also shown in Fig. 3.9, which is deviated from the straight line. This apparent invalidity of Eq. (3-11) simply originates from a thinner undoped a-Si:H layer (0.8 μm thick). The depletion layer spreads over the whole a-Si:H (i.e., W_2=L) when the reverse bias voltage exceeds some critical value, resulting in an upward break of the characteristic curve because much more fraction of reverse bias voltage is supported in p c-Si than that expected from Eq. (3-9). On other words, the slope of the $W_1{}^2$-V characteristics changes from $2\varepsilon_{s1}\varepsilon_{s2}N_I/qN_A(N_A\varepsilon_{s1}+N_I\varepsilon_{s2})$ to $2\varepsilon_{s1}/qN_A$ as the reverse bias voltage increases from the critical value to higher reverse bias. Using the value of N_I obtained from sample 7, the critical bias voltage, at which W_2 reaches to L (0.8 μm) for sample 3, was calculated as around -2 V, being in good agreement with the data in the figure.

The dependence of N_I on the p c-Si resistivity is studied. The undoped a-Si:H films of samples 5-8 were deposited simultaneously on four different p c-Si substrates. The capacitances of samples 5 and 6 (lower resistivities of p c-Si) were independent of the applied voltage, resulting from the formation of the wide depletion region only in the side of a-Si:H because N_A is much larger than N_I. On the other hand, the value of N_I obtained from sample 7 with the p c-Si resistivity of 1-2 Ωcm coincided with that of sample 8 with the resistivity of 5-10 Ωcm. And also the undoped a-Si:H films of samples 9 and 10 were deposited simultaneously by the inductively-coupled rf glow discharge on two different p c-Si substrates. Both of N_I were quite similar, as shown in Table 3-1.

From the studies of the thickness- and resistivity-dependencies, the steady-state HMC method is considered to be reasonable for the present heterojunctions. From the resistivity-dependence, one had better select p c-Si with N_A which is close to the value of N_I, indicating that several p c-Si substrates should be used in order to estimate N_I in the case that N_I is unknown at all.

3-2-3. Band discontinuity between a-Si:H and c-Si

Knowing band discontinuities at amorphous/crystalline semiconductor heterojunctions is important in order to describe their electric properties as well as to design a heterojunction-bipolar transistor (HBT) with a wide-bandgap emitter.[1] As is clear from the energy-band diagram shown in Fig. 3.6, the energy difference between the conduction band in a-Si:H and the Fermi level at the interface is expressed as $qV_{B2}+\delta_2$ in the a-Si:H side and $\Delta E_C-qV_{B1}+E_{g1}-\delta_1$ in the c-Si side. Therefore, ΔE_C is expressed by

$$\Delta E_C = \delta_1 + \delta_2 - E_{g1} + qV_B \quad . \tag{3-12}$$

On the other hand, ΔE_C is defined as

$$\Delta E_C \equiv \chi_1 - \chi_2 \quad . \tag{3-13}$$

Experimentally, the value of δ_1 is estimated from N_A as shown in Table 3-1 and the value of δ_2 is the same as the activation energy of dark conductivity of a-Si:H. By substituting quantitative data on δ_1, δ_2, χ_1, E_{g1}, and V_B to Eqs. (3-12) and (3-13), the values of ΔE_C and χ_2 are determined as

$$\Delta E_C = 0.20 \pm 0.07 \text{ eV}$$

and

$$\chi_2 = 3.85 \pm 0.07 \text{ eV} \quad ,$$

using E_{g1}=1.12 eV and χ_1=4.05 eV.[9] Figure 3.10 shows the energy-band diagrams for the diodes (samples 5-8) with four different p c-Si resistivities, sketched on the basis of the above results.

3-3. Simulation of High-frequency C-V Characteristics

3-3-1. Modeling

Though only the undoped (i.e., slightly n-type) a-Si:H/p c-

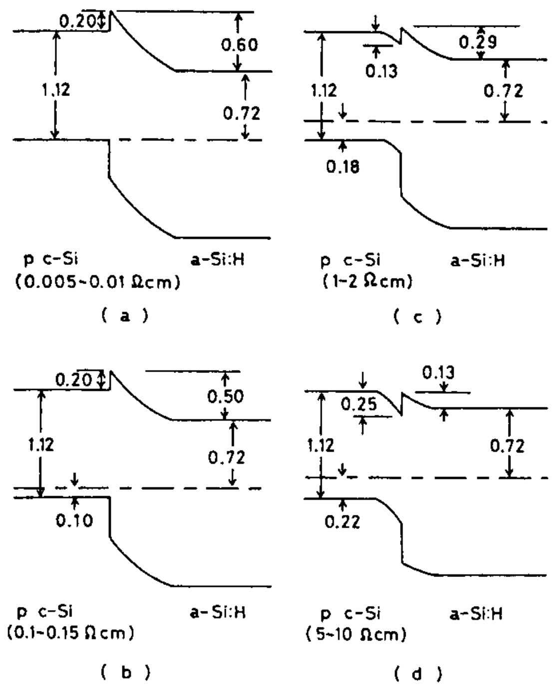

Fig.3.10. Energy-band diagrams in interface regions for heterojunctions using p c-Si with different resistivities. Resistivities of p c-Si are (a) 0.005-0.01 Ωcm, (b) 0.1-0.15 Ωcm, (c) 1-2 Ωcm, and (d) 5-10 Ωcm.

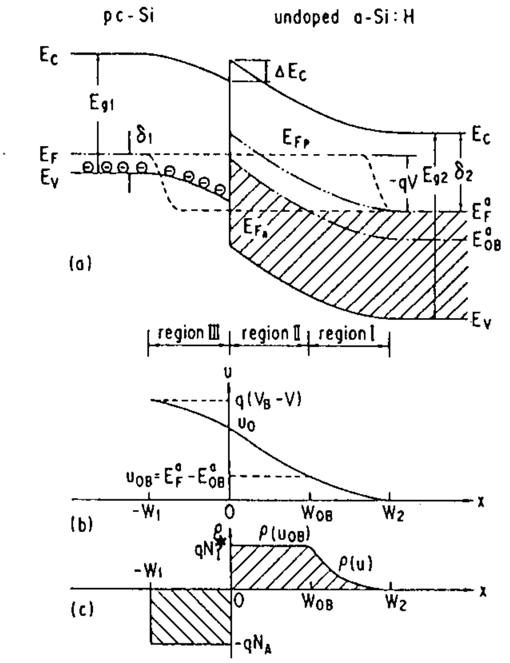

Fig.3.11. Schematic sketches of p c-Si/undoped a-Si heterojunction: (a) energy-band diagram, (b) energy variation for electron, and (c) space-charge density variation for dc reverse-bias voltage condition. Gap states indicated by hatched area of (a) are occupied by electrons.