

Stretchable Oxide TFTs on PI/SEBS Substrate

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ABSTRACT

We present stretchable amorphous indium-gallium-zinc-oxide (a-IGZO) thin-film transistors (TFTs) transferred onto styrene ethylene/butylene styrene (SEBS) thermoplastic elastomer. The fabricated stretchable oxide TFT showed electrical properties even after 40% strain without mechanical and electrical degradations. This stiff island on the stretchable substrate was demonstrated to enable for stretchable electronics.

1 INTRODUCTION

Recently, researches for realizing stretchable electronics have received much attention [1]-[4]. However, in the case of electronic devices using rigid inorganic materials, cracks are easily generated within layers due to the brittleness of material itself when mechanical stress is applied. To eliminate such drawbacks, various structures have been studied to reduce mechanical stress for electronic devices.

Especially, researches on amorphous indium-gallium-zinc-oxide (a-IGZO) thin-film transistors (TFTs) on stretchable substrate are of increasing attention due to 1) its excellent electrical characteristics such as high mobility ($>10 \text{ cm}^2/\text{Vs}$), high on-off current ratio ($>10^7$), and stability under positive and negative bias despite amorphous structure of semiconductor and 2) large-area manufacturing [5]-[7]. However, issues that degradation of electrical properties due to its brittleness of metal-oxide-semiconductor layer even with a small strain limit the scalability of applications using a-IGZO TFTs.

In order to minimize the stress applied to the semiconductor layer, several types of research have been studies to form a neutral plane or to adopt additional dual-gate to ensure the more stable electrical characteristics [8]-[9]. In addition, when the carrier glass and the flexible layer are separated after fabricating the device, carbon nanotubes/graphene oxide (CNT/GO) releasing layer or roll transfer technique to reduce damages on the flexible circuit has been studied [10]. Further, employing various structures such as a stiff island, serpentine pattern, pre-stretched elastomers have been reported to ensure stable operation of the electronic devices even after mechanical stress is applied on the stretchable substrate [11]-[13]. The various researches for implementing stretchable electronics are presented, however, there are no clear standards for producing practical devices, and still various attempts have been made.

In this study, we fabricated a-IGZO with back-channel-etched (BCE) structure on polyimide (PI) substrate and confirmed that mechanical stress can be minimized during detachment by embedding CNT layer between PI layer and glass substrate. In addition, this CNT releasing layer is applied to styrene ethylene/butylene styrene (SEBS) in the same way, which reduces the load when peeling off as well as self-standing. The fabricated a-IGZO TFT/PI transferred onto SEBS showed stable electrical properties without degradation under 40 % strain and confirmed to be robust even after repeated for 1000 times at 20 % strain. In this experiment, stretchable oxide TFTs using PI/SEBS substrate can be proposed as a suitable device structure for wearable electronics.

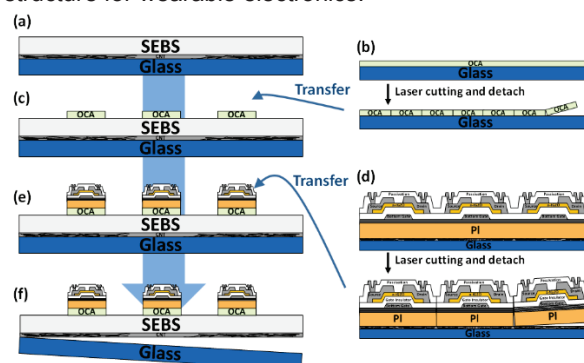


Figure 1. Schematic illustration of fabrication of stretchable a-IGZO TFTs on PI/SEBS substrate. (a) SEBS formation. (b) Cutting OCA using laser and detachment. (c) OCA transfer onto SEBS. (d) Cutting fabricated a-IGZO TFTs on PI cut using laser and detachment. (e) Transfer a-IGZO TFTs on OCA film. (f) Detach SEBS film from carrier glass.

2 EXPERIMENT

2.1 Fabrication process of stretchable oxide TFTs on PI/SEBS substrate

The detailed fabrication process of the a-IGZO TFTs on PI film appears elsewhere [14]. Figure 1 shows the fabrication process of stretchable oxide TFTs. To fabricate SEBS substrate, CNT was sprayed on glass and annealed at 290 °C for 2 hours. After coating the prepared SEBS solution, cured at 110 °C on a hot plate for 10 minutes. (Optically clear adhesive) OCA film is cut into an appropriate size using laser and then transferred to the SEBS substrate as shown in Figure 1(b). After that, the fabricated flexible oxide TFTs were cut into the same

size as the OCA layer (Figure 1(d)) and then transferred onto the OCA film (Figure 1(e)). Finally, the SEBS layer could be detached from the glass substrate in Figure 1(f).

2.2 Fabrication process of a-IGZO TFTs on PI

Figure 1(d) shows the schematic cross-section of fabricated flexible oxide TFTs. To fabricate flexible oxide TFTs, CNT was formed on the glass by spray-coating and then annealed at 290 °C for 2 hours. The CNT layer can be used to reduce the adhesion force of polyimide (PI) layer. After spin-coating PI, annealed at 450 °C for 1 hour. Then multilayer of SiO₂/SiN_x was deposited to form a gas barrier. To form the gate electrode, 120nm-thick Mo was deposited by sputtering and then patterned. The double layer of SiO₂/SiN_x layer for the gate insulator is deposited at 380 °C using plasma-enhanced chemical vapor deposition (PECVD). Then 20 nm of a-IGZO (InO₃:Ga₂O₃:ZnO = 1:1:1 mol%) is deposited using reactive sputtering without vacuum breaking and then patterned. A 150 nm-thick Mo is then deposited to form the source/drain electrode. Finally, 300 nm-thick SiO₂ for passivation layer is deposited.

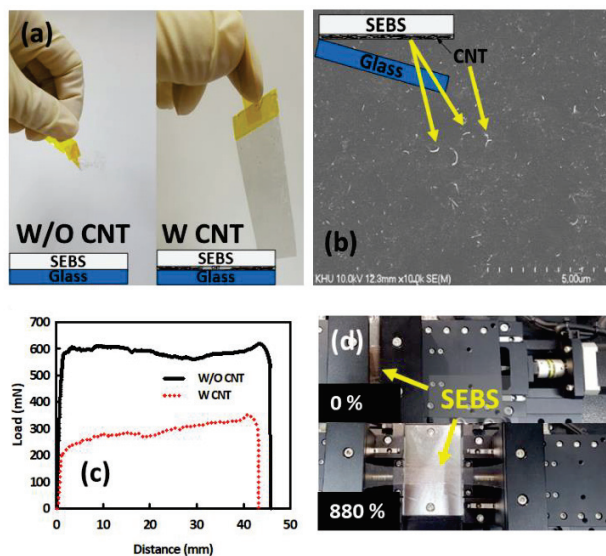


Figure 2. (a) Self-standing property of SEBS film with and without CNT. (b) SEM image of SEBS embedding CNTs. (c) Adhesion force of SEBS film with and without CNT. (d) Stretchability of SEBS.

3 RESULTS and DISCUSSION

Figure 2(a) shows the SEBS film detached from the carrier glass. In the absence of CNT releasing layer, the detached SEBS films could be easily agglomerated, but when CNTs are embedded in SEBS films, self-standing property was confirmed. Figure 2(b) shows the scanning electron microscopy (SEM) image of surface of SEBS layer with uniformly embedded CNTs. The CNT layer reduces the adhesion force of the PI on carrier glass and thus can be used as a buffer layer for mechanical detach.

Figure 2 (c) shows the measured adhesion force when the SEBS film with and without CNT releasing layer is detached to 90 degrees from the carrier glass. The adhesion force with CNT release layer is around 300 mN, whereas 600 mN is needed only the SEBS layer is directly attached to carrier glass as shown in Figure 2(c). The SEBS film with CNT embedded shows very ductile properties that can be stretched up to 880% in Figure 2(d).

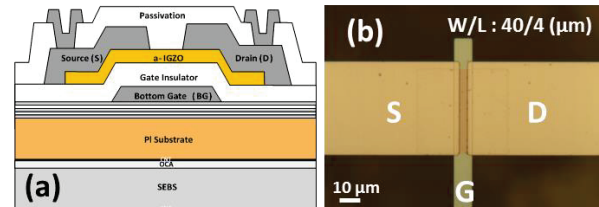


Figure 3. (a) Cross-sectional schematic illustration of a-IGZO TFT on PI/SEBS substrate. (b) Optical image of the fabricated a-IGZO TFT.

Figure 3(a) and (b) shows cross-sectional schematic illustration and optical image of fabricated a-IGZO TFT on PI/SEBS substrate. The fabricated a-IGZO TFT adopts conventional BCE structure, and the width and length of the channel are 40 μm and 4 μm, respectively.

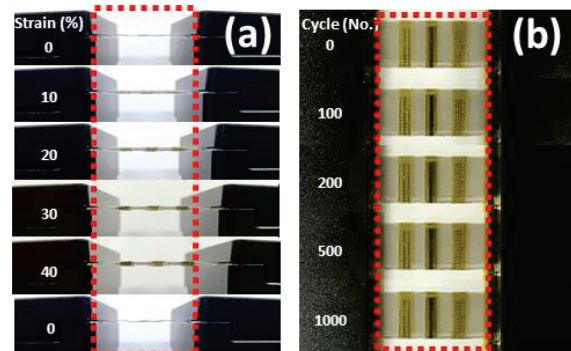


Figure 4. Optical images of (a) stretched state of SEBS up to 40 % with a-IGZO TFTs and (b) repeated tensile test for 1000 cycles at 20 %

Figure 4 shows photograph images of the fabricated stretchable a-IGZO TFT on PI/SEBS substrate. Each image in Figure 4(a) shows that the strain is applied sequentially by 10 % from the initial state to 40 % and then returned to the initial state. Figure 4(b) shows durability of SEBS after 100, 200, 500, and 1000 repeated cycle tests at 20% strain. This tells us that the SEBS could be one of the options for stretchable substrate because of mechanical robustness.

Figures 5(a) and (b) shows transfer and output characteristics of the a-IGZO TFTs when the SEBS was stretched to 40% from the initial state and then returned. Electrical characteristics of a-IGZO TFT at initial state

extracted from transfer curve exhibited threshold voltage

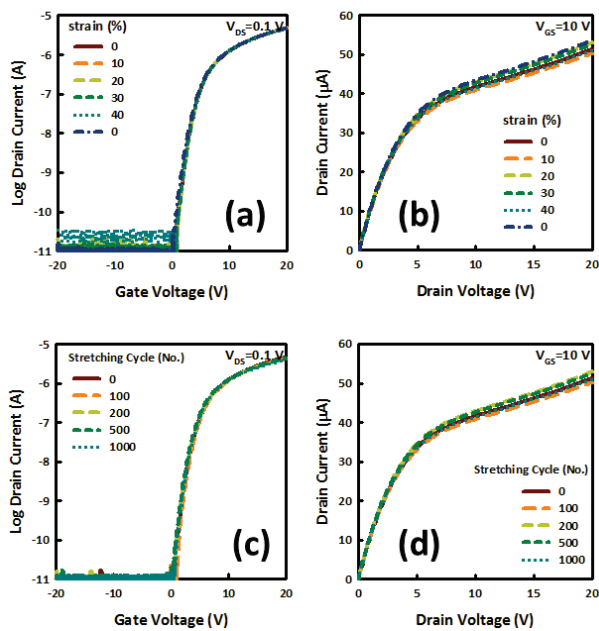


Figure 5. Transfer and output characteristics after (a), (b) stretched up to 40 % and (c), (d) repeated test for 1000 cycles at 20 % strain.

(V_{TH}) of 1.1 V, field-effect mobility (μ_{FE}) of 22.1 cm^2/Vs , and subthreshold swing (S.S) of 0.9 V/decade. Even after stretched up to 40%, V_{TH} , μ_{FE} , and S.S were 1.2 V, 22.1, and 0.91, respectively. This means that stress due to strain applied from SEBS does not have a significant effect on PI substrate. Figures 5(c) and (d) shows the cyclic test results after repeated 1000 times at 20% strain with a-IGZO TFT. Initial V_{TH} , μ_{FE} , and S.S were 1.2 V, 20.9 cm^2/Vs , 1.02 V/decade, respectively, but after 1000 cycles, the electrical properties were slightly changed to 1.1 V of V_{TH} , 16.4 cm^2/Vs of μ_{FE} , 0.89 V/decade of S.S. In this regard, mobility could be affected due to on-current degradation. These results indicate that a-IGZO TFTs on PI/SEBS substrates can be another candidate for stretchable electronics.

4 CONCLUSIONS

We present stretchable a-IGZO TFTs transferred onto SEBS thermoplastic elastomer. By CNTs in SEBS, it could be feasible to easily detachable with low force when peeling off from glass substrate, as well as self-standing property. Also, even CNTs were embedded in SEBS, they showed more than 880% elasticity. The a-IGZO TFTs fabricated on polyimide (PI) substrates were mechanically cut into proper size using laser and transferred onto SEBS substrates. Further, optically clear adhesive (OCA) was used to attach PI to SEBS, and it may be firmly attached even after repeated stretching. The fabricated stretchable oxide TFT showed electrical properties even after 1000 repetitions at 20% strain with small electrical degradations. This stiff island on the stretchable substrate can be

demonstrated to enable wearable electronics.

5 ACKNOWLEDGEMENT

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