Development of High Mobility Oxide Semiconductor Sputtering Target

Shigeki Tokuchi[1], Ryo Shiranita[2], Kyosuke Teramura[2], Tomoyasu Yano[2], and Mamoru Furuta[3]

s_tokuchi@mitsui-kinzoku.com
[1]R&D Center, Mitsui Mining & Smelting Co., LTD. Saitama 362-0021, Japan
[2]PVD Materials Division, Mitsui Mining & Smelting Co., LTD. Fukuoka 836-0003, Japan
[3]School of Environmental Science and Engineering, Kochi University of Technology, Kochi 782-8502, Japan
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ABSTRACT

We have investigated oxide semiconductor material In-Zn-O-X system to achieve high electron mobility. By choosing appropriate X material and optimizing the composition, we have realized Thin-Film Transistor (TFT) with its field effect mobility over 60 cm^2/vs, which is desirable to high-definition displays.

1 Introduction

In-Ga-Zn-O is suitable material especially to High-definition displays, because it has some favorable characteristics such as high mobility over 10 cm^2/Vs, good process uniformity and high ON/OFF ratio [1,2]. Nowadays, as some panel manufactures have commercialized 8K panel, high refresh rate panel and Organic Light Emitting Diode (OLED) panel, the demand of far higher mobility oxide semiconductor than In-Ga-Zn-O will be increased [3]. In this study, we have investigated In-Zn-O-X system, in which X is an additive to control carrier concentration. Among several additives, we have found Ta is a promising additive to control electron density, and we have fabricated TFT with its field effect mobility over 60 cm^2/Vs using In-Zn-O-Ta as an oxide channel material.

2 Experiment

8 inch circular shape In-Zn-O-X, In-Zn-O (no additives), and In-Ga-Zn-O sputtering targets were manufactured using slip casting method. In-Ga-Zn-O was used as a reference. Using Scanning Electron Microscope-Energy Dispersive X-ray Spectroscopy (SEM-EDS), and X-ray Diffraction (XRD), we have investigated sputtering targets characteristics. Single layer films were deposited by DC magnetron sputtering at room temperature under several sputtering conditions and annealed in air at several temperatures. Then, they were characterized by Hall-measurement system. To evaluate TFT characteristics, bottom gate, top contact and etching stopper type TFTs using oxide semiconductor as a channel layer were fabricated using conventional lithography technic. The TFT structure was depicted in Fig. 1. SiO_2 deposited by Plasma-Enhanced Chemical Vapor Deposition (PE-CVD) was used as a gate insulator and an etching stopper layer. All TFTs were annealed in air at 350 °C after fabrication.

3 Result

Fig. 2 (a), (b) show SEM-EDS analysis images of In-Zn-O-Ta targets. In-Zn-O-Ta (a) was mainly composed of In_2O_3 and $Zn_3In_2O_6$ phases which were identified by XRD. Ta mapping (b) shows Ta was distributed uniformly on both phases. Fig. 3 shows Hall-measurement results of In-Zn-O-Ta and In-Zn-O single layer films under several sputtering and annealing conditions. Ta addition could drastically decrease carrier density at annealing temperature especially over 350 °C, while in case of without Ta addition, carrier density could not be decreased even after annealing. We also checked crystallinity of oxide films, and found they were amorphous phase around these temperatures. TFT characteristics using In-Zn-O-Ta, In-Zn-O-W, In-Zn-O, and In-Ga-Zn-O as an oxide layer, were shown in Fig. 4. In-Zn-O-Ta TFT shows good TFT characteristics, In-Zn-O TFT, on the other hand, shows just conductive characteristics. In-Zn-O-Ta TFT shows superior characteristic to In-Ga-Zn-O TFT especially in μ_{FE}, and details were summarized in Table 1.

4 Discussion

Table 2 shows standard free energy of formation of several oxides at room temperature extracted from Ellingham diagram [4,5,6] (ΔG^0 values of oxidation reaction with 1mol O_2). Among various transition metals, Ta has large negative ΔG^0 and can form polyvalent oxides, which mean even small amount of Ta addition can control carrier concentration effectively (most likely reduction of oxygen vacancy). We have investigated sputtering target (bulk) characteristics of In-Zn-O-X. In case of In-Zn-O-Ta, as mentioned above, Ta was distributed uniformly on both In_2O_3 and $Zn_3In_2O_6$ phases without forming any complex oxides with In_2O_3 nor $Zn_3In_2O_6$ (Fig.2 (a), (b)). In case of In-Zn-O-W, however, W was mainly localized as $ZnWO_4$ (Fig.2 (c), (d)). We think these kinds of distribution of additives are maintained after sputtering process and affect TFT characteristics. In fact, μ_{FE} of In-Zn-O-W is slightly lower than that of In-Zn-O-Ta (Fig.4, Table.1).

5 Conclusions

As a high mobility oxide semiconductor material, we have investigated In-Zn-O-X system and found Ta is a favorable additive. TFT with In-Zn-O-Ta as a channel layer shows higher mobility than In-Ga-Zn-O TFT. Further investigations will be needed to make clear the effects of the additives, it is our pleasure our results contribute to the development of high mobility oxide semiconductor materials.

References

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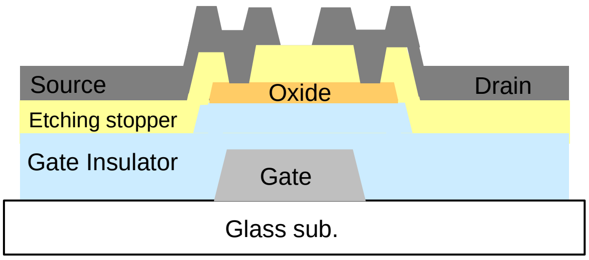

Fig. 1 TFT configuration

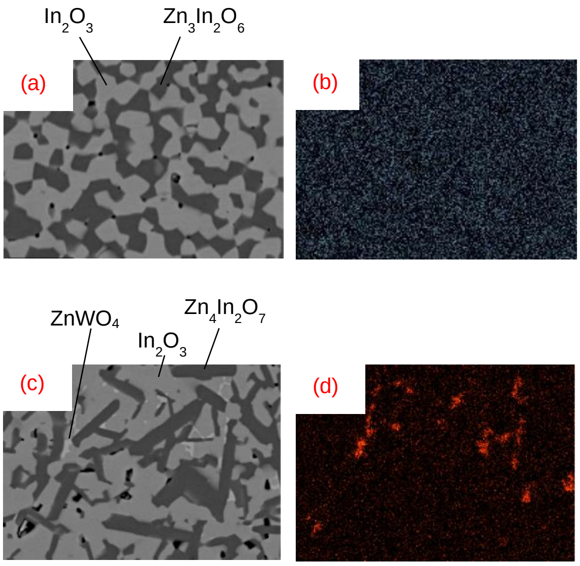

Fig. 2 SEM-BSE image of In-Zn-O-Ta (a) and In-Zn-O-W (c). EDS Ta mapping of In-Zn-O-Ta (b), and W mapping of In-Zn-O-W (d) sputtering targets

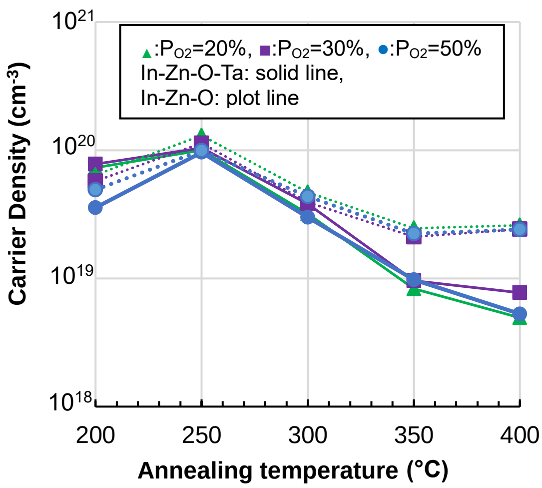

Fig. 3 Hall-measurement results of In-Zn-O-Ta (solid) and In-Zn-O (plot) films under various sputtering and annealing conditions

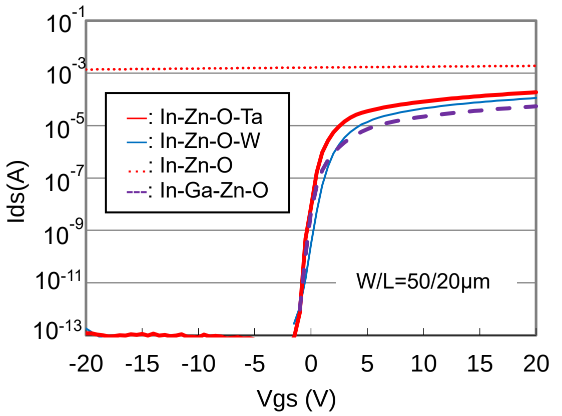

Fig. 4 Transfer curves of In-Zn-O-Ta (red solid), In-Zn-O-W (blue solid), In-Zn-O (red plot), and In-Ga-Zn-O (violet dashed) TFTs

Table 1. TFT characteristics of various oxides at V_{ds}=5 V

oxides	**μ_{FE} (cm^2/Vs)**	**V_{th}(V)**	**S.S. (V/dec)**	**ON/ OFF**
In-Zn-O-Ta	70	0.40	0.18	>10^9
In-Zn-O-W	42	0.82	0.38	>10^9
In-Ga-Zn-O	12	0.46	0.24	>10^9
In-Zn-O	Conductor			

Table 2. ΔG^0 of various oxide at room temperature (oxidation number is shown in parentheses)

	Ta(+5)	Cr(+3)	Ni(+2)	W(+6)	Zn(+2)
ΔG^0 (KJ/mol)	-770	-690	-440	-380	-650