Available online at www.sciencedirect.com
ScienceDirect
Journal of Non-Crystalline Solids 354 (2008) 2411–2415
JOURNAL OF NON-CRYSTALLINE SOLIDS
www.elsevier.com/locate/jnoncrysol

Recombination and transport in microcrystalline pin solar cells studied with pulsed electrically detected magnetic resonance

J. Behrends [a], A. Schnegg [a], C. Boehme [a,b], S. Haas [c], H. Stiebig [c], F. Finger [c], B. Rech [a,c], K. Lips [a,*]

[a] *Hahn-Meitner-Institut Berlin, Abt. Silizium-Photovoltaik, Kekuléstr. 5, D-12489 Berlin, Germany*
[b] *University of Utah, Physics Department, 115S 1400E, Salt Lake City, Utah 84112, USA*
[c] *Forschungszentrum Jülich, Institut für Energieforschung-Photovoltaik, 52425 Jülich, Germany*

Available online 17 March 2008

Abstract

An analysis of spin-dependent processes in microcrystalline silicon (μc-Si:H) pin solar cells is presented using pulsed electrically detected magnetic resonance (pEDMR). In this first study it is shown that by modulating the morphology of the n-type contact layer from amorphous to microcrystalline, pronounced changes in the pEDMR spectra may be observed. Due to the fact that pEDMR allows a deconvolution of the spin-dependent signals in time as well as in magnetic field domain, we were able to significantly reduce the complexity of the spectra compared to conventional EDMR. In the samples containing amorphous n-type contact layers we found signals from shallow localized conduction band tail states and phosphorous donor states. Upon replacement of this layer by its microcrystalline counterpart both signals disappeared. Possible spin-dependent transport mechanisms involving paramagnetic states in the various layers are discussed in view of sign and time evolution of the associated pEDMR signals.

PACS: 72.20.Ee; 72.20.Jv; 72.25.Dc; 76.90.+d

Keywords: Solar cells; Photovoltaics; Conductivity; Defects; Microcrystallinity; Electron spin resonance

1. Introduction

Solar cells made from hydrogenated microcrystalline silicon (μc-Si:H) are superior to crystalline silicon (c-Si) cells with regard to material consumption and cost effectiveness. Unfortunately, state-of-the-art μc-Si:H suffers from an inferior electronic quality compared to the crystalline counterpart. It consists of small crystalline grains with dimensions of up to a few 10 nm, which are surrounded by an amorphous silicon (a-Si:H) region. It is assumed that the a-Si:H region and the grain boundaries induce dangling bonds and tail states in the band gap of μc-Si:H which deteriorate the electronic properties through trapping and recombination [1]. Quantitative as well as structural information about such states in μc-Si:H powder samples were obtained by electron spin resonance (ESR) [1,2]. Nevertheless, it remains unclear if such information can be directly transferred to μc-Si:H incorporated in solar cells since the boundary conditions for layer growth are different. Unfortunately, ESR studies on state-of-the-art μc-Si:H solar cells are hampered by the low detection sensitivity of ESR and by the fact that the contact layers induce additional ESR signals [3]. To overcome this limitation, we applied pulsed electrically detected magnetic resonance (pEDMR), a novel technique recently developed at HMI [4,5], which is able to detect paramagnetic states that influence transport and recombination through spin-dependent processes (for a review see the Mott lecture given by W. Fuhs in this issue). pEDMR combines the benefits of conventional EDMR [6],

* Corresponding author.
E-mail address: lips@hmi.de (K. Lips).

0022-3093/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.jnoncrysol.2007.09.086

in particular ultra high sensitivity and selectivity upon recombination determining paramagnetic species, with the time resolution of pulsed ESR. Two dimensional pEDMR spectra allow the identification of defect states involved in different recombination and transport processes in a two fold way: in the field dimension by their characteristic *g* values, revealing structural details of the defect, and in time domain, by the time dependence of the resonance signal which reports about the recombination dynamics. This renders pEDMR the method of choice to study spin-dependent recombination dynamics in thin-film solar cells and thereby allows distinguishing between different processes involving the same type of defect states. In the following, we present a first application of pEDMR on μc-Si:H pin solar cells focusing on the influence the n-type contact layer has on the pEDMR signal. The results will be compared to previous continuous-wave (cw) EDMR studies on a-Si:H and μc-Si:H as well as on the a-Si:H/c-Si interface.

2. Experimental procedures

The μc-Si:H pin solar cells investigated in this study were deposited on quartz substrates using plasma enhanced chemical vapor deposition (PECVD) at the Forschungszentrum Jülich with the layer sequence shown in Fig. 1. Cell structures deposited in a similar manner were shown to reach efficiencies above 10% on areas of 1 cm^2 [7]. For the pEDMR experiments a reduction of the active area of the cell to 1 mm^2 as well as a special contact structure is mandatory in order to reduce artefacts induced by the strong microwave bursts used in the experiment. This was achieved by using laser scribing techniques. One special feature of the design, as it is depicted in the lower part of Fig. 1, is that the electric connections with the detection setup are realized outside the microwave resonator through special contact pads. To discriminate between pEDMR-signals arising from the absorber layer or the highly doped contact layers and their respective interfaces, we studied a second set of samples (in the following referred to as sample 2) where the 30 nm thick n-a-Si:H layer (sample 1) was replaced by a phosphorous (P) doped μc-Si:H layer of same thickness.

All measurements were carried out in a Bruker E580 X-band ESR spectrometer at a temperature $T = 10$ K. Excess charge carriers were generated with a halogen cold light source. A constant current source was used to establish a current I_0 between −50 and −100 μA under reverse bias. Two dimensional mappings of the spin-dependent effects were recorded by measuring the transient current changes following a microwave pulse as a function of the external magnetic field.

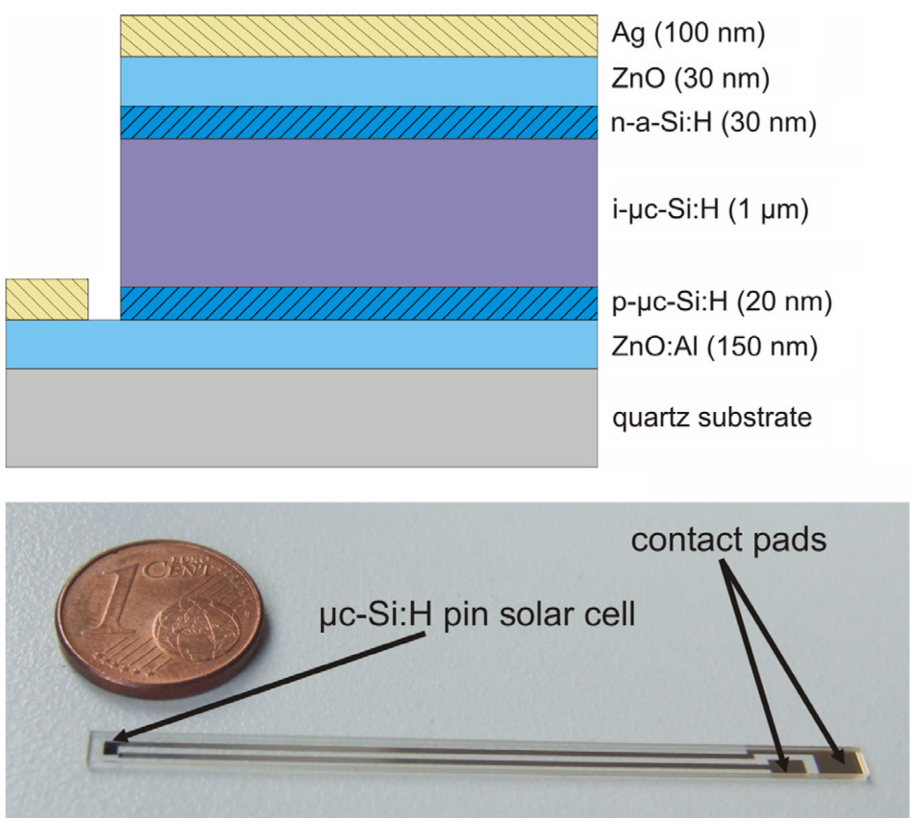

Fig. 1. Upper part: profile of the μc-Si:H pin solar cells (sample 1). In sample 2, the n-a-Si:H layer was replaced by a comparably thick n-μc-Si:H layer. Lower part: photograph depicting the pEDMR sample. The sample consists of a quartz substrate on which the solar cell (active area of 1 × 1 mm^2), the contact pads, and 5 cm long thin-film wires connecting both are deposited.