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Abstract

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ON THE THEORY OF THE CURRENT-VOLTAGE CHARACTERISTIC OF A THIN-FILM FIELD-EFFECT TRIODE

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In a number of works, on the basis of a one-dimensional model, the static current-voltage characteristic of a thin-film field-effect triode is derived (^{1}). In the one-dimensional theory, the equation of the current-voltage characteristic is obtained only up to the cutoff point—the beginning of the current-saturation region. The saturation region is usually explained with the aid of the Shockley mechanism (^{2}), consideration of which in a one-dimensional model is in principle impossible. However, if one takes into account the presence in thin-film triodes of a large number of traps lying sufficiently far from the band edge, then it can be shown that the solution of the problem within the framework of the one-dimensional theory also leads to the existence of a region of very slow current increase, which can be interpreted as a saturation region. The position of this region along the voltage axis agrees better with the experimental data than that calculated on the basis of the theory (^{2}).

Let us consider a one-dimensional model of a thin-film triode operating (for definiteness) in the electron-enrichment regime. For simplicity, suppose that the film is a dielectric with homogeneously distributed monoenergetic traps of concentration N_t and energy level E_t below the conduction band. We shall assume that the ratio $N_{ct}/N_t = N_c e^{-E_t/kT}/N_t \ll 1$, where N_c is the effective density of quantum states in the conduction band, k is Boltzmann' s constant, and T is the absolute temperature. Direct the x-axis from the source to the drain; the source is in the plane $x = 0$, and the drain in the plane $x = L$.

Let $V(x)$ be the potential at the point x; then $V(0) = 0$, $V(L) = V_L$, and the potential of the control electrode is V_g. According to the one-dimensional theory, the current is equal to (^{1}):

$$I = -\frac{hW}{L} q\mu \int_0^{V_L} n(V)\, dV, \tag{1}$$

where the electron concentration in the conduction band is

$$n = \frac{\bar{C}}{2}\left\{V_g - V_t - V_{ct} - V + \sqrt{\left[V - (V_g - V_t + V_{ct})\right]^2 + 4V_{ct}V_t}\right\}. \qquad (2)$$

Here h and W are the thickness and width of the film, respectively; μ is the mobility of the carriers; q is the absolute value of the electron charge; $\bar{C} = C/hWLq$, C is the geometric capacitance of a plane capacitor with plates formed by the metallic control electrode and the working film of the triode. Expression (2) in the one-dimensional model is obtained elementarily from the condition of charge conservation.

The cutoff voltage V_{LH} is determined by the equation $\partial I/\partial V_L = 0$. Then from (1) we obtain $n(V_{LH}) = 0$, and from (2), $V_{LH} = V_g$. In the presence of donors with concentration N_d, one would obtain $V_{LH} = V_g + V_d$, where $V_d = N_d/\bar{C}$. We note that in the literature (^{1}) it is stated that $V_{LH} = V_g - V_d$.

Substituting (2) into (1), we obtain

$$\begin{gathered}
I = -\frac{\mu C}{2L^2}\left\{(\overline{V} - V_{ct})V_L - \frac{V_L^2}{2} + \frac{1}{2}\left[(V_L - \overline{V} - V_{ct})\times\right.\right. \\
\left.\times\sqrt{(V_a - \overline{V} - V_{ct})^2 + V_0^2} + (\overline{V} + V_{ct})\sqrt{(\overline{V} + V_{ct})^2 + V_0^2}\right] + \\
\left.+V_0^2 \ln\left|\frac{V_a - \overline{V} - V_{ct} + \sqrt{(V_a - \overline{V} - V_{ct})^2 + V_0^2}}{-\overline{V} - V_{ct} + \sqrt{(\overline{V} + V_{ct})^2 + V_0^2}}\right|\right\}, \qquad (3)
\end{gathered}$$

where

$$\overline{V} = V_g - V_t, \qquad V_0 = 2(V_{ct}V_t)^{1/2}.$$

It is easy to see that in the region $\overline{V} < V_L \leq V_{LH} = V_g$ the current changes little. Indeed, for $V_{ct}/V_t \ll 1$,

$$\left|\frac{I(V_{LH}) - I(\overline{V})}{I(\overline{V})}\right| \simeq \frac{V_0^2 \ln V_t/V_{ct}}{(V_g - V_t)^2} \ll 1. \qquad (4)$$

Here it is assumed, of course, that $V_g > V_t$; otherwise no appreciable current could flow through the film.

Thus, the voltage $V_L = \overline{V}$ may be taken as the point of practical current saturation. In fact, this is connected with the fact that, for $V_L > \overline{V}$, the rate of decrease of the carrier concentration in the conducting zone near the drain becomes much less than the rate of decrease of electrons on traps n_t. Indeed, the ratio

$$\frac{dn_t/dV_L}{dn/dV_L} = -\frac{V_{tV_{ct}}}{(n/C + V_{ct})^2},$$

as follows from (2), at $V = \overline{V}$ is equal to 1 and, with further growth of V_L, can only increase as a result of the decrease of n.

In the region $0 < V_L \lesssim \overline{V}$, for the current-voltage characteristic (3) one readily obtains the simple approximate formula:

$$I = -\frac{1}{2}\mu C(\overline{V}V_L + \tfrac{1}{2}V_L^2). \qquad (5)$$

This expression, while not differing in form from that appearing in the literature, differs from it in the actual meaning of the parameters entering into it.

Taking account of the presence of donors in the film will lead to replacing V_g everywhere by $V_g + V_d$.

For a triode operating in the depletion regime, obviously, the presence of donors cannot be neglected. Carrying out exactly the same calculations, we obtain that in this case

$$V_{LH} = -|V_g| + V_d - V_t.$$

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Note: Figure translations are in progress. See original paper for figures.

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