

Phase control of Cu_xTe film and its effects on CdS/CdTe solar cell[☆]

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Abstract

Phase control is critical for achieving high-performance CdTe cells when Cu_xTe is used as a back-contact for CdTe cells. Cu_xTe phases are mainly controlled by the Cu/Te ratio, and they can also be affected by post-heat-treatment temperature. Although Cu_2Te has the highest conductivity, it is unstable and provides more Cu diffusion into the CdS and CdTe films. Cu diffusion into the CdS causes “cross-over”, and Cu diffusion into the CdTe film creates Cu-related defects that lower photogenerated carrier lifetime and result in voltage-dependent collection. A “recontact” experiment clearly indicated that the mechanism giving rise to “roll-over” is the formation of Cu-related oxides, rather than the loss of Cu on the back-contact.

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1. Introduction

Cadmium telluride has been well demonstrated as a promising photovoltaic material for thin-film solar cells because of its near-optimum bandgap of ~ 1.5 eV and its high absorption coefficient. Small-area CdTe cells with efficiencies of more than 16% have been reported [1]. Large-area monolithic CdTe modules have also demonstrated high-performance ($\sim 9\%$) and the ability to attract production-scale capital investments. However, developing a manufacturable high-performance, stable back-contact for CdTe thin-film solar cells is still an important goal for further improving CdTe module performance. Formation of the ohmic contact on the CdTe film is a critical technical issue because of CdTe's high work function and the difficulty in obtaining highly doped p^+ CdTe. Copper (Cu) has been found to be an acceptor dopant for CdTe film and is widely

used in high-efficiency CdTe solar cells. However, Cu plays two important – though opposite – roles in CdTe device performance. Cu can dope the CdTe surface as a p^+ region and form a back-contact with a lower barrier height. However, Cu also diffuses rapidly and can diffuse into the CdTe bulk and CdS film to form carrier traps that impact device performance. Although a number of papers report on Cu-containing back-contacts, a full understanding of Cu effects on CdTe device performance still remains an important topic for the CdTe community.

Cu can be deposited directly from a pure Cu element source, or from a Cu-containing alloy, such as Cu_xTe . Cu_xTe has been widely used as a back-contact to CdTe film [2–6]. Many processing parameters have been studied to investigate the effects of Cu, including Cu thickness [3], Cu deposition rate [5], and annealing temperature [6]. It is commonly reported that the use of Cu_2Te correlates with good device performance.

In this paper, we report on two aspects related to our work on a Cu_xTe back-contact: (1) phase control of the Cu_xTe film, and (2) effects of the Cu_xTe back-contact on device performance.

2. Experimental

In our work, CdTe solar cells were fabricated using the following device structure: Corning 7059 glass/ Cd_2SnO_4 (CTO)/ ZnSnO_x (ZTO)/nano-CdS:O/CSS-CdTe. The device

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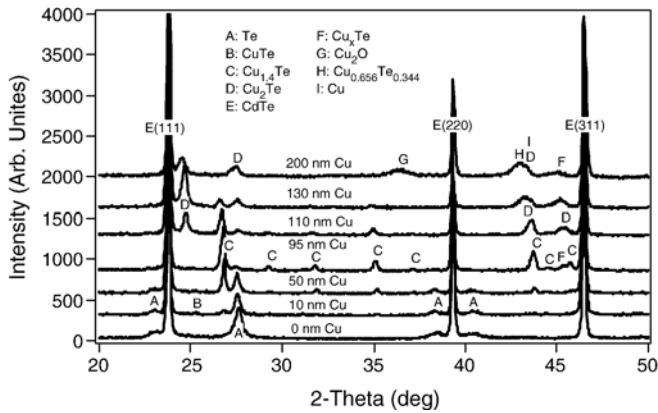


Fig. 1. XRD patterns for samples with Cu_xTe back-contact at different Cu/Te ratios.

fabrication procedures have been described elsewhere [1]. The only difference in this work is the use of a Cu_xTe back-contact to replace our conventional C:HgTe: Cu_xTe paste. The formation of the primary Cu_xTe back-contact is based on the “wet” method in this work, which includes a “three-step” process. In the first step, the CdTe film was treated in a nitric/phosphoric (NP) solution to form a Te-rich layer about 150 nm thick. Second, a Tamescal BJD-1800 E-beam evaporator was used to deposit the Cu layer with various thicknesses on the NP-etched CdTe surface at room temperature. The thickness of the Cu layer was monitored by an Inficon crystal monitor and the thicker Cu films (>50 nm) were calibrated by a Dektak depth profiler. In the third step, samples had a post-heat treatment at different temperatures (100°, 250°, or 400 °C) in He for 30 min to promote Cu diffusion and form the Cu_xTe film with different phase x . Some of these samples were used for the Cu_xTe material study. The others were processed continuously to complete device fabrication processes. Pure carbon paste and silver paste were subsequently applied to the device samples as the secondary contacts.

Scintag DMS2000 X-ray diffraction (XRD) was used to study the Cu_xTe structure. Sheet resistance of the Cu_xTe film was measured using a Keithley four-point probe. Dark and light current density–voltage (J – V) measurements were carried out to analyze device performance and barrier height. To further understand the role of Cu in the CdTe device, secondary-ion mass spectroscopy (SIMS), quantum efficiency (QE) under different voltage bias and light bias, capacitance–voltage (C – V), and time-resolved photoluminescence (TRPL) were measured. Finally, the recontacting technique was used to understand the mechanism of “rollover” in the CdTe cell with a Cu_xTe back-contact.

3. Phase control of the Cu_xTe film

From the literature, we know that the Cu–Te system is the most complex among the copper–chalcogen systems [7], and device performance broadly correlates with the phase of the Cu_xTe back-contact [2–6]. For example, the resistivity of the Cu_xTe compounds can vary from ~ 10 ohm-cm (CuTe) to 10^{-4} ohm-cm (Cu_2Te). Is the Cu_xTe compound with the lowest

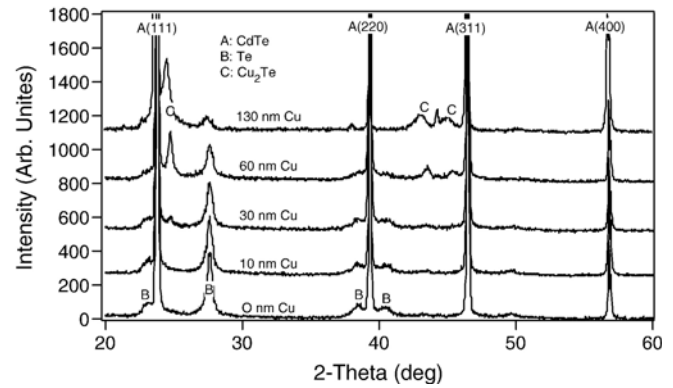


Fig. 2. XRD patterns for NP-etched CdTe samples using different amounts of Cu before annealing.

resistivity the best back-contact for device performance? And how does one control the phase of the Cu_xTe film? In this section, we try to answer the latter question, and reply to the former in Section 4.

We find that (1) the Cu_xTe phase is mainly controlled by the Cu/Te ratio, and (2) the Cu_xTe phase also can be affected by post-heat-treatment temperature.

3.1. Cu_xTe phase control by the Cu/Te ratio

Seven CdS/CdTe samples were etched by NP solution. A thin Cu layer with a thickness of 0, 10, 50, 95, 110, 130, and 200 nm was deposited onto the treated CdTe surface. All of samples were annealed at 250 °C for 30 min in He. The XRD results are shown in Fig. 1, and the Cu thickness increases from the bottom to the top in Fig. 1. For the sample prepared without intentionally adding Cu, only the peaks corresponding to CdTe and Te are easily observed. After 10 nm of Cu were deposited and annealed at 250 °C, two more peaks appeared: one corresponded to $\text{Cu}_{1.4}\text{Te}$ (27.7°) and the other corresponded to CuTe (25.6°). With 50 nm of Cu, the CuTe peak disappears and the

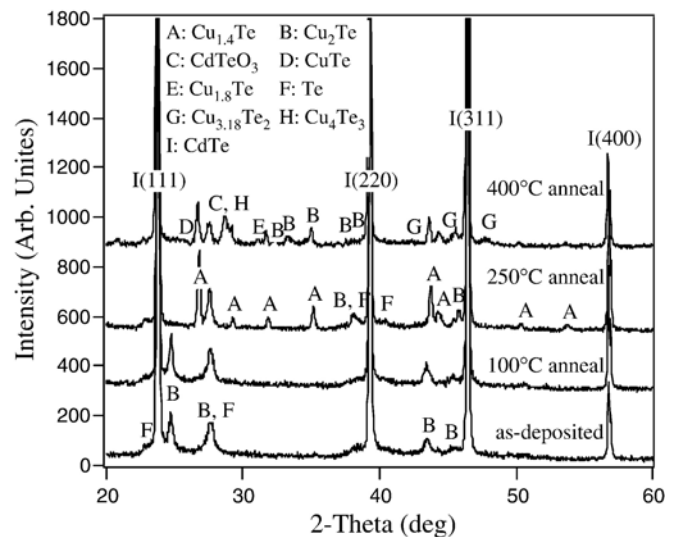


Fig. 3. XRD patterns for treated CdTe samples with different anneal temperatures.

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