CHAPTER IV CURRENT-VOLTAGE CHARACTERISTICS OF UNDOPED a-Si:H/p c-Si HETEROJUNCTIONS

4-1. Introduction

There are very few reports concerning amorphous/crystalline semiconductor heterojunctions after the first report of Grigorovici et al.[1] on amorphous germanium (a-Ge)/crystalline germanium (c-Ge) heterojunctions. Those a-Ge films had such a lot of gap states that p-n control in the films could not be made. According to Stourac,[2] for the case of chalcogenide materials as an amorphous material, the current-transport mechanism was based on space-charge-limited currents (SCLC) in the chalcogenide materials. Concerning hydrogenated amorphous silicon (a-Si:H)/crystalline semiconductor heterojunctions, almost no data had been published before this study started, where a-Si:H has been attractive for device applications because p-n control in a-Si:H has succeeded.[3]

This chapter presents a systematic study of undoped (i.e., slightly n-type) a-Si:H/p-type crystalline silicon (p c-Si) heterojunctions for the first time. The purpose in this chapter is to elucidate the current-transport mechanism of those heterojunctions.

4-2. I-V Characteristics

Figure 4.1 shows the typical I-V characteristics in (a) log-log and (b) semilog presentations for an undoped a-Si:H/p c-Si heterojunction with an acceptor density (N_A) in p c-Si of 1.0×10^{16} cm^{-3}. Two sorts of current-transport mechanisms have been proposed to explain these I-V characteristics;

(1) a bulk-limited (space-charge-limited) current-transport mechanism,[4]

(2) a junction-limited current-transport mechanism.[5]

The essential difference between (1) and (2) is whether the

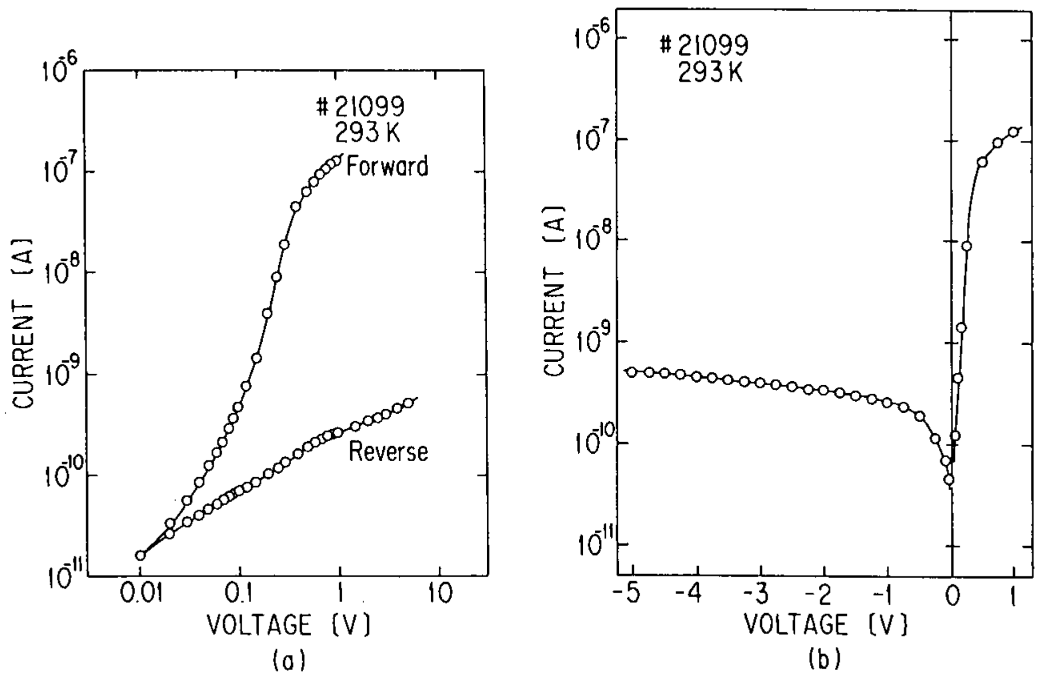

Fig.4.1. I-V characteristics of undoped a-Si:H/p c-Si (N_A=1.0x10^{16} cm^{-3}) heterojunction; (a) log I-log V plots and (b) log I-V plots.

resistance of the depletion region is higher or lower than the resistance of the amorphous film. On other words, in the bulk-limited case the applied bias drop is mainly across the whole amorphous layer, while in the junction-limited case the applied bias drop is across the depletion regions. Because the resistivity and thickness of the a-Si:H film were about 10^9 Ω cm and 1.2 μm, respectively, the expected current in the bulk-limited case should be equal to or larger than 3.3×10^{-9} A at 0.05 V for an electrode area of 0.785 mm^2. The current at bias voltages lower than 0.05 V seems to be Ohmic in nature, as Smid pointed out,[4] because the value of I seems to be proportional to V in this voltage region. The observed current, however, is much smaller than 3.3×10^{-9} A. Judging from the magnitude of the current, the current for $V \leqq 0.4$ V (close to the built-in potential, V_B) is thought to be limited by the a-Si:H/c-Si heterojunction. The voltage dependence of the junction-limited current can generally be expressed by

$$I = I_0[\exp(AV) - 1] \quad , \qquad (4\text{-}1)$$

where A is voltage-independent and I_0 is the prefacter independent of the voltage. The forward current seems to be proportional to V in the voltage range lower than 0.05 V because exp(AV) can be approximately expanded in Talyor's series of 1+AV. Therefore, the I-V characteristics should be discussed on the basis of the junction-limited current-transport mechanism in the voltage region. There is another evidence that the current flowing through this heterojunction is not an SCLC. According to the SCLC model,[6] the relationship between I/L and V/L^2 should be independent of the thickness (L) of the a-Si:H film. However, I/L-V/L^2 characteristics in this study strongly depended on the thickness, indicating that the SCLC model cannot apply to this heterojunction.

4-3. Forward I-V Characteristics