Applied Surface Science 296 (2014) 209–213

Contents lists available at ScienceDirect

Applied Surface Science

journal homepage: www.elsevier.com/locate/apsusc

Study on optical and electric properties of ultrafine-grained indium films

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ARTICLE INFO

Article history:
Received 13 May 2013
Received in revised form
26 November 2013
Accepted 16 January 2014
Available online 25 January 2014

Keywords:
Thin films
Optical properties
Electric properties
Ultrafine grain
Indium

ABSTRACT

Indium nanofilms composed of ultrafine grains have many applications in photovoltaic technology, microelectronics industry, grayscale lithography and so on. It is unquestionable that ultrafine grains have an important influence on physical properties of the films. For investigating the role of grain size in optical and electric properties of the films, we took In as an example to deeply study the relationship between grain sizes and the optical density (OD) spectra as well as the square resistance in the In, In_2O_3 and ITO nanofilms with ultrafine grains, which were prepared by multiple-oxidation fabrication technique for stopping nucleation-growth. The experimental results show that In films with ultrafine grains have a high OD value in the range from 350 to 700 nm, In_2O_3 films, nevertheless, have a smaller OD in the visible and NUV region; while the grain size can greatly improve the conductivity of In_2O_3 and ITO film but has less effect on that of the indium films. These results demonstrate that the grain size of the film is closely related to its optical and electric properties, and indicate ultrafine-grained In nanofilm, meanwhile, can be used in fabrication of grayscale masks and transparent conductive films due to its good optical and electric properties. Moreover, the morphology as well as composition and chemical bonding states of In nanofilms are analyzed, and the controllability of ultrafine grains is deeply investigated theoretically.

1. Introduction

In the last few decades, nano-thin films have been applied in many fields such as microelectronics, semiconductors, optoelectronics, optics, aerospace [1–6]. However, how to improve the properties such as roughness, electrical and optical properties by a simple and effective way is still a challenge for nano-thin films. As we know, grain size of nano-thin films is closely related to physical properties and has an important effect on optical and electrical properties of the films. Recently, we developed a new multiple-deposition preparation method for nanofilm with fine grains by ventilating oxygen into the deposition chamber during the interval between adjacent depositions for stopping nucleation-growth. Moreover, we discussed the possibility of metallic nanofilms used for fabrication of grayscale photomasks [7]. However, the influence of grain size on the physical properties of nano-thin films, especially controllability of ultrafine grain size has not been deeply studied in theory. Owing to wide applications of indium films including tin oxide (ITO) and indium oxide (In_2O_3) film in electronics and optoelectronics fields [8,9], it is necessary to study the influence of grain size on physical properties of In nano-thin films. In this work, the influence of grain size on optical and electrical properties of the films is studied, and the controllability of the grain size is deeply discussed theoretically. The results show that the indium nano-thin films with ultrafine grains, including tin oxide (ITO) and indium oxide (In_2O_3) film, have excellent performance in superior conductivity and optical density.

2. Experiments

2.1. Preparation of nano-thin films

Ultrafine-grained indium nano-thin films (thickness 90 nm) were deposited on glass substrates (thickness of 0.17 mm) by

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0169-4332/$ – see front matter © 2014 Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.apsusc.2014.01.093

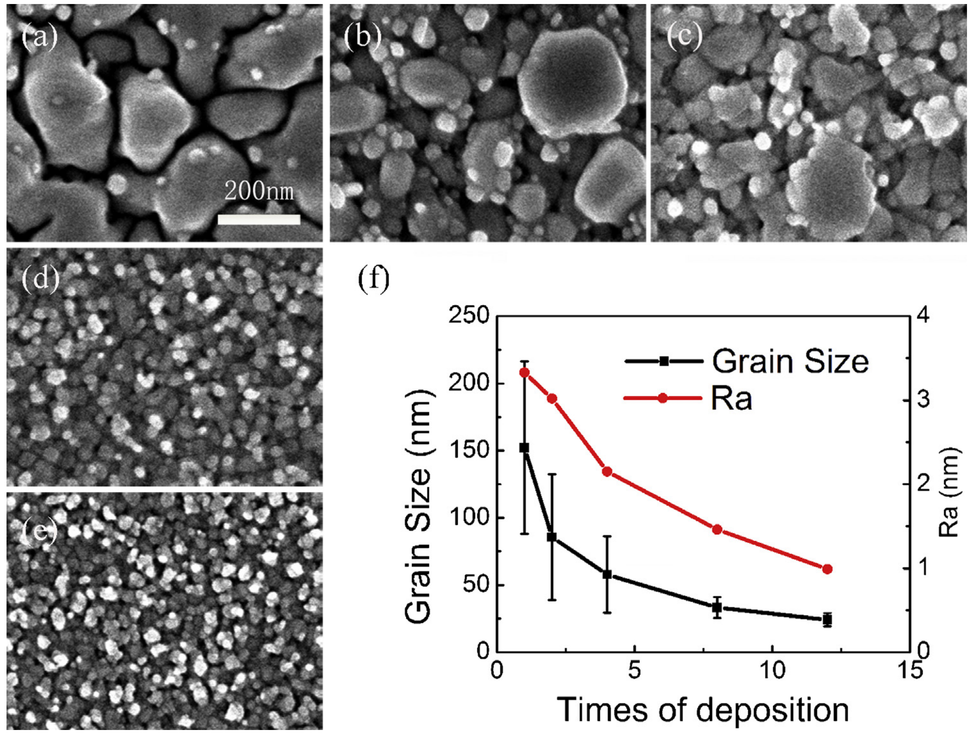

Fig. 1. SEM images, grain size and surface roughness (Ra) of indium films with deposition times. (a–e) In films deposited for once, twice, four times, eight times and twelve times, respectively, oxygen was ventilated in the deposition chamber during all the sputtering intervals; (f) grain size and Ra.

radio-frequency magnetron sputtering (ULVAC ACS400-C4) with a power of 30 W and a working pressure of 0.57 Pa. The total deposition time was 1000 s for each sample. The 90-nm-thick indium films were obtained by one-off, two-layer, four-layer, eight-layer and twelve-layer deposition, respectively. During interval between adjacent depositions, oxygen was ventilated into the deposition chamber. In_2O_3 nano-thin films were prepared by annealing the indium films at 400 °C for 3 h. ITO films were obtained by simply one-time depositing 10 nm-thick Sn layer on the indium films and being annealed at 500 °C for 8 h. During the annealing procedure, the indium and tin atoms combined with oxygen from the atmosphere to create SnO_2 and In_2O_3, mixing and melting occurred simultaneously. In our case, the films were not prepared by the standard composition 90% In_2O_3–10% SnO_2 (by weight), the final products were actually the mix of ITO and small amounts of SnO_2.

2.2. Characterization

Morphology of the indium nano-films was observed by field emission scanning electron microscopy (FESEM, Hitachi S-4800), surface profiler (Veeco Dektak 150) and field emission transmission electron microscopy (FETEM, FEI Tecnai G2 F20). Structure of the films was analyzed by high-resolution TEM (HRTEM), selected area electron diffraction (SAED) and electron energy loss spectroscopy (EELS) mapping. Ultraviolet–visible (UV–vis) spectra were measured by a UV vis–NIR spectrometer (Perkin Elmer Lambda 950).

3. Results and discussion

3.1. Morphology of the ultrafine-grained metallic films

Fig. 1(a)–(e) shows the SEM images of indium films obtained by multiple depositions from once to twelve times. It can be seen that surface grain size of the In films has a decrease with an increase of deposition times. Obviously, the more times of deposition are, the smoother surface (Ra: roughness center-line average) and the smaller grain are, as shown in Fig. 1(f). Based on this, we can fabricate indium nano-thin films with ultrafine grains, and easily control size of metallic grains by tuning times of oxidation.

3.2. Optical properties and applications

In recent years, indium and indium oxide films are in spotlight due to wide application in photoelectrical industry, and MTMO grayscale photomasks based on metallic nanofilm were proposed recently for fabrication of 3D microstructures [7]. It is no doubt that optical transmittance is important in evaluation of the optical performance of transparent-conducting film, especially a high transparency in the visible region is desired for transparent

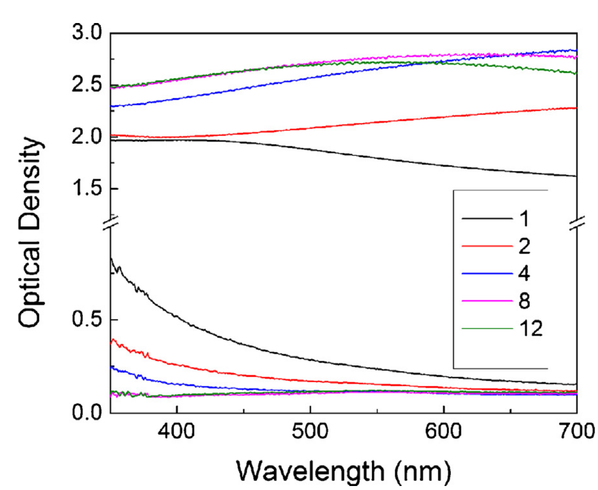

Fig. 2. NUV–vis spectra of the indium films (90 nm) deposited for different times (upper part), and those of the films annealed at 400 °C for 3 h (lower part), spectra of In films and the corresponding In_2O_3 films are in the same color. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)