B－1－2 Determination of Localized State Density Distribution in Glow Discharge Amorphous Silicon

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Introduction Spear and Le Comber have recently succeeded in the reproducible control of n- or p-type conductivity of glow discharge amorphous silicon (GD a-Si) by substitutional doping of phosphorus or boron impurities[1]. Consequently, many studies for application of GD a-Si to low-cost solar cells are in progress[2]. Detailed knowledge on electronic density of states in the mobility gap of GD a-Si is now required to improve the efficiency of the photovoltaic cells.

This paper describes a new method to determine gap state density distribution in GD a-Si from the analysis of capacitance-voltage (C-V) characteristics for metallic gate/oxide/GD a-Si (MOS) structures.

Theoretical The surface potential u^a and the space charge capacitance C^a of an a-Si MOS structure are deduced from the C-V curve. Then the density distribution of gap states N(E) is calculated by the equation[3]

$$N(E) = N(E_F^a + eu^a) = [\partial/\partial(eu^a)]\{[\int_0^{u^a} C^a(u^a)du^a/\varepsilon^a][C^a(u^a)/e]\}. \quad (1)$$

Here, E_F^a is the Fermi level of a-Si, ε^a its dielectric constant and e the electronic charge. In eq. (1) it is assumed that the thermal-release time τ for majority carriers trapped by localized states at E_F^a in the space charge layer is short enough compared with the inverse of measuring frequency τ_m.

Experimental Amorphous Si films were deposited on SiO_2/n^+-Si(100) substrates kept at 300°C by rf glow discharge of SiH_4-PH_3 or SiH_4-B_2H_6 gaseous mixture. A sketch of a fabricated MOS structure is shown in Fig. 1. The C-V curves of MOS diodes measured at 20 Hz are shown in Fig. 2. The relation $\tau \ll \tau_m$ is well satisfied over weak depletion to accumulation condition, by raising the ambient temperature up to 58°C for an n-type specimen (doped 3 ppm PH_3, $E_C - E_F^a = 0.55$ eV) and up to 97°C for a p-type one (300 ppm B_2H_6, $E_F^a - E_V = 0.65$ eV). The flat-band voltage V_{FB} for the each specimen was reasonably obtained from a gate voltage above which field induced current through the electrodes A and B (see Fig. 1) sharply increases owing to majority carrier accumulation at the surface. Figure 3 represents the calculated density of localized states for the specimens indicated in

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Fig. 2. This density of states distribution is considerably different from that measured by field effect (F-E) method[4] which exhibited two peaks of gap state density of the order of 10^{18}- 10^{19} $cm^{-3}eV^{-1}$ at 0.4 eV below and above the extended states. In case of the F-E method the surface potential u^a is evaluated by supposing that the surface band bending of a-Si is parabolic. Of course this is a zero order approximation. In contrast to this, the C-V method presented here gives exact u^a as a result of numerical integration of the C-V curve. We found that estimated values of u^a by the F-E method are 30 - 40 % smaller than those by the C-V method. This discrepancy implies that the peak density of gap states suggested by the F-E method arises from the rough evaluation of the surface potential. Surface states at the SiO_2/GD a-Si interface, if exist, may give rise to the MOS capacitance, but the influence on the C-V curve is estimated to be negligible even for the suface state density of high 10^{12} $cm^{-2}eV^{-1}$.

Conclusion The C-V method can provide a quantitative information on localized states in GD a-Si, being very useful to find optimum conditions for producing the efficient photovoltaic cells, in connection with doping concentration, substrate temperature, discharge kinetics and so on.

References (1) W.E. Spear and P.G. Le Comber: Phil. Mag. 33 (1976) 935. (2) D.E. Carlson, C.R. Wronski, J.I. Pankove, P.J. Zanzucchi and D.L. Staebler: RCA Rev. 38 (1977) 211. (3) G.H. Doehler and M. Hirose: Proc. of the 7th Intern. Conf. on Amorphous and Liquid Semiconductors (Edinburg, 1977) p.372. (4) A. Madan and Le Comber: ibid. p.377.

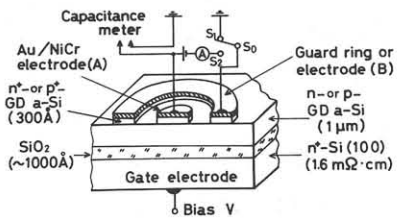

Fig. 1. Schematic of a GD a-Si MOS structure. The connection S_0-S_1 is used for the C-V method and S_0-S_2 for the F-E method.

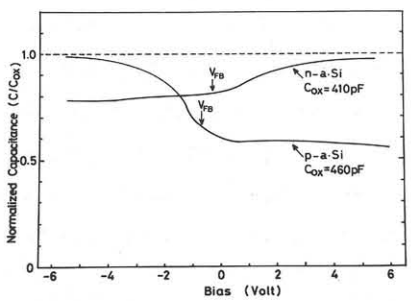

Fig. 2. C-V curves for doped a-Si MOS structure.

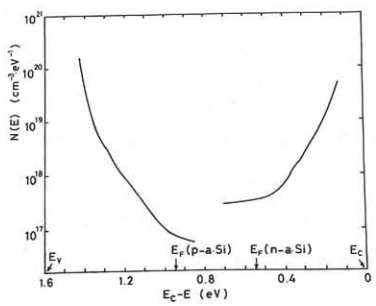

Fig. 3. Density of states distribution in doped GD a-Si.