CHAPTER Ⅶ CONCLUSION

This thesis has mainly investigated and discussed

(1) the electrical properties of undoped hydrogenated amorphous silicon (a-Si:H)/p-type crystalline silicon (p c-Si) heterojunctions;

(2) new methods for determining a density (N_I) and a profile [g(E)] of midgap states in highly resistive amorphous semiconductors using the property of those amorphous/crystalline semiconductor heterojunctions; and

(3) the nature of midgap states in undoped a-Si:H, undoped hydrogenated amorphous silicon germanium alloys (a-Si_{1-x} Ge_x:H), and undoped hydrogenated amorphous silicon carbon alloys (a-$Si_{1-x}C_x$:H).

Prior to investigation of undoped (i.e., slightly n-type) a-Si:H/p c-Si heterojunctions in diodes with metal/a-Si:H/c-Si structures, each contact in those diodes has been studied in order to know whether each contact behaves like an Ohmic contact or like a rectifying contact. From this study, Mg was found to form a good Ohmic contact with undoped a-Si:H, instead of Al, and the undoped a-Si:H/p c-Si heterojunctions exhibited good rectifying properties. Additional results from the study were that the conduction type of a-Si:H was classified into three categories such as n-type for P-doped and undoped a-Si:H, intrinsic for B-doped a-Si:H with $B_2H_6/SiH_4 \sim 10^{-6}$, and p-type for B-doped a-Si:H with $B_2H_6/SiH_4 > 10^{-5}$, which has been difficult by means of Hall measurements due to their high resistivity.

The study of high-frequency ($\geqq$ 100-kHz) capacitance-voltage (C-V) characteristics of the undoped a-Si:H/p c-Si heterojunctions has made it possible to obtain the density (N_I) of midgap states in highly resistive amorphous semiconductors such as undoped a-Si:H, whose value was checked with that obtained from simulation of high-frequency C-V characteristics of a highly resistive amorphous/lowly resistive crystalline semiconductor heterojunction. In the reasonable case that its interface-state density was less than 10^{11} cm^{-2}, the density experimentally obtained from the C-V measurement represented a bulk density of midgap states in undoped a-Si:H. This method is referred to as a steady-state heterojunction-monitored capacitance (HMC) method.

The forward currents in undoped a-Si:H/p c-Si heterojunctions were expressed as $\exp(-\Delta E_{af}/kT)\exp(AV)$, which could be explained by a multistep-tunneling capture-emission (MTCE) model proposed here, where A is a constant independent of the applied voltage (V), ΔE_{af} is a constant independent of the measuring temperature (T), and k is the Boltzmann's constant. The reverse currents were proportional to $(V_B-V)^{1/2}$, resulting from a generation process in both sides of a-Si:H and c-Si, where V_B is the built-in potential.

The investigation of transient capacitance of the undoped a-Si:H/p c-Si heterojunctions has made it possible to estimate the density-of-state distribution [g(E)] between the Fermi level and the midgap in highly resistive amorphous semiconductors. The distribution obtained from this method was considered to be unaffected by their interface states. This method is called a transient HMC method.

From the study of ESR, N_I represented the density of singly-occupied Si dangling bonds for undoped a-Si:H and undoped a-$Si_{1-x}C_x$:H [an optical gap $(E_0) \leqq 1.88$ eV], while N_I mainly was assigned to the density of singly-occupied Ge dangling bonds for undoped a-$Si_{1-x}Ge_x$:H ($E_0 \leqq 1.63$ eV). The peak of g(E) appeared clearly in a-Si:H and a-$Si_{1-x}Ge_x$:H, but it did not appear clearly in a-$Si_{1-x}C_x$:H. In a-$Si_{1-x}Ge_x$:H with E_0=1.30 and 1.44 eV, furthermore, not only a peak of g(E) originating from singly-occupied Ge dangling bonds but also a shoulder arising from singly-occupied Si dangling bonds were clearly observed.

Light soaking produced two sorts of metastable states which were annealed out completely up to 200 ℃ for 2 h; (1) one, which was dominant in short-time ($\leqq$4-h) light soaking, had a small attempt-to-escape frequency (ν_n) for electrons and coincided with the midgap states in as-deposited films, and (2) the other, which became dominant in long-time ($\geqq$75-h) light soaking, had a large ν_n. Both the metastable states were located in around

0.85 eV and they originated from singly-occupied Si dangling bonds, but the behavior by thermal annealing was quite different each other. The midgap states produced by rapid cooling from 300 ℃ were similar to those induced by the short-time light soaking.

From the fundamental research on capacitance in undoped hydrogenated amorphous silicon-based alloy/p c-Si heterojunctions, the steady-state and transient HMC methods have been developed in this thesis. The HMC methods have great potential for determining N_I and g(E) in highly resistive semiconductors with gap states.