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Solar Energy Materials & Solar Cells 90 (2006) 2201–2212

Solar Energy Materials & Solar Cells

www.elsevier.com/locate/solmat

Recombination losses in thin-film CdS/CdTe photovoltaic devices

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Available online 19 April 2006

Abstract

The losses accompanying the photoelectric energy conversion in thin-film CdS/CdTe devices faricated on the SnO_2/glass substrates are analyzed. The extent to which the incomplete collection of the photogenerated carriers is determined by recombination at the CdS/CdTe interface and in the depletion layer is shown. The former is investigated based on the continuity equation with account made for surface recombination and the latter — from the Hecht equation. A comparison of the computed results and the experimental data shows that, in general, both types of recombination losses are essential but can be practically eliminated with a choice of appropriate barrier structure and material parameters, primarily of the carrier lifetime and the concentration of uncompensated impurities.

Keywords: Photovoltaic devices; Charge collection; Surface recombination; Recombination losses

1. Introduction

Thin-film CdS/CdTe heterojunction is known to be one of the most promising candidates among photovoltaic structures for large-scale production of solar modules with acceptable conversion efficiency [1,2]. The small-area laboratory devices on glass substrates have reached efficiency up to 16–17% [3]. There are reports on the efforts of developing CdTe thin films and devices on flexible substrates [4–9]. However, the widespread manufacturing application of the CdTe-based solar modules is confronted with numerous problems and requires further investigations of the processes that cause losses in a

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0927-0248/$ - see front matter © 2006 Published by Elsevier B.V.
doi:10.1016/j.solmat.2006.02.027

photovoltaic structure. Below we present the results of our study on the losses accompanying the photoelectric conversion in thin-film CdS/CdTe devices fabricated on the SnO_2/glass substrates.

2. Experimental

The devices were fabricated by the routine thin-film-deposition techniques involving close-spaced sublimation for CdTe and chemical bath deposition for CdS [1,10–12]. The thicknesses of the layers were 1–3 and 0.1–0.2 μm, respectively. Nonrectifying contacts to the CdTe layer were formed by vacuum deposition of Ni after preliminary bombardment of the CdTe surface with ~500 eV argon ions. In order to abate the nonuniformity issues of the film properties, we used the small-area devices (0.1 mm^2).

Typical spectra of the photoelectric quantum efficiency of thin-film CdS/CdTe heterostructures are shown in Fig. 1a along with those of single-crystal Schottky devices Fig. 1b).

In CdS/CdTe heterostructure (Fig. 1a), there is a steep decay of η in the short-wavelength region caused by absorption in the CdS layer ($h\nu < E_g = 2.42$ eV). In the photon energy range 1.5–2.4 eV (550–800 nm), the uniform sensitivity or an increase towards shorter wavelengths is typically observed. The Schottky diodes based on CdTe single crystals (Fig. 1b) exhibits a relatively smooth decrease in η towards shorter wavelengths. In some instances, a sharp peak at the photon energy close to the CdTe bandgap ($\lambda \approx 850$ nm) superimposes onto such a spectrum.

The decay of the efficiency at short wavelengths is usually attributed to the surface recombination, which intensifies as the electric field decreases. From this point of view, the observed uniformity or increase in η as wavelength decreases (Fig. 1a) shows a weak effect of surface recombination onto properties of thin-film CdS/CdTe heterojunctions.

3. Electric field strength at the surface of the CdTe absorbed layer

Let us start analyzing the losses in the photoelectric conversion by considering the electric field strength in CdS/CdTe heterojunction, which has a strong influence upon the recombination velocity in the CdTe layer adjacent to the interface.

Due to high conduction of CdS, the depletion layer (the space–charge region) of the CdS/CdTe structure is virtually placed in CdTe and band bending also falls onto CdTe (Fig. 2) [13,14]. Therefore, it can be suggested that electronic processes occur in the CdTe depletion layer similar to those taking place in the depletion layer of the Schottky diode. The exception is that the hole over-barrier current (the charge transport mechanism usually considered for Schottky diode) in the CdS/CdTe heterostructure is hampered due to high barrier for holes. Hence, the behavior of the potential energy in the CdS/CdTe heterojunction can be described by the quadratic law [15]:

$$\varphi(x, V) = (\varphi_0 - qV)\left(1 - \frac{x}{W}\right)^2, \tag{1}$$

where W is the width of space–charge region.

$$W = \sqrt{\frac{2\varepsilon\varepsilon_0(\varphi_0 - qV)}{q^2(N_a - N_d)}}, \tag{2}$$