Kwansei Gakuin University
Report of Research Outcome

2024/03/13

To President

Department : Science and Technology
Position : Postdoctoral fellow
Name : Endah Kinarya Palupi

I report the outcome of the research as follows.

Name of the Fund/Program	□Sabbatical leave with grant □Sabbatical leave with no grant □KGU Joint Research □Individual Special Research ☒Postdoctoral fellow ※Please report by designated form as for "International Research Collaboration".
Research Theme	Development of solution-processed oxide thin film transistor: electrical characterization of amorphous indium silicon oxide
Research Site/Venue	Fujiwara Laboratory, Graduate School of Science and Technology
Research period	2023/04/01 ～ 2024/03/31 （ 12 month）

◆ **Summary of the research outcome** **(approx. 2,500 words)**

Please write down the outcomes in detail regarding the research theme above.

While sputtered amorphous indium-gallium-zinc-oxide (IGZO) semiconductors dominate industrial applications due to their uniformity and stability, solution-processed alternatives hold immense promise. Solution processing offers advantages such as simplicity, cost-effectiveness, homogeneity, and precise compositional control. This alternative enables cost-effective production and scalability, making them ideal for next-generation electronic devices. The fascinating properties of oxide semiconductors are delved into with a specific focus on indium silicon oxide (ISO) thin films. Silicon (Si) was introduced as a doping material because of its high bond dissociation energy with oxygen (799 kJ/mol). ISO films are developed using a solution process, which offers the potential for low-cost and high-throughput manufacturing. The Fujiwara Group has initial concerns centered around fabricating indium silicon oxide (ISO) thin films on a hydrophilic substrate. The outcome was nothing short of exhilarating: a successful deposition resulting in a TFT with a mobility of 8.1 cm^2/Vs. Solution processing was starting to live up to its promise. Armed with accomplishments in hydrophilic, we investigate hydrophobic substrates. Advantages in terms of uniformity, stability, and process compatibility are offered by depositing an oxide semiconductor thin film on hydrophobic substrates.

These considerations contribute to improved TFT performance in display applications. My stand on this research roadmap was clear: delve into the structural and electrical properties of ISO fabricated on a hydrophobic substrate. Extensive research was conducted on the device fabrication and post-fabrication treatment.

On device fabrication, material exploration on indium oxide and silicon ratios results in the ISO phase diagram; pure indium oxide has a polycrystalline structure; by adding a silicon doping, silicon stabilizes the film structure to be an amorphous phase up to 8 at%; above 8 at% silicon doping, it forms a crystalline phase. Based on the phase diagram, the structural model was constructed, and the optimum doped-silicon concentration was estimated. In addition to the material ratios, the optimum film thickness was explored by investigating spinning speed, spinning time, and layers. The optimum annealing temperature is also determined by the investigation and analysis of the annealing temperature dependence of crystallization temperatures.

In the electrical investigation, FET measurements with post-fabrication treatments were conducted. The transfer and output curves of ISO TFT device show significant differences between measurements just after fabrication and 14 days after fabrication. Parameters such as mobility, on/off ratio, and threshold voltage are analyzed from the transfer characteristics. On 0th day, a high off-current and a significant negative value of V_{TH} were observed. Negative V_{TH} and high off-current will affect transistor performance and can cause operational problems. After 14 days of storage, off-current decreased and V_{TH} shifted in positive directions, indicating better device operations. In addition to that, output characteristics are also analyzed, parameters such as total resistance, contact resistance, and channel resistance are estimated. On 0th day, just a linear zone was observed, while on the 14th day, the output characteristics show a linear and saturation zone, indicating that the device is operating as desired.

The differences between 0th day and 14th day are due to the formation of oxygen vacancies as an impact of the vacuum treatment. In the fabrication stage, the thermal evaporation deposition method was adopted for the deposited electrodes. This stage requires a high vacuum at a high temperature, and it is now known that this condition causes an oxygen desorption phenomenon, which creates vacancies in the ISO system. According to analysis of temporal evolution, this vacuum effect can be reduced by storage in air/ oxygen. Oxygen from the environment is adsorbed, resulting in a decrease in oxygen vacancies and allowing the device to operate with appropriate characteristics. The reduction of oxygen vacancies on the transfer curve was indicated by the increase in the on/off ratio and threshold voltage, which is shifting toward positive. Mobility doesn't change because it is estimated by a similar slope. Meanwhile, the oxygen vacancies on the output curve was indicated by a clearly observed linear relations between total resistance (R_T) and channel lengths (L). From the slope of the RT vs. L plot, channel resistance (R_{CH}) can be estimated, and then contact resistance (R_C) can be determined by extrapolating R_T vs. L relation to L = 0. Detailed relation between R_{CH} and R_C, and their gate voltage (V_G) dependence will clarify the effect of oxygen vacancy on the TFT device performance.

Deadline : Within two months after finishing the research period.

Sabbatical leave with grant: Submit this report to President with confirmation by the dean of school you belong to.

※Postdoctoral fellow is required to submit this report with confirmation by the dean of graduate school before the end of employment period.

Where to submit : Organization for Research and Development and Outreach (NUC)

◆We put this report on the web of KGU. If there is any problem about it because of difficulties on your research, please let us know.