Effect of sputtering pressure on the physical properties of dc magnetron sputtered cadmium oxide films

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Polycrystalline thin films of cadmium oxide were prepared using dc magnetron sputtering technique by sputtering of metallic cadmium target in the mixture of argon and oxygen atmosphere under various sputtering pressures in the range \(3 \times 10^{-2} - 1 \times 10^{-1}\) mbar. The variation of deposition rate of the films with the sputtering pressure was in correlation with the variation of cathode potential. The influence of sputtering pressure on the structural, electrical and optical properties of CdO films was systematically studied. The electrical resistivity of the films increased from \(5.6 \times 10^4\) to \(1.5 \times 10^7\) \(\Omega\) cm and the optical band gap increased form 2.45 to 2.53 eV with the increase of sputtering pressure from \(3 \times 10^{-2}\) to \(1 \times 10^{-1}\) mbar respectively.

In recent years, cadmium oxide (CdO) has been considered as a potential material for application in photovoltaic technology because of its high electrical conductivity and high optical transmittance. It has a good lattice match with CdTe which made this material attractive as a substitute for CdS and SnO\textsubscript{2} in the SnO\textsubscript{2}/CdS/CdTe heterojunctions\textsuperscript{1}. Heterojunction solar cells fabricated with CdTe\textsuperscript{2,3} and CuInSe\textsubscript{2}\textsuperscript{4} as absorber layers have shown solar energy conversion efficiencies of 9.5\% and 6.3\% respectively. Various thin film deposition methods such as reactive evaporations\textsuperscript{5}, d.c. sputtering\textsuperscript{6}, d.c. magnetron sputtering\textsuperscript{7}, spray pyrolysis\textsuperscript{8,9}, pulsed laser deposition\textsuperscript{10}, molecular beam epitaxy\textsuperscript{11} and chemical vapour deposition\textsuperscript{12,13} were employed for the preparation of CdO films. Of all these methods d.c. magnetron sputtering is most industrially acceptable technique for preparation of thin films on large areas at low substrate temperatures. The physical properties of the films prepared by d.c. magnetron sputtering depends on the deposition parameters like oxygen partial pressure, substrate temperature, sputtering pressure apart from the sputtering power and the target to substrate distance. The effects of oxygen partial pressure\textsuperscript{14} and substrate temperature\textsuperscript{15} on the physical properties of CdO films were reported earlier. In this investigation, the influence of sputtering pressure on the structural, electrical and optical properties of CdO films has been reported.

**Experimental Procedure**

CdO films were deposited onto glass substrates by d.c. magnetron sputtering technique from a metallic cadmium target in a mixture of oxygen and argon atmosphere under various sputtering pressures in the range \(3 \times 10^{-2} - 1 \times 10^{-1}\) mbar. The flow rates of oxygen and argon gases were controlled by Tylan mass flow controllers. After attaining the ultimate pressures of \(5 \times 10^{-6}\) mbar with the diffusion pump-rotary pump combination, the required quantities of oxygen and argon gases were individually admitted into the sputtering chamber through the needle valves. The sputter parameters maintained at the time of preparation of CdO films are given in Table 1. The thickness of the

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<th>Table 1—Deposition conditions of dc magnetron sputtered CdO films</th>
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<td>Sputtering target</td>
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<td>Target to substrate distance</td>
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<tr>
<td>Ultimate pressure ((P_o))</td>
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<tr>
<td>Oxygen partial pressure ((P_{O_2}))</td>
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<td>Sputtering pressure ((P_{sp}))</td>
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<td>Substrate temperature ((T_s))</td>
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<td>Cathode current ((I))</td>
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\textsuperscript{*}For correspondence
deposition films was determined by employing optical interference method. In this method, the optical transmittance was recorded as a function of wavelength. Using the wavelengths corresponding to the successive maximum or minimum transmittance and refractive index of the film the thickness was determined. The crystallographic structure of the films was analysed with X-ray diffraction. The electrical resistivity and Hall mobility of the films was measured using van der Pauw method. The optical transmittance of the films was recorded using a Hitachi double beam spectrophotometer in the wavelength range 400-1300 nm.

Results and Discussion
The variation of cathode potential with the sputtering pressure for different cathode currents is shown in Fig. 1. The cathode potential increased with the increase of cathode current. At a constant cathode current the cathode potential decreased with the increase of sputtering pressure. This is the general characteristics of planar magnetron sputtering cathode. Holland and Samuel observed the decrease of cathode potential from 360 to 290 V with the increase of sputtering pressure from 3.5×10^-3 to 1.5×10^-2 mbar for a cathode current of 100 mA while Mohan Rao and Mohan noticed a variation of 360 to 280 V for a cathode current of 250 mA for copper target. Meng and dos Santos observed that the cathode potential decreased from 355 to 304 V with the increase of sputtering pressure from 5×10^-3 to 1 mbar for zinc target. The difference in the cathode potential may be attributed to the difference in the target material and other process parameters.

Fig. 2 shows the dependence of deposition rate on the sputtering pressure of CdO films formed at a cathode current of 150 mA oxygen partial pressure of 1×10^-3 mbar and substrate temperature of 623 K. The deposition rate decreases with the increase in sputtering pressure. As the sputtering pressure increases the mean free path of the sputtered species decreases. This leads to more collisions among the sputtered particles. When the sputtered particles travel from the target to the substrate, some of the sputtered particles also reflect back to the target hence the decrease of deposition rate. In the present investigation, CdO films with thickness of about 300 nm were prepared at different sputtering pressures by proper control on the time of deposition for study the structural, electrical and optical properties.

Fig. 3 shows the X-ray diffraction spectra of CdO films formed at different sputtering pressures. The X-ray diffraction spectra indicated that the films were polycrystalline in nature. The X-ray diffraction spectrum of the films formed at a sputtering pressure of 3×10^-2 mbar correspond to the (200) orientation of CdO. The intensity of the peak increases with the increase of sputtering pressure upto 5×10^-2 mbar due to the improvement in the crystallinity of the films. As the sputtering pressure increased to 1×10^1 mbar the intensity of (200) peak decreased and with the appearance of (111) orientation. The lattice parameter evaluated from the XRD data increased from 0.4678 to 0.4692 nm with the increase of sputtering pressure from 3×10^-2 to 1×10^1 mbar. The grain size of the films evaluated from the half intensity width of the XRD peaks increased from 57 to 65 nm with the increase of sputtering pressure from 3×10^-2 to 5×10^-2 mbar. At the sputtering pressure of 1×10^1 mbar the grain size of the film decreased to 45 nm.
The variation of electrical resistivity ($\rho$), Hall mobility ($\mu$) and carrier concentration ($n$) of CdO films with the sputtering pressure is shown in Fig. 4. The low electrical resistivity of the films formed at low sputtering pressure associated with a considerable oxygen deficiency and/or presence of interstitial cadmium atoms. The electrical resistivity of the films increased from $5.6 \times 10^{-3}$ to $1.5 \times 10^{-2}$ $\Omega$cm with the increase of sputtering pressure from $3 \times 10^{-2}$ to $1 \times 10^{-1}$ mbar respectively. The Hall mobility measurements indicated that the films were $n$-type. The Hall mobility of the films decreased from 75 to 40 cm$^2$/V.s and the carrier concentration decreased from $1.5 \times 10^{20}$ to $1 \times 10^{20}$ cm$^{-3}$ with the increase of sputtering pressure from $3 \times 10^{-2}$ to $1 \times 10^{-1}$ mbar respectively. The low electrical resistivity at low sputtering pressures may be due to the higher carrier mobility and its concentration.

The optical transmittance spectra of CdO films formed at different sputtering pressures are shown in Fig. 5. The average optical transmittance above the wavelength of 600 nm increased from 75 to 85% with the increase of sputtering from $3 \times 10^{-2}$ to $7 \times 10^{-2}$ mbar. When the sputtering pressure was increased, the density of defect centres decreases so that the light loss by the scattering of defect centres decreases leading to the increase of optical transmittance. The optical absorption edge was observed around 500 nm and shifted towards lower wavelengths with the increase of sputtering pressure. Fig. 6 shows the optical reflectance spectra of CdO films formed at different sputtering pressures. The optical absorption coeffi-
Conclusions

Thin films of cadmium oxide were formed using dc magnetron sputtering onto glass substrate by sputtering of cadmium target at an oxygen partial pressure of $1 \times 10^{-3}$ mbar, substrate temperature of 623 K and at various sputtering pressures in the range $3 \times 10^{-2}$ to $1 \times 10^{-1}$ mbar. A systematic investigation was made on the effect of sputtering pressure on the structural, electrical and optical properties. The films were polycrystalline in nature with (200) preferred orientations.

References