

All-Dry Dual-Stencil Lithography for IGZO Thin-Film Transducers

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Summary:

Amorphous indium-gallium-zinc oxide (IGZO) is attractive for active thin-film transducer stacks processed at near-room temperature. Here, dual stencil lithography with alignment was used to fabricate an IGZO thin-film-transistor (TFT) stack, without photoresist or wet etching, with a maximum process temperature of 150 °C. The devices show clear field-effect operation, low gate leakage, and stable transfer characteristics. A preliminary white-light switching test confirms an electrically measurable response, suggesting an all-dry route toward IGZO transducer platforms for processing-sensitive sensor systems.

Keywords: IGZO, dual stencil lithography, all-dry fabrication, thin-film transistor, transducer

Introduction

Emerging sensing systems, such as agricultural or implantable sensors that need to degrade after their lifespan, increasingly require both sensing elements and electronics on processing-sensitive substrates. Amorphous IGZO is attractive for such a system because it can be deposited at room temperature while maintaining a mobility of $10 - 50 \text{ cm}^2 \text{V}^{-1} \text{s}^{-1}$ in amorphous films [1], better than a-Si:H or most of the organic semiconductors. Beyond electronics, IGZO TFTs have also been explored as optoelectronic and chemical sensing elements, suggesting that the same material can contribute to both electronics and sensing [2].

From a processing perspective, solvent-sensitive, swelling-prone, or biodegradable polymeric substrates can benefit from resist-free and wet-etch-minimized fabrication. Stencil lithography offers such a dry-patterning route through direct deposition or etching [3].

In our work, stencil lithography with deposition is used as a dry and resist-free route to create an IGZO-based active stack on a Si substrate. The highest temperature in the entire process reached 150 °C during annealing. Using two sequentially aligned stencils with an alignment accuracy below 5 µm, sputtered SiO₂, sputtered IGZO, and evaporated Ti/Au electrodes were integrated into a TFT configuration. The resulting device shows clear field-effect operation, with a saturation mobility of $4.88 \text{ cm}^2 \text{V}^{-1} \text{s}^{-1}$, a threshold voltage of 9.93 V, and a subthreshold swing of 226 mV dec^{-1} . A proof-of-concept illumination experiment further reveals a distinct white-light-

induced current response from the IGZO channel. This dual functionality indicates that stencil-defined IGZO can serve as a dry-patterned active stack for both transistor and photo-responsive transducer in emerging sensor systems that require low-temperature and solvent-minimized patterning.

Methods

Devices were fabricated on a $2 \times 2 \text{ cm}^2$ p-type Si chip used as the global back gate. A 100 nm SiO₂ gate insulator was RF sputtered with O₂ addition to reduce oxygen-deficient oxide formation [4]. A 10 nm IGZO layer was then RF sputtered through a first SiN_x stencil as shown in Fig.1(a). The stencil-substrate gap was ~1-3 µm, estimated by microscope focus plane. After removing the first stencil, a second stencil was aligned and placed with an alignment accuracy below 5 µm, and 5/50 nm Ti/Au source/drain electrodes were evaporated. The representative transistor has a W/L ratio of 5/50 µm and was annealed in air at 150 °C for 1 h. The stack of fabricated devices is shown in Fig.1(b).

The patterns were characterized by optical microscopy and atomic force microscopy (AFM). Transfer and output characteristics were measured with a semiconductor analyzer. For a preliminary light-response test, V_g and V_d were fixed at 20 V and 5 V, respectively, while a white-light source was manually switched on and off.

Results

Among 4 fabricated devices on the same chip, all of them showed measurable field-effect operation. The representative device in Fig.1(c) has

a clearly defined channel, with IGZO visible between the Ti/Au electrodes. The AFM profiles in both Fig.1(c) and (d) show that the evaporated metal edges are sharper than the sputtered IGZO edges, consistent with the more directional flux during evaporation. The IGZO edge blurring is approximately 1 μm over a 10 nm thickness. Therefore, the channel length is mainly defined by the evaporated source/drain electrodes rather than by the sputtered semiconductor boundary.

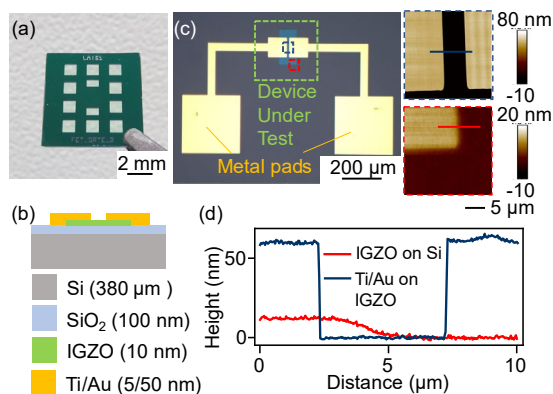


Fig.1. Stencil lithography patterned IGZO device. (a) Stencil chip with alignment marks. (b) Schematic cross-section of the SiO₂/IGZO/Ti/Au stack on a Si substrate. (c) Optical image of the device under test, with AFM scans from the marked regions. (d) Cross-section profiles extracted along the AFM cutting lines.

Fig.2. shows the field-effect operation of the fully stencil-patterned stack shown in Fig.1(c). The device exhibits $V_{th} = 9.93 \text{ V}$, an on/off current ratio of approximately 10^5 , subthreshold swing $SS = 226 \text{ mV dec}^{-1}$, and $\mu_{sat} = 4.88 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$. The gate leakage remains near $10^{-11} - 10^{-10} \text{ A}$, and the forward/backward transfer sweeps nearly overlap. These transfer, output, leakage, and hysteresis characteristics demonstrate that the dual-stencil-defined stack provides a functional transistor-type transducer platform

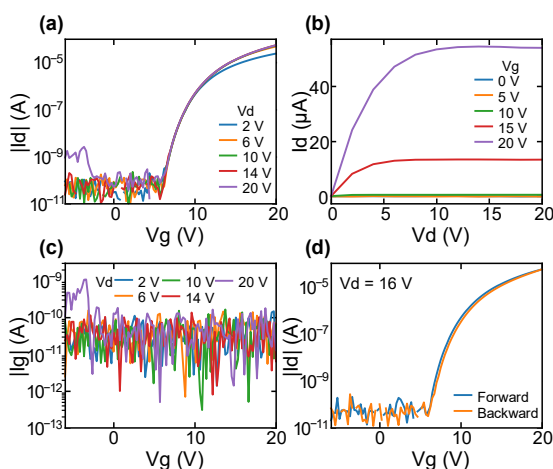


Fig.2. Characteristics of a representative IGZO TFT patterned by stencil lithography. (a) Transfer characteristics at different drain voltages. (b) Output

characteristics at different gate voltages. (c) Gate leakage current. (d) Forward and backward transfer sweeps.

The same IGZO channel also shows a measurable light response, as shown in Fig. 3. Switching on white light increases the drain current, with a relative response of 65-75% calculated as $(I_{light} - I_{dark})/I_{dark}$. After the light is turned off, the recovery contains a fast component and a slower tail, suggesting a persistent photoconductivity (PPC) [5].

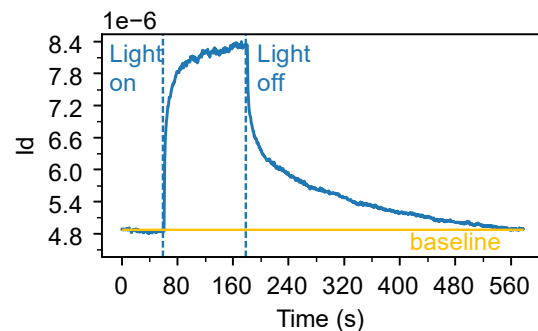


Fig.3. Time-resolved white-light response of the IGZO device patterned by stencil lithography, measured at $V_g = 20 \text{ V}$ and $V_d = 5 \text{ V}$, under white light.

In this work, dual-stencil lithography with alignment was used to fabricate an IGZO TFT device with a maximum thermal budget below 150°C , supporting compatibility with processing-sensitive and biodegradable substrates. The device shows transistor operation and a qualitative response to white-light illumination. Further quantitative measurements are ongoing and will be presented at the conference.

References

- [1] K. Nomura, et al., Room-temperature fabrication of transparent flexible thin-film transistors using amorphous oxide semiconductors, *Nature* 432, 488–492 (2004); doi: 10.1038/nature03090.
- [2] Y. Han, et al., IGZO-based electronic device application: advancements in gas sensor, logic circuit, biosensor, neuromorphic device, and photodetector technologies, *Micromachines* 16, 118 (2025); doi: 10.3390/mi16020118.
- [3] O. Vazquez-Mena, et al., Resistless nanofabrication by stencil lithography: a review, *Microelectronic Engineering* 132, 236–254 (2015); doi: 10.1016/j.mee.2014.08.003.
- [4] S. Suyama, et al., The effects of oxygen–argon mixing on properties of sputtered silicon dioxide films, *Journal of The Electrochemical Society* 134, 2260–2264 (1987); doi: 10.1149/1.2100867.
- [5] K. Park, et al., Endurable IGZO/SnSx/IGZO heterojunction phototransistor arrays for image sensors, *ACS Applied Materials & Interfaces* 17, 3620–3630 (2025); doi: 10.1021/acsami.4c18491.