Session 16: Solid State Devices V — Semiconductor Device Physics

Thursday, Oct. 19, 2:15 p.m. to 5:15 p.m.

South Cotillion Room

Chairman: A. S. Grove Organizer: C. A. Bittmann

16.1 AN ACCURATE NUMERICAL ONE-DIMENSIONAL SOLUTION OF THE P-N JUNCTION UNDER ARBITRARY TRANSIENT CONDITIONS, Andrea De Mari, California Institute of Technology, Pasadena, Calif.

A numerical iterative method of solution of the one-dimensional basic two-carrier transport equations describing the behavior of semiconductor junctions under both steady-state and transient conditions is presented. The method is of a very general character: none of the conventional assumptions and restrictions are introduced and freedom is available in the choice of the doping profile, recombination-generation law, mobility dependencies, injection level, and boundary conditions applied solely at the external contacts. For a specified arbitrary input signal of either current or voltage as a function of time, the solution yields terminal properties and all the quantities of interest in the interior of the device (such as carrier densities, electric field, electrostatic potential, particle and displacement currents) as functions of both position and time.

Considerable attention is focused on the numerical analysis of the problem in order to achieve a numerical algorithm sufficiently sound and efficient to cope with several fundamental difficulties of the problem, such as stability conditions related to the discretization of partial differential equations of the parabolic type, small differences between nearly equal numbers, and the variation of most quantities over extremely wide ranges within short regions.

Results for a particular single-junction structure under typical external excitations are reported. The iterative scheme of solution for a single device is applicable also to ensembles of active and passive circuit elements. As a simple example, results for the combination of a P-N diode and an external resistor, analyzed under switching conditions, are presented. The inductive behavior of the device for high current pulses, and storage and recovery phenomena under forward-to-reverse bias switching, are also illustrated. "Exact" and conventional approximate analytical results are compared and discrepancies are exposed.

16.2 CURRENT GAIN (h_{FE}) AND CUTOFF FREQUENCY (f_T) FALLOFF AT HIGH CURRENT DENSITIES, R. J. Whittier and D. A. Tremere, Fairchild Semiconductor, Palo Alto, Calif.

A theoretical and experimental study of bipolar transistor performance at high current densities has been performed. The analytical treatment is based upon the existence of a high level injection condition in the collector. Two models which describe the high current behavior of the collector junction space-charge region are discussed. The first deals with the formation of a current-induced base region at high current densities; [1,2] the width of this current-induced base depends on the current density. The second model assumes that two-dimensional effects are predominant; at sufficiently high current densities lateral injection of carriers takes place.[3] Theoretical curves for the current density necessary to bring about the space-charge limitation have been computed.

These phenomena were studied experimentally using silicon double-diffused transistor structures. The existence of space-charge-limited current in the reverse biased collector depletion layer manifests itself in significant changes in the ac and dc parameters of the transistor. In particular, it is shown that the cutoff frequency (f_T) and large signal current gain (h_{FE}) begin to decrease rapidly with increasing current density at the onset of space-charge-limited current. A comparison of experimental results with predictions of the above theories indicates that, while both the formation of a current-induced base region near the collector-base metallurgical junction and lateral injection do take place, the latter mechanism controls device performance.

The effects of deep-lying impurities on the space-charge region at high currents have been determined. By introducing a large number of such cen-