Power Diodes — Introduction

NEW PRODUCTS

Philips Semiconductors are working intensively on bringing new Power Diode products to the market. The products listed below appear for the first time in this data handbook.

25 V SCHOTTKY DIODES

A range of low voltage schottky diodes with a reverse voltage rating of 25 V, with extremely low forward voltage and ultra fast switching. These products are intended for use in switched mode power supplies with 3 V and 3.3 V outputs. They are also ideal for use as or-ing diodes in fault tolerant designs or current sharing configurations. Types: BYV116, PBYR225CT, PBYR1025, PBYR1525CT, PBYR2025CT, PBYR2525CT.

DEFLECTION DIODES

Further extensions to our range of high voltage, fast recovery diodes, designed for use in the horizontal deflection stages of multisync computer monitors with scan rates up to 82 kHz. These devices complement our range of high voltage bipolar deflection transistors and have fast forward recovery time, low forward recovery voltage and reverse voltage ratings up to 1700 V. Types: BY479X-1700, BY559-1500.

ISOLATED 45 V SCHOTTKY AND 200 V EPITAXIAL DIODES

A wide range of 45 V schottky diodes and 200 V ultrafast recovery epitaxial diodes in the SOT186A envelope. This package is an isolated version of TO220AB with 2500 Vrms isolation between leads and case. Types: BYV118X, BYV133X, BYV143X, PBYR745X, PBYR1045X, PBYR1545CTX, PBYR1645X, PBYR2045CTX, PBYR2545CTX, BYQ28X, BYQ28EX, BYW29EX, BYV32EX, BYV42EX,

SURFACE MOUNT POWER DIODES IN SOT404

A wide range of schottky and 200 V epitaxial diodes in a SOT404 envelope suitable for surface mounting. This package is a surface mounting version of TO220AB with the same thermal resistance and current rating. Types: BYV118B, BYV143B, PBYR745B, PBYR1045B, PBYR10100B, PBYR1545CTB, PBYR1645B, PBYR2045CTB, PBYR20100CTB, PBYR2545CTB, BYQ28EB, BYW29EB, BYV32EB, BYV42EB, BYV79EB.

SURFACE MOUNT BREAKOVER DIODES IN SOD106

The BR211 range of breakover diodes in a SOD106 surface mounting envelope. Used for transient overvoltage protection in line based telecommunications equipment. BR211SM series.

FORTHCOMING PRODUCTS

The products listed below are planned for release within the next 12 months, before the next edition of this data handbook. Contact your Philips Regional or National Sales office for further details.

SURFACE MOUNT POWER DIODES IN SOT428

Available towards the end of 1996, a range of schottky and 200 V epitaxial diodes in a SOT428 envelope suitable for surface mounting. The SOT428 envelope is slightly larger than our present subminiature surface mounting package, SOT223 and may be mounted on the same printed circuit pad layout. However, it has lower thermal resistance and can accommodate larger crystal sizes, thereby allowing higher current ratings to be achieved in a smaller package.

SCHOTTKY AND 200 V EPITAXIAL DIODES IN TO247

Available during the first quarter of 1997, a range of schottky and 200 V epitaxial diodes in a TO247 envelope suitable for high power applications, featuring low thermal resistance and output current ratings up to 60 Amps.

POWER FACTOR CORRECTION DIODES

Available during the first quarter of 1997, a range of ultrafast, 600 V epitaxial diodes specifically designed for power factor correction and other forced commutation applications. These diodes are designed to minimise switching losses both in the diode and in the switching transistor. Other applications include freewheeling diodes in full and half bridge switched mode power supplies, where they complement our new range of 400 V, 500 V and 600 V power mosfets.

APPLICATIONS

Application information for Power Diodes and other Philips power products is published in Philips Power Semiconductor Applications Handbook. (Order code: 9398-652-85011)

POWER DIODE CHARACTERISTICS

Back diffused rectifier diodes

A single-diffused P-N diode with a two layer structure cannot combine a high forward current density with a high reverse blocking voltage.

A way out of this dilemma is provided by the three layer structure, the so-called P-I-N diode, where 'I' is a lightly doped (nearly intrinsic) layer. This layer, called the base, is sandwiched between the highly doped diffused P^+ and N^+ outer layers giving a P^+-P-N^+ or P^+-N-N^+ structure. Generally, the base gives the diode its high reverse voltage, and the two diffused regions give the high forward current rating.

Such a three layer diode can be realised using a 'back-diffused' structure. A lightly doped silicon wafer is given a very long N^+ diffusion on one side, followed by a relatively shallow P^+ diffusion on the opposite side. This asymmetric diffusion allows better control of the thickness of the base layer than the conventional double diffusion method, resulting in a better trade-off between low forward voltage and high reverse blocking voltage. Generally, for a given silicon area, the thicker the base layer the higher the V_R and the lower the I_F. Reverse switching characteristics also determine the base design. Fast recovery diodes usually have N-type base regions to give 'soft' recovery with a narrow base layer to give fast switching.

Ultra fast rectifier diodes

Ultra fast rectifier diodes, made by epitaxial technology, are intended for use in applications where low conduction and switching losses are of paramount importance and relatively low reverse blocking voltage (V_{RWM} = 150V) is required: e.g. Switched mode power supplies operating at frequencies of about 50 kHz.

The use of epitaxial technology means that there is very close control over the almost ideal diffusion profile and base width giving very high carrier injection efficiencies leading to lower conduction losses than conventional technology permits. The well defined diffusion profile also allows a tight control of stored minority carriers in the base region, so that very fast turn-off times (35 ns) can be achieved. The range of devices also has a soft reverse recovery and a low forward recovery voltage.

Schottky-barrier rectifier diodes

Schottky-barrier rectifiers find application in low-voltage switched-mode power supplies (e.g. a 5 V output) where they give an increase in efficiency due to the very low forward drop, and low switching losses. Power Schottky diodes are made by a metal-semiconductor barrier process to minimise forward voltage losses, and being majority carrier devices have no stored charge. They are therefore capable of operating at extremely high speeds. Electrical performance in forward and reverse conduction is uniquely defined by the device's metal-semiconductor 'barrier height'. Philips process minimises forward voltage drop, whilst maintaining reverse leakage current at full rated working voltage and $T_{j\,max}$ at an acceptable level.

Philips range of power schottky-barrier diodes can withstand reverse voltage transients and have guaranteed reverse surge capability.

Power diode ratings

A rating is a value that establishes either a limiting capability or a limiting condition for an electronic device. It is determined for specified values of environment and operation, and may be stated in any suitable terms. Limiting conditions may be either maxima or minima.

All limiting values quoted in this data handbook are Absolute Maximum Ratings - limiting values of operating and environmental conditions applicable to any device of a specified type, as defined by its published data, which should not be exceeded under the worst probable conditions.

VOLTAGE RATINGS

V_{RSM} Non-repetitive peak reverse voltage. The maximum allowable instantaneous reverse voltage including all non-repetitive transients. duration ≤ 10 ms.

V_{RRM} Repetitive peak reverse voltage. The maximum allowable instantaneous reverse voltage including transients which occur every cycle, duration ≤ 10 ms, duty cycle ≤ 0.01.

V_{RWM} Crest working reverse voltage. The maximum allowable instantaneous reverse voltage including transients which may be applied every cycle exluding all repetitive and non-repetitive transients.

V_R Continuous reverse voltage. The maximum allowable constant reverse voltage. Operation at rated V_R may be limited to junction temperatures below $T_{j\,max}$ in order to prevent thermal runaway.

CURRENT RATINGS

$I_{F(AV)}$ Average forward current. Specified for either square or sinusoidal current waveforms at a maximum mounting base or heatsink temperature. The maximum average current which may be passed through the device without exceeding $T_{j\,max}$.

$I_{F(RMS)}$ Root mean square current. The rms value of a current waveform is the value which causes the same dissipation as the equivalent d.c. value.

I_{FRM} Repetitive peak forward current. The maximum allowable peak forward current including transients which occur every cycle. The junction temperature should not exceed $T_{j\,max}$ during repetitive current transients.

I_{FSM} Non-repetitive forward current. The maximum allowable peak forward current which may be applied no more than 100 times in the life of the device. Usually specified with reapplied V_{RWM} following the surge.

I_{RRM} Repetitive peak reverse current. The maximum allowable peak reverse current including transients which occur every cycle.

I_{RSM} Non-repetitive reverse current. The maximum allowable peak reverse current which may be applied no more than 100 times in the life of the device.

Forward current ratings

The forward voltage/ current characteristic of a diode may be approximated by a piecewise linear model as shown in fig:1. where R_S is the slope of the line which passes through the rated current and V_O is the voltage axis intercept. The forward voltage is then $V_F = V_O + I_F.R_S$, and the instantaneous dissipation is $P_F = V_O.I_F + I_F^2.R_S$. where I_F is the instantaneous forward current.

It can be shown that the average forward dissipation for any current waveform is: $P_{F(AV)} = V_O.I_{F(AV)} + I_{F(RMS)}^2.R_S$, where $I_{F(AV)}$ is the average forward current and $I_{F(RMS)}$ is the rms value of the forward current. Graphs in the published data show forward dissipation as a function of average current for square or sinusoidal waveforms over a range of duty cycles and form factors.

To ensure reliable operation, the maximum allowable junction temperature $T_{j\,max}$ should not be exceeded repetitively, either as a result of the average dissipation in the device or as a result of high peak currents

The average junction temperature rise is the average dissipation multiplied by the thermal resistance; $R_{th\,j\text{-}mb}$ or $R_{th\,j\text{-}hs}$. Subtracting the junction temperature rise from the maximum allowable junction temperature $T_{j\,max}$, gives the maximum allowable mounting base or heatsink temperature.

The peak junction temperature rise for a rectangular current pulse may be found by multiplying the instantaneous power by the thermal impedance. Analysis methods for non-rectangular pulses are covered in the Power Semiconductor Applications handbook.

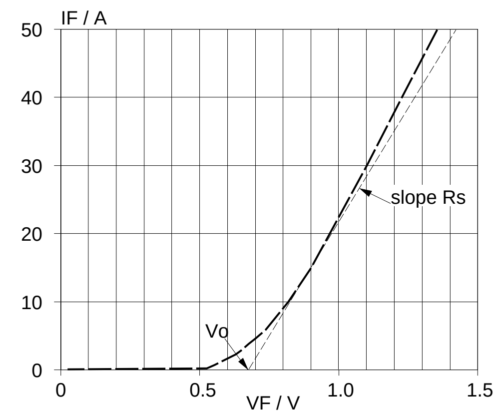

Fig.1. Piecewise linear approximation to diode forward characteristic.

Power diode characteristics

A characteristic is an inherent and measurable property of a device. Such a property may be expressed as a value for stated or recognized conditions. A characteristic may also be a set of related values, usually shown in graphical form.

REVERSE RECOVERY

When a semiconductor rectifier diode has been conducting in the forward direction sufficiently long to establish the steady state, there will be a charge due to minority carriers present. Before the device can block in the reverse direction this charge must be extracted. This extraction takes the form of a transient reverse current and this, together with the reverse bias voltage results in additional power dissipation which reduces the rectification efficiency. At sine-wave frequencies up to about 400Hz these effects can often be ignored, but at higher frequencies and for square waves the switching losses must be considered. The parameters of reverse recovery are defined in fig:2.

Stored charge

The area under the I_R versus time curve is known as the stored charge (Q_s) and is normally quoted in microcoulombs or nanocoulombs. Low stored charge devices are preferred for fast switching applications.

Reverse recovery time

Another parameter which can be used to determine the speed of the rectifier is the reverse recovery time (t_{rr}). This is measured from the instant the current passes through zero (from forward to reverse) to the instant the current recovers to either 10% or 25% of its peak reverse value. Low reverse recovery times are associated with low stored charge devices.

The conditions which need to be specified are:

a. Steady-state forward current (I_F); high currents increase recovery time.

b. Reverse bias voltage (V_R); low reverse voltage increases recovery time.

c. Rate of fall of anode current (dI_F/dt); high rates of fall reduce recovery time, but increase stored charge.

d. Junction temperature (T_j); high temperatures increase both recovery time and stored charge.

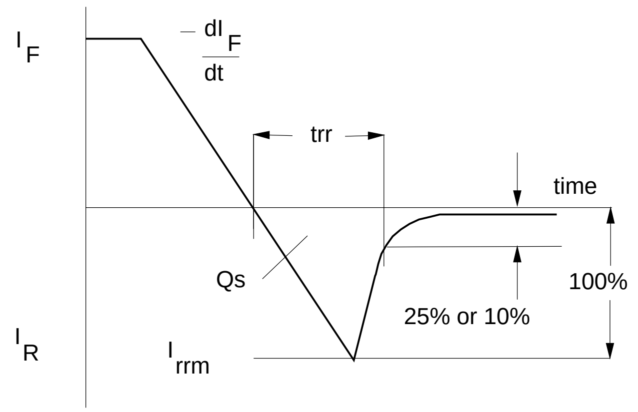

Fig.2. Definition of t_{rr}, Q_s and I_{rrm}

Softness of recovery

In many switching circuits it is not just the magnitude but the shape of the reverse recovery characteristic that is important. If the positive-going edge of the characteristic has a fast rise time (as in a so-called 'snap-off' device) this edge may cause conducted or radiated radio frequency interference (rfi), or it may generate high voltages across inductors which may be in series with the rectifier. The maximum slope of the reverse recovery current (dI_R/dt) is quoted as a measure of the 'softness' of the characteristic. Low values are less liable to give rfi problems. The measurement conditions which need to be specified are as above.

Reverse recovery current

The peak value of the reverse recovery current (I_{rrm}) is an important parameter in many switched mode power supply circuits. This is because the high transient current produced by a diode with a high I_{rrm} can be interpreted by the circuit as a short circuit fault, which may cause the power supply to shut down or have apparently poor load regulation. Like the stored charge and reverse recovery time, I_{rrm} increases with increasing temperature, so the effects sometimes only become apparent when the equipment gets hot. I_{rrm} correlates with stored charge Q_s. Thus choosing an Ultrafast diode with low Q_s usually avoids this problem.

SWITCHING LOSSES

The product of the transient reverse current and the reverse voltage is power dissipation, most of which occurs whilst the reverse recovery current is decreasing from the peak value (I_{rrm}) to zero. In repetitive operation an average power can be calculated and added to the forward dissipation to give the total power. The peak value of transient reverse current is known as I_{rrm}. The origin of reverse recovery losses is illustrated in fig:3.

The conditions which need to be specified are:

a. Forward current (I_F); high currents increase switching losses.

b. Rate of fall of anode current (dI_F/dt); high rates of fall increase switching losses. This is particularly important in square-wave operation. Power losses in sine-wave operation for a given frequency are considerably less due to the much lower dI_F/dt.

c. Frequency (f); high frequency means high losses.

d. Reverse bias voltage (V_R); high reverse bias means high losses.

e. Junction temperature (T_j); high temperature means high losses.

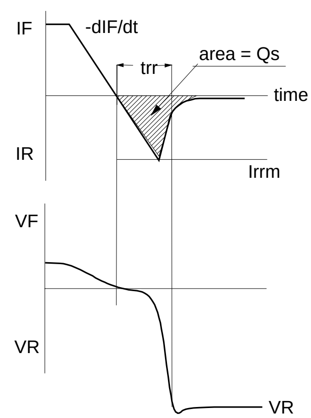

Fig.3. Waveforms showing the origin of reverse switching losses.

FORWARD RECOVERY

At the instant a semiconductor rectifier diode is switched into forward conduction there are no carriers present at the junction, hence the forward voltage drop may be instantaneously of a high value. As the stored charge builds up, conductivity modulation takes place and the forward voltage rapidly falls to the steady state value. The peak value of forward voltage drop is known as the forward recovery voltage (V_{fr}). The time from the instant the current reaches 10% of its steady-state value to the time the forward voltage drops below a given value (usually 5V or 2V) is known as the forward recovery time (t_{fr}). The forward recovery parameters are defined in fig:4.

The conditions which need to be specified are:

a. Forward current (I_F); high currents give high recovery voltages.

b. Current pulse rise time (t_r); short rise times give high recovery voltages.

c. Junction temperature (T_j); The influence of temperature is slight.

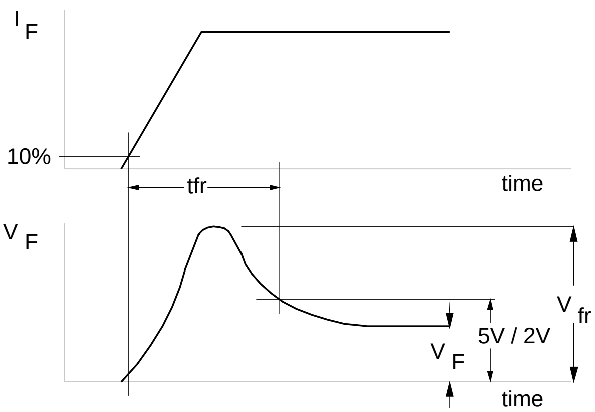

Fig.4. Definition of V_{fr} and t_{fr}

Breakover diodes

Breakover diodes (BOD's) are two terminal devices that operate in either an off (non-conducting) or an on (conducting) state. A BOD will remain in the off state until the maximum breakover voltage is applied across its terminals. A BOD will then conduct with a low on-state voltage until the current is reduced below the minimum holding current.

BOD's are available as Single Symmetric (operation in 1st and 3rd quadrants) in a hermetically sealed axial leaded SOD84 envelope, and also in a surface mount SOD106 package. BOD's are graded according to breakover voltage.

BREAKOVER DIODE CHARACTERISTICS

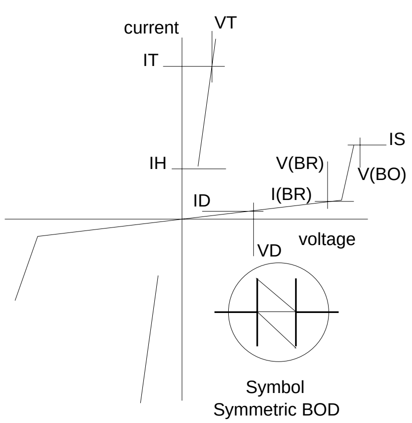

Fig.5. Breakover diode symbol and characteristics.

The main characteristics are illustrated in fig:5. These characteristics are:-

- $V_{(BO)}$ Breakover voltage, the maximum voltage appearing across the BOD before switching to the on-state.
- V_D Stand-off voltage, maximum normal operating voltage.
- I_D Off-state current, normally quoted at V_D.
- $V_{(BR)}$ Breakdown voltage, below which the BOD will not go into avalanche breakdown.
- $I_{(BR)}$ Breakdown current, with $V_{(BR)}$ applied.
- I_S Switching current, the avalanche current required to switch the BOD to the on-state.
- I_T On-state current.
- V_T On-state voltage, specified at a given I_T.
- I_H Holding current, the minimum current at which the BOD will remain in the on-state.

USE OF BREAKOVER DIODES

BOD's are primarily designed to protect electronic equipment connected to transmission lines against transient overvoltages. However, there are many uses for BOD's as breakover switches.

In designing BOD circuits the following must be considered:-

Off-state conditions

- V_D Must not be exceeded in normal off-state operation. In the off-state the BOD will not pass more current than I_D.
- dV_D/dt The rate of rise of voltage must not exceed that quoted for the device. If this is exceeded the BOD may switch to the on-state.
- $V_{(BR)}$ To ensure the BOD remains in the off-state, the voltage must remain below $V_{(BR)\,min}$. If this is exceeded, the BOD will either clip the voltage or switch to the on-state.
- I_S If $V_{(BR)}$ is exceeded but the current limited to below I_S minimum, the BOD is prevented from switching to the on-state.
- C_j The off-state capacitance across the BOD. In transmission line protection applications this will be across the termination of the line.

Switching conditions

- $V_{(BO)}$ A transient voltage greater than $V_{(BO)\,max}$ is required to switch the BOD. $V_{(BO)}$ may be greater than the voltage across the BOD when it is passing a current of $I_{S\,max}$.
- I_S To enable the BOD to switch to the on-state a current greater than I_S maximum is required.

On-state conditions

V_T The on-state voltage is quoted for a given I_T

I_H To enable the BOD to switch to the off-state the current must fall below I_H minimum.

I_{TSM} I_{TSM} specifies the rate of rise and duration of a transient peak on-state current. The waveshape is defined according to CCITT Rec. K17, illustrated in Fig:6. The waveform is referred to as 10/700 µs waveform.

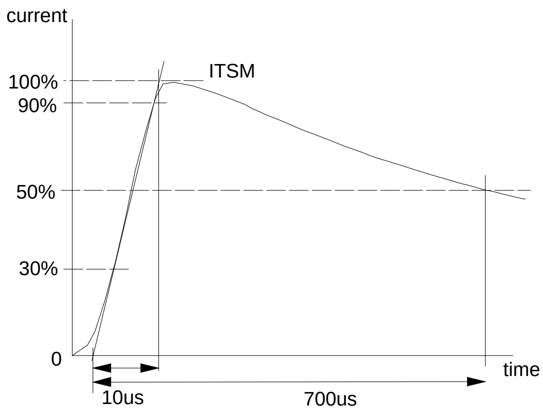

Fig.6. Definition of I_{TSM} waveform.

Thermal conditions

R_{th} For extended on-state operation (> 0.1 ms) the steady-state thermal resistance should be considered. Total thermal resistance to ambient should be sufficiently low to dissipate the heat generated by the device.

Z_{th} If the BOD is used only during transient overvoltages then the transient thermal impedance to ambient should be considered.

QUALITY

Total Quality Management

Philips Semiconductors is committed to be a world class, customer driven, volume supplier of semiconductors.

To achieve this, we operate a Total Quality Management (TQM) system, based on Continuous Improvement and Quality Assurance in all our business activities, and Partnerships with our customers and suppliers.

The top priority throughout the company is Continuous Improvement.

To focus on this we will:

- Work closely with key customers, as our partners.
- Monitor progress, using customer-driven data, of our product and services.
- Benchmark against the best.

Furthermore, all parts of the organisation must always demonstrate:

- The presence of a strong, management-led improvement structure.
- Commitment and participation in all areas.
- Measurable progress towards our Quality Improvement goals.

Organisation

An organisation is in place which ensures that personnel with the necessary organisational freedom and authority can identify and solve quality problems, prevent occurrence of product non-conformity and protect the customer from non-conforming product.

Design control

A comprehensive design and development procedure is in place which ensures that the requirements of good design practice are met.

Particular emphasis is placed on ensuring that the initial specification is agreed by the Customer and the Marketing and Development functions.

There are regular formal reviews of design progress to ensure that the initial specification will be met by the design.

Detailed measurements are made on initial samples to ensure that the initial specification has been met.

Process control

All processes which directly affect quality are carried out under controlled conditions. Documented work instructions are available for all production processes and the appropriate environmental controls are in place to ensure consistent processing. Monitoring of the product, processes and the environment takes place during production.

Approval exercises are run to ensure that new processes and new equipment perform at an acceptable level.

Written, photographic or visual standards are available at the appropriate points in the production processes.

Corrective action

Non-conforming product found in process is investigated and the root causes identified. Changes to product or process are then introduced to prevent recurrence of the problem.

Quality assurance

Based on ISO 9000 standards, customer standards such as Ford TQE. Our factories are certified to ISO 9000.

Partnerships with customers

These include: PPM co-operations, design-in agreements, ship-to-stock, just-in-time, self-qualification programmes and application support.

Partnerships with suppliers

In addition to ISO9000 audits and close monitoring of supplier delivery performance, we operate a Supplier Excellence Award scheme which requires suppliers and their sub-suppliers to use statistical process control, perform gauge studies and use failure mode and effect analysis (FMEA) techniques to identify and correct the root causes of quality and delivery problems.

Product reliability

With the increasing complexity of Original Equipment Manufacturer (OEM) equipment, component reliability must be extremely high. Our research laboratories and development departments study the failure mechanisms of semiconductors. Their studies result in design rules and process optimizations for the highest built-in product reliability. Highly accelerated tests are applied in order to evaluate the product reliability. Rejects from reliability tests and from customer complaints are submitted to failure analysis and the results applied to improve the product or process.

Customer responses

Our quality improvement depends on joint action with our customer. We need our customers inputs and we invite constructive comment on all aspects of our performance. Please contact your local sales representative.

Recognition

The high quality of our products and services is demonstrated by many Quality Awards granted by major customers and international organisations.