Channel Layer Thickness Dependence of In-Ti-Zn-O Thin-film Transistors Fabricated Using Pulsed Laser Deposition

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Amorphous indium-titanium-zinc-oxide (ITZO) thin-film transistors (TFTs) with various channel thicknesses were fabricated at room temperature by using pulsed laser deposition. The channel layer thickness (CLT) dependence of the TFTs was investigated. All the ITZO thin films were amorphous, and the surface roughnesses decreased slightly first and then increased with increasing CLT. With increasing CLT from 35 to 140 nm, the on/off current ratio and the field-effect mobility increased, and the subthreshold swing decreased. The TFT with a CLT of 210 nm exhibited the worst performance, while the ITZO TFT with a CLT of 140 nm exhibited the best performance with a subthreshold voltage of 2.86 V, a mobility of 53.9 cm²V⁻¹s⁻¹, a subthreshold swing of 0.29 V/decade and an on/off current ratio of 10⁹.

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I. INTRODUCTION

Thin-film transistors (TFTs) using amorphous oxide semiconductors have attracted considerable attention because of their advantages over conventional TFTs, such as high electron mobility, high transparency, low-temperature processing and low cost. Among them, amorphous indium-gallium-zinc-oxide (IGZO) TFTs have been extensively studied since the first report in 2004 [1]. However, finding devices with high performance and improved stability for practical mass production remains the most important and critical issue.

So far, several research groups have studied modifying the device structure and the process parameters to understand and improve the device performance and stability [2-4]. Meanwhile, various amorphous oxide semiconductors, based on indium- and zinc-oxide compounds, have been considered as device channel layers to enhance the device performance by employing other elements in place of Ga, such as Hf [5], Zr [6] and Ta [7]. Previous reports revealed that titanium showed the same effect as Ga in suppressing the carrier concentration [8,9]. However, the effect of the channel layer thickness (CLT) on the performance of indium-titanium-zinc-oxide (ITZO) TFTs has not been reported yet.

In this study, bottom-gate ITZO TFTs with various channel thicknesses were fabricated using pulsed laser deposition (PLD). The CLT dependences of the TFT performances were investigated and are discussed.

II. EXPERIMENT

Heavily-doped p-Si wafers with thermally-grown SiO₂ (100 nm) were used as the substrates. An ITZO TFT with a bottom gate and top contact structure of Ni/ITZO/SiO₂/Si is schematically illustrated in Fig. 1. A KrF excimer laser (λ = 248 nm, τ = 25 ns) with a pulse energy of 200 mJ and a repetition rate of 5 Hz was used for the ablation of the ITZO target (In:Zn = 1:1 molar ratio, Ti: 0.5 at.% in the target). The target was pre-ablated for 10 min to remove surface contamination. All the thin films were fabricated at 35 mTorr, and the deposition time was varied from 5 min to 30 min. Under these conditions, the thicknesses of ITZO layers were 35, 70, 105, 140, 175, and 210 nm, respectively. The
nickel source/drain electrodes were thermally evaporated through a shadow mask with a channel width of 1000 μm and channel length of 200 μm. Finally, the ITZO TFTs were annealed at 350 °C in air for 30 min in a furnace to make the ohmic contact.

The crystal structures of the ITZO thin films were investigated using X-ray diffraction (XRD, X'Pert-PRO MPD and MRD, PANalytical). Atomic force microscopy (AFM, SPA-400) was used to measure the surface morphologies of the thin films. The transmittances of the thin films were investigated using a spectrophotometer in the UV-VIS range (S3100, Scinco). In order to analyze the optical transmittances of the ITZO thin films, these ITZO thin films were fabricated on glass substrates under the same conditions. The electrical properties of the ITZO TFTs were measured at room temperature in a dark box by using a semiconductor parameter analyzer (Agilent 4155C).

III. RESULTS AND DISCUSSION

Figure 2 shows the XRD patterns of ITZO thin films with various thicknesses.

Films show two broad peaks, one at around 22.5° and the other at 32.5°. The first broad peak at around 22.5° is attributed to the glass substrate, and has been reported by other groups [10]. The broad peak at around 32.5° cannot be ascribed to any particular phase of the ITZO thin films. This indicates the amorphous nature of the ITZO thin films fabricated at room temperature by using PLD.

Figure 3 shows the surface morphologies of ITZO thin films with various thicknesses on SiO₂/Si substrates. Several islands are observed on the 35-nm-thick ITZO thin film, which results in a large root-mean-square (RMS) roughness. However, as the thickness of ITZO thin film was increased from 35 to 140 nm, the islands disappeared and smoother surfaces were observed. The RMS roughness and grain size investigated by using AFM are summarized in Table 1. The RMS roughnesses of the ITZO thin films with the CLT of 35, 70, 105 and 140 nm are 0.21, 0.18, 0.17, and 0.15 nm, respectively. However, when the thickness was increased from 140 to 210 nm, the grain size grew much larger, certainly resulting in the increase of roughness.

Figure 4 shows the transmittances of ITZO thin films with various thicknesses on glass substrates. All the thin films are highly transparent with an average optical transmittance of larger than 80%. The high transmittances of the ITZO thin films meet the requirements of next-generation transparent TFTs. The inset of Fig. 4