Supporting Information for

Narrower Nanoribbon Biosensors Fabricated by Chemical Lift-Off Lithography Show Higher Sensitivity

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Supplemental Methods

Artificial cerebrospinal fluid (aCSF) was prepared from stock solutions. The 10× base stock contains NaCl (1470 mM), KCl (35 mM), NaH_2PO_4 (10 mM), and $NaHCO_3$ (25 mM) in deionized distilled water. The base stock is aliquoted and stored at room temperature. It is stable for at least one year. **<u>Preparation note:</u>** Neither $CaCl_2$ nor $MgCl_2$ should be added directly to the 10x base stock solution due to their low solubility in aqueous solution at pH >7.5. The Mg^{2+} and Ca^{2+} precipitate as $Mg(OH)_2$ and $Ca(OH)_2$ causing the stock solution to appear cloudy and/or for a visible precipitate to form. Stock solutions of $CaCl_2$ (901 mM) and $MgCl_2$ (1050 mM) in deionized distilled water are each prepared separately. **<u>Safety note:</u>** The addition of $CaCl_2$ or $MgCl_2$ to water is exothermic. Use caution, cold water, and slow stirring when preparing these solutions. The $CaCl_2$ and $MgCl_2$ stocks are aliquoted into 1-mL Eppendorf tubes and stored at -80 °C indefinitely.

Before experiments, the working aCSF solution (physiological concentration, "1×") was prepared. One aliquot each of the $CaCl_2$ and $MgCl_2$ stocks was thawed. Deionized distilled water was added to a beaker at ~80% of the final volume of the working solution. The 10× base stock was added, *e.g.*, 50 mL 10× base stock was added to ~400 mL water for 500 mL final volume of working solution. The pH was initially adjusted to 7.4-7.5 with ~1% HCl. The $CaCl_2$ stock was then added dropwise slowly using a pipette. The working solution was constantly stirred to avoid precipitation for a final concentration of 1.0 mM $CaCl_2$, *e.g.*, 555 µL for a final volume of 500 mL working solution. Next, the $MgCl_2$ stock solution was added dropwise slowly while stirring, for a final concentration of 1.2 mM, *e.g.*, 571 µL for a final volume of 500 mL working solution. The pH of the working solution was adjusted to 7.30 ± 0.03 using ~1% HCl. Finally, the solution was brought to the final volume with deionized distilled water, *e.g.*, final volume 500 mL. The final concentrations of the working aCSF solution (1×) were NaCl (147 mM), KCl (3.5 mM), NaH_2PO_4 (1.0 mM), $NaHCO_3$ (2.5 mM), $CaCl_2$ (1.0 mM), and $MgCl_2$ (1.2 mM). The working solution was stored at 4 °C for ≤2 weeks.

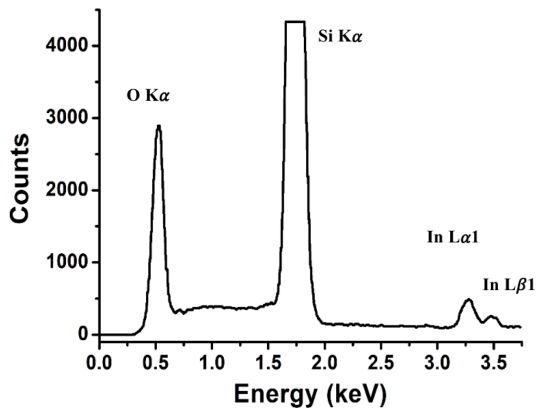

Figure S1. Elemental energy spectrum for In_2O_3 nanoribbons from energy-dispersive X-ray mapping.

Table S1. Elemental quantification analysis of In_2O_3 nanoribbons by energy-dispersive X-ray mapping.

Element Line	Net Counts	Element wt.%	Element wt.% Error	Atom%	Atom% Error
O K	26915	50.60	---	66.48	±0.51
Si L	0	---	---	---	---
Si K	213374	43.30	±0.14	32.40	±0.11
In M	0	---	---	---	---
In L	10378	6.10	±0.26	1.12	±0.05
Total		100.0		100.0	

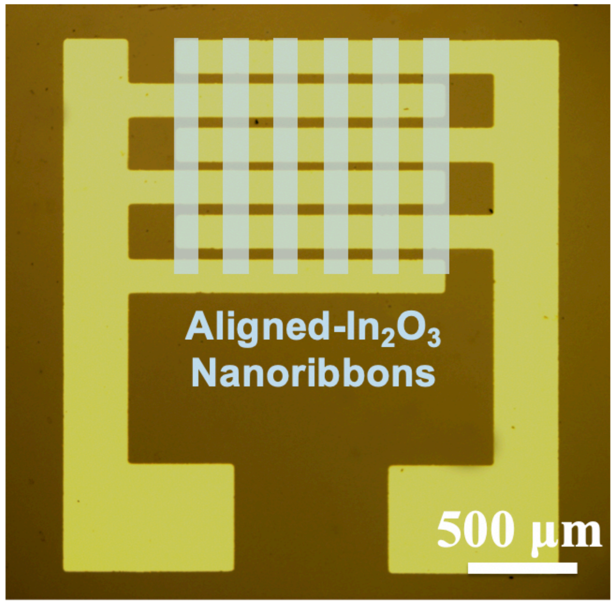

Figure S2. Optical microscope image of interdigitated electrodes (yellow). Orientations of In_2O_3 nanoribbons are depicted in overlay (light blue).

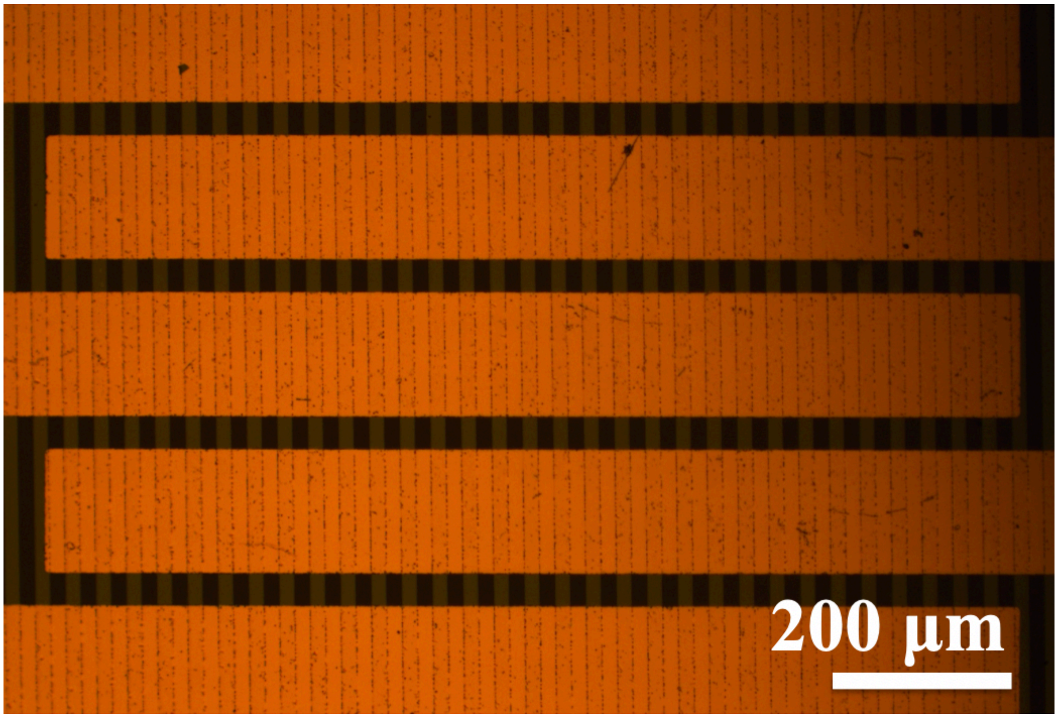

Figure S3. Optical microscope image of 20-µm wide In_2O_3 nanoribbons with source and drain electrodes.

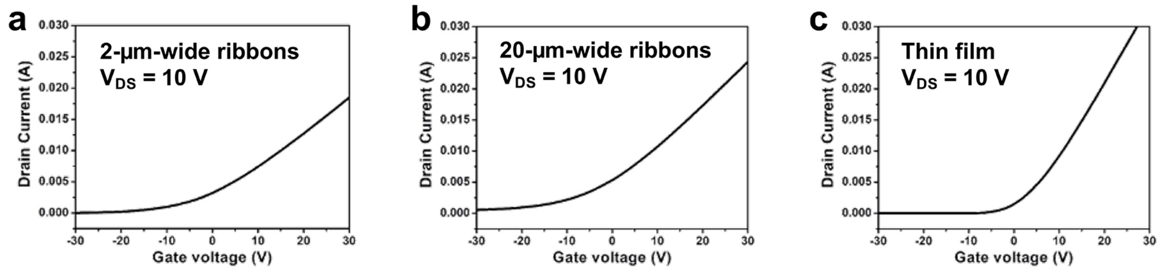

Figure S4. Solid-state transfer characteristics of In_2O_3 FETs with different nanoribbon widths, **(a)** 2 µm, **(b)** 20 µm, and **(c)** thin film.

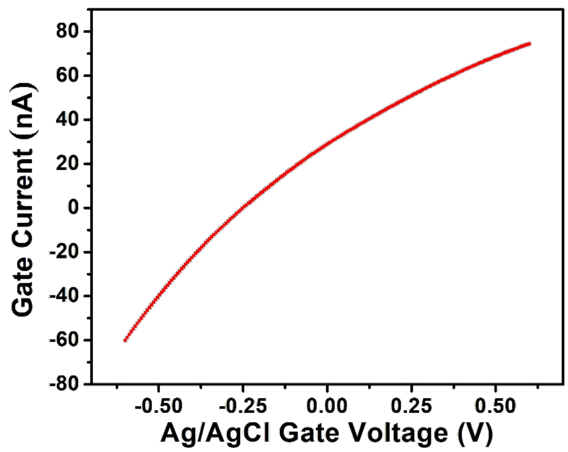

Figure S5. Gate leakage current (gate current to gate voltage) in buffer solution (pH = 7.4) at V_{DS} = 100 mV.

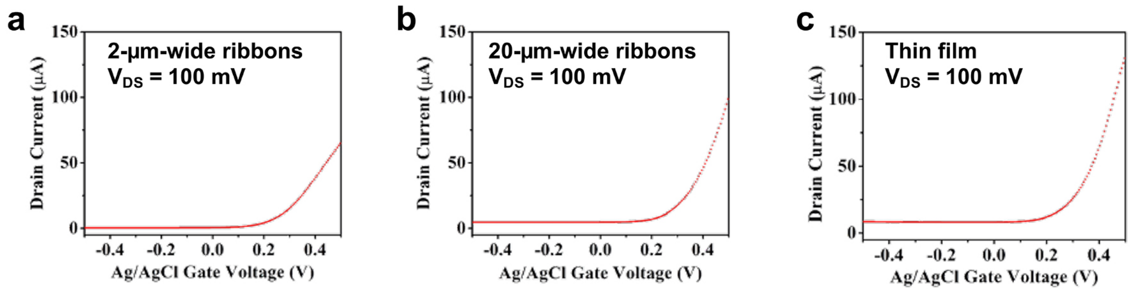

Figure S6. Liquid-state transfer characteristics of In_2O_3 FETs with nanoribbons of different widths, **(a)** 2 μm, **(b)** 20 μm, or **(c)** thin film.

Calculation of surface-to-volume ratios

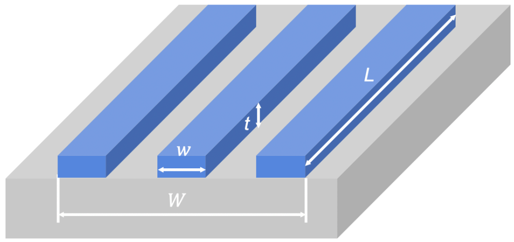

Figure S7. Schematic of nanoribbons for calculation of surface-to-volume ratios.

Consider a nanoribbon array, where the surface-to-volume ratio of an arbitrary area with width W is calculated. For each In_2O_3 nanoribbon, the length is denoted as *L*, width as *w*, and thickness as *t*. The pitch of the nanoribbons is 2*w* for different widths of nanoribbons. For nanoribbon surface area calculations, only the top surface and the two side surfaces are included. Results are summarized in **Table S2**.

Number of ribbons (per arbitrary area): $N = \frac{\mathrm{W}}{2w}$ Eq. 1

Surface area: $S = (w * L) + (2 * L * t)$ Eq. 2

Volume: $V = w * L * t$ Eq. 3

Surface-to-volume ratio (per nanoribbon): $\frac{S}{V} = \frac{w*L+2*L*t}{w*L*t} = \frac{w+2*t}{w*t} = \frac{1+2*\frac{t}{w}}{t}$ Eq. 4

Surface-to-volume ratio (per arbitrary area): $\frac{S}{V} = \frac{(w*L+2*L*t)*N}{(w*L*t)*N} = \frac{(w*L+2*L*t)}{(w*L*t)} = \frac{1+2*\frac{t}{w}}{t}$ Eq. 5

For w_1 = 350 nm:

$$\frac{S}{V} = \frac{1+2*\frac{t}{w}}{t} = \frac{1+2*\frac{20\,nm}{350\,nm}}{20\,nm} = \frac{1+0.11}{20} nm^{-1} = \frac{1.11}{20} nm^{-1}$$

For w_2 = 2 µm:

$$\frac{S}{V} = \frac{1+2*\frac{t}{w}}{t} = \frac{1+2*\frac{20\ nm}{2000\ nm}}{20\ nm} = \frac{1+0.02}{20} nm^{-1} = \frac{1.02}{20} nm^{-1}$$

For w_3 = 20 µm:

$$\frac{S}{V} = \frac{1+2*\frac{t}{w}}{t} = \frac{1+2*\frac{20\ nm}{20000\ nm}}{20\ nm} = \frac{1+0.002}{20} nm^{-1} = \frac{1.002}{20} nm^{-1}$$

For thin-films:

$$\frac{t}{w} \rightarrow 0, \frac{S}{V} = \frac{1+2*\frac{t}{w}}{t} = \frac{1}{20} nm^{-1}$$

Table S2. Surface-to-volume ratios calculated for different configurations of In_2O_3 FETs

Width	Pitch	Thickness	Surface-to-Volume Ratio	Surface-to-Volume Ratio Increase *vs* Thin Film
350 nm	700 nm	20 nm	$\frac{1.11}{20}\ nm^{-1}$	11%
2 μm	4 μm	20 nm	$\frac{1.02}{20}\ nm^{-1}$	2%
20 μm	40 μm	20 nm	$\frac{1.002}{20}\ nm^{-1}$	0.2%
Thin Film	—	20 nm	$\frac{1}{20}\ nm^{-1}$	—

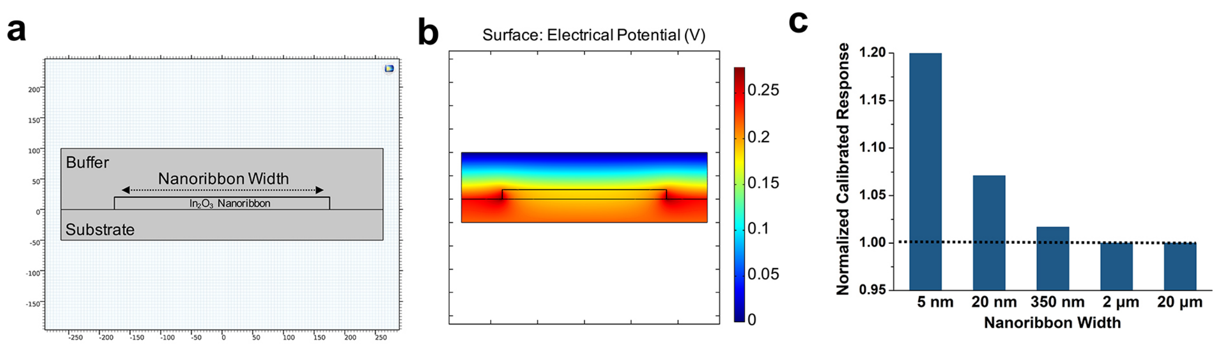

Figure S8. COMSOL simulations of effects of nanoribbon width on surface-to-volume ratio. (a) Model used in the simulation, where nanoribbons are 20-nm-thick with widths varying from 5 nm to 20 µm. (b) Simulation results of the electrostatic potential due to the charge of the biomolecules. (c) Simulated normalized calibrated responses at different ribbon widths showing that the sensitivity of In_2O_3 nanoribbon FETs is predicted to increase at widths below 2 µm. Simulated calibrated response values were normalized to responses for 20-µm microribbons. Simulated responses are not directly comparable with experimental results in the main text due to the nature of the simulation complexity for the semiconductor system under study.

Table S3. Field-effect transistor data were analyzed by two-way analysis of variance with nanoribbon width and target concentration as the independent variables.

Type	Figure	Interaction Term	Nanoribbon Width	Concentration
pH	Fig. 4f	$F_{(5,24)} = 3.395$ $P = 0.019$	$F_{(1,24)} = 13.09$ $P = 0.001$	$F_{(5,24)} = 307.0$ $P < 0.0001$
Serotonin	Fig. 5c	$F_{(5,18)} = 0.375$ $P = 0.859$	$F_{(1,18)} = 4.010$ $P = 0.061$	$F_{(5,18)} = 9.107$ $P = 0.0002$
DNA	Fig. 5f	$F_{(3,10)} = 0.054$ $P = 0.982$	$F_{(1,10)} = 7.293$ $P = 0.022$	$F_{(3,10)} = 1.518$ $P = 0.269$