Impedance spectroscopy of solid-state and photoelectrochemical solar cells emphasizing negative capacitance behaviour

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Impedance spectroscopy is a well known technique used for the study of electrochemical systems. In solar cells, AC measurements are normally applied only in reverse conditions to obtain information on interfacial characteristics (admittance spectroscopy). In this work we aim to extend the application of impedance spectroscopy to solar cells in a wider set of conditions. Negative capacitance (or inductive behaviour) has been previously observed in a variety of electronic devices such as polymer light-emitting diodes,[1] and dye-sensitized solar cells.[2] We report on negative capacitance observed in a variety of polycrystalline and nanostructured solar cells[3] at high forward bias, indicating that this unexpected phenomena constitutes a general behaviour for a broad type of solar cells.

Four different types of solar cells have been characterized by impedance spectroscopy: thin film CdS/CdTe devices, an extremely thin absorber (*eta*) solar cell made with microporous $TiO_2/In(OH)_xS_y$/PbS/PEDOT, an *eta*-solar cell of nanowire ZnO/CdSe/CuSCN, and a solid state Dye Sensitized Solar Cell (DSSC) with Spiro-OMeTAD as transparent hole conductor. As shown in the representation of capacitance vs. frequency in Fig. 1, negative capacitance behaviour has been observed in all of them at high forward bias,[3] independently of the different materials types (organic and inorganic), configuration and geometry of the cells studied.

Figure 2(a) shows the basic model of a solar cell composed of an absorber material with electrons and holes selective contacts.[4] Fig. 2(b) shows the corrersponding, fundamental equivalent circuit[5] composed of a chemical capacitance and recombination resistance. Fig. 2(c) shows a modified equivalent circuit with an additional recombination pathway consisting of recombination resistance and inductor.[3] In. Figs. 2d)-(e) it is observed that the modified equivalent circuit explains the main features of inductive impedance and negative capacitance observed in the measurements of the reported solar cells.

The analysis with equivalent circuit models indicates that negative capacitance reveals a major failure of the operation in photovoltaic devices, due to some dynamic effect that prevents the accumulation of photogenerated carriers.

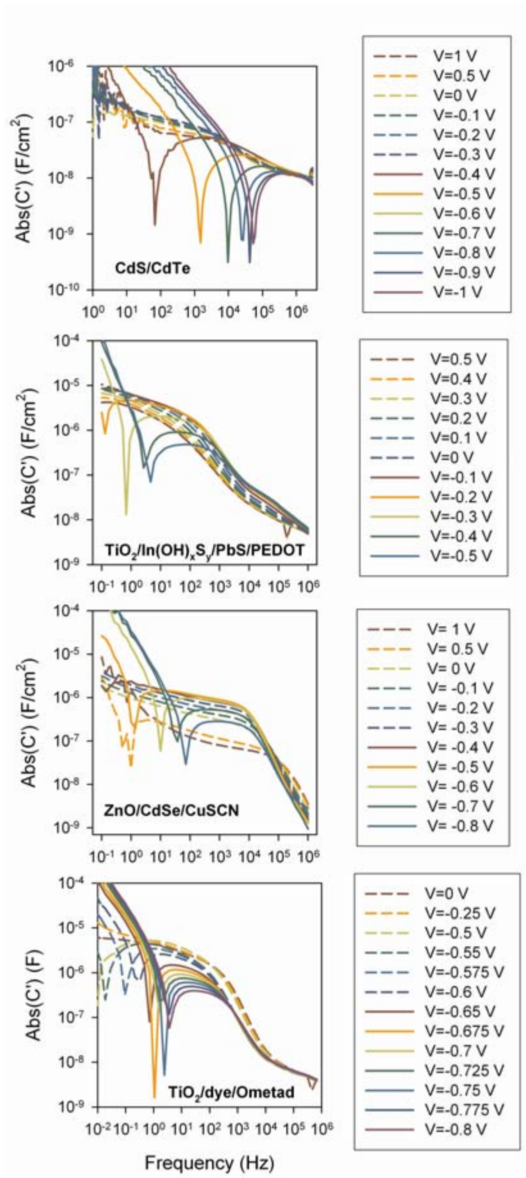

Fig. 1. Experimental observation of negative capacitance in several solar cells.

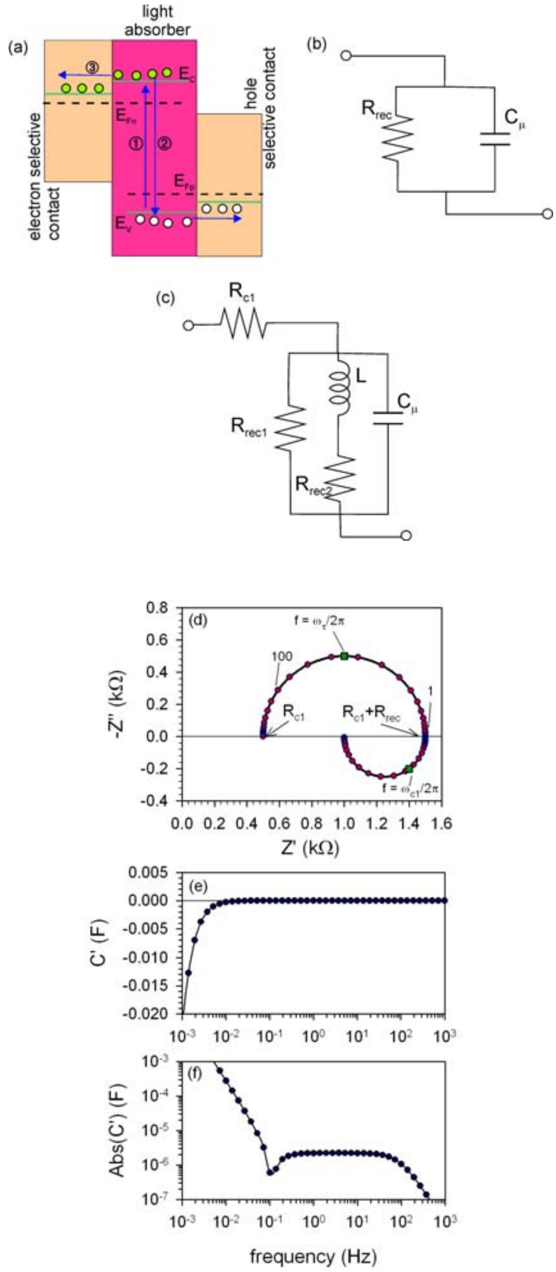

Fig. 2. Model system, equivalent circuits, and simulation of impedance and capacitance.

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