperature T_{VJM} = 125°C (difference of temperature = 60°C).
When comparing these modules with types of the competition, one has to make sure that the two modules to be com-pared share the same difference of tem-perature between heatsink (case) and junction, because this is what determines the maximum allowable forward current.

Furthermore, the current ratings for the FRED modules include the blocking losses of the diode at T_{VJ} = 125°C and at a duty cycle of d = 50 %.

Parallel and Series Connection of the Modules

All FRED modules consist of several individual diode chips, which are con-nected in parallel internally to obtain the desired current rating of the module. In order to get a good current sharing be-tween the diode chips, they are selected in such a way that the forward voltage drop V_F is nearly the same for all chips in parallel. This V_F selection facilitates the parallel connection as well as the series connection of several modules.

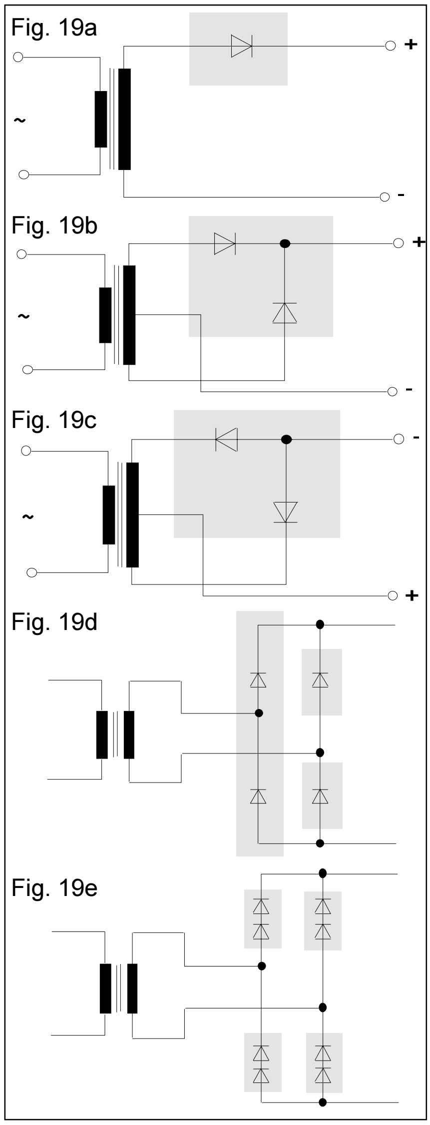


Fig. 19a-e Examples of different FRED modules as output rectfiiers in power supplies

Parallel Connection

To simplify the parallel connection of several modules, they are tested for V_F categories which are indicated on the type label. The part number is followed by a digit or letter, which stands for the V_F category of the device. Example: MEO260-12DA3 or MEK160-06DAD.

If several modules are connected in parallel to get a higher output current, only modules of the same V_F category should be used. There are, of course, exceptions to the rule: It is also possible to use two adjoining V_F categories; however, due to the saftey in operation, this should only be the exception. The current handling capability of the modules connected in parallel is calculated as follows:

$I_P \approx n \cdot I_n \cdot 0.8$
n = number of modules
I_n = current of one module (see table 3)
I_P = total current of the modules in parallel

Example: 3 modules MEO 260-12DA1 are connected in parallel:
The allowable continuous forward current I_{FAVM} at T_{VJ} = 65°C equals:
$I_P = 3 \cdot 262\ A \cdot 0.8 = 629\ A$

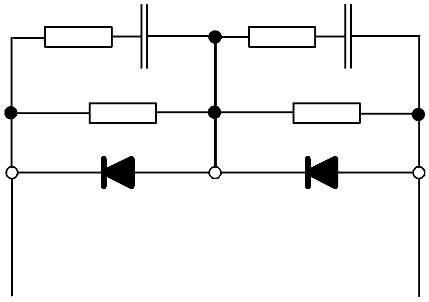


Fig. 20 Voltage sharing networks for FRED modules when its diodes are to be used in series

Series Connection

The series connection of FRED modules requires a static resistor circuit to equalize the different blocking currents of the diodes and a dynamic RC snubber circuit to equalize the different reverse recovery charges (Q_r) of the diodes. The calculation of these snubber circuits has to take into account a great number of conditions which can differ from application to application. The snubber circuits can only be optimized, if one is really familiar with these conditions.

The rough setup of these snubber circuits is illustrated in Fig. 20. What is of special interest is that, for the individual diode chips within a module, the selection in V_F categories also means that there exists a selection in I_{RM} and thus in Q_r.

A detailed databook (publication no. D94013DE) for the whole range of ultrafast diodes exists to help the design engineer to choose the right diode for his application.

Literature

[1] Heumann, K: Impact of turn-off Semiconductor devices on power electronics, EPE Journal, Vol. 1 (1991), No. 3, page 181 - 192