APPENDIX

At thermal equilibrium (i.e., in the neutral region of an amorphous semiconductor film), the densities [$n_T(E)$ and $p_T(E)$] of traps [$g(E)$] occupied by electrons and holes (which mean vacancies of electrons), respectively, are expressed as

$$n_T(E)/g(E) = f(E) \tag{A-1}$$

and

$$g(E) = n_T(E) + p_T(E) \quad , \tag{A-2}$$

according to the Fermi-Dirac statistics, where $f(E)$ is the Fermi-Dirac distribution function.

A rate equation for capture and emission processes of electrons and holes at gap states, which are located in an energy of E, is given by

$$\begin{aligned} dn_T(E)/dt = n\sigma_n(E)v_{th}p_T(E) - e_n(E)n_T(E) \\ - p\sigma_p(E)v_{th}n_T(E) + e_p(E)p_T(E) \quad , \end{aligned} \tag{A-3}$$

where n and p are concentrations for free electrons and free holes in the extended states, respectively, $\sigma_n(E)$ and $\sigma_p(E)$ are capture cross sections for electrons and holes at E, respectively, $e_n(E)$ and $e_p(E)$ are thermal emission rates of electrons and holes into the extended states, respectively, and v_{th} is the thermal velocity of electrons.

At the steady state and in the depletion region, Eq. (A-3) is considered. The condition [$dn_T(E)/dt=0$] holds for the steady state, and free electrons and free holes are swept out (i.e., the product of p and n is much smaller than n_i^2) in the depletion region, indicating that the first and third terms in the right-hand sides of Eq. (A-3) can be neglected, where n_i is the intrinsic carrier density. Therefore, Eq. (5-11) in Chapter V

$$F_\infty(E) \equiv n_T(E)/g(E) \qquad \text{(A-4)}$$

$$= e_p(E)/[e_n(E) + e_p(E)] \qquad \text{(5-11)}$$

is obtained from Eqs. (A-2) and (A-3).

In the depletion region, Eq. (A-3) can be rewritten as

$$dn_T(E)/dt = e_p(E)g(E) - [e_n(E) + e_p(E)]n_T(E) \quad , \qquad \text{(A-5)}$$

using Eq. (A-2), and this solution is

$$n_T(E;t) = [f(E) - F_\infty(E)]g(E)\exp\{-[e_n(E) + e_p(E)]t\} + e_p(E)g(E)/[e_n(E) + e_p(E)] \quad , \qquad \text{(A-6)}$$

using the relations of $n_T(E;0)=f(E)g(E)$ obtained from Eq. (A-1) and $n_T(E;\infty)=F_\infty(E)g(E)$ obtained from (A-4). Therefore,

$$\Delta N_I(t) = \int_{E_V}^{E_C} [n_T(E;\infty) - n_T(E;t)]dE$$

$$= - \int_{E_V}^{E_C} [f(E) - F_\infty(E)]g(E) \times \exp\{-[e_n(E) + e_p(E)]t\}dE \quad , \qquad \text{(A-7)}$$

is obtained, and then Eq. (5-14) in Chapter V

$$H(t) = \int_{E_V}^{E_C} [f(E) - F_\infty(E)]g(E)[e_n(E) + e_p(E)]t \times \exp\{-[e_n(E) + e_p(E)]t\}dE \qquad \text{(5-14)}$$

is derived from Eq. (A-7) easily.

On the other hand, the energy E_{0B} is derived from the condition of $F_\infty(E_{0B})=0.5$. Since

$$e_p(E)/[e_n(E) + e_p(E)] = 0.5 \quad , \qquad \text{(A-8)}$$

the following equation is obtained;

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$$e_p(E) = e_n(E) \quad . \tag{A-9}$$

Therefore, the equation appeared in Chapter Ⅲ

$$E_{0B} = E_V + E_{g2}/2 + (kT/2)\ln(\nu_p/\nu_n) \tag{3-2}$$

is obtained from the following equations in Chapter Ⅴ ;

$$e_n(E) = \nu_n \exp[(E - E_C)/kT] \tag{5-12}$$

and

$$e_p(E) = \nu_p \exp[(E_V - E)/kT] \quad . \tag{5-13}$$

In the case of a metal-oxide-semiconductor (MOS) diode, a current does not flow across the junction, which means that the Fermi level can be defined even in the depletion region because the quasi-Fermi level for electrons coincides with the quasi-Fermi level for holes. Thus a relation ($np=n_i^2$) in the depletion region is valid and $n_T(E)/g(E)$ coincides with $f(E)$ as described by Eq. (A-1) instead of $F_\infty(E)$ as described by Eq. (A-4), indicating that the energy of E_{0B} and the occupation function of $F_\infty(E)$ cannot be defined even in the depletion region. Therefore, Eq. (3-2) in Chapter Ⅲ and Eq. (5-11) in Chapter Ⅴ are valid only when a current flows across the junction, i.e., the quasi-Fermi level for electrons does not coincide with the quasi-fermi level for holes in the depletion region.