Electrical Properties of CdTe Layer Electrodeposited from Ammoniacal Basic Aqueous Electrolytes

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Electrodeposition of CdTe for thin-layered photovoltaics has been well investigated by many research groups.[1] Although acidic aqueous sulfate solutions have historically been employed as the electrolytes in electrodeposition, we have proposed that ammoniacal basic aqueous solutions are also suitable,[2] since the basic solutions have a relatively high solubility of Te(IV) species as TeO_3^{2-} ions. However, the electrical properties of the CdTe layer obtained from the basic solutions have not been clarified. In this study, electrical properties, such as specific resistance, carrier type, carrier density, and mobility were determined from *I-V* (current-voltage) characteristics and Hall effect measurements. The temperature dependence of resistivity was also discussed.

Aqueous basic electrolytes containing 40 mM $CdSO_4$, 10 mM TeO_2, 4.0 M NH_3(aq), and 0.5 M $(NH_4)_2SO_4$ (pH 10.7; M = mol dm^{-3}) were used for the electrodeposition of CdTe. Cathodic electrodeposition was performed at 70 ˚C under potentiostatic conditions using a conventional three electrode setup: WE, Au-plated Cu sheet; CE, Pt sheet; RE, Ag/AgCl electrode immersed in 3.3 M KCl. The cathode potential was –0.7 V vs SHE. The electrolyte was agitated at 500 rpm with a magnetic stirring unit. During the electrodeposition, the cathode surface was irradiated with white light by a 500 W xenon arc lamp. The integrated irradiance of the white light just in front of the electrolytic vessel was about 250 mW cm^{-2}. The thickness of the CdTe layer was determined from the total quantity of charge passed during the electrodepositions, assuming that the current efficiency for CdTe deposition under photo-irradiation was nearly 100%. The deposits were transferred mechanically from the conducting substrate onto non-conductive epoxy resin. In the case of the Hall effect measurement, four circular Au electrodes (1.5 mm diameter, 100 nm thickness) were formed on the surface of the transferred CdTe by vacuum evaporation, followed by attaching Au lead wires to the electrodes with Ag paste.

Compositions of the deposits determined by EPMA were nearly stoichiometric, ca. 49 at.%Cd and 51 at.%Te. The deposits were confirmed to be polycrystalline CdTe by X-ray diffraction.

The *I-V* characteristic (Figure 1) showed an Ohmic behavior and indicates high resistivity of the CdTe. The resistivity determined by the van der Pauw method as well as by a simple two-probe method had an order of 10^7 -10^8 Ω cm. The electrical properties of CdTe layers are summarized in Table 1. The results of the Hall effect measurements indicated that the CdTe layers had a p-type conduction with carrier density in the range 10^{10}-10^{11} cm^{-3}. In contrast, it has been reported that as-deposited CdTe from acidic sulfate solutions are usually n-type and heat treatment in the air is necessary to obtain p-type.[3] The hole mobility for

the deposited CdTe, about 1 cm^2 V^{-1} s^{-1}, was much smaller than that reported for single crystal CdTe, 80 cm^2 V^{-1} s^{-1}.[4] The major reason for the small mobility could be a scattering of carriers at grain boundaries, since the grain size of the CdTe is as small as 10 nm.

Figure 2 shows the temperature dependence of the resistivity of the CdTe layer determined by a two-probe method. The resistivity decreased with increasing temperature, which is a characteristic property of semiconductors. The activation energy of conductivity was 0.67 eV, indicating the presence of an electron-accepting level in the middle of the band gap, *i.e.* about 1.5 eV.

1. For example, J. L. Stickney, Electroanalytical Chemistry, A. J. Bard et al. (eds.), Marcel Dekker, NY, p.75 (1999) and references cited therein.
2. K. Murase et al., *J. Electrochem. Soc.*, **146**, 4477 (1999) and references cited therein.
3. B. M. Basol, *J. Appl. Phys.*, **55**, 601 (1984)
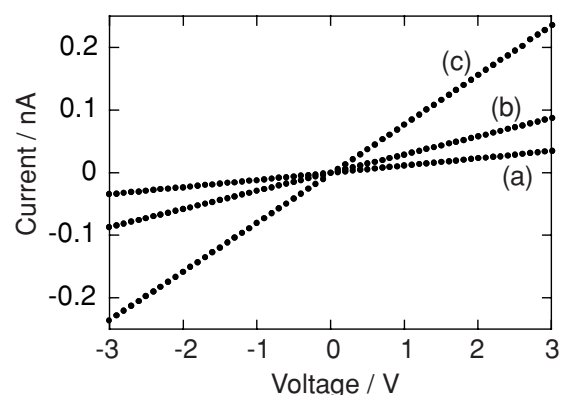4. O. Mandelung, Grundlagen der Hulbesterphysik, Springer-Verlag, Berlin (1970).

Figure 1. *I-V* characteristic for CdTe layer with a thickness of (a) 10, (b) 20, and (c) 30 μm. Contact material is evaporated Au. Length between two contacts is 2.5 mm.

Table 1. Electrical properties of deposited CdTe layers

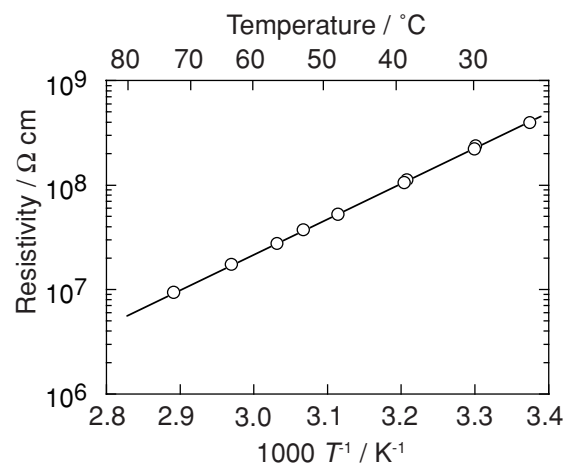| Thickness (μm)	Resistivity (Ω cm)	Carrier type	Carrier density (cm^{-3})	Mobility (cm^{-2} V^{-1} s^{-1})
10	1.3×10^8	p	6.2×10^{10}	0.76
20	9.6×10^7	p	5.5×10^{10}	1.2
30	5.0×10^7	p	1.0×10^{11}	1.2

Figure 2. Temperature dependence of resistivity of CdTe layer of 10 μm thick