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Properties of indium tin oxide films deposited using High Target Utilisation Sputtering

S. Calnan [a,*], H.M. Upadhyaya [a], M.J. Thwaites [b], A.N. Tiwari [a]

[a] Centre for Renewable Energy Systems Technology, Loughborough University, Loughborough, LE11 3TU, UK
[b] Plasma Quest Ltd, Hook, RG27 9UT, UK

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Abstract

Indium tin oxide (ITO) films were deposited on soda lime glass and polyimide substrates using an innovative process known as High Target Utilisation Sputtering (HiTUS). The influence of the oxygen flow rate, substrate temperature and sputtering pressure, on the electrical, optical and thermal stability properties of the films was investigated. High substrate temperature, medium oxygen flow rate and moderate pressure gave the best compromise of low resistivity and high transmittance. The lowest resistivity was 1.6×10^{-4} Ω cm on glass while that on the polyimide was 1.9×10^{-4} Ω cm. Substrate temperatures above 100 °C were required to obtain visible light transmittance exceeding 85% for ITO films on glass. The thermal stability of the films was mainly influenced by the oxygen flow rate and thus the initial degree of oxidation. The film resistivity was either unaffected or reduced after heating in vacuum but generally increased for oxygen deficient films when heated in air. The greatest increase in transmittance of oxygen deficient films occurred for heat treatment in air while that of the highly oxidised films was largely unaffected by heating in both media. This study has demonstrated the potential of HiTUS as a favourable deposition method for high quality ITO suitable for use in thin film solar cells.

Keywords: Indium tin oxide; TCO; Sputtering; Polyimide

1. Introduction

High quality tin doped indium oxide (ITO) can readily be prepared with properties superior to other common transparent conducting materials using conventional methods such as magnetron sputtering and chemical vapour deposition [1–3]. For this reason, ITO is widely used as a contact in opto-electronic devices including solar cells, but as indium is a trace element, it is very expensive. Magnetron sputtering is favoured by many manufacturers for depositing ITO for solar cells because it is easily applied to large area with good uniformity while maintaining significant deposition rates. However, due to race track formation, targets require replacement before a significant portion of the material has been used. Moreover, as target sizes increase to accommodate the need for larger area substrates, the expenditure on the unused target material becomes undesirable. An innovative process known as High Target Utilisation Sputtering (HiTUS), which eliminates the use of magnetrons, can increase the target utilisation to above 90% compared to magnetron sputtering thereby potentially reducing the production cost of expensive materials such as ITO [4]. If HiTUS is used in reactive mode by using a metallic In/Sn target, fabrication costs of ITO can further be reduced.

Soda lime glass is a proven and cheap substrate for thin film solar cells but where weight is critical, such as in space and for terrestrial mobile applications, lighter materials such as plastics and metal sheets are more desirable. These materials are also flexible permitting cost effective solar cell production by web coating. Unlike metal sheets, plastic materials do not diffuse into and degrade the subsequently deposited solar cell absorber layers, though their maximum operating temperature is limited. However, new polyimide materials such as Upilex [5] and Kapton are thermally stable to 450 °C and can be used to prepare high quality ITO films which normally require elevated substrate temperatures during deposition.

* Corresponding author. Tel.: +44 1509 63 5323; fax: +44 1509 63 5301.
E-mail address: S.Calnan@lboro.ac.uk (S. Calnan).

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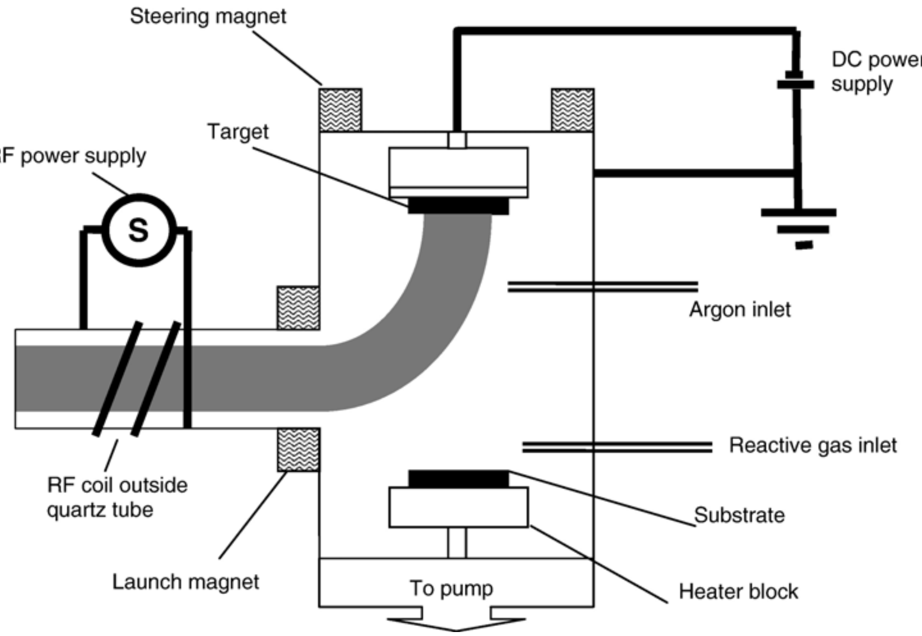

Fig. 1. The basic set-up of a HiTUS system. Target–substrate separation is 160 mm. Ionisation of argon occurs in the quartz tube and it is independent of the applied voltage which accelerates the ions towards the target.

Also important is the thermal stability of the ITO films when used as substrates for chalcogenide solar cells, which typically require substrate temperatures during preparation of about 450 °C for high film quality [6–8]. Based on the above, the work described in this paper was aimed at developing high quality ITO films using HiTUS, on both glass and polyimide substrates.

2. Experimental details

The ITO films presented in this report were prepared using a high target utilisation sputtering (HiTUS) deposition system whose basic set-up is shown in Fig. 1. The sputtering target block and the substrate holder are contained in the main chamber, to which a quartz tube is attached. A cylindrical (launch) electromagnet is concentric to the end of the quartz tube near the chamber, while another (steering) electromagnet is concentric to the target end of the main chamber. This layout of magnets eliminates the need for magnetrons and hence racetrack formation on the target is avoided. Soda lime glass and Upilex brand polyimide were used as substrates for the ITO films. Before each deposition the sputter chamber was evacuated to a base pressure of about 0.5×10^{-3} Pa. Depositions were run in the reactive sputter mode from a circular 108 mm diameter In/Sn (90/10 wt.%) target, with oxygen added to form ITO. The sputter pressure was determined by adjusting the argon flow rate and the plasma was ignited by applying 650 W of RF power to quartz tube via an antenna coil to give a target ionisation current of 400 mA. A negative DC voltage of 500 V was applied to the target to give an effective discharge power of 200 W to commence sputtering. A pre-sputtering process was initially run with argon only for 5 min to expose pure metal on the target's surface prior to the deposition of the ITO layers. Oxygen at the required flow rate was then allowed into the process chamber for reactive sputtering. Since the degree of target poisoning during reactive sputtering, is correlated to the target voltage at a fixed current (or power) level [9], stable process operation was possible without active feedback control. Table 1 summarises the range of parameters used for depositing the ITO films.

The film resistivity (ρ) was determined from the film thickness measured using a Talystep surface profiler and the sheet resistance (R_s) measured using a four-point probe. The transmittance from 400 nm up to 1100 nm, of the ITO films on glass (excluding the substrate) was measured using an Advantis spectrometer.

Thermal stability tests were conducted on the ITO films to examine their ability to withstand deterioration in resistivity and transmittance after the deposition of the active solar cell layers. Identical ITO samples were heated either in air or in vacuum at a constant substrate temperature of 300 °C for 30 min. Since it took 40 min to raise the substrate temperature from 25 °C to 300 °C in air, compared to 15 min in vacuum, the former ambient condition was considered equivalent to those typical for processing chalcogenide solar cell materials. The thermal

Table 1
Investigated range of deposition conditions used for the growth of ITO layers

Parameter	Units	Range of values
Substrate temperature	[°C]	25–460
Argon flow rate	[sccm]	20–60
Sputter pressure	[Pa]	0.15–0.45
Oxygen flow rate	[sccm]	4.0–4.4
Film thickness	[nm]	380–420

In all cases, the target was biased at 500 V and the target ionisation current of 400 mA was independently generated by 650 W of RF power applied to the quartz tube.