

## Supporting Information

# Enhancing Proton Irradiation Tolerance of a-IGZO Thin-Film Transistors through Hydrogen Doping

Seongjin Oh<sup>a</sup>, Hwijoong Kim<sup>a</sup>, Jiseong Oh<sup>b</sup>, Hyunjung Kim<sup>b</sup>, Sejoong Kim<sup>c</sup>, Hyun-Seok Cho<sup>a</sup>, Choongik Kim<sup>a\*</sup>

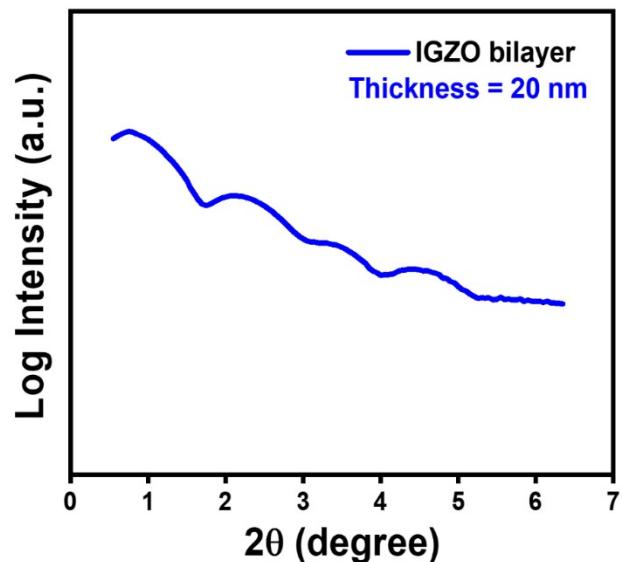
<sup>a</sup> Department of Chemical and Biomolecular Engineering, Sogang University, 35 Baekbom-ro, Mapo-gu, Seoul 04107, Republic of Korea

<sup>b</sup> Department of Physics, Sogang University, 35 Baekbom-ro, Mapo-gu, Seoul 04107, Republic of Korea

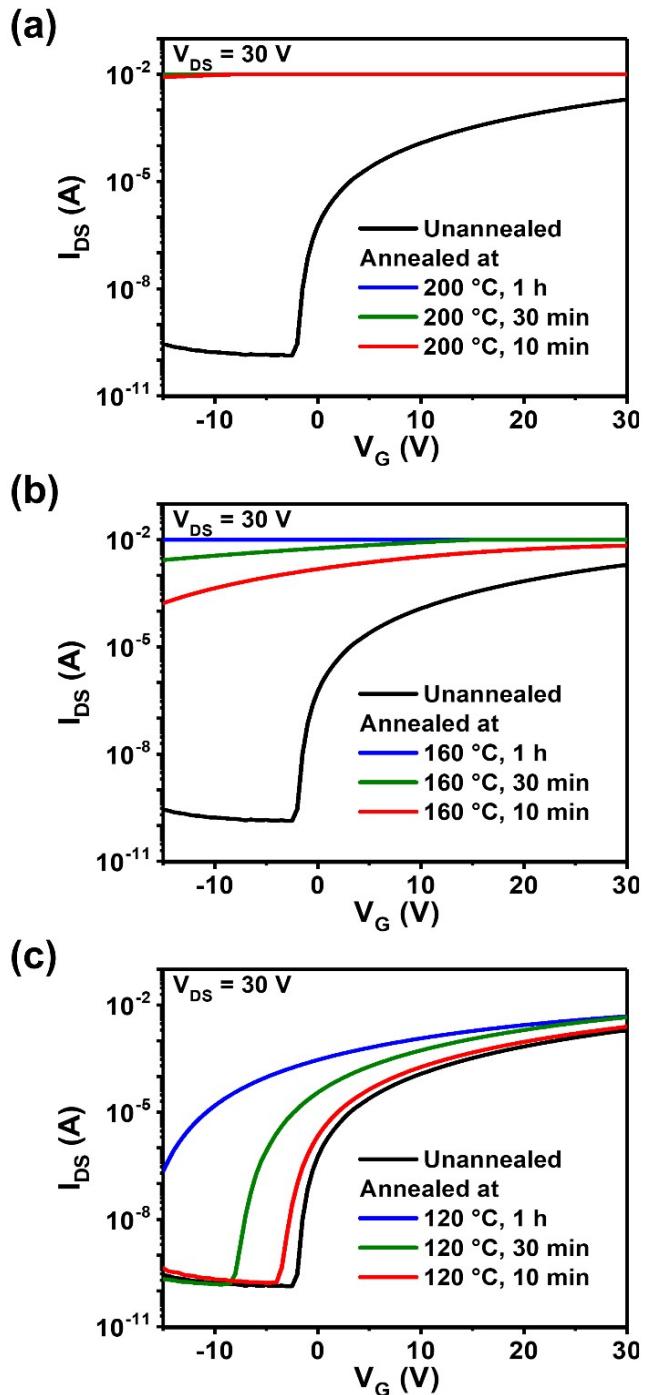
<sup>c</sup> Department of Electronic and Electrical Convergence Engineering, Hongik University, 2639 Sejong-ro, Jochiwon-eup, Sejong 30016, Republic of Korea

\*E-mail: choongik@sogang.ac.kr

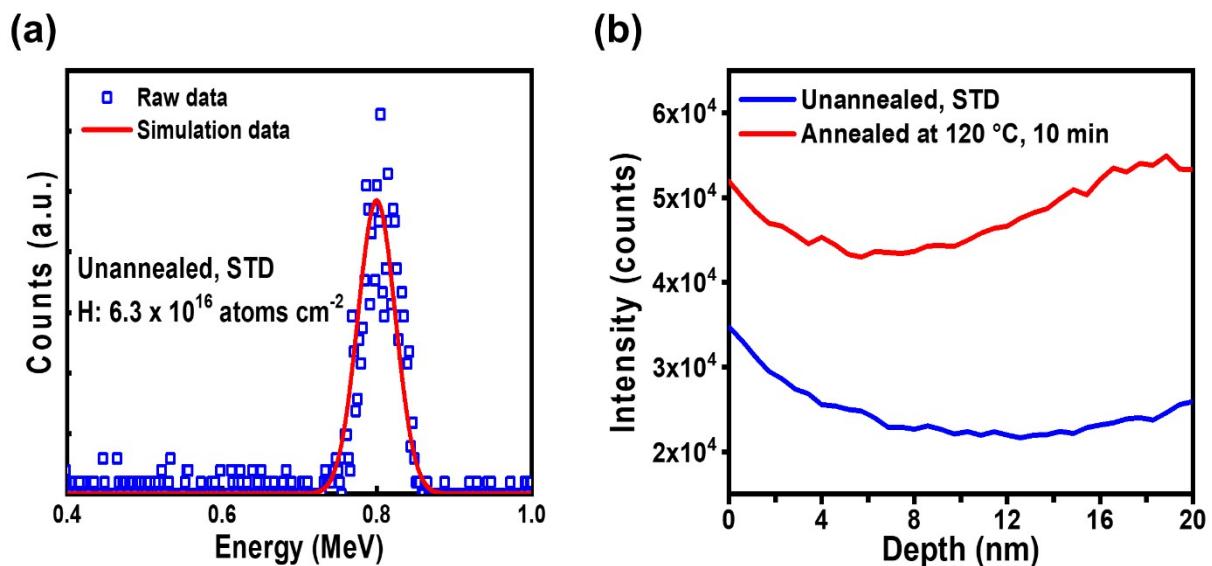
Keywords: indium-gallium-zinc oxide; thin-film transistor; hydrogen doping; proton irradiation; radiation hardness



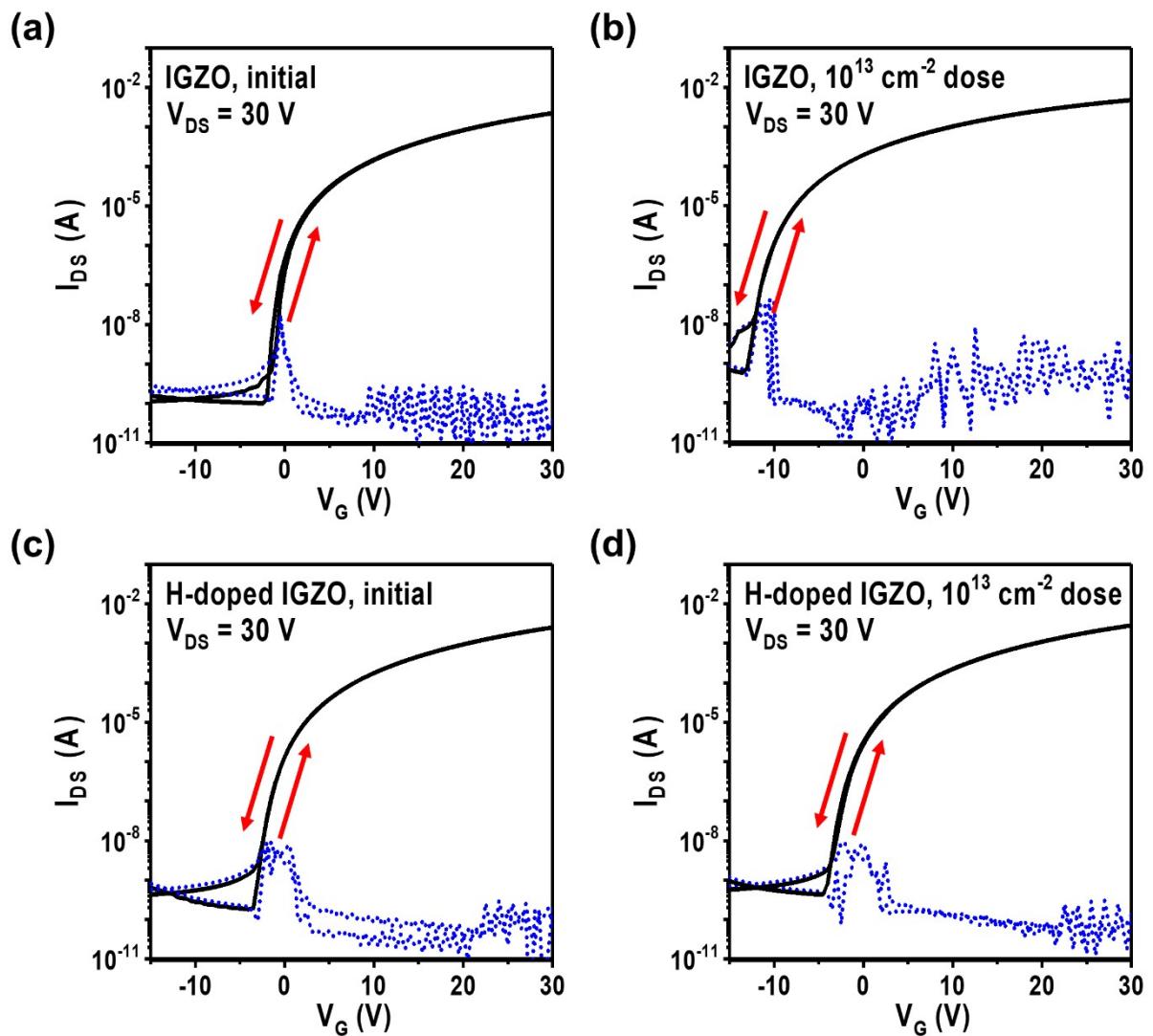
**Fig. S1.** X-ray reflectometry (XRR) of IGZO bilayer thin films.



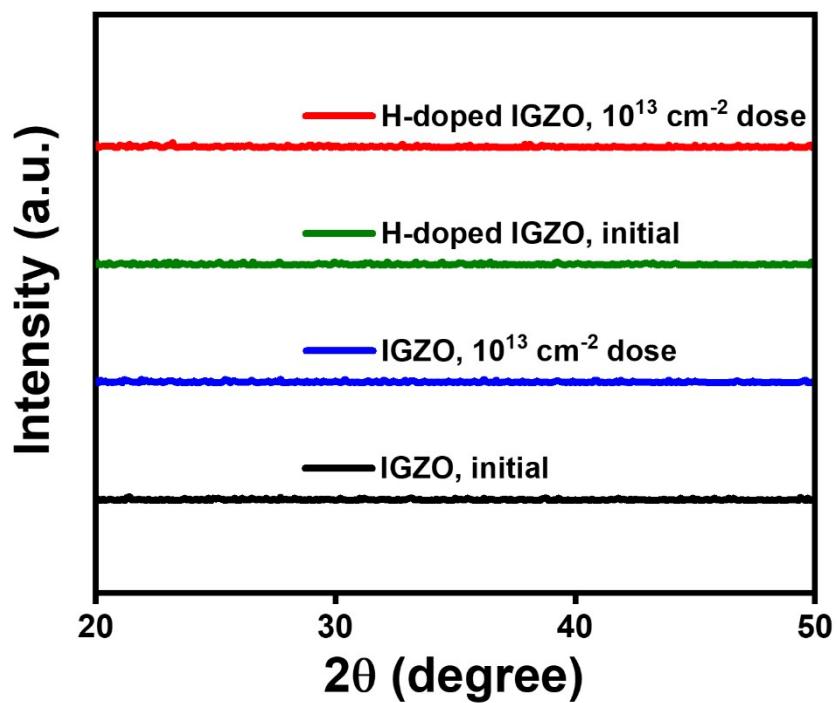
**Fig. S2.** Transfer characteristics of IGZO TFTs before and after post-annealing in a forming gas atmosphere composed of 5%  $\text{H}_2$  and 95% Ar at different temperatures: (a)  $200\text{ }^\circ\text{C}$ , (b)  $160\text{ }^\circ\text{C}$ , and (c)  $120\text{ }^\circ\text{C}$ .



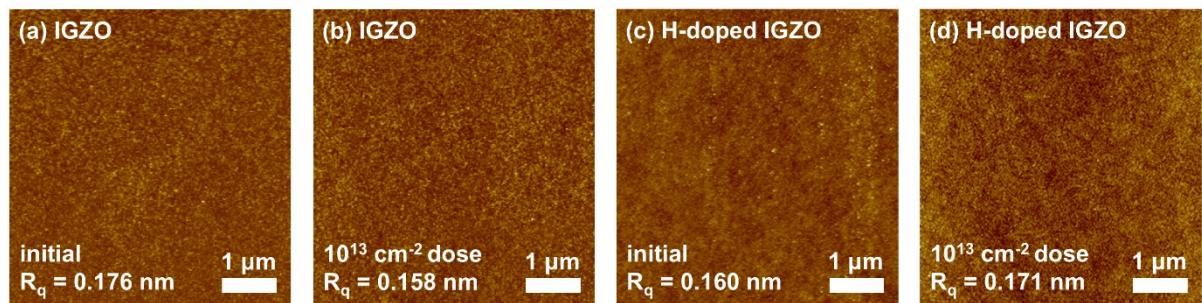
**Fig. S3.** (a) Elastic recoil detection (ERD) spectrum of the unannealed IGZO film used as the standard sample for time-of-flight secondary ion mass spectrometry (TOF-SIMS) hydrogen quantification. (b) Depth-resolved TOF-SIMS hydrogen intensity profiles of unannealed IGZO films and those post-annealed at 120 °C for 10 min.



**Fig. S4.** Bidirectional transfer characteristics of IGZO and H-doped IGZO TFTs under proton irradiation ( $10^{13} \text{ cm}^{-2}$  dose): (a) IGZO TFT before irradiation, (b) IGZO TFT after irradiation, (c) H-doped IGZO TFT before irradiation, and (d) H-doped IGZO TFT after irradiation. The gate leakage current is indicated by the blue line in each transfer curve.



**Fig. S5.** Grazing-incidence X-ray diffraction (GIXRD) spectra of IGZO and H-doped IGZO thin films before and after 5 MeV proton irradiation at a dose of  $10^{13} \text{ cm}^{-2}$ .



**Fig. S6.** Atomic force microscope (AFM) images of oxide semiconductor thin films before and after 5 MeV proton irradiation at a dose of  $10^{13} \text{ cm}^{-2}$ : (a) IGZO before irradiation, (b) IGZO after irradiation, (c) H-doped IGZO before irradiation, and (d) H-doped IGZO after irradiation. The scale bars correspond to 1  $\mu\text{m}$ .  $R_q$  denotes the root-mean-square roughness.