TRIBOELECTRIFICATION DRIVEN FIN-FACT (FLIP-FLOP ACTUATED CHANNEL TRANSISTOR) FOR SECURITY APPLICATION

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ABSTRACT

A silicon-nanowire (Si-NW) switch with triboelectricity is proposed for the first time for future electronics with enhanced security application. The dimensions of the mechanical NW switch are width 50 nm and thickness 100 nm with a 50-nm-thick airgap, fabricated with aid of CMOS fabrication technology. By hand-touch on gate pad, the fabricated switch can turn-on as well as turn-off by destruction of fin-channel which comes from electrostatic force by triboelectricity. This technology is expected as a security-enhanced future electronics.

INTRODUCTION

At present, the potential to harvest mechanical energy from the ambient environment is attracting interest due to the ubiquitous and abundance of such a source. Thus far, various energy harvesting technologies for scavenging mechanical energy have been developed based on piezoelectrics, and electromagnetics, which have some drawbacks for use in real application [1]. As an alternatives of them, a recently invented triboelectric nanogenerator (TENG) has provided an effective approach to convert mechanical energy into electrical energy, based on the conjugation of two physical phenomena, triboelectrification (also known as contact-electrification) and electrostatic induction [2]. The triboelectricity has been usually considered as an uncomfortable phenomenon because it often brings breakdown of electric circuits, discomforts of human, and fires in natures. However, if triboelectricity is well-controlled in a rationally designed energy harvesting device, such strong power of triboelectricity can be an effective energy harvesting source. The triboelectric energy harvester, which is also called triboelectric nanogenerator, intentionally generates strong triboelectricity and uses it to current driving source.

So far, many researcher have studied MOSFET-based devices as well as focused on the miniaturization of these devices. However, scaling down of MOSFETs has recently been retarded by short-channel effects such as fundamental limit of the subthreshold slope and off-state current increase, thus it is required novel devices in order to solve these issues. In this regard, the nano electro-mechanical (NEM) switch device has been highlighted as one of the most potential alternatives to overcome the shortcomings of MOSFETs due to its off-state current of nearly zero and its low sub-threshold slope below 60 mV/dec. However, several critical issues related to NEM switching devices, such as their unacceptably high operation voltage, stiction, and poor compatibility with the conventional CMOS technology. Among various NEM switching devices, the fin flip-flop actuated channel transistor (Fin-FACT) has advantages due to its CMOS-compatible fabrication process and the mitigation of Joule heat. However, Fin-FACT requires high operation voltage which is a chronic problem associated with typical NEM switching devices [3,4].

In this paper, we demonstrate a novel NEM switching device which operated by triboelectrification. By hand-touch on pad, we can turn-on switch without applying an external voltage. Subsequently, by hand-touch on another pad, this NEM switch is self-destructed if it is required to erase data. This suggested NEM switching device show its potential as a security application.

WORKING PRINCIPLE

The triboelectric effect is a type of contact electrification in which certain materials become electrically charged after they come into contact with another different material through friction. When two

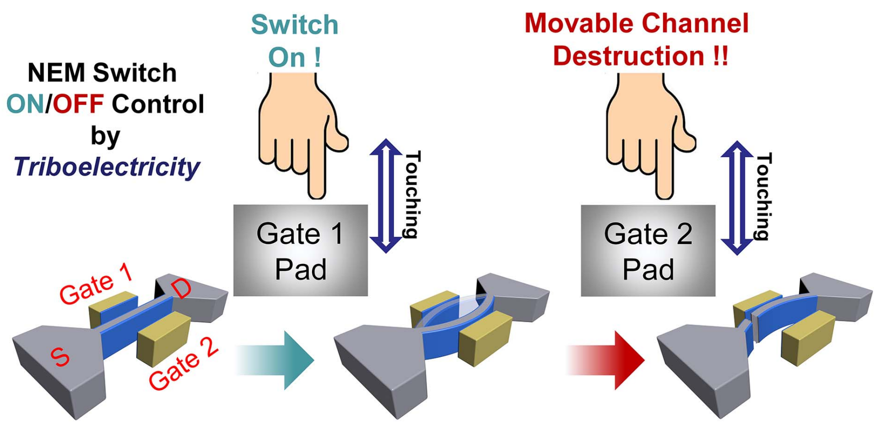

Figure 1: Illustrated schematic for NEM switch ON/OFF control process by use of triboelectricity. Fin channel in initial device can be movable when hand touch on gate 1 occurs. Then fin channel is attached to gate 1 and switch turns on. Then, when hand touch on gate 2 occurs, fin channel is under destruction by electrostatic force which comes from triboelectricity.

different materials are pressed or rubbed together, the surface of one material will generally steal some electrons from the surface of the other material. The material that steals electrons has the stronger affinity for negative charge of the two materials, and that surface will be negatively charged after the materials are separated. Materials are often listed in order of the polarity of charge separation when they are touched with another object. A material towards the bottom of the series, when touched to a material near the top of the series, will acquire a more negative charge. The farther away two materials are from each other on the series, the greater the charge transferred. Structure of the device is composed two parts (Fig.2).

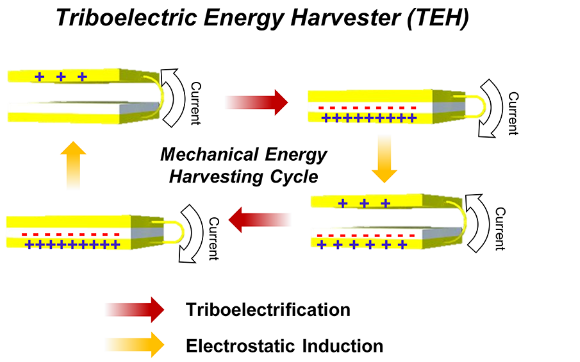

Figure 2: Operation principle of a triboelectric energy harvestor (TEH). TEH shows several features. Particularly, TEH generates higher output voltage than any other energy harvesting methods.

Top part is composed of a single metal layer, and bottom part is composed of a dielectric-metal double layer. Polymer is widely used for the dielectric material due to its flexibility and strong triboelectricity. When top metal and bottom polymer layer contacts, contact surface at the polymer part is negatively charged while the other surface at the top metal part is positively charged. Then the surfaces are separated apart, and then force equilibrium is broken. In this situation, as explained before, negative charges at the polymer surface are fixed in its position, while positive charges at the top electrode redistributes. If separation distance is far enough, the negative charges at the polymer now bring counter positive charges at the bottom electrode. Therefore, most of the positive charges in the top electrode flow to the bottom electrode, and this charge flow generates induced current. When the surfaces are contacted again, now negative triboelectric charges in polymer bring counter positive charges to the top electrode, then current flows back in reverse direction. The mechanical energy to make contact and separation is converted into the electrical energy.

FABRICATION OF FIN-FACT

The Si-NW NEM switch was fabricated by top-down technology. A silicon-on-insulator (SOI) substrate with 100 nm top silicon and 140 nm buried oxide was used. A 50 nm Si_3N_4 layer was deposited as an etch stopper during subsequent chemical–mechanical polishing (CMP). A NW with a width of 50 nm was patterned and clamped at both ends (Fig. 3).

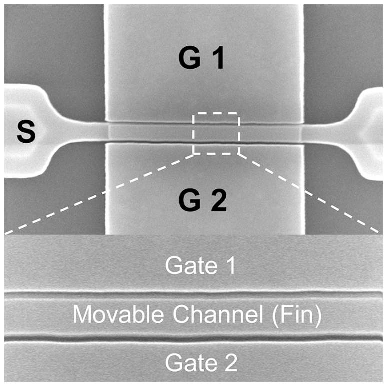

Figure 3: Top-view image of fabricated Fin-FACT using SEM. The magnified SEM image is also obtained for verification of thickness of movable Si-channel.

To achieve horizontal actuation, a rectangular NW with a width smaller than the height is preferred. In other words, a NW with an aspect ratio larger than 1 is desirable but not essential. The cross-sectional aspect of the NW was thus designed with height 100 nm and width 50 nm. A conformal deposition of 30 nm SiO_2 was carried out. This SiO_2 layer later served as a sacrificial layer, which determined the thickness of the air gap. In situ doped poly-Si was deposited and separated by CMP. The poly-Si was then patterned to later serve as a landing electrode. The length of the poly-Si was 500 nm. Next, the sacrificial SiO_2 was completely removed and the buried oxide underneath the NW was partially recessed by diluted HF solution. Then, the NW was then fully surrounded by gas (Fig. 4).

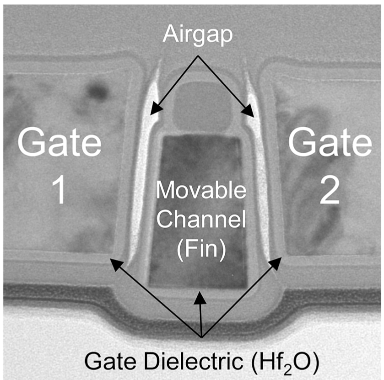

Figure 4: Cross section image of Fin-FACT by use of TEM. Airgap and thickness of gate dielectric is 50 nm and 30 nm, respectively.

Subsequently, an in-plane suspended NW was formed. The NW was centered between two adjacent poly-Si electrodes, and thus the grounded NW could be attracted and displaced to a stable position according to the force balance between the electrostatic attraction energy from the landing electrode and the elastic restoring energy of the NW.

RESULTS AND DISCUSSION

The fabricated device is connected to the electrometer (Keithley6514) for measuring open-circuit voltage (V_{OC}). It was also connected to the low-noise amplifier (SR570) to measure the short-circuit current (I_{SC}). Thereafter, the short-circuit charge transfer (Q_{SC}) was extracted by integration of I_{SC} with respect to duration time (Fig. 6).

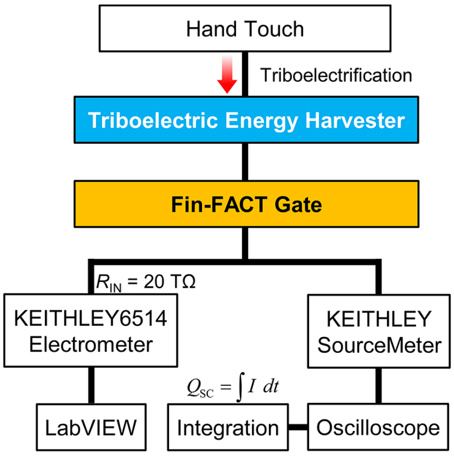

Figure 6: Diagram of experimental set-up for characterization of the fabricated Fin-FACT.

To confirm the electrostatic effect of Si-NW movement in Fin-FACT, FEM simulation was conducted for visualization of electric potential and displacement change (Fig. 5).

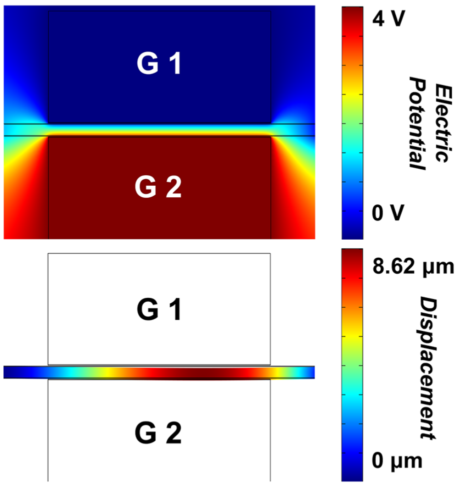

Figure 5: FEM simulation of electric potential and displacement at movable fin channel is demonstrated when gate bias is applied.

Two mechanical states of the Fin-FACT was electrically characterized (Fig. 7). The Si-NW is located at the center, thereby remaining straight in the initial state. After a hand-touch on gate 1 (G1) takes place, the Si-NW come into contact with G1 for bit '1'. Otherwise, a hand-touch on gate 2 (G2) occurs, then, Si-NW is detached from the G1. We expected that detached Si-NW is attached to G2, but this Si-NW was destructed due to its inherent modulus. Hence, no current flows through the Si-NW so that this device cannot work at all.

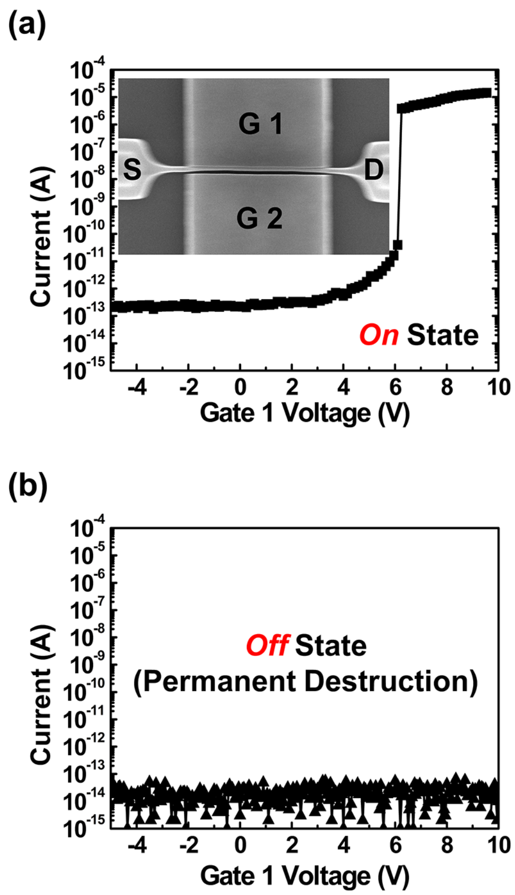

Figure 7: Electrical characteristics of NEM switch in two states. (a) Drain current according to gate voltage for switch turn-on. (b) Drain current according to gate voltage for destruction of movable fin channel.

CONCLUSIONS

In summary, a Si-NW switching device was proposed for future security electronics. The dimensions of the fabricated switching device are width of 50 nm, thickness of 100 nm, and air gap of 30 nm, respectively. In addition, by using triboelectricity, high-output voltage can be applied to the fabricated switching device which requires high input voltage to operate switching behavior. Therefore, this switching device can turn-on and -off without no external power, because flip-flop operation is accomplished through balance between the electrostatic force and the elastic force by triboelectricity. It is expected that this Si-NW switching device could be exploited for mobile security electronics.

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