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TURN-ON SIMULATION OF FIELD-CONTROLLED THYRISTOR

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ABSTRACT

The turn-on process of a field-controlled thyristor (FCTh) and the turn-off of its clamping diode in a real circuit (snubberless clamped inductive load including stray inductors) was analyzed through simultaneous 2D-device simulation (ABBPISCES) of both devices . Full understanding of FCTh turn-on transient behavior, the diode's turn-off and the drive requirements has been achieved . Exponential current growth under constant clamping voltage, a turn-on time constant less than 100 ns and high overcurrent capability of the FCTh have been observed . The simulated results are in good accordance with experiments . For the first time a complete description of the interaction between power devices (FCTh and diode) and external circuit thus is presented .

The desire to better understand and utilize power electronic devices and circuits has required improved simulation tools which are capable to deal with the system down to the level of the silicon structure. The ABBPISCES software package [1] based on the device simulator PISCES [2,3] has such capabilities; it is able to carry out simulations of electrical circuits comprising silicon devices 2D (two dimensional) modelled. Through these simulations the researcher/engineer can analyze the device behavior during transient and steady-state operation. Its interactions with the different components of the circuit can be fully understood, and the circuit can be designed and optimized till its performances better fit to the required specifications. Extended laboratory activities thus will shrink to a minimum necessary for a validation of the proposed device structures and circuitry.

The present contribution deals with the turn-on transient behavior of a field-controlled thyristor (FCTh) [4,5,6] operating in a real circuit configuration shown in Fig.1

The components of the circuit are: the FCTh (SD-Switching Device), the clamping diode (D_{clamp}), the pure inductive load represented by means of a constant current source (Ind. Load), a clamping voltage source and a gate unit comprising a resistor (R_{gate}) and a voltage source (V_{gate}) ramped from -15V (blocking condition) to 5V in 200ns. Also shown in the figure are the parasitic components L_{para} and R_{para}.

Such a configuration, equipped with different switching devices (GTO, IGBT, BJT, Power Fet) can be encountered in many power electronic applications, e.g. power supplies, industrial electric drives, traction systems and others, covering a power range from few watts to megawatts.

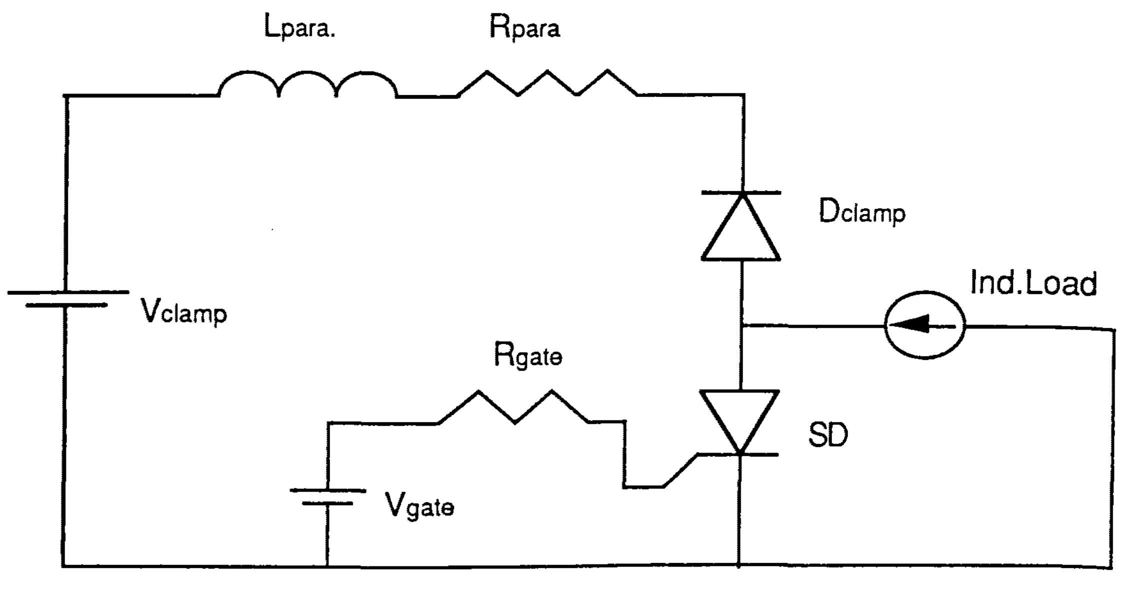

Fig.1 Simulated and tested circuit

The whole circuit was simulated by means of ABBPISCES with both switching devices modelled 2D in silicon.

1.Simulation

Different turn-on simulations of a 3.5kV blocking FCTh were carried out at Vclamp=1000V. Figure 2 shows the anode current, anode voltage, gate current and gate voltage with an initial diode current density of 15 A/cm2 .

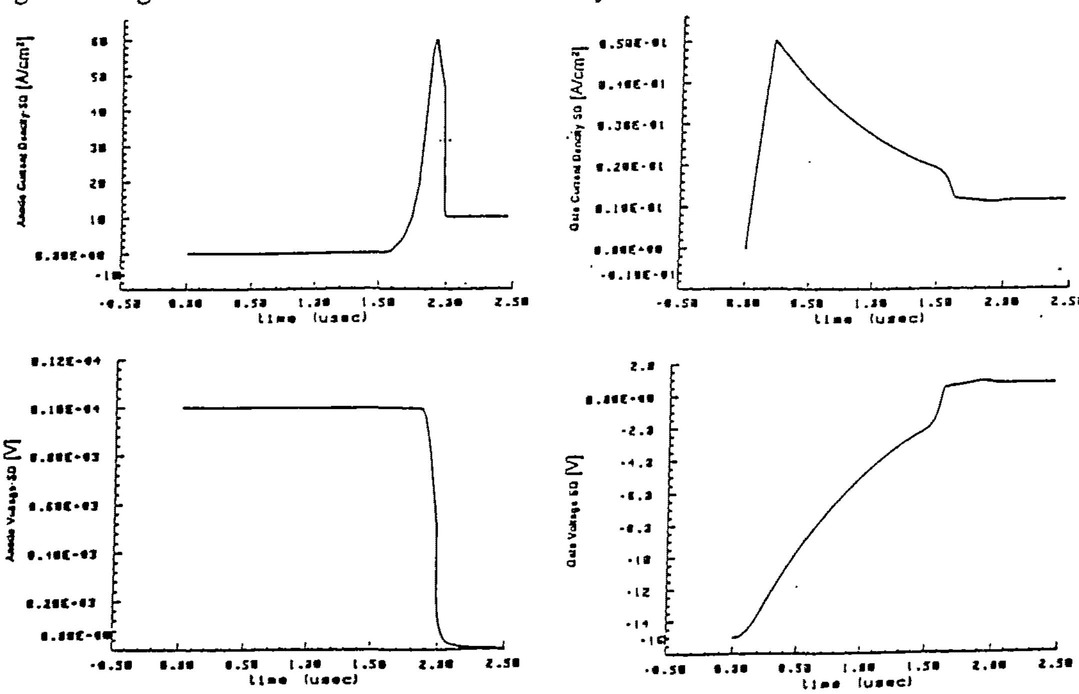

Fig.2 Current and voltage transients during FCTh turn-on process.

Based on Figure 2 one may observe the following phases during the FCTh turn-on process :

***Phase 1**-At t=0.0μs a constant current flows through the diode, and the FCTh blocks the clamping voltage Vclamp=1000V. The voltage source Vgate is ramped up to 5V in 200 ns. A capacitive current flows into the gate-cathode junction of the soft-driven FCTh and the gate voltage increases almost linearly up to the pinch-off voltage of -2V.The time constant of the gate circuit is 1.0-1.5 μs (with Rgate=15 kΩ and a gate-cathode junction capacitance of 100 pF). In one time constant the gate voltage will reach the pinch-off voltage. During this period the potential barrier in the fingers decreases (see Fig.3a), and electrons are allowed to leave the cathode (see Fig. 3b).

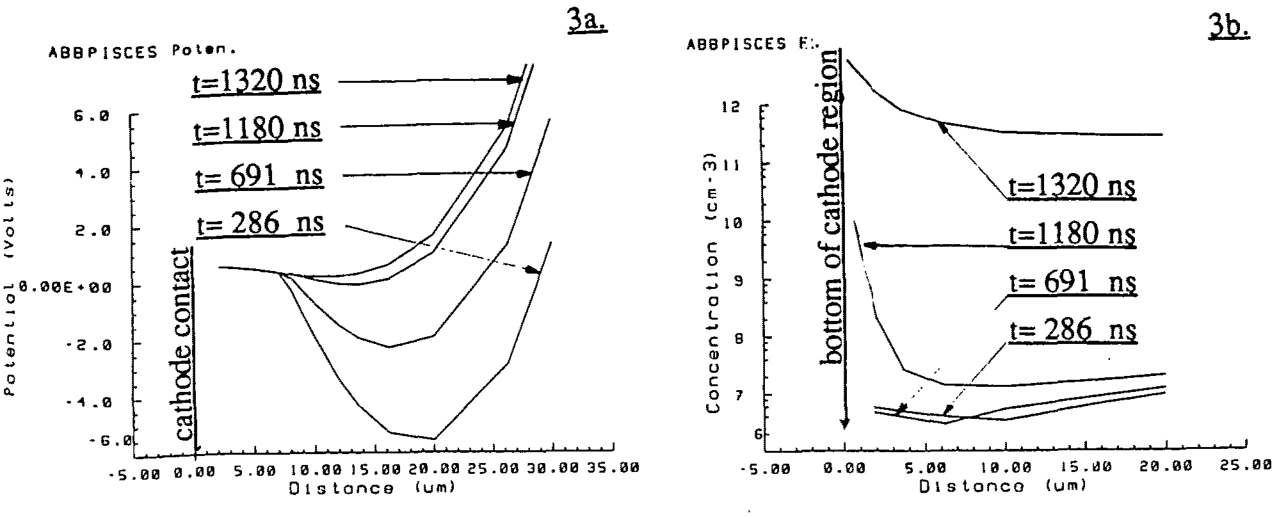

Fig.3 Potential and electron concentration in the middle of FCTh´s cell.

***Phase 2**-At t=1.5μs, the FCTh behaves like a unipolar device, only its JFET part is in operation. Holes are injected by the anode, and due to the gate´s low potential ,they are collected first by it (the gate). Consequently, its voltage increases more rapidly and after the saturation of gate-cathode diode the bipolar operation of the FCTh begins.

***Phase 3**-At t=1.6μs with saturated gate voltage the FCTh is behaving like a P-i-N diode fed by a voltage source of 1000V. The current of the FCTh increases exponentially according to the law:

$$I(t)=I(t=1.6\mu s)\ \exp\left[(t-1.6\mu s)/\tau\right] \quad (1)$$

In Figure 4 the anode current of the FCTh is presented. The calculated τ was $\approx$80ns.

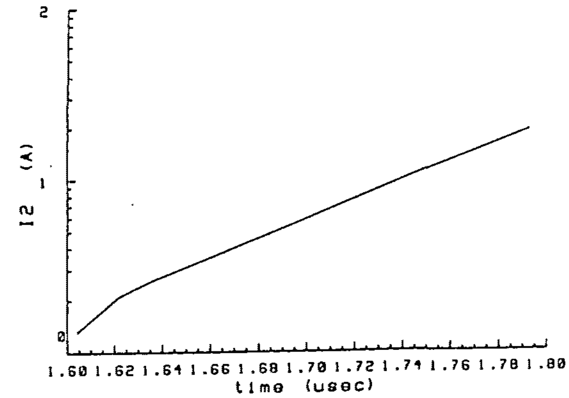

Fig.4 Logarithmic plot of anode current during turn-on(simulation).

***Phase 4**-At t$\approx$1.74μs the whole source current flows into the FCTh (10A/cm^2). The diode current is zero, but still a lot of carriers are present in the power diode. Consequently the current reverses: the diode enters the reverse recovery state.

***Phase 5**- Due to its high reverse current the excess carriers in the diode are swept out at t$\approx$1.9μs and its voltage increases rapidly. Some ringing is observed between the parasitic inductance and the diode's variable capacitance (due to the space charge region). Depending on the value of L_{para}, current and voltage oscillations will occur and in many cases overvoltages are expected. Only careful lay-out design of such a circuit can avoid the overvoltages and a possible device destruction.

Simulated results are presented in Fig.5 for two different final current densities in the FCTh : J_{1f}=10A/cm^2 and J_{2f}=135A/cm^2.

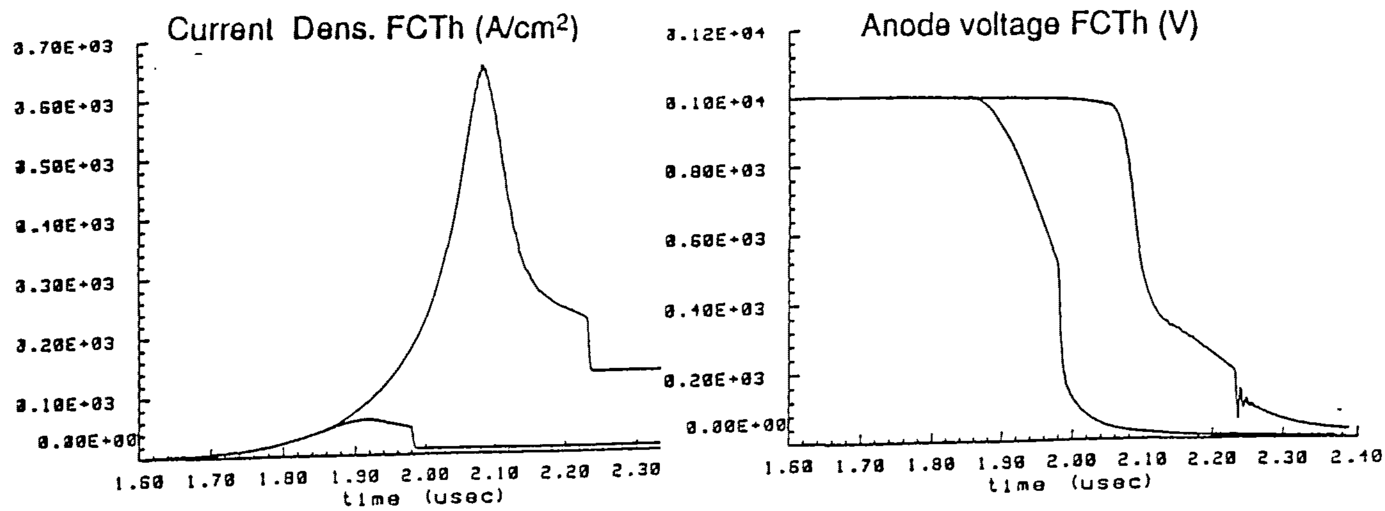

Fig.5 Simulated results at J_{1f}=10A/cm^2 and J_{2f}=135A/cm^2

As seen in Fig.5 the turn-on process is almost identical for the two cases with a time constant of τ=80ns. High overcurrent due to the reverse recovery of the clamping diode and high dV/dt over the FCTh because of the snappy behavior of the diode are also observed. With a maximum current density of 660 A/cm^2 some oscillations are present in the FCTh's voltage.

2.Experimental

10A and 200A, 2.5kV FCTh were fabricated and tested in one and multi-pulse operation. For both devices the measured turn-on time constant was in the range 70-110 ns [5]. In Figure 6 the turn-on current of a 10A device is shown (with current on logarithmic scale) and τ was 105 ns.

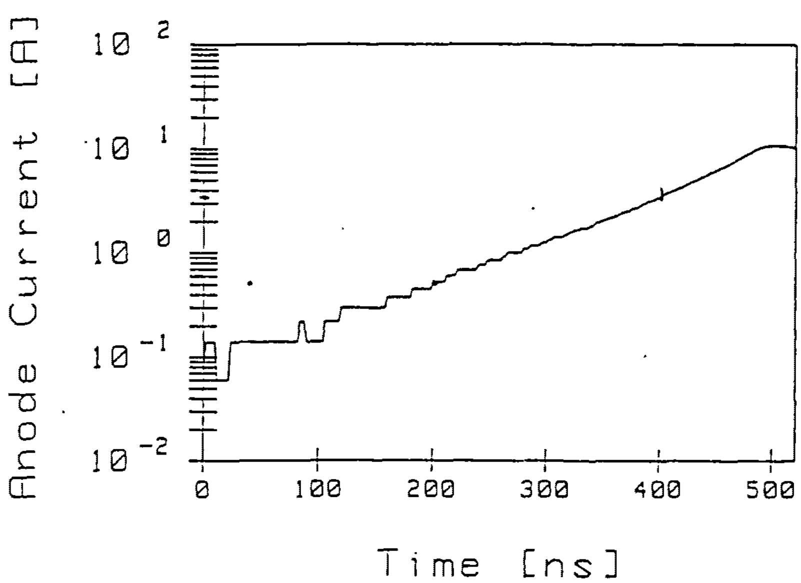

Fig.6 Logarithmic plot of anode current during turn-on(experiment).

In Figure 7, the voltage and current of the FCTh operated in a circuit configuration as per Figure 1, are presented.The steady state current density was 60 A/cm^2 and the clamping voltage was 1000 V. The stray inductance was very low (no voltage oscillations present) but some parasitic capacitance caused by the windings of the "inductive load" was observed.

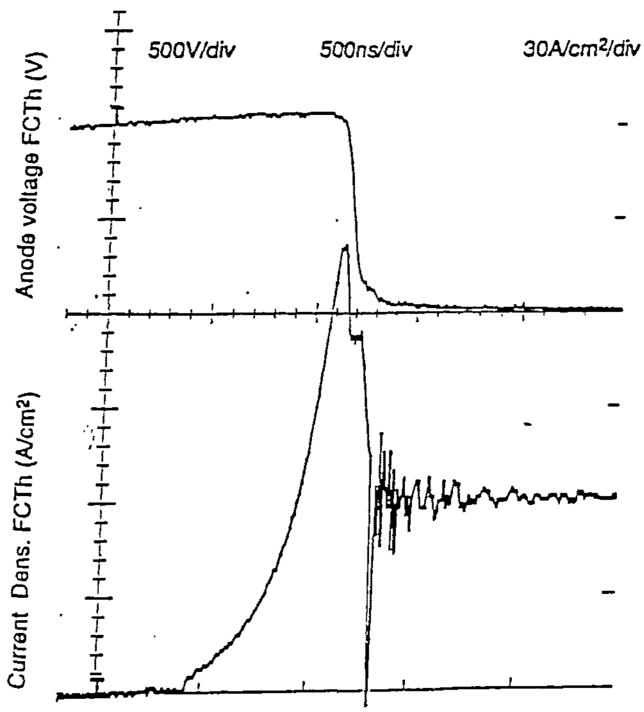

Fig.7 Experimental results - anode voltage and current at turn-on.

3.Conclusions

For the first time such a study, comprising both 2D simulation of a controlled switching device at turn-on and a power diode has been carried out. It seems worth noting that the silicon devices are operated in a real circuit configuration and the simulations were done by means of ABBPISCES software package.

The main conclusions from this work are:

*At turn-on the FCTh current grows exponentially with a time constant of t≈80ns.

*This time constant is independent of the gate-unit voltage/current waveforms (this is not the case with GTO´s).

*Due to the gate voltage saturation a stable and uniform turn-on will occur even at current density gradients >2kA/(cm^2*µs) .

*Some disagreements between simulated and experimental results were observed:

** J_{max}/J_f(sim)=4.88 and J_{max}/J_f(ex)=2.35.

**V_{anode} waveform at high current density (J_{2f}=135A/cm^2) differs from the measured one.

**The experimental set-up comprises a higher stray inductance and some additional parasitic capacitance than the simulated one.

*More care thus would have been necessary in order to adjust the diode´s carrier lifetime (and lifetime profiles), in particular.And, of course, a number of different cases have to be studied in the future, and perhaps then even some fine-tuning of Si-parameters may become mandatory.

4.References

[1]ABBPISCES-Program reference manual,ABB-Internal Publ.

[2]M. R. Pinto et. al. " Pisces-2 Poisson and continuity equation solver " Tech. Rep. Stanford Univ.1984.

[3]M. R. Pinto et. al. "Pisces-2 supplementary report " Tech.Rep.Stanford Univ.1985.

[4]H. Grüning et. al. " Properties of a high-power field controlled thyristor " Proc. IEDM 1986.

[5]H. Grüning et. al . " Snubberless superfast high power module.."IEEE PESC 1990.

[6]K. Johansson et. al " System simulation and realization of a resonant inverter with a FCTh " Trans. on Power Electronics ,Vol.6, No.2, April 1991.