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The influence of the temperature on the power structure behaviour

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The functional limits of a thyristor are defined by an essential parameter: the allowable maximum junction temperature. It can be of 125°C. The technical specification of each type of thyristor gives the limit values of the functional temperature, which will be for example of –55°C to 125°C.

The electrical energy dissipated in the thyristor at any direction of the current, appears under the form of a thermal energy across the junctions, where the total power lost in the crystal causes an increase of the junction temperature.

In fact, this value represents only a very little part of the power available in the circuit. But it shouldn't be forgotten that the ambient temperature represents an energetic level from which the increase of the junction temperature is done. However, this latter can reach a value relatively increased, especially if we know that the industrial ambient temperature is very often approximately equal to 50°C or 60°C.

1. INTRODUCTION

The high power asymmetrical developing lately has permitted the total improvement of the basic physical trade-offs between the three main characteristics i. e. forward blocking voltage, current switching capability, and turn-off speed. [1]

The progress made in asymmetrical thyristor technology has included great categories of device size and applications. One area of special interest to power electronic design engineers deals with the devices having as a specific function the operation at high frequencies, at voltages compatible with the modified industrial mains, requiring blocking capabilities for high voltages, and turn-off times t_q, of about 5 micro-second. That is why the switching of many hundreds of Ampers at frequencies superior to 20 kHz corresponding to switched power of up to many hundred kW is actually quite possible.

This definition is indispensable, since in all the experiments and the demonstrations, we have used an asymmetrical structure thyristor, having regard to its capability and reliability in the domain of high power, for very short switching times.

This paper offers a new explanation on the temperature effect on the device performance. Our calculation using the two-dimensional device simulator shows that the leakage current through the device is one of the dominant causes of losses in function of the temperature.

The junction temperature T_j of a power semiconductor in any particular situation profoundly affects its reliability. During its operating life, a thyristor can experience a wide range of temperatures. Note that the forward and off-state blocking capability of the device determines the maximum junction temperature $T_{j\max}$. Maximum blocking voltage and leakage current ratings are established at elevated temperatures near to the maximum junction temperature; therefore, operation in excess of these limits may result in unreliable operation of the thyristor.

2. IMPORTANT THERMAL NOTES

At normal temperatures, in an extrinsic semiconductor, electrons are excited from donor levels to the conduction band or from the valence band to the acceptor levels by a relatively small amount of energy. As a temperature increases, the donor levels become exhausted, or the acceptor levels saturated. As the temperature increases even more, the electrons become excited from the valence band to the conduction band in large numbers by now abundant thermal energy. At this point, the carrier concentration does not depend on the temperature. At low intermediate temperatures, the conduction electrons are the majority carriers.

The beginning of the intrinsic conduction is linked to the energy gap E_g which is equal to 1.1 eV for silicon semiconductor, at approximately 200°C. This temperature is the maximum limit at which the semiconductor can work. By approaching this temperature, the device's operating properties start to degrade. Actually several silicon components are characterised for the maximum junction temperature, T_j =125°C.

We notice that the junction temperature is usually many degrees higher than the case and ambient temperature. When we understand the effect of the temperature on the life of product, we can arrive at a compromise between cost and life. Thus we can increase the competitiveness upon the cost of the device.

The semiconductor manufacturer specifies the junction-to-case thermal resistance R_{jc} and the maximum junction temperature $T_{j\max}$. The case-to-heat sink thermal resistance R_{ch} is also specified.

We have also to note that the maximum storage temperature T_S is very superior to the maximum operating temperature. Maximum storage temperature is restricted by material limits defined not so much by the silicon but by peripheral materials. The forward and OFF-STATE blocking capability of the device determines the maximum junction temperature. The establishment of leakage current and maximum blocking voltage ratings are realised when the temperature is increased.

3. ASYMMETRICAL STRUCTURE DEVICE

The asymmetrical silicon controlled thyristor rectifier possesses a diffusion structure slightly different from that of the standard thyristor, and a very interdigitated amplificator gate structure (figure 1) [2].

In fact, a supplementary layer N_1^+ is put between the emitter P_1 and the basis N_1. This layer reduces certainly the thyristor behaviour in terms of inverse voltage, but if its doping level is enough increased, it would be possible to decrease the thickness of the basis N_1 for a same behaviour in terms of direct voltage (20 V per micron of the thickness of the N_1 layer) [3, 4].

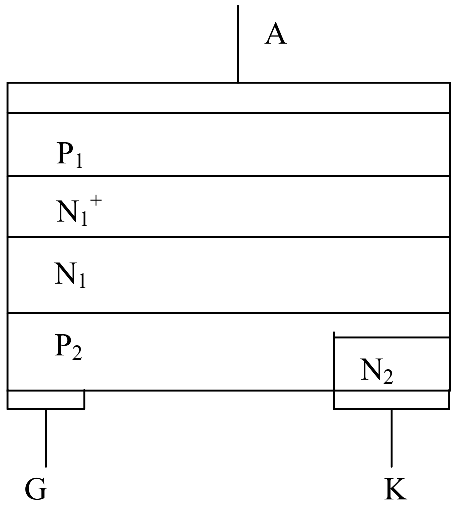

Fig. 1. Thyristor asymmetrical structure

For same behaviour in terms of direct voltage, and with an asymmetrical diffusion structure, it is possible to reduce the commutation losses for devices of the same velocity.

It is also possible to realise more fast thyristors without leading to unacceptable losses.

This structure presents an acceptable compromise between the different major electrical parameters: time of extinction, high frequency commutation losses, and the behaviour in terms of direct voltage V_{DRM}. The asymmetrical thyristor application field is the high power with high frequencies. It means that high frequency energy conversion, above 20 kHz

4. TEST CIRCUIT

A semiconductor switch for circuit may be used for other aims different from that of switching the circuit on and off at many moment. If the switches cyclically triggered and quented at a special switching frequency, the power drawn by a load from a direct voltage source can be controlled. **DC** power controllers perform the basic function of **dc-dc** conversion.

The switching frequency with which the main thyristor is cyclically triggered is designed by f_s. The circuit is fed by a constant direct voltage source U_e = 230 V.

The tyhristor switch has a snubber circuit consisting of a capacitor C_S, resistor R_S and an auxiliary diode D_S.

Figure 2 shows the *RCD* snubbers design. It has several advantages over the *RC* snubbers:

- In addition to peak voltage limiting, the circuit can reduce the total circuit losses, including both switching and snubber losses [5, 6].
- Much better load lines can be achieved, lowing the load line to pass well with the *SOA*.
- For a given value of C_S, the total losses will be less.

But because of the diode across R_S, the effective value for R_S during the charging of C_S, is essentially zero.

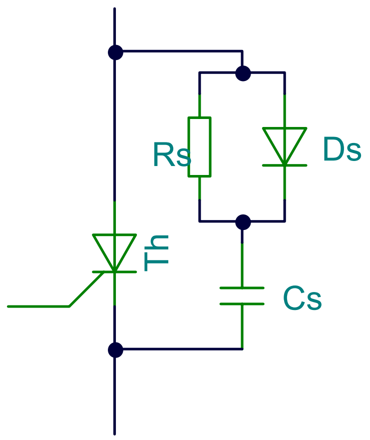

Fig. 2. Snubbers circuit

5. RESULTS AND DISCUSSION

Figure 3 shows the voltage across the thyristor for variable junction temperatures T_j. T_j=125°C is chosen as the design maximum value, because above this value the current begins to increase rapidly, causing by this way the degradation of the voltage rating. The thyristor becomes very sensitive to over-voltage transients, as well as to high $\frac{dv}{dt}$, and to $\frac{di}{dt}$. In the case of the forward blocking junction there is an increasing possibility of forward recover triggering.

According to the waveform, we notice that up to given temperature value, the voltage across the device remains constant then rapidly decreases to become very poor above some values. We can say that above of the operating temperature there will be a very important thermal agitation created by the excessive behaviour of the carrier causing an excessive heating then an eventual destruction.[6]

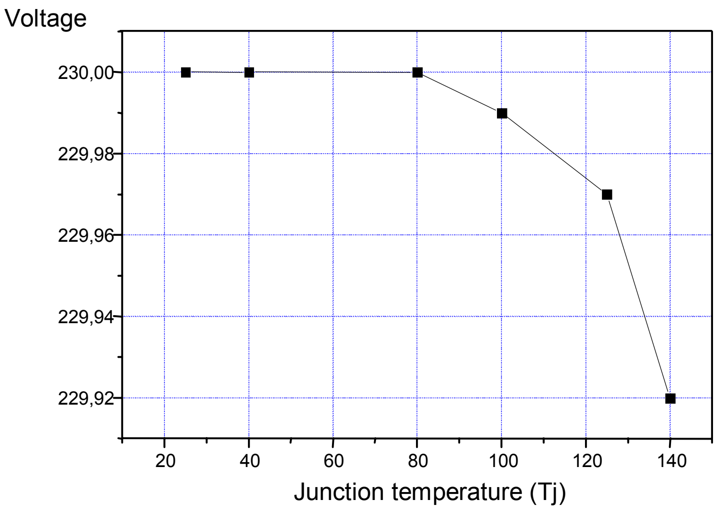

Fig. 3. Voltage thyristor at different temperature

Operating at low temperature is not harmful, but we should allow it be for increased gate trigger current, latching current and holding current as well as slow turn-on. So operating in the range between ambient temperature and 125°C gives the best compromise between the quality and the operational life [7].

Figure 4 shows the characteristic in direct conduction system for two different temperatures (T_j =80°C and 125°C) .

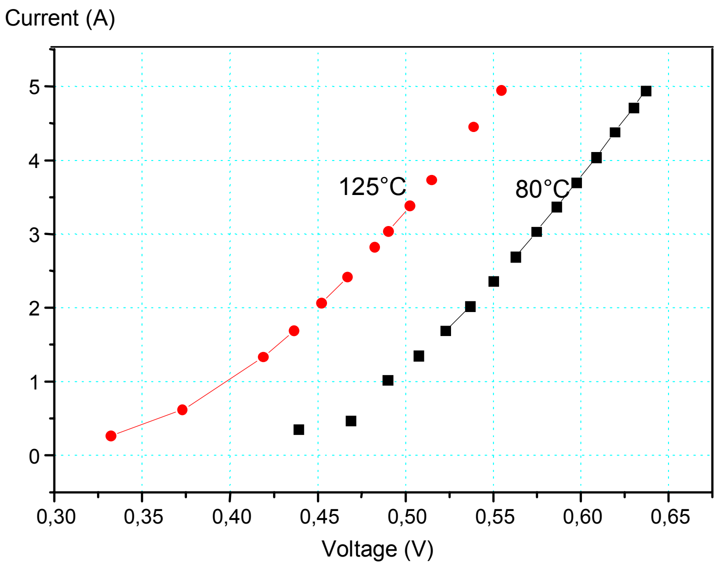

Fig. 4. Current vs Voltage (T_j =80°C and 125°C)

We notice that voltage fall is relatively reduced for high temperatures whereas the current does not stop its increase. This behaviour leads to power losses which heat the device, limiting like that its possibilities of conduction for a given temperature.

Figure 5 and 6 show the variation of the recovery time t_{rr} (the recovery charge Q_{rr}) and the leakage current.

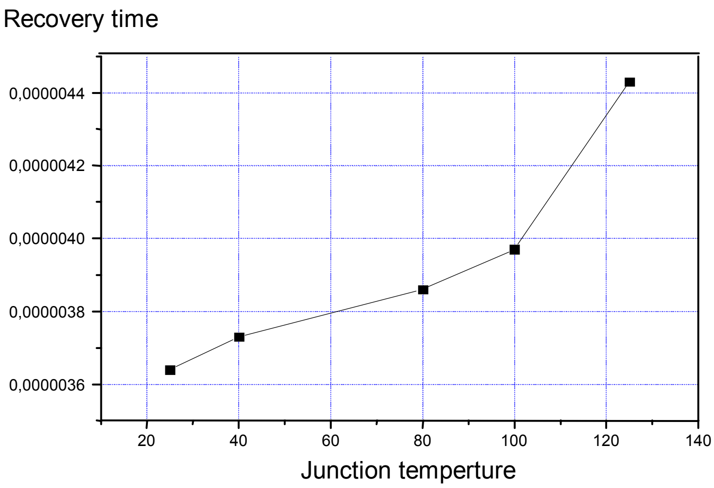

Fig. 5. Recovery time at different temperatures

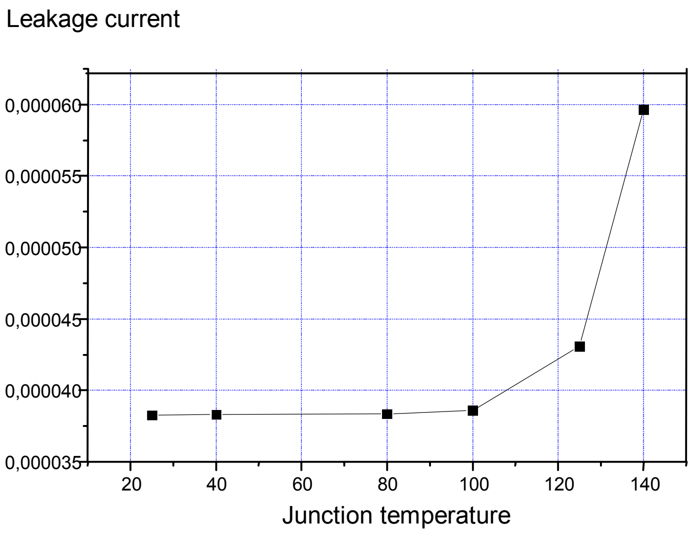

Fig. 6. Leakage current at different temperatures

We have seen that when the device is enough doped with gold, the recombination mechanism of electron hole pairs determines the recovery time in volume. We can say then that recovery charge and the recovery time depend greatly on the junction temperature where its effects are also important on a localised basis. Thus, if the thyristor is accidentally switched on before recovery, this self-switching will occur near the gate where the localised temperatures are higher than in the surrounding regions. The actual temperature in this region is a function of such operating parameters as duty cycle and repetition rate.

As far as the turn-off time is concerned, which the expression is proportional to the life duration of the electron hole pair:

$$t_q = \tau_p(T_j)\ln\left(I_F/I_h\right),$$

where τ_p is the minority-carrier lifetime in layer N_1, I_h is the holding current.

We can say that it also depends on the temperature, and on gate bias during the turn-off interval. To obtain a small turn-off time, we must reduce the lifetime in layer N_1. t_q is lengthened for higher temperatures so the higher junction temperature is specified.

The inductive voltage spikes from reverse recovery of the device are also visible. A thyristor with a shorter carrier lifetime, or longer transit time will exhibit smaller voltage spikes.

In some applications the device is protected by fuse. In this case, if the current is interrupted by this latter, little or no reverse voltage appears across the dispositif. Then, very high reverse recovery power dissipation can result from the reapplication of reverse voltage if temperature is higher. Some overloads require that the device survives with both reverse and then forward voltage being reapplied [7].

At the time of the switch-on process, the conduction area is reduced to a portion of the emitter nearly the command electrode [8]. If the exterior circuit imposes a fast intensity increase during this phase, the current density across the switched-on surface may reach an important value.

Parallaly, the power decrease at the device bounds, at the time of the passage from the blocking state of the condition state, does not happen instantaneously. However, there will be a simultaneous presence of the current and the voltage.

Through these two parameters the instantaneous power can reach very high value. The dissipated energy in a poor volume begets then a considerable heating. When the critical thermal limit is reached, this heating will destroy by the silicon fusion the conductor area, it is the destruction by di/dt. Figure 7 shows the evolution of this power as well as the evolution of this power at two variable temperatures (80°C and 125°C).

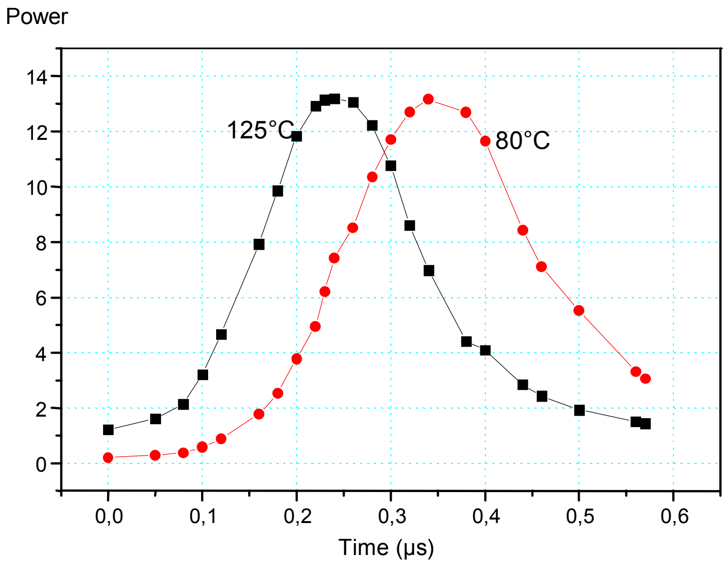

Fig. 7. Power vs Time (T_j=80°C and 125°C)

There are other important temperatures among which the temperatures under $T_{j\,max}$ where ion migration on the silicon surface under passivation an expected degradation, or the continuous temperature tolerated before thermal runaway occurs. If the temperature changes suddenly, and if di/dt is higher, this may cause micro cracking.

CONCLUSION

Actually, in this research phase realised on the optimisation on the power devices, we are oriented towards the realisation of structures which are capable of switching at very high frequencies that the ones allowed by the first generation. The new structures of the actual generations have allowed to have much more poor switching losses, by trying to reduce mainly the ones caused by the relative increase slowness of the residual parasitic current.

These new interdigitated structures with reference to the conventional ones, will accept at the time of the current turn-off, that the voltage would be reapplied at their bounds without an allowed time, as soon as the current is interrupted. We should wait many hundreds of microseconds.

Calculation of temperature rise for short pulses needs more complex analysis, possibly involving finite element analysis techniques. Device turn-on behaviour and its dependency on voltage, temperature, di/dt and gate drive has to be taken into account.

If the semiconductor junction is over 180°C, the operation properties begin to degrade. Many silicon semiconductors on today's market are characterised for the maximum junction temperature, T_j=125°C. A few go as high as 170°C.

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