Fabrication of sub-20 nm Nanopore Arrays in Membranes with Embedded Metal Electrodes at Wafer Scales: Supporting Information

Jingwei Bai[*+], Deqiang Wang[*], Sung-wook Nam, Hongbo Peng, Robert Bruce, Lynn Gignac, Markus Brink, Ernst Kratschmer, Stephen Rossnagel, Phil Waggoner[$], Kathy Reuter, Chao Wang, Yann Astier, Venkat Balagurusamy, Binquan Luan,Young Kwark, Eric Joseph, Mike Guillorn, Stanislav Polonsky, Ajay Royyuru, Satyavolu Papa Rao[#], Gustavo Stolovitzky[#]

1101 Kitchawan Road, IBM T.J.Watson Research Center, Yorktown Heights, NY 10598

* Both authors contributed equally to this work;
+ Current address: Illumina, 5200 Illumina Way, San Diego, CA 92122
$ Current address: Ion Torrent by life Technologies, 246 Goose Lane, Suite 100, Guilford, CT 06437
# Corresponding authors: gustavo@us.ibm.com; sspapara@us.ibm.com

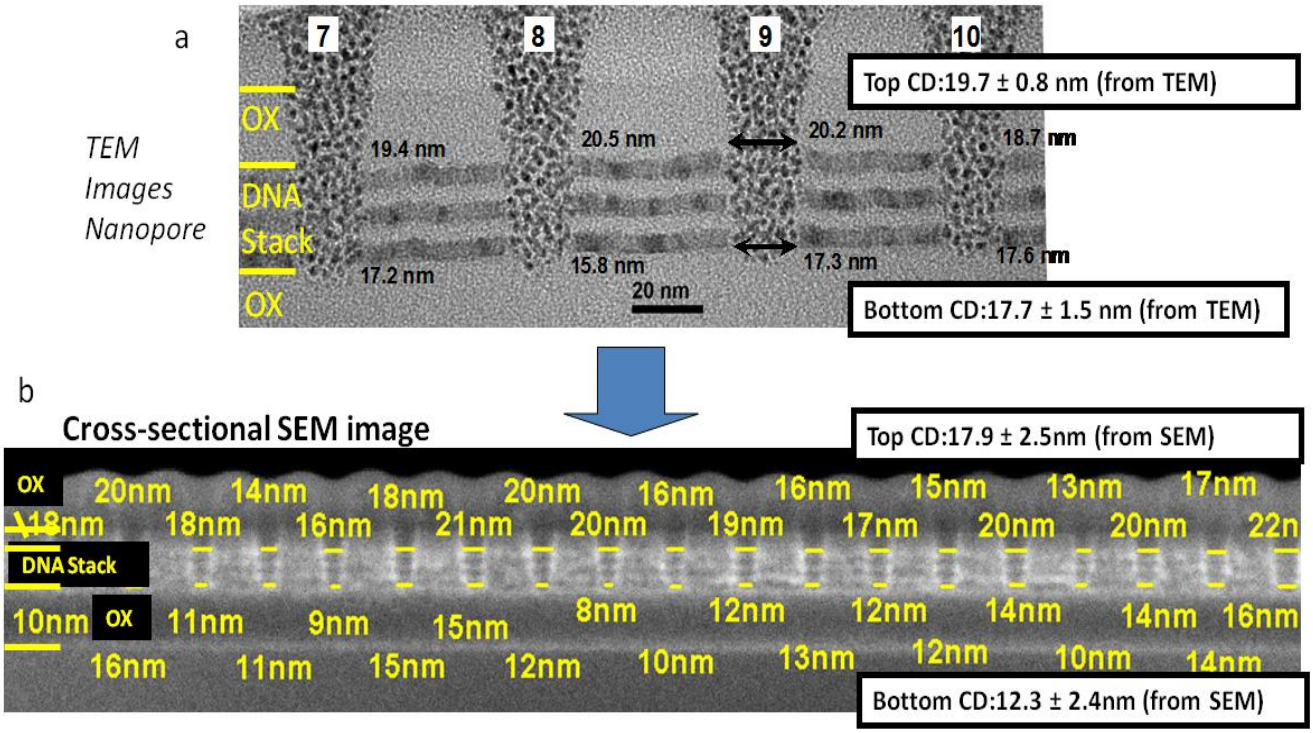

Figure S1. Cross-section of a nanopore array fabricated with the pore-first RIE method. (a) The TEM cross-sectional image shows top CD and bottom CD are about 19.7 ± 1.5 nm and 17.7 ± 1.5 nm, respectively. (b) The SEM cross-sectional image shoes that top CD and bottom CD are about 17.9 ± 2.5 nm and 12.3 ± 2.4 nm, respectively.

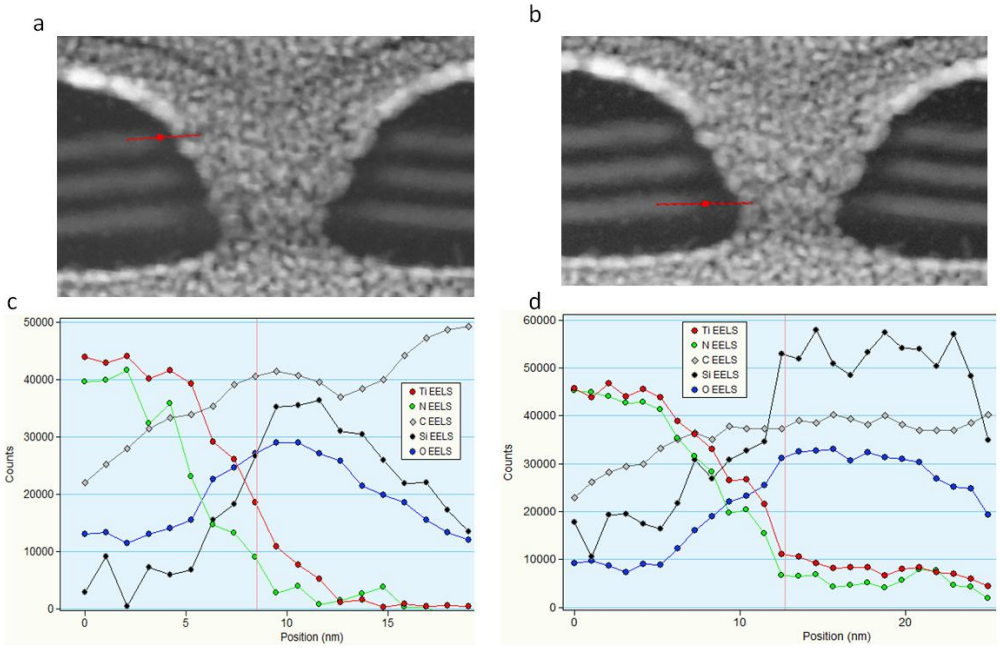

Figure S2. Electron Energy Loss Spectroscopy (EELS) gives the element distribution inside nanopore surface. (a) and (b) are dark field TEM images. (c) and (d) are the EELS analysis results along the red solid line in (a) and (b), respectively. Both shows there were no metal (TiN) found inside nanopore surface.

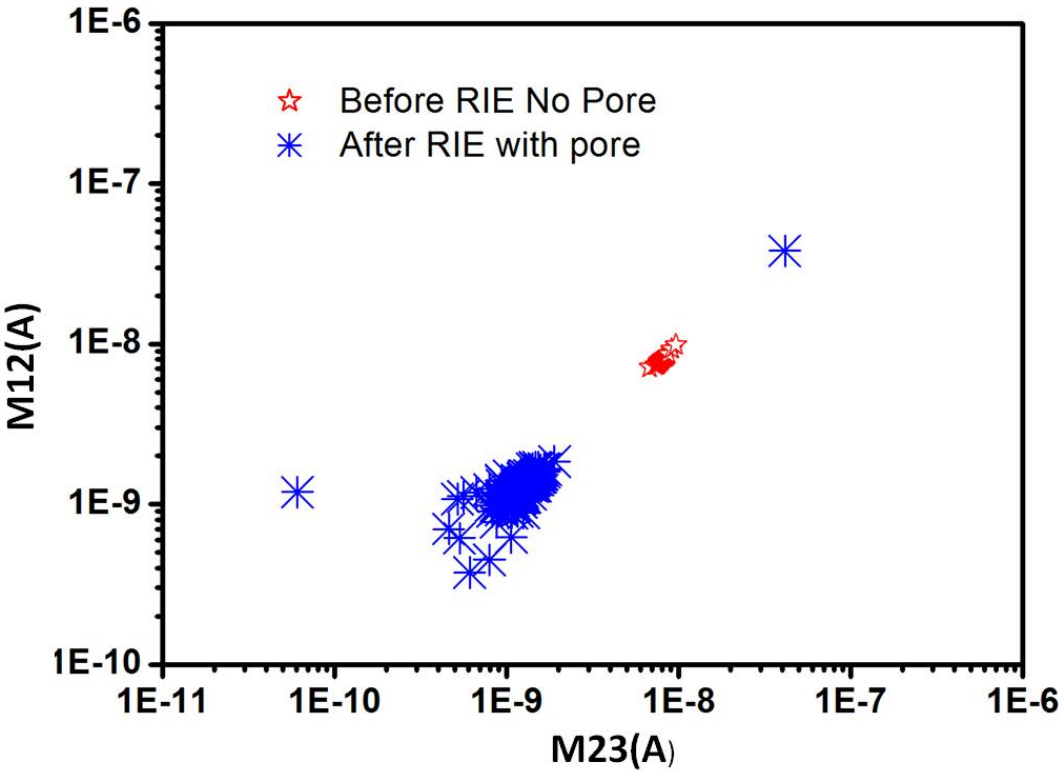

Figure S3. Scatter plot of the electrical current between metal layers before (red, N = 61) and after (blue, N =121) nanopore formation with the pore-first RIE method. These devices have less leakage current after the nanopore was formed with RIE, which indicates that semiconductor process may improve the insulation between metal layers.

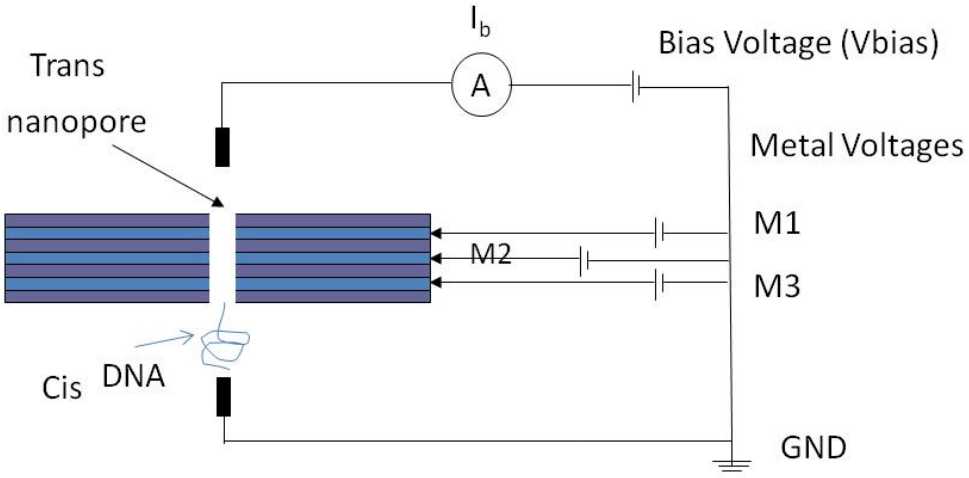

Figure S4. Configuration of translocation experiments. The membrane with a nanopore separates the solution into Cis and Trans sides. The DNA samples is injected into Cis side. The ionic current (Ib) through the nanopore is monitored when a bias voltage is applied across the membrane. The potential of the membrane-embedded metal electrodes can be controlled by external voltages.

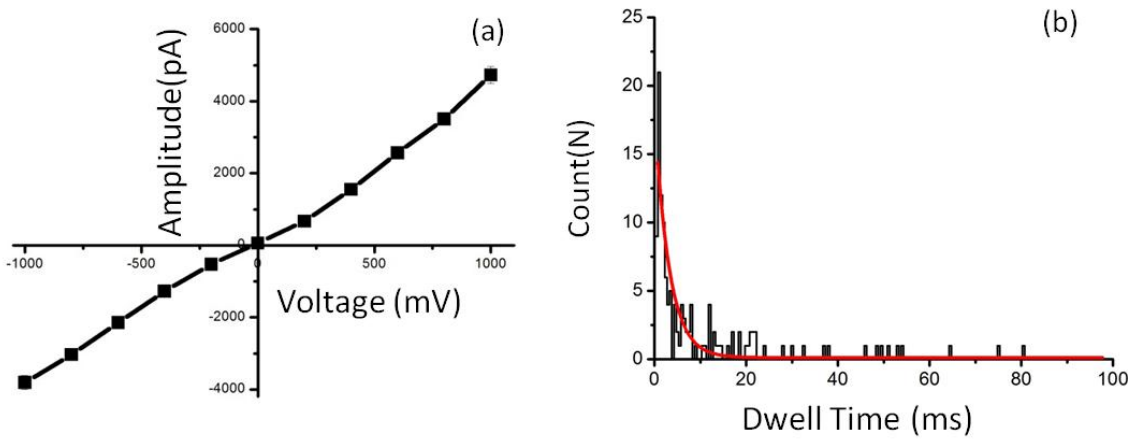

Figure S5 (a) I-V curve for the single solid-state nanopore at 10 mM KCl aqueous and pH 5.5 when the bias voltage swept from -1V to 1V. (b) Zoomed-out histogram of dwell time for dsDNA translocation events (Black--histogram, red--fitting).

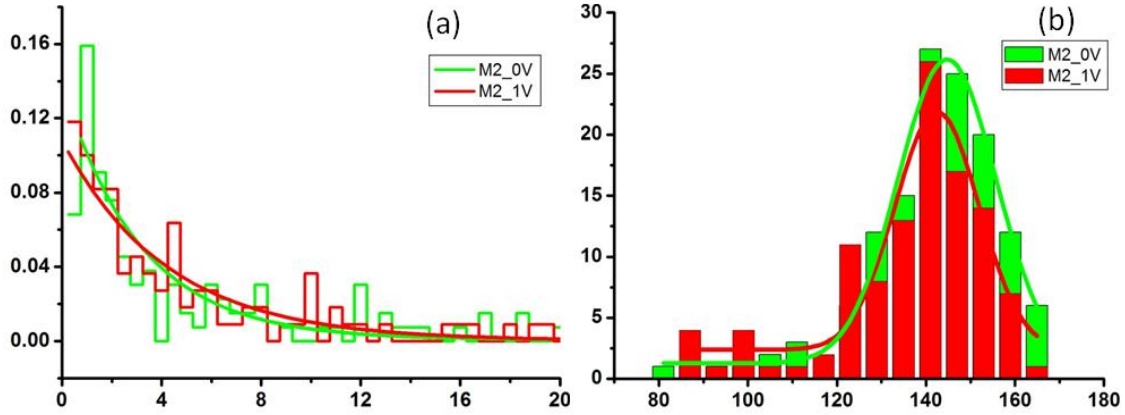

Figure S6. (a) Histogram of dwell times of dsDNA translocation events at 600mV bias voltage and two metal voltages (Green--M2=0V, Red-- M2= 1 V)); (b) Histogram of amplitudes of dsDNA translocation events for the same pore (Green--M2=0V, Red--2= 1 V).

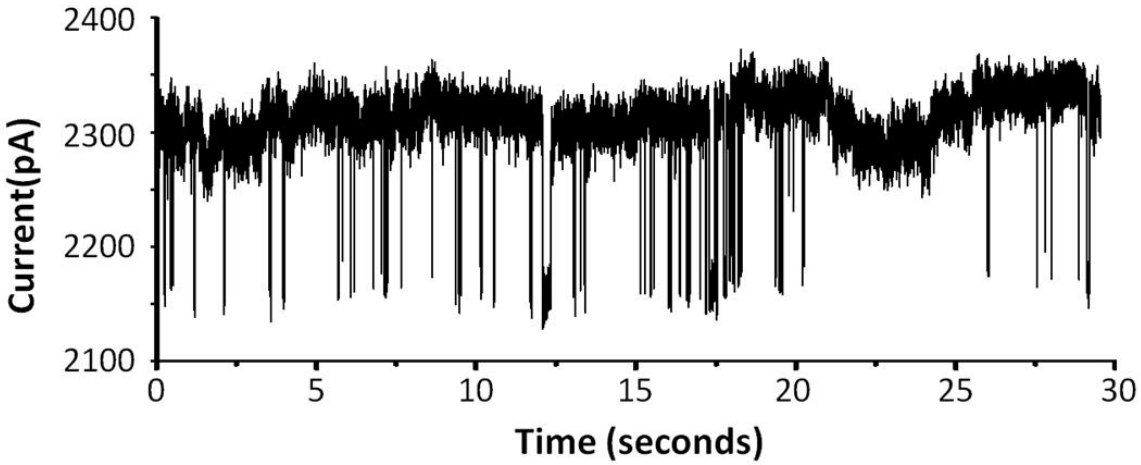

Figure S7. Thirty seconds recording of ionic current from experiments of DNA translocation through a single solid-state nanopore. The nanopore was fabricated using the pore-first RIE method described in the paper. The cis chamber contained 50 nM of dsDNA in an aqueous solution with 10mM KCl . The bias voltage was 600 mV.

Instruments and data analysis

The experiments reported in this paper used chips made on 8-inch wafers (each wafer containing 121 chips) following the semiconductor processes described in the main text. When completed, the wafer was diced into 10 mm by 10 mm single chips for usage in fluidic cells. Each chip used in our experiments had only one nanopore at the center of suspended membrane. The chip is subsequently mounted in a fluidic cell connecting both ends of the nanopore to reservoirs filled with an aqueous electrolyte/DNA solution. Two Ag/AgCl electrodes are immersed into the reservoirs and electronically connect the flow cell to an ionic current measurement setup consisting of a computer controlled patch clamp amplifier (Axon Axopatch 200B, Molecular Devices), and a DAQ card (Digidata 1440A, Molecular Devices). All data is acquired and analyzed at 20 KHz sampling using a 1 KHz low-pass filter. Different setting will be indicated in the text. The setup allows to apply a voltage $V_{cis\ to\ trans}$ to the electrodes generating an electric field between the two reservoirs through the wetted nanopore, threading electrolyte ions and

DNA-molecules through the pore from the cis side, and thus creating an ionic current flow through the nanopore. Every time a DNA-molecule translocates through the pore the monitored ionic current signal shows a distinct peak varying in duration and shape depending on the type of translocation event. The data was analyzed with the software clampfit 10.2 (Axon Axopatch 200B, Molecular Devices).