CHAPTER V TRANSIENT HMC METHOD

CHAPTER V MIDGAP-STATE PROFILES DETERMINED BY TRANSIENT HMC METHOD

5-1. Introduction

The optoelectronic properties of hydrogenated amorphous silicon (a-Si:H) films are critically linked with the density and distribution of gap states in a-Si:H. In order to enhance the performance of a-Si:H-based devices, such as solar cells and thin-film transistors, a low density-of-state (DOS) distribution [g(E)] in the mobility gap is essential. Measurements of the g(E) and understanding of the nature of the gap states are, therefore, very important. The problem has received considerable attention, and many techniques have been developed to determine the g(E). These include both optical and electrical methods as mentioned in Chapter I .

This chapter has tried to determine the g(E) below the Fermi level in highly resistive amorphous semiconductor, such as undoped a-Si:H films and undoped hydrogenated amorphous silicon germanium alloy ($a\text{-}Si_{1-x}Ge_x$:H) films, the importance of the latter arising from the low band-gap component in tandem-type amorphous solar cells.

Prior to this, from the study of the capacitance-voltage (C-V) characteristics of undoped (i.e., slightly n-type) a-Si:H/p-type crystalline silicon (p c-Si) heterojunctions under high frequency ($\geq$ 100 kHz), a midgap-state density (N_I) of a-Si:H and its electron affinity (χ_2) were obtained, as discussed in Chapter Ⅲ. The analytical approach there has been that at a high-frequency small ac voltage the capacitance of a-Si:H becomes equal to geometric capacitance of the a-Si:H film due to its longer dielectric relaxation time, while that of c-Si is associated with the depletion width of c-Si which reflects the space charge of the depletion region in a-Si:H by a dc reverse bias. This method is called a steady-state heterojunction-monitored capacitance (HMC) method.

In this chapter, it has been demonstrated that the g(E) below the Fermi level in highly resistive amorphous films can be determined from the experimental results involving measurements of transient capacitance as well as its temperature-dependence of those heterojunctions.

5-2. Transient Capacitance

Figure 5.1 shows the change in the capacitance after a reverse-bias voltage (-4 V) is applied to an undoped a-Si:H/p c-Si ($N_A=1.0\times10^{16}$ cm^{-3}) heterojunction which was under the zero-bias condition for a certain time. In almost of the whole a-Si:H, the gap states between E_F and E_{0B} are full of electrons under the zero-bias condition. After applying the reverse-bias voltage, the electrons trapped at the gap states between E_F and E_{0B} are going to be re-emitted to the conduction band, which results in the change of the positive space-charge density in the depletion region of undoped a-Si:H. Because a-Si:H possesses deep gap states whose emission rates are small, the capacitance gradually decreases with time (t). Since the steady-state HMC method has made it possible to get the midgap-state density, this transient HMC must include information on the g(E) of the midgap states. From the transient behavior of the capacitance, the g(E) in undoped a-Si:H can be determined as discussed in the following sections. This method is a powerful technique for determining the g(E) below the Fermi level in undoped a-Si:H because it has been difficult to obtain the g(E) in such a highly resistive semiconductor by the conventional transient capacitance methods, such as deep-level transient spectroscopy (DLTS)[1] and isothermal capacitance transient spectroscopy (ICTS)[2] using Schottky barrier diodes and homogeneous p-n diodes, as mentioned in Chapter I .

5-3. Theory of Transient HMC Method

In order to estimate the g(E) below the Fermi level, the