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Preparation of IGZO sputtering target and its applications to thin-film transistor devices

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Abstract

Nano-scale In_2O_3, Ga_2O_3 and ZnO powder mixture prepared by a hybrid process of chemical dispersion and mechanical grinding was adopted for the In–Ga–Zn–O (IGZO) sputtering target fabrication. A pressure-less sintering at 1300 °C for 6 h yielded the target containing sole $InGaZnO_4$ phase with relative density as high as 93%. Consequently, the thin-film transistor (TFT) devices containing amorphous IGZO channels were prepared by using the self-prepared target and the electrical measurements indicated the TFT subjected to a post annealing at 300 °C exhibits the best device performance with the saturation mobility = 14.7 cm^2/V s, threshold voltage = 0.57 V, subthreshold gate swing = 0.45 V/decade and on/off ratio = 10^8. Capacitance–voltage measurement indicated that post annealing effectively suppresses the interfacial traps density at the IGZO/SiO_2 interface and thus enhances the electrical performance of TFT.

Keywords: IGZO; Thin-film transistor; Interfacial traps density

1. Introduction

Recently, amorphous oxide semiconductors (AOSs) such as Sn–Zn–O (SZO), In–Zn–O (IZO) and In–Ga–Zn–O (IGZO) have received a considerable attention in the large-area flat panel display (FPD) industry since they may overcome the difficulties encountered in the amorphous and polycrystalline silicon thin-film transistor (*a*-Si:H and poly-Si TFT) technologies [1]. The poor field-effect mobility (<1 cm^2/V s) and small on-current property are drawbacks of *a*-Si:H TFTs although their processing temperature is low and may save the product cost [2]. The poly-Si possesses a much higher carrier mobility (>10 cm^2/V s) than that of *a*-Si:H; however, its processing temperatures are comparatively high and the complicated recrystallization methods to eliminate the grain boundaries in the poly-Si layer might escalate the cost of TFT production [3].

As the attractive active channel materials for TFT in FPD products, AOSs provide the advantages including high saturation mobility ($\mu_{sat} > 10$ cm^2/V s), low deposition temperatures, good film uniformity and compatibility to conventional sputtering processes [4–6]. Among various AOS types, the quaternary IGZO system based on In_2O_3, Ga_2O_3 and ZnO oxide components is of particular interest because of its relatively high μ_{sat} property in the range of 10–50 cm^2/V s, high transparency in visible-light wavelength region and capability to produce the films with various conductivities [7]. Nomura et al. prepared the transparent and flexible TFTs on a polyethylene terephthalate (PET) substrate by a room-temperature physical vapor deposition process [1]. In their TFT devices, amorphous $InGaZnO_4$ (*a*-IGZO) served as the channel layer and the μ_{sat} about 12 cm^2/V s was achieved. TFTs containing *a*-IGZO channels were also reported by Abe et al. and their devices exhibited the $\mu_{sat} > 9.0$ cm^2/V s, off current <10 pA and subthreshold gate swing (*S.S.*) <0.2 V/decade [8]. Jeong et al. prepared the *a*-IGZO TFT devices *via* a co-sputtering of IGZO and indium zinc oxide (IZO) targets [9]. By adjusting the IGZO/IZO ratio in the channel layer, they were able to improve the μ_{sat} and *S.S.* parameter up to 19.3 cm^2/V s and 0.35 V/decade, respectively.

Highly transparent feature facilitates another promising application for IGZO as the transparent conducting oxide (TCO) electrode which is an essential part to FPDs and photovoltaic devices. Indium tin oxide (ITO) is the most common TCO; nevertheless, the scarcity of In and recent

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flourishing of FPD and solar cell industries drastically tightens the supply of ITO. Besides, the deposition temperature of ITO layer is relatively high for optimizing the optical and electrical properties [10]. Presently, the doped ZnO such as aluminum-doped ZnO (ZnO:Al or AZO) and multi-component oxides such as IGZO are recognized as the promising alternatives for ITO. However, their physical properties are still required further refinement for practical applications.

Nano-scale In_2O_3, Ga_2O_3 and ZnO oxide powders were prepared in this study *via* a hybrid process of chemical dispersion and mechanical grinding and applied to the IGZO sputtering target fabrication. Sintering process to form the sputtering target comprised of sole $InGaZnO_4$ phase was also established and the TFT devices containing *a*-IGZO channel layers were prepared by using the sole-phase target. The microstructure, composition and transmittance of *a*-IGZO layers, the transfer characteristics of *a*-IGZO TFTs as well as the influence of post annealing on the defect configurations of samples were characterized and presented as follows.

2. Experimental

As-received ZnO (purity = 99.999%, Seedchem/Australia), Ga_2O_3 (purity = 99.995%, ELECMAT/USA) and In_2O_3 (purity = 99.99%, CERAC/USA) raw oxide powders were first rinsed in ethanol. The oxide powders were mixed at the molar ratio = 1:1:2 (*i.e.*, the stoichiometric ratio of $InGaZnO_4$ phase) and then transferred to a hybrid process of chemical dispersion and mechanical grinding [11] to form the aqueous suspension containing nano-scale In_2O_3–Ga_2O_3–ZnO powder mixture. Such a hybrid process was able to produce the oxide particles with average diameter of 74 ± 10 nm as determined by the particle size analyzer (BECKMAN COULTER Delsa^{TM} Nano C) and a representative micrograph obtained by scanning electron microscopy (SEM, JEOL-6700) is given in Fig. 1(a). In comparison with oxide powders prepared by traditional ball milling method, the nano-scale oxide powders subjected to surface modification exhibited good dispersion behaviors and allowed the formation of compact green body with uniform composition distribution. Moreover, the high specific-surface-area feature of nano-scale oxide powders might promote the sintering process and effectively suppress the sintering temperature for desired phase formation [11]. This provides an efficient method for preparing the high-density, sole-phase IGZO sputtering target with the saving of thermal budget.

After drying, the powder mixture was pressed into the disc form at pressure = 100 MPa and consequently sintered without external pressure at temperatures ranging from 900 to 1300 °C for various time spans. Phase constitutions of the sintered IGZO targets were analyzed by *x*-ray diffraction (XRD, MacScience M18XHF) within the Cu-K_α radiation (wavelength = 0.154 nm) at scanning rate of 3°/min. The relatively densities of target samples were measured by the Archimedes method with the aid of an electronic balance (Ax105,

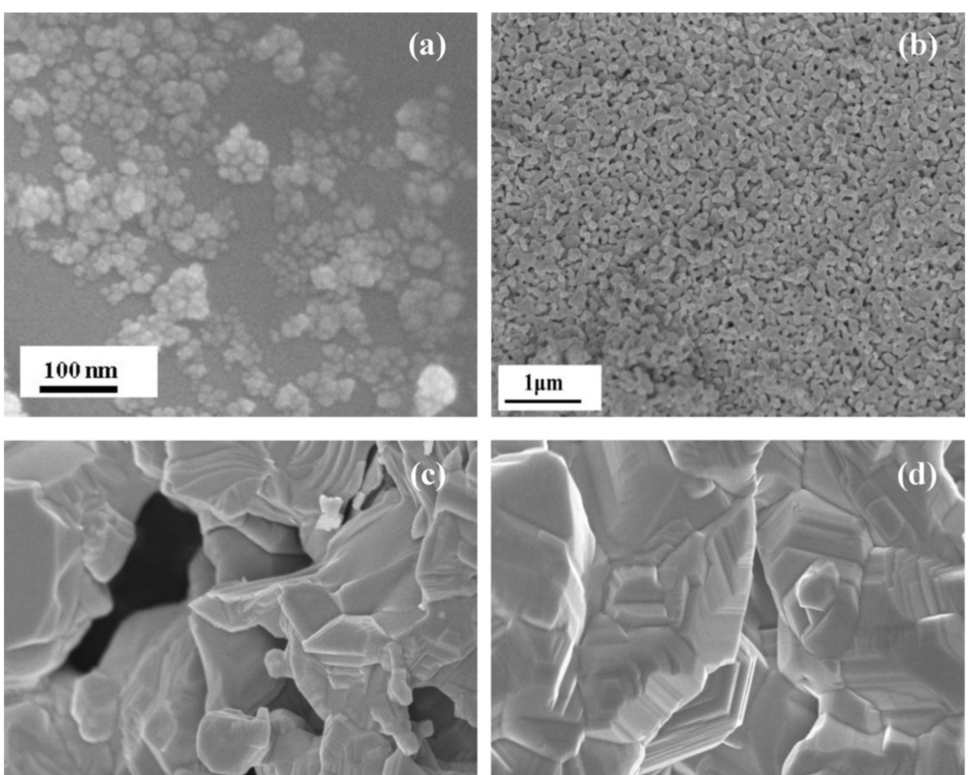

Fig. 1. SEM micrographs of (a) as-prepared In_2O_3–Ga_2O_3–ZnO powder mixture and morphologies of IGZO targets subjected to sintering treatments at (b) 1100 °C, (c) 1200 °C and (d) 1300 °C for 6 h.