Highly Stretchable Metal Oxide TFTs Array Using Acrylic Adhesive for Deformable Display Applications

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ABSTRACT

Stretchable electronics are a promising technology for bringing in a new style of display applications. We demonstrate a high-performance stretchable metal oxide thin-film transistors (TFTs) array using an acrylic adhesive structure. The TFTs array exhibit stable electrical performance under 50% strain and excellent switching characteristics.

1 Introduction

Displays are an essential device for interacting with media and people. As displays improve, they become better in terms of picture quality, resolution, thinness, and size, allowing for more realistic images. Nowadays, bendable and rollable displays are made possible by an innovative plastic film-based flexible active-matrix organic light-emitting diode technology. However, future prevalent electronics will require new styles such as domes, spheres, and other unique three-dimensional (3D) shape display to provide a more realistic and immersive media experience (**Fig.1**). We are exploring a wide variety of viewing styles to enjoy and experience immersive and realism-based content [1].

Stretchable electronics are a promising technology for bringing in a new era of display styles [2-6]. Currently, flexible displays are limited in two-axis deformation, such as folding and rolling. Realizing the various deformed styles requires the stretchability of displays to enable any free shapes to integrate 3D shapes. Wearable applications are also expected to be a promising technology for making electronics more pervasive. Therefore, display stretchability is needed as a future technology for displays to meet the requirement at all times and in all areas of daily life.

Deformable and stretchable organic light-emitting diode displays have been extensively investigated to date, but they are still in the early stages of development and require breakthroughs before they can be used in practical applications. Most research is based on passive matrix-drive displays with a limited amount of pixels and low stretchability [5, 6]. A method for stretchable thin-film transistors (TFTs) array for active-matrix driving is essential for future deformable displays to be realized.

In this study, reliable stretchable metal oxide TFTs array is investigated using acrylic adhesive with excellent switching characteristics even under deformed shapes. We integrated metal oxide TFTs array onto stretchable substrates owing to their high mobility, good reliability, scalability, and high on–off ratio characteristics [7]. The developed structure also enables easy and reliable transfer processes from film to elastic stretchable substrate, allowing for the fabrication of stretchable metal oxide TFTs array.

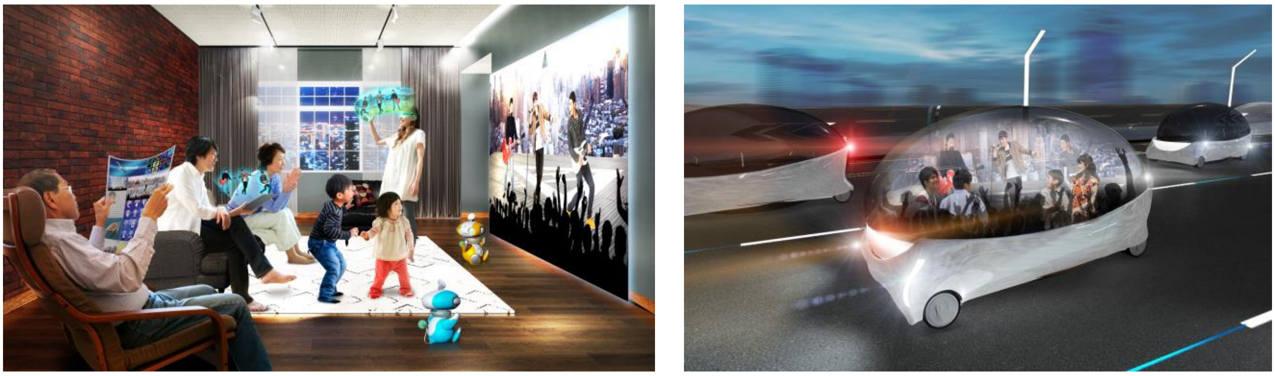

Fig. 1. Future living space and automated driven vehicle with sophisticated display devices: three-dimensional shapes, wearable, newspaper style, and dome-style display etc. Stretchability can explore a whole new display styles with its unique functions.

2 Experimental

Figure 2 shows the fabrication process of stretchable metal oxide TFTs array with acrylic adhesives and surface modification layer to obtain reliable stretchability. The process involves the following steps: i) fabrication of flexible TFTs array, ii) TFTs isolation, and iii) TFTs transfer to a stretchable substrate.

Firstly, the bottom-gate top-contact of In-Sn-Zn-O (ITZO) TFTs was fabricated on a flexible polyimide film with carrier glass substrate [8]. After the formation of a SiO_x underlayer on a glass substrate, a Mo-alloy gate electrode was deposited and patterned, and then formed a SiO_x gate insulator film. An ITZO film was formed by sputtering deposition with a composition that was optimized for high mobility. After the film was annealed at 300°C in air, source/drain electrodes of Mo-alloy were produced by sputtering deposition. Then, a photo-patternable passivation layer was formed by a photoresist polymer on top of TFTs. Finally, to obtain the flexible TFTs array, flexible polyimide films are mechanically peeled.

In the next fabrication process, the fabricated flexible TFTs were laminated on a double-coated silicone tape with carrier glass substrate. Then, each of the TFTs was isolated using a laser processor. After forming a surface modification layer of SiO_x on the reverse side of the polyimide film, unnecessary perimeter parts are removed by mechanical peering. Finally, the stretchable substrate with acrylic adhesives was conformably laminated on the fabricated array. After removing the double-coated silicone tape, stretchable metal oxide TFTs array on the stretchable substrate was obtained. For integrated TFT array in elastic polymer, rubber passivation was also formed on the top of TFTs.

3 Results and discussion

Figure 3 shows the fabricated 32 x 32 stretchable metal oxide TFTs array with acrylic adhesive and surface modification layer. Generally, metal oxide TFTs for stretchability are needed to be fabricated on a stiff island that is isolated from elastic materials due to its brittle characteristics [9]. However, most conventional stretchable oxide TFTs have delamination issues of a stiff island from elastic soft material that limits its reliable stretchability due to weak adhesion [10]. Most previous metal oxide TFTs were simply placed or embedded on elastic stretchable parts without specific modification [9]. Therefore, a unique structure that prevents delamination is one of the most important factors in ensuring a reliable stretchable TFTs array [11].

Figure 4 shows the comparisons of the stiff island of polyimide on differential elastic materials to investigate the delamination problems at the interface between the elastic substrate and the polyimide film. As the figure shows, conventional silicone elastomer (Ecoflex, Smooth-On, Inc.) showed significant delamination after a small strain of less than 20%. These trends are also the same as the polystyrene-block-poly(ethylene-ran-butylene)-block-polystyrene (SEBS) polymer, which is a commonly used elastomer for stretchable substrates. The delamination issues at the interface are observed between an elastic soft material and rigid materials due to the weak bonding strength. Our proposed structure, which uses an acrylic adhesive with a SiO_x modification layer demonstrated great stable integrated performance even when subjected to 100% strain without any delamination issues. After releasing 0% strain, it does not show any displacements or delamination at the interface. Thus, we

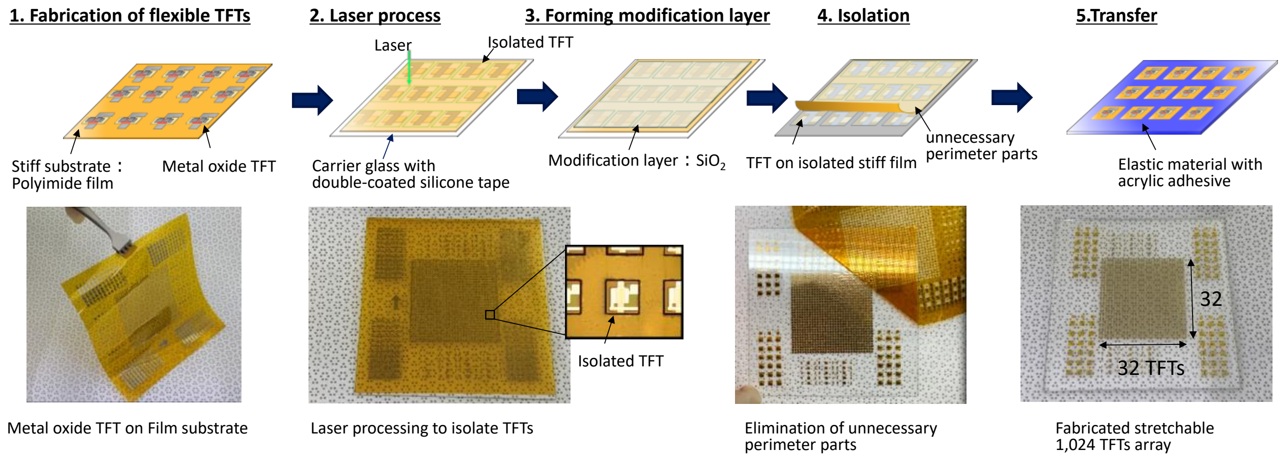

Fig. 2. The fabrication process of stretchable metal oxide TFTs array with acrylic adhesives to obtain reliable stretchability. Processes are consisted of mainly 3 steps: i) fabrication of flexible TFTs array, ii) isolation process of TFTs, iii) transfer process to the stretchable substrate.

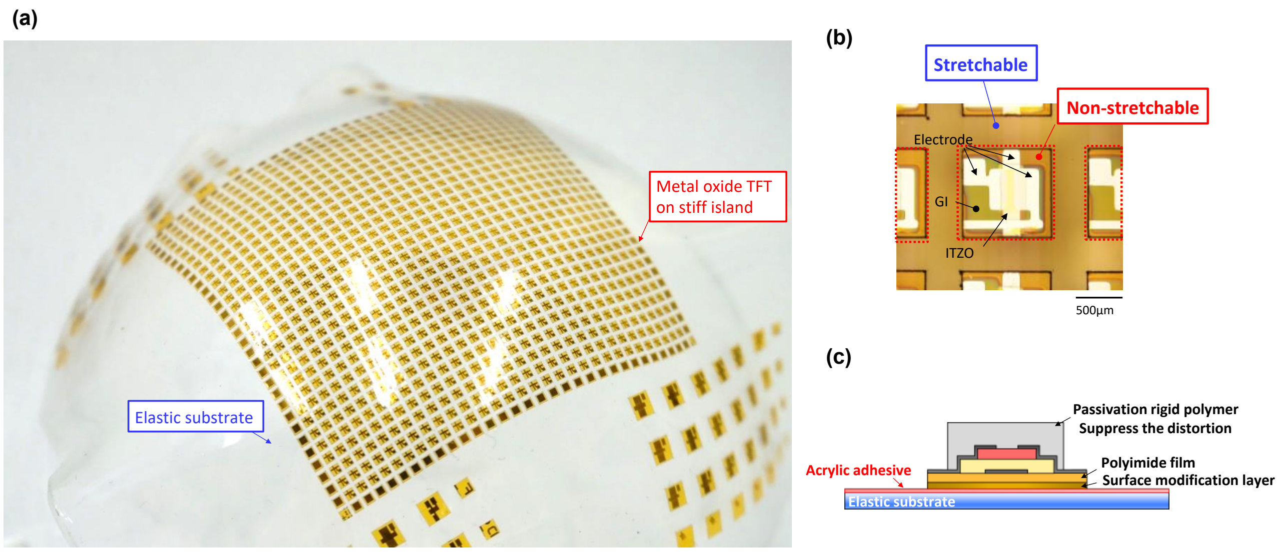

Fig.3. (a) A photograph of fabricated dome-shape stretchable metal oxide TFTs array with acrylic adhesive and (b) Magnified image of metal oxide TFT, and (c) Schematic of the TFT structure with acrylic adhesive and modification layer to achieve better integration between polyimide film and elastic substrate.

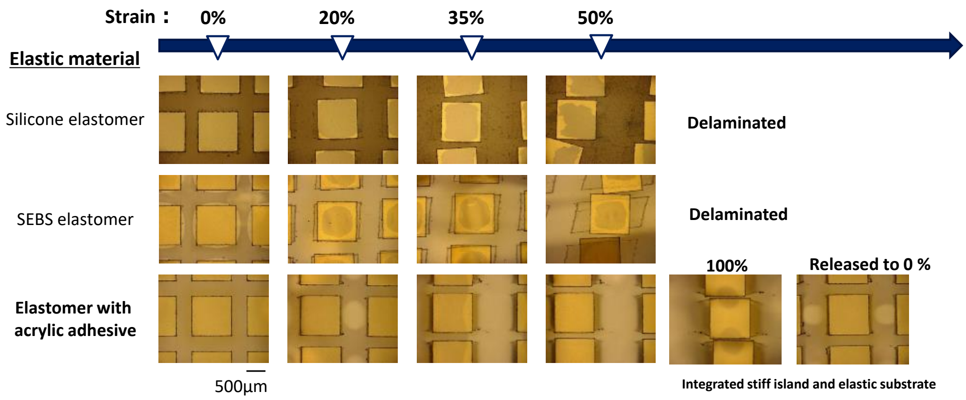

Fig. 4. Experimental results of delamination at the interface between elastic substrate and polyimide film. The silicon elastomer stretchable substrate, when placed under a strain test, showed delamination at less than 20% strain. The SEBS stretchable substrate also fails at around 20% strain. Elastomer with acrylic adhesive showed very stable integrated characteristics without any delamination even under 100% strain. It also exhibits any displacement of polyimide film after stretched at 100% strain.

confirmed the advantages of this structure for obtaining stable and reliable stretchability.

This adhesive structure is also helpful in achieving reliable mass transfer of 1,024 TFTs from carrier glass to the stretchable substrates without any defects. We carefully selected the type of silicon double-sided tape with weak adhesive on the acrylic adhesive to achieve selective transfer of the stiff polyimide film on the elastic substrate. Thus, as shown in figure 2, the mass-transfer process from film to elastomer can be easily carried out by the strong adhesiveness between the elastomer and the modification layer on the polyimide film without any defects.

The performance of stretchable ITZO TFTs array was evaluated. Figure 5 shows (a) the stretched metal oxide TFTs array and (b) the microscope images of metal oxide TFT stretched by 0%, 10%, 20%, 30%, 40%, 50%, (c) the transfer characteristics of TFT. The transfer characteristics of the ITZO TFT at gate voltages (V_g) ranging from −20 V to 20 V were assessed at the fixed drain voltage (V_d) of 20 V. The device demonstrated good stability characteristics under stretched conditions. The electrical performance showed no changes when stretched by 0%, 10%, 20%, 30%, 40%, 50%, and released to 0%. Furthermore, ITZO TFT exhibited high mobility of about 30 cm^2/Vs, and a high on-to-off ratio of $>10^8$. These advantages of metal oxide TFT such as high mobility, high on–off ratio, and good switching characteristics, are also confirmed with this developed structure using stretchable elastomer with acrylic adhesive.

4 Conclusion

A fabrication method to realize a reliable and highly

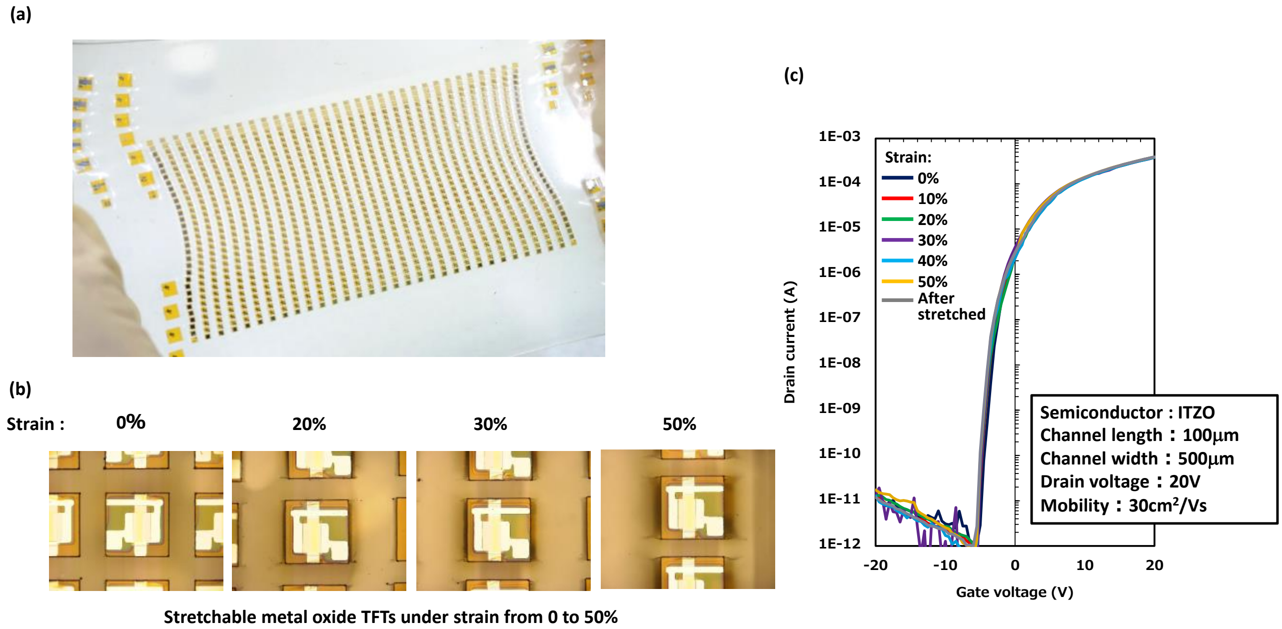

Fig. 5. (a) photograph of the stretchable metal oxide TFT under 50 % strain. (b) Photograph of a stretchable metal oxide TFT on an elastomer with acrylic adhesive. (c) Transfer characteristics of the metal oxide transistor stretched by 0%, 10%, 20%, 30%, 40%, 50%, and released to 0%.

stretchable metal oxide TFTs array was developed using acrylic adhesive. The stretchable metal oxide TFTs array showed excellent and stable characteristics under stretched conditions with good switching characteristics. This stretchable structure also enables easy and reliable transfer processes from film to the elastic stretchable substrate without any defects. We consider that this stretchable metal oxide is a promising vital technology for realizing future various displays such as dome or sphere, as well as other unique 3D curved shapes using the stretchable metal oxide TFT backplane technology.

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