Surface Photovoltage Spectroscopy for Real n- and p-Type (110) CdTe Surfaces in the Visible and near Infra-Red Spectral Range

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Abstract. Surface photovoltage spectroscopy has been carried out on real n- and p-type (110) CdTe surfaces in the wavelength range 0.36–1 μm at room temperature (300 K), and at atmospheric pressure. The measurements show the existence of surface states at 1.3; 1.48, and 1.2; 1.46 eV within the energy gap of n- and p-type CdTe, respectively. Surface states greater than the energy gap at 2.24, 2.38, 2.68, and 3.1 eV have also been detected in n-type samples and at 1.66, 2.12, 2.69 eV in p-type samples.

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The electronic surface states of zinc-blende type II–VI CdTe surfaces have been investigated by different techniques such as electron spectroscopy [1], x-ray photoelectron and Auger electron spectroscopy [2] and contact potential difference [3, 4]. Most of these measurements have been done on cleaved clean surfaces in ultra-high vacuum. Only few measurements have been carried out on real surfaces at normal ambient conditions.

The method of surface photovoltage spectroscopy developed by Gatos and co-workers [5–7] has been applied to study the surface properties of high bandgap semiconductors. This method has proven to be more suitable for detecting surface states, where other conventional methods such as the field effect are ineffective owing to poor communication of the surface states with the bulk. The height of the surface potential barrier can be determined from the result of measurements of the contact potential difference (CPD) between the semiconductor and the reference metal electrode. A change in the band bending induced by illumination is called the surface photovoltage $V_p$ and its value can be obtained from the corresponding change in the steady-state contact potential difference $\Delta$ (CPD) [8].

In this paper we will present some recent results for the surface states existing within and outside the energy gap of n- and p-type CdTe real surfaces at normal conditions of pressure and temperature in atmospheric air.

Experimental

The CdTe samples used for the measurements were p-type and n-type with doping concentration of $\approx 5 \times 10^{16} \text{cm}^{-3}$. The investigated (110) surface was mechanically polished and etched in a diluted bromine in an ethyl alcohol solution. After etching, the samples were washed in alcohol and distilled water, and kept in the dark for 24 h in a semiclosed volume for attaining thermal equilibrium for both bulk, and surface energy states. Ohmic contacts at the back side (parallel to the investigated surface) have been obtained using eutectic Ga–In alloy. The measurements were performed at atmospheric pressure at room temperature. The contact potential difference (CPD) measurements are based on the vibrating capacitor Kelvin method. Details concerning the experimental arrangement and precautions which need be taken in making such measurements have been given previously [9, 10].

The effect of the Dember potential was minimized by applying homogeneous illumination to the samples. Prior to the Ohmic contacts, the sample was adhered to a copper electrode with conducting silver paste, so that its (110) surface under investigation is capacitively coupled to the reference electrode at a clearance...
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distance of 0.6 mm. The reference electrode was mech-

anically excited using an oscillator tuned at its natural

frequency (≈40 Hz). The vibrations induce capacity

variations in a capacity plate connected to a vibration
detector [9, 10]. The excitation can be prevented if the

contact potential and other potentials existing are

compensated by an adjustable voltage derived from a

potentiometer.

Results and Discussion

The measured results for the change in the contact

potential difference $\Delta \text{CPD} = (\text{CPD})_{\text{light}} - (\text{CPD})_{\text{dark}}$

dark, versus photon energy are presented in Fig. 1 for

n-type and in Fig. 2 for p-type CdTe samples. All

measurements have been taken at steady-state con-

dition at the saturation level of the contact potential
difference (Fig. 3), at every excitation photon energy.

The CPD value in the dark (−1.2 V) is taken as the 0

zero point. In each of the two cases (Figs. 1 and 2) a

clearly evident step-like dependence of the photovol-
tage $\Delta \text{CPD}$, on photon energy $h\nu$, is observed. The

associated transients are related to surface-state de-
population corresponding to a decrease in the surface

barrier $-V_s$ [increase in $\Delta \text{CPD}$]. Surface photovol-
tage quenching caused by a photostimulated popu-

lation of surface states is manifested as an increase in

$-V_s$ [decrease in $\Delta \text{CPD}$] [11].

The energy positions of the surface states are
determined from the positions of the step-like increase

in the surface, photovoltage spectrum by means of

graphical differentiation. A positive $d(\Delta \text{CPD})/d(h\nu)$
slope change at the energy $E_0 = h\nu_0$ corresponds to a

transition which implies a change from a level $E_0$ below

the conduction-band edge. Conversely, a negative

d(\Delta \text{CPD})/d(h\nu)$ slope change at an energy $E_1$ corre-
sponds to a transition, filling the level $E_1$ above the

valence band.

Table 1 summarizes all the transitions observed in

n-type and p-type samples.

It can be observed from Table 1 that the transitions

within the energy gap near 1.44 ± 0.04 eV in both n-

and p-type samples are due to transitions from filled

flat surface energy states (n-type) and partially filled

flat surface energy states in (p-type) lying at an energy

of about 0.08 eV above the valence-band edge to the

corresponding conduction band edge. These surface

states have also been observed by Kuzminski and

Hady [4] in p-type samples. The transition at $\sim 1.2$ eV

(n-type) has not been observed before. Surface energy

states greater than the energy gap ($E_g \approx 1.52$ eV at

300 K) at $E_0 = 2.68, 3.1$ eV (n-type) and $E_0 = 2.24$ and

2.38 eV (p-type) and at $E_1 = 1.66$ eV (n-type) and $E_1$

= 2.12 and 2.69 eV (p-type) are new results for such real

CdTe surfaces. It has been proved that polishing

followed by chemical etching, as well as cleavage in air

and vacuum, causes a decrease in the surface, barrier

$-V_s$.

Fig. 1. Spectral distribution of surface photovoltage at 300 K under atmospheric pressure for a real (110) n-type CdTe surface

Fig. 2. Spectral distribution of surface photovoltage at 300 K under atmospheric pressure for a real (110) p-type CdTe surface