Doctoral thesis/dissertation Digest Form

Title of Doctoral Thesis: Analysis of Performance and Reliability Improvement in Fully Solution-Processed Oxide Semiconductor for Flexible Device Applications
(フレキシブルデバイス応用完全溶液プロセス酸化物半導体の性能および信頼性改善に関する解析)
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(Summary)

Next-generation electronic devices are moving towards flexible and wearable devices that can be produced at a large scale using cost-effective and low-energy techniques. Thin-film transistors (TFT) are known as critical elements in electronic systems and should also follow requirements to fulfill target functionalities. Solution-processed approach has been widely explored in recent years owing to its simplicity, affordability, and scalability, which meet the requirements for the next generation devices. Several approaches have been demonstrated to enhance the performance of oxide TFTs incorporating single solution-processed layers of either a channel, gate insulator, or electrodes. Nevertheless, the fabrication of TFTs would be more simplified if all-solution components were successfully integrated, enabling high-throughput production through roll-to-roll processing. For other concerns, AOSs still suffer from poor reliability under the bias stress tests. Therefore, other treatments need to utilize to enhance performance and reliability.

This dissertation aims to: (1) study the effect of several post-treatments to improve the performance and stability of AOS TFTs while maintaining low fabrication temperature and performing in ambient atmospheric condition; (2) elucidate the mechanism of stability improvement by oxygen vacancies defect modification and moisture-related impurity reduction on the treated-area; and (3) adopt the solution-processed approach with post-treatments to obtain TFT characteristics on the flexible polyimide substrate. High performance and better device stability of AOS TFTs were achieved by utilizing various post-treatments at low-temperature conditions.

UV irradiation combined with low-heating treatment for improving the performance and reliability of fully solution-processed a-IZO TFT was investigated. Our self-aligned TFT structure employs IZO as both channel and electrode and fluorinated polysilsesquioxane (F-PSQ) as the gate insulator. The IZO electrode was activated through UV irradiation (λ=254 nm) combined with low-heating (115^{o}C) treatment. In addition, the a-IZO TFT characteristics were also investigated as a

function of UV irradiation time. The as-fabricated sample displayed non-switching behavior because of the inadequate conductivity of the IZO electrodes since it is not yet functionalized. Conversely, high-performance a-IZO TFT with the highest mobility up to 17.45 cm^2/Vs was achieved by UV combined with low-heating treatment for 90 minutes of irradiation time. Furthermore, the stability behavior was also investigated under positive bias stress (PBS) and negative bias stress (NBS) tests with the smallest threshold voltage (ΔV_{th}) of 2.4 V and 0.5 V. The improvement is owing to the reduction of interface trap density and moisture-related impurities, especially on the activated electrode area.

This research also introduces other post treatments such as plasma treatment. By using inductively coupled plasma (ICP), we successfully obtain high mobility up to a maximum of 31.12 cm^2/Vs by 75 sccm Argon gas flow rate. This value is relatively high for the mobility of IZO-based materials and comparable to other vacuum-approach TFTs. The stability behavior of a-IZO TFT was also investigated under PBS and NBS tests resulting in smallest ΔV_{th} of -0.3 V and 0.7 V, respectively. More mobile carriers, lower interface trap density, and film densification are the main reasons behind the performance and stability improvement after Argon plasma treatment. Since the Argon plasma treatment is an effective method for achieving good performance and stability, we also attempted to introduce atmospheric pressure plasma (APP) treatment. Despite performing all processes in ambient conditions, APP treatment TFTs recorded high mobility up to 13.68 cm^2/Vs. The application of a fully solution-processed approach for TFT on the flexible substrate was also reported. Utilizing SiO_2 deposited as the buffer layer successfully led to a smooth surface which is beneficial for the TFT deposition. Moreover, the SiO_2 buffer layer also shows good uniformity and high transparency which is suitable for optoelectronic devices. TFT characteristics show saturation mobility around 5×10^{-3} cm^2/Vs which confirms the suitability of the solution-processed approach on the flexible substrate. For enhancing the performance of the device, it is necessary to conduct further optimizations, such as choosing an appropriate buffer layer and other treatment method.

This research demonstrated the versatility of various post-treatments for improving the performance and stability of fully solution-processed oxide TFTs. These presented approaches of performing post-treatments on the fully solution-processed oxide semiconductors are significant steps in achieving high throughput and affordable-cost device realization.