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# A Novel Side-gated Ultrathin-channel Nanopore FET (SGNAFET) Sensor for Direct DNA Sequencing

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**Abstract**

A novel side-gated ultrathin-channel nanopore FET(SGNAFET), for fast and label-free DNA sequencing with high resolution and sensitivity, is proposed. The goal of the SGNAFET is to identify the four types of nucleotides in DNA by changes in the channel current of the SGNAFET. Aiming to reach that goal, a SGNAFET with channel thickness ($t_{ch.}$) of 2 or 4 nm was successfully operated.

**Introduction**

“Nanopore” technologies have a potential to achieve single-molecule DNA sequencings with high throughput at low cost, and many sequencing methods have been proposed [1-8]. Especially, nanopores formed from semiconductor-related materials [4-8] have advantages in terms of robustness and possible large-scale integration. It has recently been reported that DNA translocation through a nanopore modulates the current in a silicon nanowire beside the nanopore, which suggests a potential for DNA sequencing with FET-based detections [7]. In this study, to advance FET-based DNA sequencing, a novel SGNAFET sensor is proposed and demonstrated. Ultrathin channels will enable high spatial resolutions, and side-gate voltages can control the optimum current in the channel of each sensor during detections.

**Concept of SGNAFET**

The proposed sensor is shown schematically in Fig. 1. A nanopore is located between a control gate (CG) and the channel. CG voltage is applied, and channel current ($I_D$) is generated in the vicinity of the edge of the channel close to the nanopore, leading to high sensitivity, and $I_D$ changes according to the effective charges produced by each nucleotide of DNA in the nanopore. The spatial resolution is determined by the channel thickness, and the state that only one carrier exists in the thickness direction is desirable. When $t_{ch.}$ is less than 5 nm, the Coulomb energy between two electrons in silicon exceeds $k_B T$ at room temperature, and a two-dimensional carrier system starts to be constructed. Accordingly, a SGNAFET with $t_{ch.}$ of 2 and 4 nm was fabricated.

**Device structure**

A TEM image of the SGNAFET is shown in Fig. 2. The nanopore is fabricated with focused electron beam etching via TEM and located close to the channel to maximize the sensitivity of the sensor. The diameters of the nanopores are typically 4 to 9 nm.

**Experimental results and discussions**

$V_{CG}$-$I_D$ characteristics of the SGNAFET before and after formation of the nanopores are shown in Figs.3 and 4. By annealing the SGNAFET in hydrogen atmosphere to cure the defects caused by the irradiation by TEM, stable operations of both p-type and n-type SGNAFETs were confirmed after formation of nanopores..

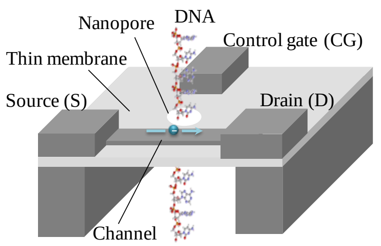


Fig. 1. Schematic diagram of SGNAFET.

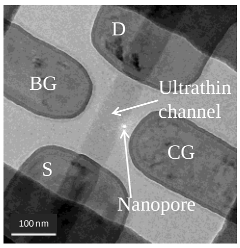


Fig. 2. TEM image of SGNAFET.

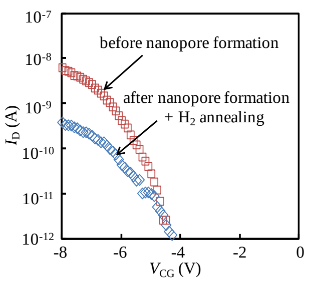


Fig. 3. $V_{CG}$-$I_D$ characteristics of p-type SGNAFET before and after nanopore formation. $t_{ch.}$ = 4 nm.

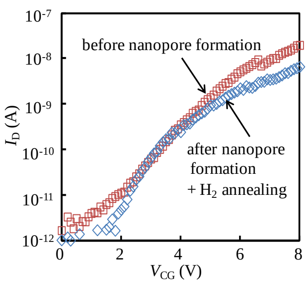


Fig. 4. $V_{CG}$-$I_D$ characteristics of n-type SGNAFET before and after nanopore formation. $t_{ch.}$ = 4 nm.

**References**:[1] Bala Murali Venkatesan, *et al*., *Nature Nanotech*. 6, 615-624 (2011) [2] J. Clarke, *et al*., *Nature Nanotech*. **4**, 265-270 (2009) [3] Elizabeth A Manrao, *et al*., *Nature Biotech*. **30**, 349-353 (2012) [4] S. Garaj, *et al*., *Nature* **467**, 190-193 (2010) [5] Kimberly Venta, *et al*., *ACS Nano*, **7** (5), pp 4629–4636 (2013) [6] Makusu Tsutsui, *et al*., *Nature Nanotech*. **5**, 286 - 290 (2010) [7] P. Xie, *et al*., *Nature Nanotech*. **7**, 119-125 (2012). [8] R. M. M. Smeets, *et al*., *Nano Lett.* **6**, 89-95 (2006)