

Principles and Elements

of

POWER ELECTRONICS

Devices, Drivers, Applications, and Passive Components

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2.2.1 Punch-through voltage

The reverse voltage extends the scl to at least one of the ohmic contacts and the device presents a short circuit to that voltage in excess of the *punch-through* voltage, V_{PT} . Punch-through tends to occur at low temperatures with devices which employ a low concentration region (usually the n-side), as is usual with high-voltage devices. The punch-through voltage for silicon can be approximated by

$$V_{PT} = 7.67 \times 10^{-16} N_c W_c^2 \quad (V) \quad (2.2)$$

where N_c is the concentration in /cc of the lighter doped region and W_c is the width of that region in μm .

2.2.2 Avalanche breakdown

Avalanche breakdown or *multiplication breakdown*, is the most common mode of breakdown and occurs when the peak electric field, ξ_m , in the scl at the junction exceeds a certain level which is dependent on the doping level of the lighter doped region. Minority carriers associated with the leakage current are accelerated to kinetic energies high enough for them to ionise silicon atoms on collision, thereby creating a new hole-electron pair. These are accelerated in opposite directions, because of the high electric field strength, colliding and ionising repeatedly - hence the term avalanche, impact ionisation or carrier multiplication. If the lighter doped silicon region has a concentration of

$$10^{13} < N_c < 5 \times 10^{14} \quad (/cc)$$

then the avalanche voltage may be approximated by

$$V_b = 5.34 \times 10^{13} N_c^{-3/4} \quad (V) \quad (2.3)$$

The peak electric field at the junction will be

$$\xi_b = 3.91 \times 10^5 N_c^{1/8} \quad (V/m) \quad (2.4)$$

and the width of the scl, mainly in the lighter doped region, at breakdown is given by

$$\begin{aligned} W &= 2 V_b / \xi_b \\ &= 2.73 \times 10^8 N_c^{-7/8} \quad (\approx 1 \times 10^{-14} V_c) \quad (m) \end{aligned} \quad (2.5)$$

2.2.3 Zener breakdown

Field or Zener breakdown occurs with heavily doped junction regions and at usually less than 5V reverse bias. It occurs when the scl is too narrow for avalanche yet the electric field grows very large and electrons tunnel directly from the valence band on the p-side to the conduction band on the n-side. This reverse current is called the *Zener effect*.

These three modes of reverse voltage breakdown are not necessarily destructive provided the current is uniformly distributed. If the current density in a particular area is too high, a local hot spot may occur, leading to device thermal destruction.

2.3 Thermal effects

The pn junction current, I , shown in figure 2.2, is related to the scl voltage, V , according to

$$I(V) = I_o [e^{-qV/kT_j} - 1] \quad (A) \quad (2.6)$$

where I_o , is the reverse (saturation) leakage current in amps.

The forward conduction voltage decreases with increased junction temperature, T_j . That is, the on-state voltage has a negative temperature coefficient. In practical silicon pn diodes, at low currents, the temperature coefficient is typically -2.4 mV/K, becoming less negative with increased current. At higher currents, the coefficient becomes positive because of the reduced carrier mobility at higher temperatures, which causes non-scl regions to increase in resistance. The effects of the change in temperature coefficient at higher currents, in practical devices, are shown dotted in figure 2.2. Neglecting the exponential silicon band gap temperature dependence, the temperature effects at high current, on the diffusion constant component of the leakage current I_o in equation (2.6), called the saturation current, is given by

$$I_o(T) = I_o(25^\circ\text{C}) \times \left(\frac{T}{300} \right)^{1.8}$$