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A New Amorphous Silicon (a-Si) Interface Evaluation Method by Quasi-Static C-V Measurement

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A new amorphous silicon interface evaluation method by quasi-static C-V measurement is proposed. It has been found that this new method is effective to evaluate the defect density at the interface between two intrinsic a-Si layers. Also, it has been found that mercury-sensitized photochemical vapor deposition (photo-CVD) method scarcely causes damage to the bottom layer and also scarcely generates the defect density at the a-Si interface.

1. Introduction

Amorphous silicon (a-Si) device performances were intensely influenced by the defect density at the interface, which was fabricated between two a-Si layers (a-Si interface)[1]. Low interface state density is realized by depositing an upper a-Si layer without causing damage to the bottom a-Si layer. However, no method which can directly observe the defects conditions at a-Si interface has ever been reported. Therefore, development of this method has been intensively sought. Here, the authors propose a new method to evaluate the defects conditions at the a-Si interface fabricated between two intrinsic (i-type) a-Si layers (i/i a-Si interface) by quasi-static C-V measurement[2]. This new method has been only applied to evaluating i/i a-Si interface. However the authors consider that this new method to evaluate the defects conditions at i/i a-Si interface can effectively contribute the development of an a-Si deposition method, which will realize an a-Si interface with a lower defect density than ever.

In this paper, the authors show the difference in defect density at i/i a-Si interface varied by changing a-Si deposition method. Here, the authors compared mercury-sensitized photochemical vapor deposition (photo-CVD) method[3] with conventional plasma-CVD method. Mercury-sensitized photo-CVD method does not produce any electric charge species, when SiH_4 is decomposed. So, this method has not been considered to cause damage to the bottom layer, compared with conventional plasma-CVD method[4]. Throughout this investigation, it has been found that, 1) this new method is effective to directly evaluate the defect density at a-Si interface. It has also been found that, 2) mercury-sensitized photo-CVD scarcely causes damage to the bottom layer and scarcely generates defects at the interface.

2. Sample Preparation

The sample structure used in this investigation is illustrated in Fig.1. It is a-Si i-p diode structure. However, the i/i a-Si interface was located intentionally in the middle of the i-type a-Si layer. The i/i a-Si interface was fabricated by the

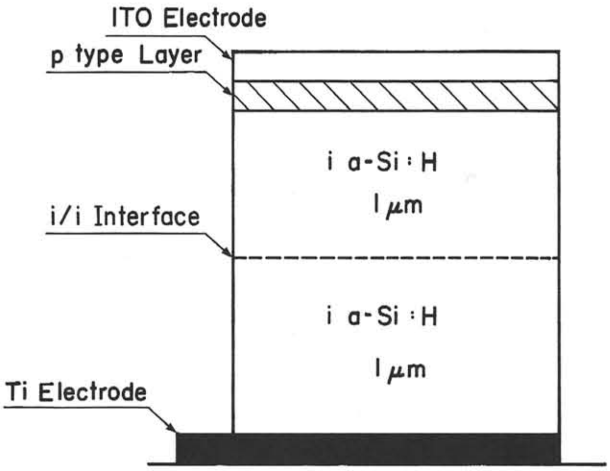

Fig.1 The a-Si i-p diode diagram

following processes. 1) An a-Si layer was deposited 1 μm thick on the Ti electrode at substrate temperature (Ts) = 200 °C. 2)Then, the sample was kept at Ts = 200 °C in vacuum for 5 minutes. 3)Successively, another a-Si layer was again deposited 1 μm thick at Ts = 200 °C. The i-type a-Si layer fabrication methods for four prepared samples are shown in Table I. In the plasma-CVD method, conventional capacitively coupled reactor was used, where the electrode diameter was 170 mm and the distance between the electrodes was 60 mm. A plasma is generated at a radio frequency (RF) of 13.56 MHz. Also, in the mercury-sensitized photo-CVD method, a low-pressure mercury lamp was used as a light source. SiH_4 is introduced into the reaction chamber through a thermally controlled mercury saturature. The deposition conditions for mercury-sensitized photo-CVD method and plasma-CVD method are shown in Table II. Properties of individual a-Si films, produced by mercury-sensitized photo-CVD method and plasma-CVD method, are shown in Table III. Ns denotes spin density, estimated by the electron spin resonance. N_{min} denotes a minimum in the density-of-states obtained by the space-charge-limitted current method.

Table I I-type a-Si layer fabrication conditions for four samples

Sample	I-type a-Si layer	
	Bottom layer	Upper layer
A	Photo-CVD	Photo-CVD
B	Photo-CVD	Plasma-CVD
C	Plasma-CVD	Photo-CVD
D	Plasma-CVD	Plasma-CVD

Table II Deposition conditions for a-Si, produced by mercury-sensitized photo-CVD method and plasma-CVD method

	Mercury-sensitized Photo-CVD method	Plasma-CVD method
SiH_4 Flow Rate (sccm)	20	25
H_2 Flow Rate (sccm)	—	25
Substrate Temperature (°C)	200	200
Pressure (Torr)	0.2	0.4
RF Power Density (mW/cm^2)	—	44
254nm Light Intensity (mW/cm^2)	7	—
Hg Saturator Temperature (°C)	82	—

Table III Properties of a-Si, produced by mercury-sensitized photo-CVD method and plasma-CVD method

	Mercury-Sensitized Photo-CVD method	Plasma-CVD method
Hydrogen Content (at %)	13.3	11.3
Optical Band Gap (eV)	1.71	1.78
Activation Energy (eV)	0.97	0.89
Ns (cm^{-3})	7.6×10^{15}	1.1×10^{16}
Nmin (cm^{-3} eV^{-1})	2.4×10^{15}	2.0×10^{15}

3. Measurement and Calculation Method

The space charge density at i/i interface for the four samples was measured using quasi-static C-V measurement[1]. Here, capacitance C is calculated by the following equation, C = (Io -Is) / B . Is

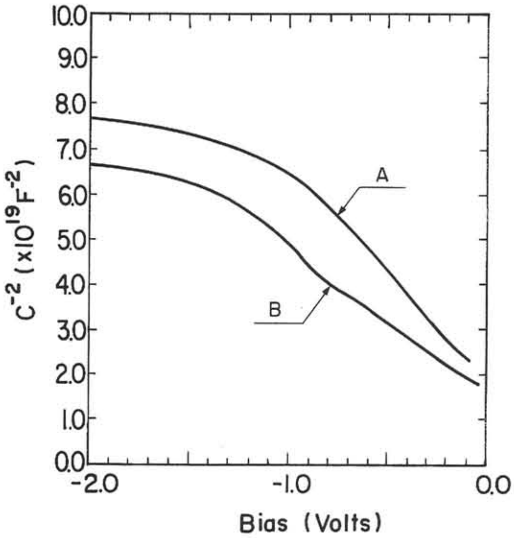

Fig.2 C^{-2} as a function of V for samples A and B

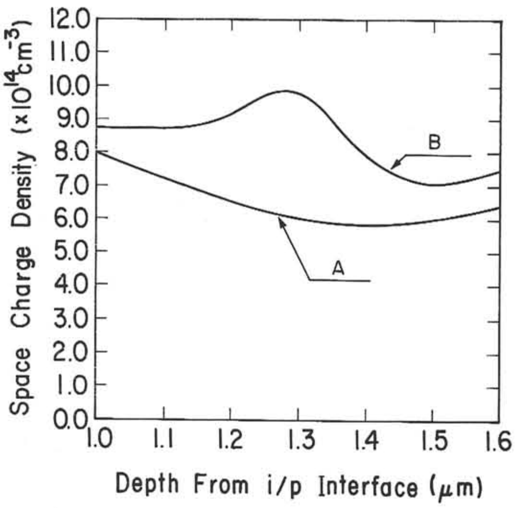

Fig.3 Space charge density distributions near the i/i interface for samples A and B

denotes the steady-state forward current evaluated at the end of the hold time. Io denotes the current measured just after sweeping the voltage acccording to the ramp rate B (5 mV/sec). The space charge density distribution near the i/i interface was calculated using the following two equations[5].

$$N_I(x) = -2(dC^{-2}/dV)^{-1} / (q\varepsilon_r \varepsilon_o S^2) \qquad (1)$$

$$x = \varepsilon_r \varepsilon_o S / C \qquad (2)$$

Here, x means the distance from i/p interface , because the depletion region expands from the i/p interface to the i-type a-Si layer. ε_r denotes a-Si dielectric constant (12.4 in this investigation) and S denotes sample area 0.02 cm^2.

4. Results

Figure 2 shows C^{-2}-V characteristics for samples A and B. Both samples A and B have the a-Si bottom layer, which was deposited by mercury-sensitized photo-CVD method. However, individual a-Si deposition methods differ for the upper i-type layer. For sample A, the upper layer was deposited by mercury-sensitized photo-CVD method. For the sample B, it was deposited by plasma-CVD method. C^{-2} for the sample A decreases monotonically with increasing the applied voltage. On the contrary, C^{-2} for the sample B does not show monotonic decrease with increasing the applied voltage. For sample B, the decrease rate of C^{-2} changes at about -0.8V. Calculated space charge density distributions, near the i/i a-Si interfaces for samples A and B, are shown in Fig. 3. Space charge density distribution for sample A shows a smooth change with the minimum 5.9×10^{14} cm^{-3} in the x region from 1.0 μm to 1.6 μm. However, that for sample B shows a unique change with a 9.9×10^{14} cm^{-3} peak. Sample B, where the upper layer was deposited by plasma-CVD method, has more space charge density at 1.3 μm by about 4×10^{14} cm^{-3} than sample A, which was deposited by mercury-sensitized photo-CVD method.

Space charge density distributions for all four samples are shown in Fig. 4. Four samples are evidently divided into two groups. Samples A and C, where the upper layer was deposited by mercury-sensitized photo-CVD method, differ from samples B and D which were deposited by

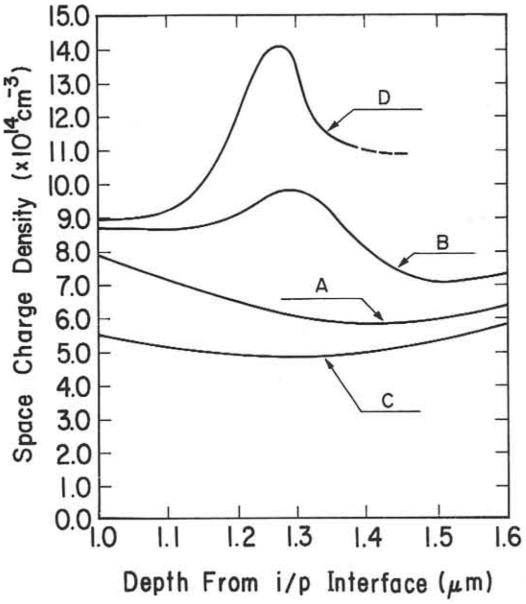

Fig.4 Space charge density distributions near the i/i interface for four samples

plasma-CVD method. Both samples B and D show space charge density distributions with a peak at about 1.3 μm. On the other hand, samples A and C do not show any peak. However, it is not obvious yet about the 0.3 μm difference between the actually fabricated i/i interface position and the calculated position. Thus, the authors prepared sample E which was fabricated by the same fabrication method as sample B, but where the upper i-type layer was deposited on the bottom i-type layer, after exposing the bottom layer to 132 mW/cm^2 H_2 plasma. It was found that the space charge density at 1.3 μm for sample E was about 5 times more than that for sample B. Therefore, the authors consider the estimated increases in the space charge density at about 1.3 μm for samples B and D, as increases in the defect density at the i/i a-Si interfaces, which were generated by the plasma damage. Both samples A and C where the upper layers were fabricated by the mercury-sensitized photo-CVD method, do not show any increase in the space charge density at about 1.3 μm. These results mean that the mercury-sensitized photo-CVD method scarcely generates defect density. Even if defect density were to be, it would be less than 10^{14} cm^{-3} at the i/i a-Si interface.

4. Conclusion

Based on the above investigation results, the following conclusions are reached,

1) This new amorphous silicon interface evaluation method can be used to directly evaluate the defect density at the i/i a-Si interface.
2) While using this new method effectively, it was found that mercury-sensitized photo-CVD method scarcely generates defect density at the a-Si interface.

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