COMPANY CONFIDENTIAL

PROJECT STRETCH

CIRCUIT FILE MEMO #2

SUBJECT: Computation of Turn-on Time for a Drift Transistor
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Introduction:

The computational technique described in this memo was developed as part of the program being directed by K. Y. Sih of the Research Department, to investigate drift transistor characteristics from the viewpoint of the diffusion equation. To simplify the computation a simple one dimensional model of the transistor is used.

Future work on this subject will involve a comparison of theoretical and experimental results, and if these are satisfactory, an investigation of the effect of various physical parameters on the turn-on time.

The movement of holes in the base region is described by the diffusion equation:

$$\vec{I}_p = q\,\mu_p\, p\, \vec{E} - q\, D_p\, \vec{\nabla}\, p$$

where $\vec{I}_p$ is the hole current, q the electronic charge, p the hole concentration, $\vec{E}$ the electric field, D_p the diffusion constant, and μ_p the hole mobility. At all times the continuity equation must also be satisfied:

$$\frac{\partial p}{\partial t} = \frac{p_n - p}{\tau p} - \frac{1}{q}\, \vec{\nabla} \cdot \vec{I}_p$$

where p_n is the thermal equilibrium concentration of holes in N-type material and τp is the lifetime of holes in N-type material.

For the one-dimensional case these reduce to:

$$I_p = q\,\mu_p\, pE - q\, D_p \frac{\partial p}{\partial x} \qquad (1)$$

and

$$\frac{\partial p}{\partial t} = \frac{p_n - p}{\tau_p} - \frac{1}{q} \frac{\partial I_p}{\partial x} \qquad (2)$$

Substitution from the first into the second equation gives

$$\frac{\partial p}{\partial t} = D_p \frac{\partial^2 p}{\partial x^2} - \mu_p\, E \frac{\partial p}{\partial x} - \left(\mu_p \frac{\partial E}{\partial x} + \frac{1}{\tau_p}\right) + \frac{p_n}{\tau_p} \,. \qquad (3)$$

In a drift transistor the field in the base may be assumed to depend only on the impurity concentration N.

$$E = -\frac{Kt}{q}\,\frac{1}{N}\,\frac{dN}{dx} \qquad (4)$$

This assumption will be invalid if there is a very high concentration of minority carriers in the base region.

We may write (3) as

$$\frac{\partial p}{\partial t} = A \frac{\partial^2 p}{\partial x^2} + B \frac{\partial p}{\partial x} + C\, p + D \qquad (5)$$

D may be assumed zero, since p_n will be small and may be neglected. Applying finite difference methods to (5) and rearranging, results in the expression:

$$p_{i,j+1} = k\left[\left(\frac{A_i}{h^2} + \frac{B_i}{2h}\right)p_{i+1,j} + \left(\frac{1}{k} + C_i - \frac{2A_i}{h^2}\right)p_{i,j} + \left(\frac{A_i}{h^2} - \frac{B_i}{2h}\right)p_{i-1,j}\right] \tag{6}$$

Here a number of discrete points x_i at uniform intervals h have been chosen in the base. The concentration p is then considered at each of these points at successive times t_j separated by a uniform time interval k. The subscripts on p and the constants A, B, and C indicate at which points in space and time they should be evaluated.

A program for the 704 computer has been written, based on (6). The coefficients A, B, and C may be determined from the donor concentration at various points in the base and such constants as the diffusion constant and lifetime of holes. This program uses the following boundary conditions. The hole concentration at the collector junction is assumed to be zero at all times. This simply says that the collector junction is a perfect sink for holes. At time $t = 0$ a perfect step current, I_e, is applied at the emitter. Thus starting at this time, a constant hole current enters the base at the emitter junction. From (1):

$$I_e = q\mu_p E_o p_{o,j} - q D_p \frac{\partial p_{o,j}}{\partial t}$$

$$= q\mu_p E_o p_{o,j} - q D_p \frac{p_{i,j} - p_{o,j}}{h}$$

The concentration at the emitter, $p_{o,j}$, may be found from this. At time $t = 0$ the hole concentration of all points in the base except at the emitter junction is assumed to be zero. This provides all the necessary boundary conditions to solve (6).

The collector current I_c is found from (1). Since at the collector $p = 0$, this reduces to

$$I_c = -q D_p \frac{\partial p}{\partial x}$$

$$= -q D_p \frac{p_{w,j} - p_{w-1,j}}{h}$$

$$= +\frac{q D_p}{h} p_{w-1}$$

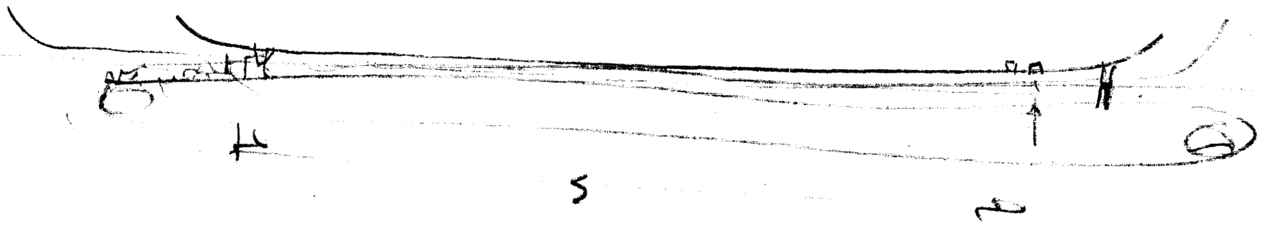
since p_W, the concentration at the collector, is zero.

The program requires as input quantities, besides various physical constants, the values of base width W, original resistivity ρ, time of diffusion of donor impurity into the original material T, emitter current I_e, and distance and time increments h and k. These increments determine the accuracy of the solution and the computer time necessary to obtain a solution.

It is found that in order for the integration to remain convergent, the ratio $k\, D_p/h^2$ must be maintained less than 1/2. A value of about 1/4 has been found to work quite satisfactorily. With this value, and taking 25 points across the base, an error of about eight or ten percent is obtained. The error seems to be inversely proportional to the number of points. Thus, 100 points would give 2% error. With 25 points, the computing time is about a minute and a half for one solution. The computing time is proportional to the cube of the number of points.

The output data from the solution consists of a curve of collector current versus time.

A trial solution was run with a base width of 10 microns, a resistivity of 2 ohm-cm, a diffusion time of 40 hours, and an emitter current of 5 ma. The collector current curve showed a diffusion delay time to the 10% point of 3 millimicroseconds and a rise time from 10% to 90% points of 20 millimicroseconds. These values seem reasonable for this type of unit.



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