# Oxide TFT Technologies for Deformable Display Applications

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**ABSTRACT**

*A defomable display is promising to change the display styles drastically due to its unique function includes bendable, foldable, rollable, and stretchable. In this report, we present solution-processed oxide TFT technology for such future displays.*

## 1 Introduction

Electronics with displays, such as televisions, smartphones, and tablets, are becoming more common in our daily lives. Display devices are becoming brighter, higher resolution, larger, thinner, and lighter as display technology advances. Nowadays, flexible displays are regarded as a promising technology that has the potential to drastically change the current display style. When the glass substrate is replaced with film, it bend, fold, and roll. In 2019, we collaborated with Sharp Display Technology Corporation to successfully develop a prototype of a 30-inch 4 K rollable active-matrix organic light-emitting diode (AMOLED) display (**Fig.1**) [1]. We can confirm the advantages of flexible AMOLED in terms of display quality, thinness, lightness, and rollability.

With the advancement of advanced IoT technology and artificial intelligence, as well as the increasing ubiquity of high-speed, high-capacity networks, we anticipate further drastic style changes in future display devices towards 2030–2040. Accordingly, the future of broadcasting media will be diversified to enhance user experiences offering new adventures and emotional journeys beyond anything television has ever provided and deeper connections between people by new forms of content. To cover a wide variety of viewing styles, we need more ubiquitous electronics with new deformable displays such as large-size rollable, dome, sphere, and other unique three-dimensional shape displays to pursue more realistic and immersive media experience. A future living space will be equipped with sophisticated display devices: wall-size display, wearable, newspaper style, dome-style, and three-dimensional shapes display. We are exploring more wide variety of viewing styles and display devices to enjoy and experience content featuring immersive, and realism as future vision [2].

In this presentation, we will present our recent research on oxide thin-film transistor (TFT) technology for future deformable displays. To realize various kinds of displays, development of facile processable TFTs is essential to drive the display [3, 4]. From the viewpoint of cost-effectiveness, easy-fabrication, and feasibility, we are focusing on the solution-processed oxide semiconductor TFTs. They have the potential to provide the high mobility required to drive various kinds of devices [5-7]. The simplicity of atmospheric solution processing is promising technology to cover various future deformable displays.

## 2 Solution process for high-performance TFTs

In general, solution-processed metal oxide is formed by chemical conversion via oxidation and condensation reactions of a precursor to form dense metal–oxide–metal (M-O-M) bonds by decomposition of the solvents

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| **Display size** | 30 inches diagonal |
| **Aspect ratio** | 16:9 |
| **Resolution** | 3840 × RGB × 2160 (4K) |
| **Frame rate** | 60 frame/sec |
| **OLED structure** | Top emission/RGB side by side |

**Fig. 1. 30-inch flexible AMOLED display collaborated by NHK and Sharp Display Technology Corporation**[1].

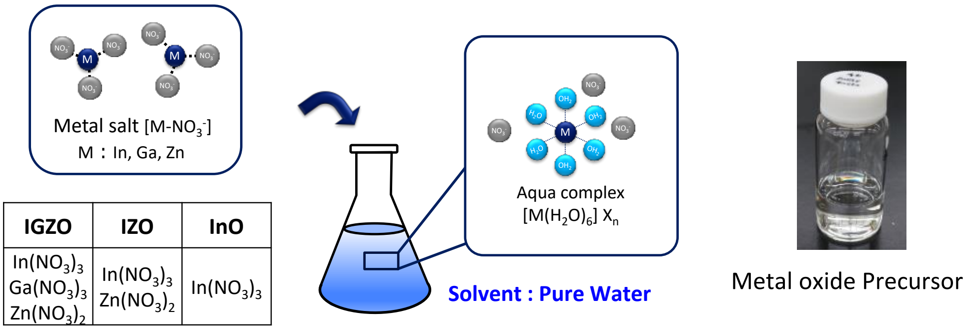


**Fig. 2. Carbon-free aqueous metal oxide precursor for low-temperature processing. Aqueous IGZO, IZO, and InO precursor are synthesized by only nitrate salts and pure water.**

and the ligands of the metal salts[7]. Although a high-temperature oxidation reaction is efficient to obtain better film quality, film process doesn't allow the high-temperature processing due to the decomposition of films at high temperature. Thus, we are focusing on carbon-free aqueous metal oxide precursor to realize high-performance solution processed metal oxide TFTs at a reasonable process temperature below 400 °C for plastic substrate[8-10]. Aqueous precursor has advantages to enhance film quality even at low-temperature due to the simple composition of its precursor without any organic compounds [11, 12]. We adopted only nitrate salts for metal and pure water for solvent for eliminating the carbon impurities as much as possible (**Fig.2**). A low-temperature solution-process metal oxide technology will be a significant driving force in introducing various deformable displays includes large-sized, rollable, and three-dimensional shapes display.

## 3 Direct patterning for high-performance TFTs

TFT patterning processes are unavoidable for device integration. To maximize the benefits of solution processing, we also focus on a simple and dependable direct patterning method. For obtaining high-performance carbon-free oxide TFTs, a simple and reliable direct patterning method using a carbon-free aqueous precursor was demonstrated [8].

We developed the direct patterning, which is achieved by selective photoreaction of water molecules as precursor solvent under ultraviolet irradiation. Furthermore, an environment-friendly chemical etching process using a non-toxic organic acid using citric acid is followed by an annealing process at 350°C to obtain carbon-free oxide films for In-Ga-Zn oxide (IGZO), In–Zn oxide (IZO), and In-oxide (InO).

By optimizing the deposition conditions and precursor concentration, the efficient photooxidation during UV exposure allows for denser solution-processed oxide films. The TFTs with those oxide films on $SiO_2$ dielectrics that were fabricated by a direct patterning method with sputtered Mo electrode exhibited high mobility of 4.2 $cm^2/V{\cdot}s$ for IGZO, 11.4 $cm^2/V{\cdot}s$ for IZO, and 39.0 $cm^2/V{\cdot}s$ for InO, respectively. These devices showed excellent switching properties. Furthermore, flexible TFT was developed with this direct patterning process (**Fig.3**).

## 4 Printing process for solution-processed TFTs

For various future electrical applications, a simple solution-based technology for not only semiconductors but also other TFT components, such as conductors, is required to maximize the benefits of solution processing. We developed printed metal oxide TFTs by spontaneous direct printing methods for the electrode In–Sn–O (ITO) with directly patterned metal oxide semiconductors In–Zn–O (IZO) [13]. The spontaneous direct printing methods were demonstrated using a simple bar coater and selective wettability achieved by a photo-patterned surface modification layer on the semiconductor. The schematic fabrication process is shown in figure 4. We confirmed that this direct printing could achieve fine patterning of ITO films of less than 10 μm, yielding

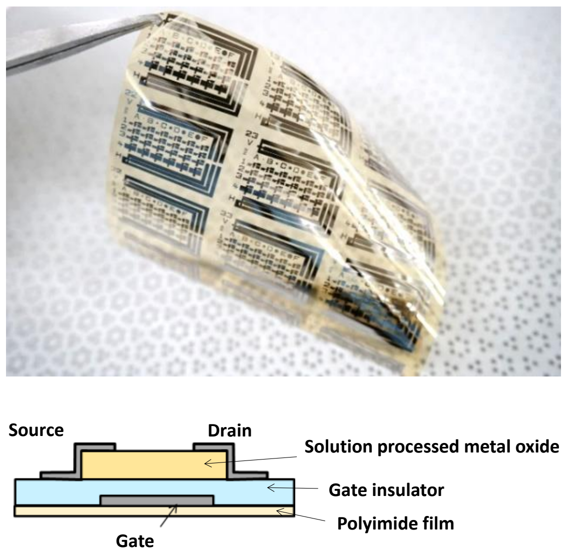


**Fig. 3. Photograph of the direct patterned metal oxide TFT on plastic substrate and a schematic diagram of fabricated TFT structure.**

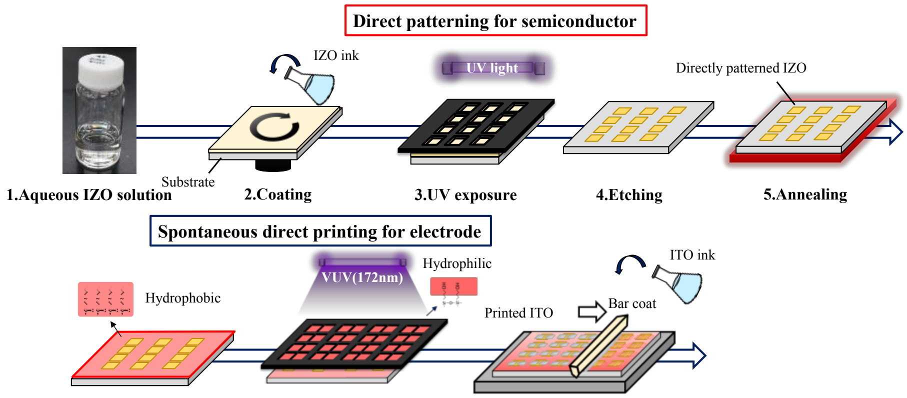


**Fig. 4. Process flow for printed metal oxide TFTs using a direct patterning for semiconductor and spontaneous direct printing process for ITO inks.**

electrodes using a simple bar coater and no additional process. The performance of IZO TFTs with printed ITO electrodes showed mobility of approximately 6 $cm^2/Vs$, Vth of −2.0 V, the on-to-off ratio of $>10^7$, and subthreshold swing (SS) of 0.5 $Vdecade^{-1}$ with minimal hysteresis. The printed TFT achieved good TFT characteristics by using a simple printed ITO electrode formed on a directly patterned metal oxide semiconductor.

## 5 Summary

We reviewed and discussed our recent work on solution-processed oxide TFT development. In terms of cost-effectiveness, ease of fabrication, and feasibility, solution-process metal oxide TFTs are a promising technology for covering a wide range of display applications. We believe that these findings will aid in the development of various deformable displays suitable for next-generation media in order to meet the requirements of the future display device.

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