MODELLING OF PLASMA SPREADING VELOCITY IN THYRISTORS WITH NON-PERMANENT EMITTER-SHORTS

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Abstract

Because of being complex and multidimensional, thyristor devices has been a subject of fruitfull investigations both theoretically and experimentally for the last two decades. The main purpose of the majority of studies in this field has been to minimize the turn-on time without adversely effecting the other characteristics . In this thesis a new CAD. model is developed to determine the turn-on times and parameters of a thyristor given its technological and fabrication data .The CAD. model is based on the two-dimensional two-transistor model to account for both axial and lateral turn-on processes in the large area devices. The essential features of this model can be summerized in the following jobes:

1-The calculation of the current amplification factors (betas) and bases transit times (tv's) as functions of the emitter current density for the two-transistor pairs of the two-dimensional two-transistor model. This task is performed using a new one-dimensional numerical solution of the basic semiconductor equations by the initial-value shooting methods

2-The obtained numerical results are fitted in polynomials and coupled with the transit function recurrence relations of the turn-on process and then excuted by a computer program for obtaining the turn-on characteristics and parameters .

The effect of circuit parameters on the turn-on behaviour are discussed . Moreover, the plasma spreading velocity is

calculated as a function of the anode current density and compared with the measured values .Good agreement has been found at relatively high current densities even if the variations of the lateral currents with time are neglected.

LIST OF SYMBOLS AND ABBREVIATIONS.

SYMBOLS:

B_v	Auger capture coefficient.
C	Specific heat.
C_v	Shockley-Read-Hall capture coefficient.
C	Shunt capacitance.
d	Lateral length of bar-shaped thyristor.
D_a	Ambipolar diffusion coefficient.
D_v	Carrier diffusion coefficient.
D_v^T	Thermal diffusion coefficient.
e	Electronic charge.
E_V , E_C	Edges of valence and conduction bands.
E_{fv}	Quasi-Fermi level energy.
$\bar{E}_v$	Effective electric field.
E_{cv}	Critical electric field.
E_t , E_{ts}	Volume traps and surface states energy levels.
G_{Ev}	Emitter Gummel number.
H	Thermal generation rate.
i	Time-cycle number.
I_e , I_h	Lateral electron and hole currents.
I_B, I_c, I_E	Base, collector and emitter currents.
I_{B1}^* , I_{B2}^*	Off-state currnts of the n-base and p-base.
I_{co}	Collector reverse saturation current.
I_a, I_k, I_g	Anode, cathode and gate currents.
J_v	Carrier current density.

J	Total current density.
J_{vr} , J_{sr}	Volume and Surface recombination current desity.
J_{scr}	Space-charge recombination current density.
k	Lateral position number.
k_{th}	Thermal conductivity.
L_v	Carrier diffusion length.
M	Multiplication factor.
n	Electron concentration.
n_{ie}	Effective intrinsic concentration.
N	Net doping concentration.
N_d^+ , N_a^-	Ionized donor and acceptor concentration.
N_B, N_C, N_E	Base, collector and emitter doping concentration
N_{Bo}	Maximum doping concentration in the P-base.
N	N-base doping concentration.
N_C , N_V	Effective density of states in the conduction and valenc bands.
N_t , N_{ts}	Density of volume traps and surface states.
p	Hole concentration.
R_{sh}	Emitter-short resistance.
S_v	Surface recombination velocity of carriers.
t	Time.
t_v	Transit time.
t_d , t_r , t_s	Delay, rise and spreading times.
T	Lattice temprature.
U	Net generation / recombination rate.

V_{BE}	Base to emitter junction voltage.
V_{j1}, V_{j3}, V_{j2}	Anode, cathode and middle junction voltages.
V_s	Spreading Velocity.
W_v	Effectiv base width.
W_{EB}	Emitter-base space-charge width.
$\bar{x}$	Axial position vector.
$\bar{z}$	Lateral position vector.
Zl	Elemental lateral length.
α	Common-base current gain.
α_T	Current transport factor.
β	Current amplification factor.
γ	Emitter injection efficiency.
γ_{sh}	Shorted-emitter injection efficiency.
θ	Injection level parameter.
ξI_{Gv}	Lateral gate current.
ϵ	Absolute permitivity.
λ	Wavelength.
μ_v	Carrier mobility.
ρ	Specific mass density.
$\bar{\rho}_B$	Average base resistivity.
τ_v	Carrier lifetime.
ψ	Electrostatic potential.
η_{av}	Injection constant (1--> 2).
∇	Napla or del operator.
π	Pi-Product.

ABBREVIATIONS:

Au.	Auger.
B.C.(s)	Boundary condition(s).
ERFC.	Error function complementary.
EPI.	Epitaxial.
E.F.	Electric field.
G.N.	Gummel number.
H.I.L	High injection level.
L.L.I	Low injection level.
M.I.L	Medium injection level.
R.K.N.	Runge-Kutta-Nystrom.
S.R.H.	Shockley-Read-Hall.
S.C.R.	Space charge recombination.
S.C	Semiconductor.

SUBSCRIPTS.

V stands for (n) electrons or (p) holes.

i stnds for the time after the ith cycle.

k stands for the lateral position of the kth element.

I stands for the ionized impurity scattering.

L stands for the lattice vibrations scattering.

E stands for the velocity saturation at high field.

1, 2 stands for the npn and pnp transistor sections.

B,C,E stands for the base, collector and emitter.

CONTENTS

INTRODUCTION

When a thyristor is fired by a gate current, the initial conducting region in the device is confined to the area adjacent to the gate periphery . A relatively slow lateral spreading of the electron-hole plasma in the the base region immediately follows and eventually the whole area of the device becomes conductive.

The plasma spreading in a thyristor influnces several important characteristics of the device such as the allowable (dIa/dt), short-time surge current,switching losses and dynamic thermal resistance .

One of the most interesting facts in thyristor physics is that the permanent emitter shorts introduced by CHANG. CHU [1],[2], to increase the (dV/dt) capability of the device ,adversely affect the plasma spread rate.

Other factors that affect plasma spreading are the device geometry and fabrication technological parameters as well as external circuit parameters.

The experimental studies of the turn-on process are able to measure plasma spreading velocity as a function of anode current density by many methods such as:

-The electrical probes method [3],[4]

-Infrared recombination method [5],[6],[7].

-Recovery current measurement method [8].

-Microwave absorption method [9].

These methods are not able to determine the physical mechanisms underlying the plasma spread process. Moreover,the initial turn-on phases occur within few microseconds before any significant current begins to flow that these methods may cease to be effective.

For these reasons, different theoretical approaches and models were introduced for the purpose of calculation of plasma spreading velocity.

Several theoretical studies proposed plasma spreading models based on ambipolar diffusion [10],[11],[12], while others assumed that the spreading process is due to the spread of the emitter region that is injecting carriers [13].

Using the diffusion model Longini and Melngailis derived an approximate relation for the velocity Vs given by:

$$V_s = F/N_o - (N_o/F)(D/\tau + \pi D^2/a^2)$$

Where $2F/\pi$ = Flux of carriers that is fed to the off-region per unit base thickness per unit length of periphery of the on-region.

a = Thickness of each base of the thyristor.