ELECTROTHERMAL SIMULATION OF POWER SEMICONDUCTOR DEVICES

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Self-heating of a semiconductor structure by high forward current pulses strongly affects power device current-voltage characteristics and diminishes the reliability of the device in power engineering applications. The electron and hole mobilities and intrinsic carrier concentration temperature dependencies are the major factors which determine forward current squeezing and probably determine the local burn-out of the semiconductor structure as well.

A numerical model for the simulation of non-isothermal transient processes in a packaged rectifier has been used to analyze the possibilities of the exact prediction of surge current values. The present model is based on the self-consistent numerical solution of the fundamental set of semiconductor equations (including Poisson's and continuity equations for electrons and holes) and on the heat flow equation. Finite difference approximation and the coupled algorithm (Newton's method) was used for the iterative solution of the set of nonlinear equations. The heat flow equation is solved separately in an appropriate iterative procedure. The theoretical basis of the model is described in [1].

The present model incorporates an improved method of accounting for electron-hole scattering (EHS). From references [2,3], it can be shown that EHS not only reduces carrier mobility but also necessitates additional terms in the electron and hole current equations:

$$j_p = q\left(\mu_{p1}\, pE - \psi_T\mu_{p2}\frac{\partial p}{\partial x} - \psi_T\mu_{p3}\frac{\partial n}{\partial x}\right)$$

$$j_n = q\left(\mu_{n1}\, nE + \psi_T\mu_{n2}\frac{\partial n}{\partial x} + \psi_T\mu_{n3}\frac{\partial p}{\partial x}\right)$$

or, for more convenient discretization:

$$j_p = \frac{\mu_{p2}}{\mu_{p0}} j_{p0} - \frac{\mu_{p3}}{\mu_{n0}} j_{n0} = \frac{1 + p\mu_{n0}J^{eh}}{M} j_{p0} - \frac{\mu_{p0}pJ^{eh}}{M} j_{n0}$$

$$j_n = \frac{\mu_{n2}}{\mu_{n0}} j_{n0} - \frac{\mu_{n3}}{\mu_{p0}} j_{p0} = \frac{1 + n\mu_{p0}J^{eh}}{M} j_{n0} - \frac{\mu_{n0}nJ^{eh}}{M} j_{p0}$$

where:

$$M = 1 + \left(p\mu_{n0} + n\mu_{p0}\right)J^{eh} \text{ and } j_{p0} = q\left(\mu_{p0}\, pE - D_{p0}\frac{\partial p}{\partial x}\right) \qquad j_{n0} = q\left(\mu_{n0}\, nE + D_{n0}\frac{\partial n}{\partial x}\right)$$

are the commonly used current equations but without EHS accounting. The EHS function J^{eh} can be derived from conductivity measurements. All auxiliarly physical parameters and dependencies are included in the physical model: Mobilities and diffusion coefficients $\mu_{n,p}$, $D_{n,p}(N,p,n,E,T)$, bandgap narrowing $\Delta E_g(N,T)$, and Shockley-Read-Hall capture times $\tau_{n0}, \tau_{p0}(N,T)$.

Current squeezing is essentially a 2-D process and can not be directly modeled by a 1-D approximation. But, an acceptable estimation of the surge current value can be made by analyzing the structure's temperature-dependent resistance in a 1-D approximation. It is apparent from Figure 2 that, at high current levels, the dynamic current-voltage characteristics have the shape of a bird's beak. Specifically, a segment on the dynamic non-isothermal characteristics will appear, where the structure resistance is diminishing over the period of time ($t \geq 0.5t_i$) $\frac{\partial R}{\partial t} < 0$. It means that somewhere in the semiconductor structure $\frac{\partial R}{\partial T} < 0$ due to high temperature and that current squeezing is possible. However, for current filamentation a certain time period (≈1-2 ms) is needed. For current pulses of lesser duration, a current filament can not be formed and the surge current is limited by other processes, e.g. by local melting of the structure or contact alloys (Figure 3).

REFERENCES
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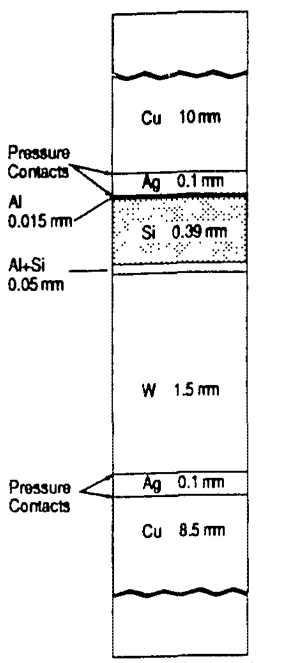

Figure 1: Packaged rectifier used for a one-dimensional thyristor surge current simulation.

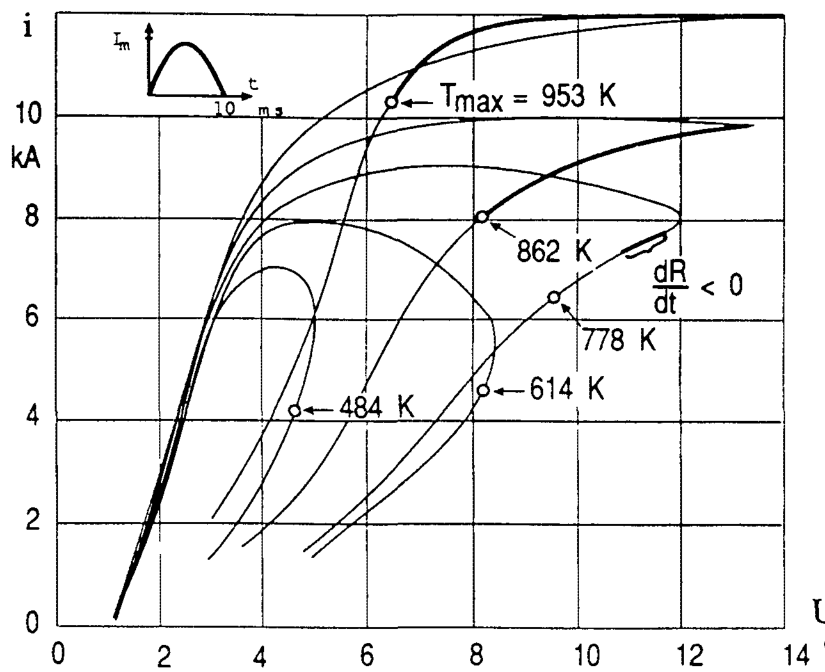

Figure 2: Dynamic current-voltage characteristics for different peak values of half-sine current pulse

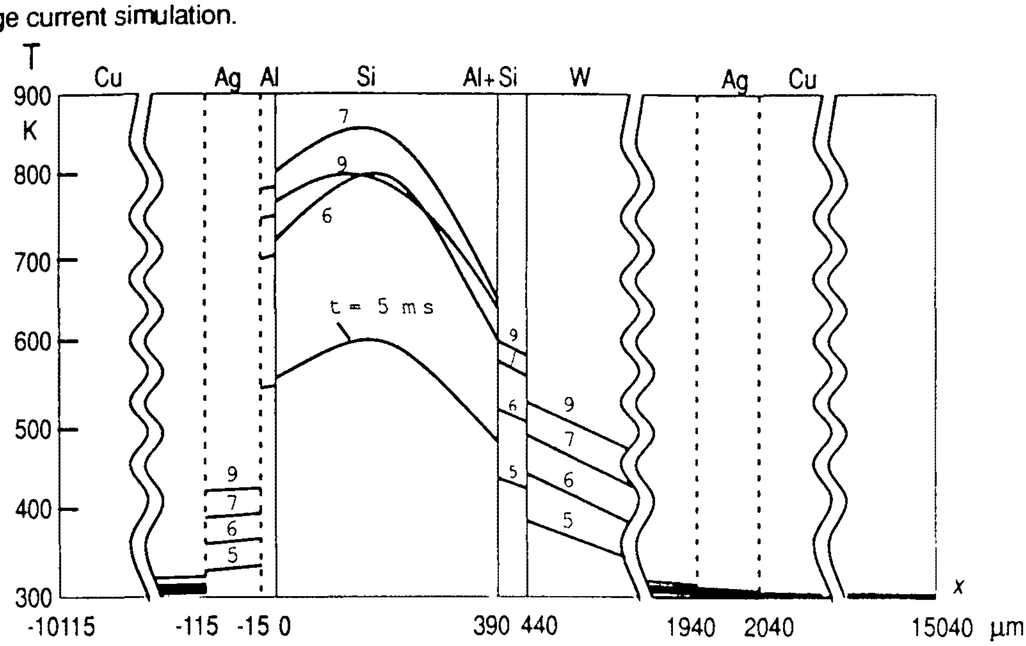

Figure 3: Temperature distributions in a thyristor structure with a cooling package at different instants for a 10 ms half-sine current pulse of 10kA.