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Transparent, high mobility InGaZnO thin films deposited by PLD

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Abstract

Transparent oxide semiconductor, InGaZnO, thin films were prepared by pulsed laser deposition at room temperature. The carrier concentration was found to vary by several orders of magnitude from insulating to 10^{19} carriers/cm^3 depending on the oxygen partial pressure during deposition. Hall mobilities as high as 16 cm^2/V s were observed. This is approximately an order of magnitude higher than the mobility of amorphous silicon and indicates that $InGaO_3(ZnO)_x$ with $x \leq 5$ may be suitable for transparent, thin film transistor applications. Post-deposition annealing was found to strongly influence the carrier concentration while annealing effects on the electron mobility was less influential.

Keywords: AOS; Amorphous semiconductor; Amorphous oxide semiconductor; IGZO; a-IGZO; PLD; Mobility; Transparent conducting oxide; TCO

1. Introduction

High performance electronic devices such as microprocessors and power transistors rely on crystalline materials because of their superior electronic properties. However, there are numerous niche applications where the speed or power performance of the transistor is not the key parameter. In applications such as liquid crystal displays, uniform deposition of materials over large areas using scalable technologies such as sputtering is necessary. For displays to be integrated into the windshields of automobiles or airplanes it would be advantageous for the materials to be transparent. In flexible electronic applications, such as displays that can be rolled up or folded, the durability of the material and its ability to accommodate large strains are the key parameters. In flexible electronics it is also usually important to develop low-temperature processes to be compatible with the polymer substrate.

While there have been significant advances in flexible polymer electronics that show promise, the workhorse material for thin film transistors for these types of applications has been amorphous silicon. However, both the polymer-based materials such as pentacene [1] and amorphous silicon [2] have low mobilities of less than 1 cm^2/V s which limit the transistor's performance. In general, low mobilities are typical of amorphous materials because the conduction occurs via an electron hopping mechanism. Recently, advances in amorphous oxide semiconductors (AOS) by Takagi et al. and Nomura et al. [3,4] have shown that significantly higher mobilities on the order of ~10 cm^2/V s can be obtained; furthermore, these materials can be transparent throughout the visible spectrum.

The origin of high mobilities of AOS semiconductors is believed to be the result of the overlap of spherical *s*-orbitals of the heavy metal cations with $(n-1)d^{10}ns^0$ $(n \geq 4)$ electronic configurations [5–7]. Various transparent semiconductors using the above scheme have been reported, including $AgSbO_3$ [8], Cd_2GeO_4, [9], Cd_2PbO_4 [10,11], indium tin oxide [12], indium oxide [13], zinc indium oxide [14,15], zinc tin oxide [16,17], and zinc rhodium oxide [18,19].

AOS films based on ternary–quaternary oxides in the In_2O_3-Ga_2O_3-ZnO system have several advantages over other AOS materials including low toxicity, and higher observed electron mobilities. The use of a multi-component system helps ensure that the films remain amorphous under conventional processing conditions [5,17]. In this study, $InGaO_3(ZnO)_x$-based, highly transparent and *n*-type electrically conductive films were deposited at room temperature, using pulsed laser deposition (PLD). The oxygen ambient in the chamber was used to control

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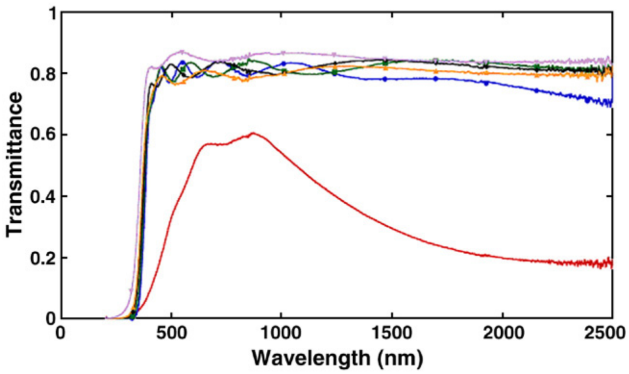

Fig. 1. Optical transmission spectrum of the IGZO films deposited at various oxygen partial pressures. Note that the optical absorption edge blue shifts with increasing oxygen partial pressure and that the transmission decreases with decreasing oxygen partial pressure as the conductivity increases. Pressures were (−) 5.8×10^{-4} mTorr, (●) 5 mTorr, (■) 10 mTorr, (♦) 20 mTorr, (▲) 40 mTorr and (▼) 80 mTorr.

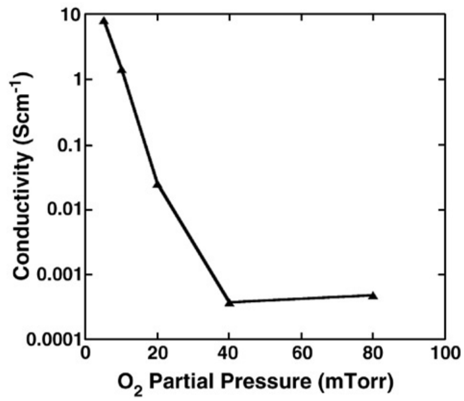

Fig. 3. Conductivity of IGZO films as a function of oxygen partial pressure during film growth.

the conductivity over several orders of magnitude. Post-deposition annealing studies showed that conductivity can also be controlled by oxygen diffusion into the film.

2. Experimental

The $InGaO_3(ZnO)_5$ ablation targets were prepared by mixing In_2O_3, Ga_2O_3 and ZnO powders in a 1:1:10 molar ratio and then compressed under 5000 psi at room temperature to form a disc. The compressed disc was then sintered for 9 h at 1250 °C to increase its hardness.

Pulsed laser deposition (PLD) was used to deposit uniform IGZO films at room temperature in an oxygen ambient by ablating material from the prepared target. The oxygen partial pressure was varied between vacuum and 80 mTorr. Oxygen gas flow is regulated by a mass flow controller while a variable-position gate valve maintains the desired chamber pressure. A KrF excimer laser, operating at 248 nm, 10 Hz and with a power of up to 4 J/cm^2 per pulse, was used for target ablation.

The structure of the films was studied by θ–2θ and glancing angle X-ray diffraction. The film composition was studied using the XPS technique. Hall mobility and carrier concentration were measured at room temperature using the Van der Pauw configuration at magnetic fields of 0.5 T. Conductivity measurements were carried out using a four-point probe stand, equipped with rounded osmium tips, spaced 1 mm apart. Post-deposition annealing studies were carried out by annealing the samples in air on a temperature-controlled hot plate.

3. Results

The room temperature deposited $InGaO_3(ZnO)_5$ films when studied using the θ–2θ X-ray showed only the peaks corresponding to the (0006) and (00012) crystal planes from the sapphire substrate. Glancing angle X-ray using a Phillips Xpert MRD triple axis diffractometer with a high intensity X-ray source option and Ge [220] crystal in a double bounce configuration was performed to remove the influence of the substrate and used to investigate the possibility of nanocrystallites. Initially no secondary peaks were observed, but when the instrument configuration was altered to remove Ge [220] crystal to obtain an open detector geometry relatively low intensity crystalline peaks appeared. The broad width of these

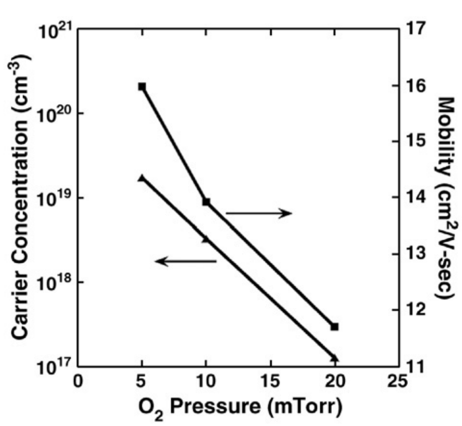

Fig. 2. Carrier concentration and Hall mobility measurements as a function of oxygen partial pressure during film growth.

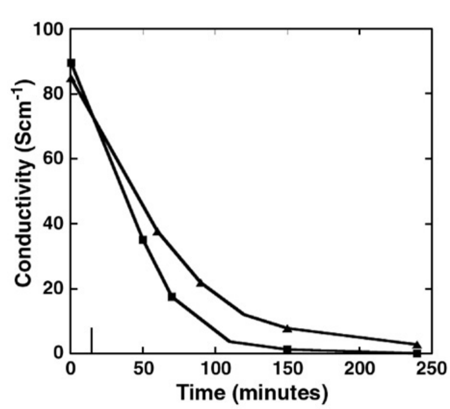

Fig. 4. Effect of post-deposition annealing in air on electrical conductivity as a function of time for two different temperatures, (▲) 175 °C and (■) 200 °C.