ABSTRACT

This thesis describes the electrical properties of hydrogenated amorphous silicon-based alloy/crystalline silicon heterojunctions and development of new methods for getting information on midgap states in undoped hydrogenated amorphous silicon-based alloys. In order to investigate the heterojunctions in metal/amorphous/crystalline diodes, the property (Ohmic or rectifying) of each contact has been studied first. Then, characteristics of their current-voltage (I-V), capacitance-voltage (C-V) and transient capacitance have been measured and discussed. From the above fundamental studies, methods for determining a midgap-state density and its profile in highly resistive amorphous semiconductors, such as undoped hydrogenated amorphous silicon (a-Si:H), undoped hydrogenated amorphous silicon germanium alloys ($a\text{-}Si_{1-x}Ge_x:H$) and undoped hydrogenated amorphous silicon carbon alloys ($a\text{-}Si_{1-x}C_x:H$), have been developed. Furthermore, the nature of midgap states in them has been researched.

First of all, it has investigated the I-V characteristics of metal/undoped a-Si:H/n^+ (or p^+) crystalline silicon (c-Si) structures using Mg, Au, Pt and Al as a metal. Although Al has been thought to form an Ohmic contact with not only P-doped but also undoped a-Si:H, Al as well as Au and Pt is found to form a Schottky barrier junction with them. On the other hand, Mg is found to form a good Ohmic contact not only with P-doped a-Si:H but also with undoped a-Si:H. This contact does not exhibit the thermal degradation at least up to 100 ℃. Next, investigated are the I-V characteristics of metal(Au,Mg)/B-doped a-Si:H/c-Si(n^+,p^+) diodes for various doping levels of B in a-Si:H. The junction studies determine the conduction type of B-doped a-Si:H on the basis of "dominant" carrier concentration, and find that the p-n transition occurs at $B_2H_6/SiH_4 \sim 10^{-6}$ although the conductivity minimum appears at $B_2H_6/SiH_4 \sim 10^{-4}$.

From the study of the C-V characteristics of undoped a-Si:H/p c-Si heterojunctions under high frequency ($\geq$ 100 kHz), a

midgap-state density (N_I) of a-Si:H and an electron affinity (χ_2) of a-Si:H are obtained. This method is called a steady-state heterojunction-monitored capacitance (HMC) method. The analytical approach is that the capacitance in the a-Si:H side becomes equal to the geometric capacitance of the a-Si:H film due to its longer dielectric relaxation time, while that in the c-Si side is associated with the depletion width in c-Si which reflects the space charge of the depletion region in a-Si:H by a dc bias. In order to understand the physical background of N_I which is experimentally obtained from the steady-state HMC method, a model for simulating high-frequency C-V characteristics of highly resistive amorphous/lowly resistive crystalline semiconductor heterojunctions has been developed. In the reasonable case that its interface-state density is less than 10^{11} cm^{-2}, the results experimentally obtained from the steady-state HMC method are found to be valid.

It has also measured the temperature dependence of the I-V characteristics of undoped a-Si:H heterojunctions on p c-Si with different resistivities. The forward current of all the junctions studied shows voltage- and temperature-dependencies expressed as $\exp(-\Delta E_{af}/kT)\exp(AV)$, where ΔE_{af} and A are constants independent of an applied voltage (V) and a measuring temperature (T), being successfully explained by a multistep-tunneling capture-emission (MTCE) model proposed here. The reverse current is proportional to $(V_B-V)^{1/2}$, where V_B is the built-in potential. This current is probably limited by a generation process in the depletion regions.

A novel technique (transient HMC method) has been proposed for determining a midgap-state profile in highly resistive amorphous semiconductors from the study of the transient capacitance of highly resistive amorphous/lowly resistive crystalline semiconductor heterojunctions. The transient HMC method has been applied to undoped a-Si:H, undoped a-$Si_{1-x}Ge_x$:H and undoped a-$Si_{1-x}C_x$:H. These midgap states are found to correspond to singly-occupied dangling bonds (D^0). The density of the midgap states increases slowly with the Ge content in the film, while it increases rapidly with the C content. The peak of

the midgap-state profile appears clearly in a-Si:H and $a\text{-}Si_{1-x}Ge_x:H$, but it does not appear clearly in $a\text{-}Si_{1-x}C_x:H$. Next, changes of the midgap-state profile of light-soaked undoped a-Si:H have been measured in the process of a 150-℃ annealing by the transient HMC method. Monomolecular annealing kinetics are found to be suitable for explaining the results, and the thermal activation energy for annealing decreases with an increase in the energy position measured from the conduction-band edge. Finally, midgap-state profiles in undoped a-Si:H have been measured after light soaking, rapid cooling, and thermal annealing using the HMC method. After short-time ($\leq$ 4-h) light soaking under AM1 with 100 mW/cm^2 at room temperature, the increase in midgap states which are assigned to D^0 in as-deposited films are observed. The attempt-to-escape frequency (ν_n) for electrons of those states is $7x10^{11}$ s^{-1}. Successive long-time ($\geq$ 75-h) light soaking, however, mainly produces another midgap states with ν_n of $2x10^{13}$ s^{-1}. Both light-induced metastable states with two kinds of ν_n are located at around 0.85 eV below the conduction-band edge. After annealing those samples up to 200 ℃ for 2 h, both states are completely recovered, but recovering behavior is quite different from one with a small ν_n to the other with a large ν_n. On the other hand, the states produced by rapid cooling from 300 ℃ are similar to those induced by the short-time light soaking in their ν_n as well as in recovering behavior by the annealing.