MicroNOTE # 602

UPGA301A Pulse Circuit Analysis

by:

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The dynamic on-state characteristics of the UPGA301A are described. This device is assembled in Microsemi's PowerMITE3® low profile, surface-mount package. The UPGA301A is an E-processed high speed silicon controlled rectifier.

Typical applications for the UPGA301A are current pulse drivers for laser diodes and squib firing circuits. These circuits require high speed switching, low dynamic on-state impedance, signal fidelity, and efficient energy transfer.

In these applications, UPGA301A offers high efficiency for thermal diffusion of heat transfer and excellent electrical characteristic matching to RF circuit boards.

The dynamic on-state characteristics of the UPGA301A are modeled. This allows the circuit designer to accurately access the dynamic device electrical and thermal behaviors in these circuits.

A forward voltage on-state model is generated using typical measured on-state characteristics V_T, as a function of on-state forward current I_T.

The on-state model for V_T, for the UPGA301A was developed from a curve fit of typical test data produced from values of short duration I_T pulses applied to the UPGA301A. The model is:

$$V_T = A + B\ 1n(I_T)+C(I_T)+D\sqrt{(I_T)}$$

figure 1

I_T, is the forward on-state current (amperes) and V_T, is the on-state voltage (volts). The accuracy of the model is tested by comparing calculated values to the measured values and is found to be within one-half percent over the range of current from the micro-ampere range up to the current limit of the device. Note, the model will not work for zero current.

The values of the constants apply specifically to the UPGA301A device. They are listed below:

A = 0.8775 volt
B = 0.0389 volt
C = 0.0503 volt
D = 0.0223 volt

Junction power dissipation is the product of the applied current I_T, and the on-state voltage V_T. The on-state voltage V_T, responds non-linearly to the applied current I_T. The instantaneous power is calculated using a piece-wise approach over the time span of the applied current range.

The advantage of using the V_T - I_T model is in applications where non-repetitive, non-linear current pulses are delivered through the UPGA301A SCR powermite switch.

LED, Laser Diodes, and fusible squibs are applications where current sources resulting from capacitor discharges are passed through the SCR switch into a series connected load.

The model describes the dynamics of the voltage and effects such as internal power dissipation. Device energy may be determined from this. A thermal diffusion model is developed for the UPGA301A using the properties of the semiconductor material, and the specific geometry of the UPGA301A. This model allows the designer to predict the SCR's thermal loading during the application of the power pulse delivered to the load.

UPGA301A is specifically designed for delivering narrow high current pulses. The width of the pulse should be much smaller than the thermal time constant of the silicon die and PowerMITE3 package combination to prevent thermal run-away during high current switching. Examples are shown to illustrate the effects in the accompanying design descriptions. The thermal diffusion model and its derivative developed for the UPGA301A is:

$$T_J(t) = \frac{2P_T(t)}{\sqrt{\pi}} \cdot \frac{1}{K_{\theta si}} \cdot \frac{1}{A_J} \cdot \sqrt{D_{\theta si} t} + T_A$$

figure 2

$$T'_J(t) = 2\frac{\frac{d}{dt}[P_T(t)]}{\sqrt{\pi} \cdot K_{\theta si} \cdot A_J} \cdot \sqrt{D_{\theta si} \cdot t} + \frac{P_T(t)}{\sqrt{\pi} \cdot K_{\theta si} \cdot A_J \cdot \sqrt{D_{\theta si} \cdot t}} \cdot D_{\theta si}$$

figure 2b

$T_J(t)$ is the junction temperature, $P_T(t)$ is the junction power dissipation, and T_A the operating ambient temperature.

The material and physical properties of the UPGA301A used in the analysis are:

UPGA301A chip area	A_C = 2860 mil2
Active junction area	A_J = 442 mil2
chip mass	M_C = 1.092 mg
Silicon density	ρ_{si} = 2.33 gm/cm3
Silicon thermal conductivity	$K\theta_{si}$ = 1.45 watt/cm C
Silicon specific heat	cp_{si} = 0.7 watt sec/gm C
Silicon diffusivity	Dθsi = 0.9 cm2/sec
Chip thermal resistance	Rθsi = 0.949 C/watt
Chip thermal capacitance	$C\theta_{si}$ = 7.644 x 10-4 watt sec/ C
Chip thermal time constant	$\tau\theta_{si}$ = 726 µs

The first example is a half-sinusoidal, non-repetitive pulse applied to the anode of the UPGA301A with a series connected cathode 1Ω resistive load.

The circuit operates at an ambient temperature T_A. The half-sine current pulse $i_T(t)$ is applied to the anode of the UPGA301A. The peak value is 100 amperes. The response of the SCR to the applied current is calculated and illustrated in the accompanying graphs. These are $P_T(t)$ and junction temperature $T_J(t)$.

The current pulse and its derivative is represented by:

$$i(t) = I_{pk} \cdot sin\ (a\ t)$$

figure 3

$$i'_T(t) = I_{pk} \cdot cos\ (a \cdot t) \cdot a$$

figure 3b

The UPGA301A presents a dynamic resistance to the applied pulse. The dynamic resistance of the SCR is in series with the resistive load. Although the load in our example is pure resistance it may be non-linear as well. In this example the dynamic resistance is represented and the total circuit resistance by:

$$Z_{SCR}(t) = \frac{v_T(t)}{i_T},\ Z = Z_{SCR}(t) + R_{LOAD}$$

figure 4

The period of the applied non-periodic, half-sine pulse is 500ns. The peak current is 100A. The peak forward on-state voltage V_T is determined from equation (*figure 1*) by setting I_T to 100A. The value is 6.32V at the peak current point. The peak thermal junction temperature T_J, occurs slightly after the peak current point at 148ns. This is the result of the thermal time constant of the UPGA301A. The combined delay t_d, and rise time t_r, of the UPGA301A is 50ns maximum. This results in a delay and rise of the response voltage and junction temperature. The calculated peak junction temperature is about 83°C.

The voltage source required to provide 100 amps peak is determined by multiplying the required peak current times the dynamic resistance Z. So, for a 1Ω load the required source voltage to produce the 100 amp peak is 106.32 volts.

The second example illustrates another common application. Capacitor C_O, the energy storage device, discharges through the SCR switch and a low impedance load. The circuit inductance L_O, capacitor C_O with its initial charge voltage V_O, and the load resistance R_L are specified. The equation defining the current as a function of time is:

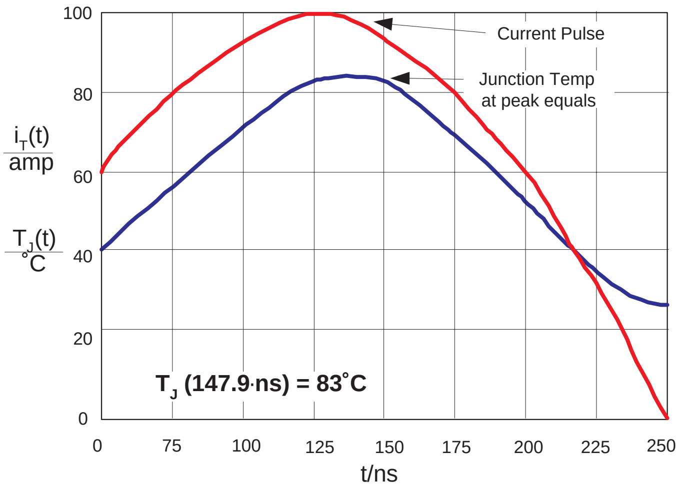
$$i_T(t) = \frac{V_o}{\sqrt{L_o over C_o}} \cdot exp\ [\frac{-Z(t) \cdot t}{2L_o}] \cdot sin\sqrt{\frac{1}{L_o \cdot C_o}} \cdot t$$

figure 5

In this example the current pulse is not sinusoidal and is non-linear. The capacitor charged initially to V_O delivers current through the dynamic resistance of the SCR and the series connected load. The value Z is determined as in (4.) above. The components used in this example analysis are L_O = 75nH, C_O = 10µF, and R_L = 1O. A peak current of 85.6A occurs at 125ns, SCR V_T(pk) is 5.57V, and T_J(pk) is 72°C at 215.6ns.

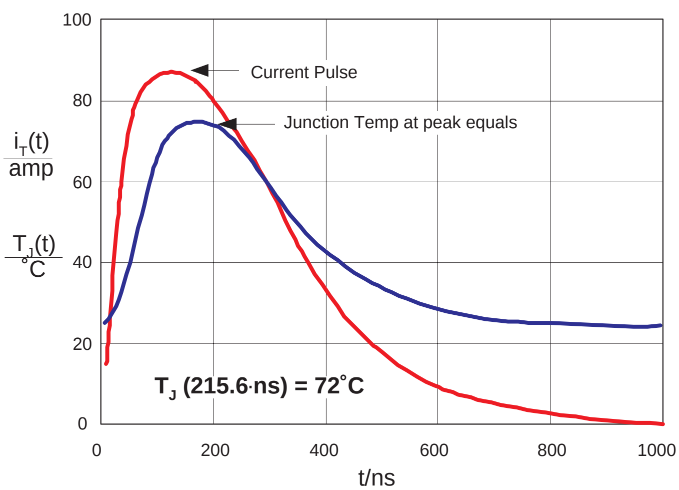
The current pulse $i_T(t)$, the SCR forward voltage $P_T(t)$ and the junction temperature $T_J(t)$ are shown in the accompanying graphs. The calculations may be performed on a spread sheet, using the piece-wise approach described above.

Fusing of the internal wires is not an issue for narrow current pulses for the wire size used in the device. The DC fuse rating is 18A and at a pulse width of 150ns, the fusing current limit is 2,483A.



Example 1

Half-Sine non-repetitive current pulse applied to a low resistance load in series with the anode of the UPGA301A. The graph illustrates the half-sine current pulse commencing from the point just after the combined delay and rise time of the SCR. The lower trace in the graph shows the junction temperature response. The peak junction temperature occurs at 148ns.



Example 2

A current pulse generated from a capacitor discharge through the UPGA301A with a low impedance load in series. Note the SCR presents a non-linear impedance to the current pulse. The graph shows the current pulse with a peak of 85.5A at 125ns. The lower trace shows the junction temperature response with a peak of 72°C at 216ns.