Defects in the passivating buffer (i) a-Si:H layer of a-Si:H/c-Si heterojunction solar cells

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The Heterojunction with Intrinsic Thin layer (HIT) is the silicon technology having the world record of photovoltaic efficiency conversion [1]. Using a very thin layer of intrinsic hydrogenated amorphous silicon, (i) a-Si:H, as a buffer between the doped a-Si:H emitter and the c-Si base wafer is known to provide excellent passivation properties of the c-Si surface. However, the density of gap states in this (i) a-Si:H layer, which is supposed to be very low, could never be measured so far. The main reason is that the optoelectronic techniques used to test the quality of the interface are sensitive to unknown parameters, e.g. the capture cross sections of the defects, making such techniques unsuitable for determining absolute defect density values.

Here we use a quasi equilibrium technique: the measurement of the planar conductance of (p) a-Si:H / (i) a-Si:H / (n) c-Si structures. This does not depend on the dynamics of the gap states (i.e. capture cross sections) but it is very sensitive to the quantity of defects in the (i) a-Si:H buffer. From 2D numerical modeling we demonstrate that the planar conductance reflects the lateral current flow of holes in the (n) c-Si wafer along the interface in a inversion channel, and that the conductance value allows to deduce the Fermi level position E_F-E_V at the (i) a-Si:H/(n) c-Si interface. Temperature dependent measurements and simulation show that the activation energy of the conductance also reflects this position.

We have measured the planar conductance of a set of (p) a-Si:H/ (i) a-Si:H / (n) c-Si heterojunctions (Fig.1a) where the (i) a-Si:H layer thickness was varied in the range of 0-50 nm, all other deposition and geometrical parameters being kept identical. The normalized conductance (G_{norm}=G×d/L, d being the inter-electrode distance and L the length of the electrodes) is plotted as a function of the thickness of (i) a-Si:H in Fig.1b (symbols). The data obtained from 2D calculations are also shown (curves in Fig. 1b) for various values of the dangling bond (DB) density, N_{DB}, in (i) a-Si:H. While N_{DB} is known to be below 10^{16} cm^{-3} in thick device grade a-Si:H our results show that N_{DB} is much larger in the thin buffer layers (N_{DB} >>10^{16} cm^{-3}). Indeed low defect density yields to calculated conductance values that are much larger than experimentally measured for samples with (i)a-Si:H thickness larger than 5 nm. Moreover, we find that N_{DB} monotonously increases when the (i) a-Si:H thickness decreases, and it reaches values larger than 10^{18} cm^{-3} for thicknesses below 5 nm (Fig. 1c).

Such high defect densities are not due to a problem of quality of the structures. Indeed, there is no doubt on the quality of the interfaces, which are at the state of the art, the solar cells using these interfaces fabricated at INES exhibiting efficiencies above 22%. Such high values and the dependence of the DB density upon (i) a-Si:H thickness will be explained in the frame of the thermodynamic equilibrium model for the formation of defects in a-Si:H (Defect-Pool Model [2]). Detailed analysis shows that not only the DB density but also the density of valence band tail states increases when the (i) a-Si:H buffer layer becomes thinner [3]. Finally we explain why values of DB densities as large as 10^{18} cm^{-3} in the buffer layer do not limit the solar cell performance.

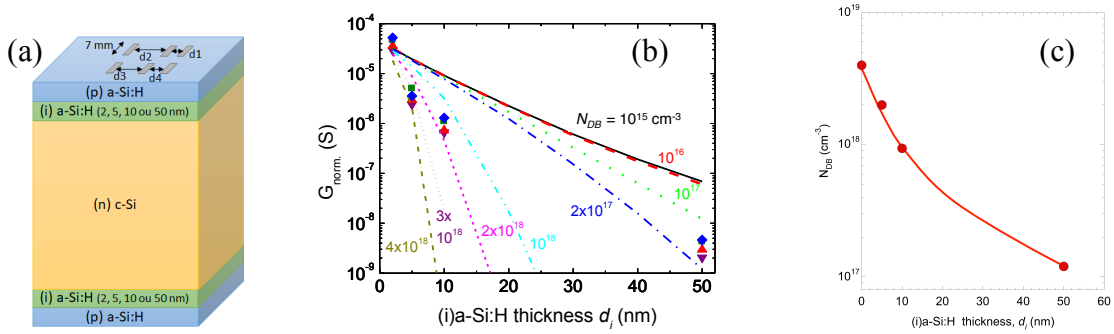

Fig. 1 (a): sample structure; (b): normalized conductance vs. (i) a-Si:H thicknesses. Dots are the experimental data (different symbols for different samples and/or different inter-electrode distances), lines are the calculated data using various dangling-bond densities, N_{DB}, in the (i) a-Si:H layer; (c): extracted dependence of N_{DB} on (i) a-Si:H thickness.

References

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