



HOKKAIDO UNIVERSITY

Title	Effect of zinc incorporation on electron transport properties of indium oxide thin-film transistors [an abstract of dissertation and a summary of dissertation review]
Author(s)	呉, 宇璋
Degree Grantor	北海道大学
Degree Name	博士(工学)
Dissertation Number	甲第16505号
Issue Date	2025-03-25
Doc URL	https://hdl.handle.net/2115/95024
Rights(URL)	https://creativecommons.org/licenses/by/4.0/
Type	doctoral thesis
File Information	Wu_Yuzhang_abstract.pdf, 論文内容の要旨



学 位 論 文 内 容 の 要 旨

博士の専攻分野の名称 博士（工学） 氏名 呉 宇 璋

学 位 論 文 題 名

Effect of zinc incorporation on electron transport properties of indium oxide thin-film transistors
(亜鉛導入が酸化インジウム薄膜トランジスタの電子輸送特性に及ぼす影響)

Transparent oxide semiconductor (TOS)-based thin-film transistors (TFTs), represented by amorphous InGaZnO₄ TFTs, have been widely employed as the backplanes of active-matrix flat-panel displays of OLED and LCD TVs. Since amorphous InGaZnO₄ TFTs exhibit one or two orders of magnitude higher field-effect mobility ($\mu_{FE} \sim 10 \text{ cm}^2/\text{Vs}$) than that of previously used amorphous Si TFTs ($\mu_{FE} \sim 0.5 \text{ cm}^2/\text{Vs}$), 4 K definition displays (3840×2160 pixels) with a frequency of 240 Hz single scan have been realized.[1-4] In the future, with an increasing demand for higher-definition display (8 K with 7680×4320 pixels) with high frequencies (480 Hz, single scan), TOS-TFTs that exhibit higher $\mu_{FE} \geq 50 \text{ cm}^2/\text{Vs}$ would be required for pixel-driving circuits.[5-8]. Among numerous reports on TOS-TFTs with higher μ_{FE} , In₂O₃ TFTs are considered a promising candidate because of $\mu_{FE} \sim 100 \text{ cm}^2/\text{Vs}$ [9]. However, they suffer from the following serious drawbacks: In₂O₃ TFTs typically show poor reliability, especially after applying negative gate bias stress, owing to the adsorption and/or desorption of gas molecules at the grain boundaries [9,10].

To address the drawback, there are currently two strategies. The first is using a passivation layer such as Y₂O₃ [11]. The second is Zn incorporation that stabilizes the amorphous phase without incorporating carrier scattering center. For detail, although there are homologous phases of In₂O₃(ZnO)_m ($m \geq 3$, integer) in In-Zn-O system, the crystallization temperature is relatively high ($\geq 500 \text{ }^\circ\text{C}$) and therefore the amorphous phase is stabilized. There have been numerous reports on Zn-incorporated In₂O₃ (IZO)-TFTs [12, 13]. For instance, Liang et al. reported that the 40 % Zn-incorporated In₂O₃ TFT exhibited a high μ_{FE} of $53.6 \text{ cm}^2/\text{Vs}$ [14]. However, due to complex interdependence structural and electrical parameters, systematic investigation of Zn ratio effect on the physics properties such as electron transport properties, crystallinity, as well as on the TFT characteristics and reliability is highly demanded for further research. In this thesis, I aim to systematically investigate the effect of Zn incorporation into In₂O₃ films on electron transport properties of the TFT.

In chapter 1, the background and objective of this research are introduced.

In chapter 2, I mainly introduced analysis method and technology of structure, electron transport properties, and TFT performance.

In chapter 3, I explore the structural and electrical properties of IZO films with varying Zn concentration and annealing conditions. GIXRD revealed amorphous structures in as-deposited films, with

films only crystallized in thicker IZO (Zn 10 wt.%) films (100 nm) and In_2O_3 (30 nm) after annealing at 300 °C. Furthermore, annealing temperature critically influenced electron transport. At 200 °C, partial recovery of oxygen vacancies reduced carrier concentration and mobility, whereas at 300 °C, oxygen vacancy suppression decreases carrier concentration to $\sim 10^{17}$ magnitude, which is lower than common reported carrier concentrations $\sim 10^{20}$.

In chapter 4, I detailed investigate the electrical transport properties of 300 °C annealed (IZO) films and TFTs across a wide range of Zn concentrations (9–86 at.%, observed with ICP-MS), which correspond different crystallized nature. In amorphous IZO films, mobility decreases with increasing Zn content due to reduced carrier concentration. DOS effective mass remained $0.2 m_0$ independent with Zn concentrations. Amorphous IZO TFTs with 25% Zn exhibited superior performance with a μ_{FE} of $41 \text{ cm}^2/\text{Vs}$, a subthreshold swing of 0.10 V/decade, and excellent reliability. In contrast, polycrystalline TFTs showed μ_{FE} values below $12 \text{ cm}^2/\text{Vs}$ as well as poor reliability under NBS and PBS treatment.

In chapter 5, electric field thermopower modulation analyses were proceeded to observed changes in effective thickness (t_{eff}) of amorphous and polycrystalline IZO TFTs as a function of effective gate voltage (V_{geff}), and so that investigate the operating mechanism in different crystallinity. For amorphous IZO, t_{eff} increased with V_{geff} and converse to 1.6 nm, followed well with field-effect theory. In polycrystalline IZO, t_{eff} started at 5 nm and decreased to 1.7 nm with increasing V_{geff} due to fermi-level located above conduction band minimum when V_{geff} is zero.

In chapter 6, the present study is summarized.

- [1] K. Nomura et al., Nature 432, 488 (2004).
- [2] T. Kamiya and H. Hosono, NPG Asia Mater. 2, 15 (2010).
- [3] E. Fortunato et al., Adv. Mater. 24, 2945 (2012).
- [4] H. Hosono, Nat. Electron. 1, 428 (2018).
- [5] J.Y. Kwon and J.K. Jeong, Semicond. Sci. Technol. 30, 024002 (2015).
- [6] Y. Hara et al., J. Soc. Inf. Disp. 26, 169 (2018).
- [7] H. I. et al., Inf. Disp. 38, 5 (2022).
- [8] T. Kim et al., Adv. Mater. 35, e2204663 (2023).
- [9] Y. Magari et al., Nat. Commun. 13, 1078 (2022).
- [10] J. K. Jeong et al., Appl. Phys. Lett. 93, 123508 (2008).
- [11] P. R. Ghediya et al., Small Methods 2400578 (2024).
- [12] A. Illiberi et al., J. Vac. Sci. Technol. A. 36, 4 (2018).
- [13] Y. K. Liang et al., IEEE Trans. Electron Dev. 70, 1067 (2023).
- [14] M. H. Cho et al., ACS Appl. Mater. Interfaces. 14, 18646 (2022).