

Electroless Ni and NiTe₂ ohmic contacts for CdTe/CdS PV cells

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Abstract

The preparation and characterization of electroless Ni and NiTe₂ back-contacts to CdTe/CdS solar cells are described. NiTe₂, formed by a modification of the electroless Ni process, produces cells with PV properties superior (efficiencies > 10% have been obtained) to those contacted with electroless Ni. NiTe₂-contacts offer promising cell-stability in dry air, but exhibit reversible degradation on exposure to ambient H₂O vapor. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

The difficulty in forming stable back contacts to CdTe is an important problem for the commercialization of CdTe/CdS solar cells. Due to its high work function, no metal exists which can form an Ohmic contact to p-CdTe. Cu is often added to back contact materials to improve contact properties [1]. However, since degradation that occurs in some cells with Cu-containing back contacts has been attributed to the Cu [1,2], there has been an effort to find alternative high-performance contacts.

One approach for alternative contacts is to focus on constituents and structures which do not allow significant diffusion into the cells [3]. Ghosh et al. [4] have reported the formation of low-resistance electroless Ni back-contacts to CdTe. The anneal conditions used (250°C for 90 min in air) for this material suggest it may be a stable back contact.

Here we describe the preparation and characterization of electroless Ni and NiTe₂, the latter formed by a

modification of the electroless Ni process. Cells contacted with NiTe₂ exhibit superior PV properties to those contacted with Ni and offer promising cell stability.

2. Experimental section

Electroless Ni and NiTe₂ deposition on CdTe/CdS/SnO₂/glass cells (First Solar Inc.) was carried out in aqueous chemical baths. No prior activation or etching of CdTe was required for deposition of either material. A typical plating bath contained ~0.1 M NiCl₂·6H₂O, 0–0.3 M sodium hypophosphite (abbreviated as HP), ~0.2 M sodium citrate (all BDH) and ~1 M NH₄Cl (Merck). NH₄OH was added until the solution turned from green to blue (pH 8–9). Depositions were carried out at 90–95°C in vials with plastic caps, pierced to release overpressure but with minimal NH₃ loss. Shiny metallic-Ni contacts were obtained with HP concentrations > ~0.2 M, while NiTe₂ was found to form in baths of low HP concentrations. The shiny Ni layers begin to form on CdTe, with rapid H₂(g) evolution, after a short immersion time. During NiTe₂ deposition (low [HP]), a gray deposit begins to form almost immediately on CdTe, with little H₂ evolved. After ~30 min, the dull-brown NiTe₂ begins to form from the cell edges, reaching comple-

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tion after ~ 60 min. Both Ni and NiTe_2 were annealed at 200°C in air for 90 min.

Photovoltaic properties of the cells were recorded using a computerized homemade I - V setup. Measurements under illumination were taken using a QTH lamp, calibrated to AM 1 solar illumination (100 mW cm^{-2}). X-Ray diffraction (XRD) patterns were obtained using a Rigaku RU-200B Rotaflex diffractometer. X-ray photoelectron spectroscopic (XPS) surface analysis was carried out on an AXIS HS Kratos XPS/Auger surface analysis system. Secondary ion mass spectrometric (SIMS) measurements were obtained using an 8 keV O_2^+ beam in a Cameca IMS4f ion microscope

3. Results and discussion

Fig. 1 shows the illuminated I - V curves of Ni- and NiTe_2 -contacted cells, both before and after annealing. Both contacts show an improvement in I - V characteristics with the anneal step. The NiTe_2 contact exhibits superior PV behavior (typically $V_{\text{oc}} \sim 800\text{ mV}$, J_{sc} up to 25 mA cm^{-2} , fill factor $\sim 65\%$ and efficiency exceeding 10%) to the Ni contact.

The XRD patterns obtained for a Ni film deposited on a CdTe/CdS cell, with and without contact anneal, are shown in Fig. 2a. The spectra are dominated by the CdTe pattern and a single broad peak at 44.5° , due to the Ni(111) plane. This peak shows a dramatic increase

in intensity following anneal. No other non-CdTe related peaks are observed. The broadness of the Ni peak may be indicative of small crystal size or strain in the film.

Fig. 2b shows the XRD patterns of a bare CdTe/CdS solar cell and of the respective gray and brown regions formed on CdTe during NiTe_2 deposition. The spectrum of the gray region indicates the presence of elemental Te. The pattern of the brown area contains two new peaks at 32° and 34° . These features correlate to the (101) and (002) planes of NiTe_2 (melonite, PDF $n08-0004$). No metallic-Ni is observed in either area.

XPS measurements of Ni on CdTe/CdS cells (not shown), showed up to 10% P (originating from HP) at the surface. Little change was observed following anneal. Fig. 3 shows the Ni 2p and Te 3d core level regions from XPS spectra of the brown NiTe_2 deposit, recorded at increasing sputter depths. The 853.0-eV peak in the Ni 2p region agrees with a previous XPS study of NiTe_2 [5]. The spectra confirm Ni is present in the form of Ni^{2+} (d^8) (e.g. $\text{Ni}^{2+}\text{Te}_2^{2-}$). The NiTe_2 was found to be $\sim 0.1\text{ }\mu\text{m}$ thick. XPS measurements (not shown) found the gray region to be Te-rich, but contained no Ni. No P was found in either region, even when HP had been present in the bath. In the early stages of deposition, the chemical bath appears to act as an etchant solution, forming the gray Te-rich CdTe surface. In time, NiTe_2 is formed possibly via a surface-replacement reaction with Ni^{2+} ions. NiTe_2 is a known metallic semiconductor, and has been previously proposed as an interfacial material in Ni-contacted CdTe/CdS solar cells [4].

Cell stability is an important consideration for determining the success of a new back contact. Diffusion of species from back-contacts has been proposed to be a possible degradation mechanism of CdTe/CdS cells [2]. SIMS investigations of NiTe_2 contacted cells (not shown), have found that following thermal stress (200°C in air for 20 h), there is no Ni movement or accumulation in the cell, as has been previously seen for Cu from Cu-containing back contacts [1,2]. However, when cells are stored in ambient air, a decrease in cell PV

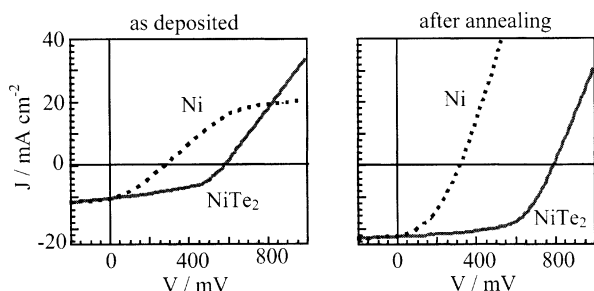


Fig. 1. Illuminated I - V curves for Ni ([HP] = 0.3 M) and NiTe_2 ([HP] = 0.05 M) contacted CdTe/CdS solar cells, with and without contact anneal (200°C in air for 90 min).

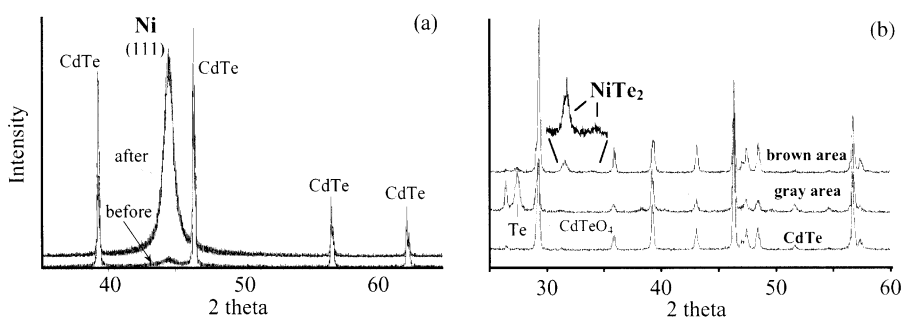


Fig. 2. XRD patterns of (a) electroless Ni back-contact, before and after anneal, deposited on a CdTe/CdS solar cell and of (b) bare CdTe and the 'brown' and 'gray' areas formed during NiTe_2 deposition on CdTe/CdS solar cells.

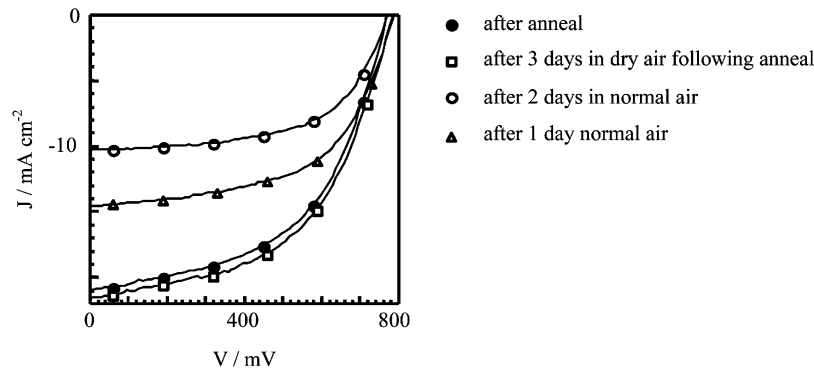


Fig. 4. The effect of exposure to H_2O vapor on the illuminated I - V curve of a NiTe_2 -contacted CdTe/CdS solar cell.

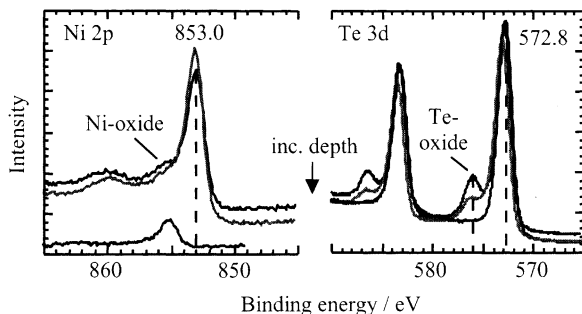


Fig. 3. XPS spectra of Ni 2p and Te 3d core levels of the brown NiTe_2 deposit.

behavior is observed (see Fig. 4), due to a substantial decrease in J_{sc} . No effect is seen on storage in dry air. These observations indicate that NiTe_2 or the back contact interface is susceptible to H_2O vapor. However, cell behavior can be restored upon returning the cell to dry air (not shown). We note that this effect could be overcome by cell encapsulation. Investigations are continuing and will be presented in a future full paper.

4. Summary

A promising new back contact to CdTe/CdS solar cells, NiTe_2 , has been prepared and characterized. This

material is formed, based on electroless Ni deposition. Cells contacted with NiTe_2 exhibit superior PV behavior (efficiencies $> 10\%$) to those contacted with electroless Ni. NiTe_2 offers promising cell stability considerations, though contacted cells exhibit a reversible degradation of PV behavior when exposed to H_2O vapor.

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