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A Novel Thin-film Transistor with Suspended Nanowire Channels and Side-gated Configuration

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1. Introduction

Nanowires (NWs) show great potential in various applications to many areas, including thin film transistors (TFTs), nano-scale CMOS, memories, and sensors of biological or chemical species [1]. Recently, we have proposed a new poly-Si nanowire-channel thin-film transistor with side-gated configuration [2, 3]. The device fabrication is very simple and requires no advanced lithographic tools (i.e., deep UV steppers or e-beam writers) to generate the NWs. In this work we further propose a novel TFT structure which features suspended NW channels. Interesting hysteresis phenomenon with large window is observed in the transfer characteristics of the fabricated devices, indicating the action of the suspended channels.

2. Device Fabrication

Figure 1 shows the key device fabrication steps. After the definition of an *in situ* doped n^+ poly-Si gate electrode on a 6-in. Si substrate capped with a 250nm thermal oxide [Fig.1 (a)], a 25nm SiN layer and a 50 nm tetraethylorthosilicate (TEOS) oxide layer were deposited by LPCVD. The TEOS oxide layer served as a sacrificial oxide that would be removed later. An amorphous silicon (a-Si) layer was then deposited by LPCVD at 550 ℃ and transferred into poly-Si by a solid-phase crystallization (SPC) treatment executed at 600 ℃ in N_2 for 24 hours [Fig.1(b)]. Next, source and drain (S/D) were defined by photolithography and then etched by reactive ion etching (RIE) for forming the sidewall NWs [Fig.1(c)]. Afterwards the NW channels were masked by a photoresist layer, followed by the S/D doping with P_{31}^+ ion implantation with a dose of 5×10^{15} cm^{-2} at 15keV [Fig.1(d)]. After the post-implant annealing step, the sacrificial TEOS oxide was selectively etched by BOE to free the suspended NW channel [Fig.1 (e) (f)]. Device characteristics were characterized by an HP-4156 parameter analyzer.

3. Results and Discussion

Figure 2 displays the top-view SEM images of a fabricated device, from which the *suspended* NW channel can be observed and the thickness of air-gap is around 57nm. Fig.3 shows the transfer characteristics of a device without stripping the TEOS oxide [NWs are not suspended, Fig.1(c)]. In the measurements the gate voltage was swept forward from -2V to 10V, and then backward from 10 to -2V. Threshold voltage (Vth) and subthreshold slope (SS) for the forward sweeping are 5.8V and 1312 mV/dec, respectively. Also can be seen is the hysteresis phenomenon. The origin of the hysteresis is related to the electron trapping and de-trapping processes associated with the traps contained in the poly-Si channel [4]. However, the difference in Vth between the forward and reverse sweeping is small (~0.4V).

Fig.4 shows the transfer characteristics of a device with suspended NW channels [Fig.1(e)]. As compared with Fig.3 (see Table 1), Vth (3.62V) and SS (309 mV/dec) of the forward sweeping is significantly reduced, although the nominal equivalent oxide thickness (EOT) of the gate dielectric of the device is much larger (due to the air gap). Besides, a large hysteresis window (2.7V) is recorded in this case. These phenomena are clearly related to the action of the suspended channels during operations.

Figure 5 illustrates the operation principles of the suspended NW-channel devices. In the beginning, the NWs and gate dielectric are separate as shown in Fig.5 (a). When the gate voltage increases, electrons tend to be induced in the suspended NW channel [Fig. 5(b)] and result in an attractive electric force between the channel and the gate. The suspended channel thus would be pushed toward and eventually in contact with the gate. However, the contact action would happen first at the central portion of the channel, as shown in Fig.5(b). The contact region would widen as the gate voltage further increases (Fig.5(c)). In the reverse sweeping, most of the channel would remain contact with the gate until the gate voltage is sufficiently low to turn off the device and release the electrons induced in the channel.

Unlike the former works [5][6], there is no clear and abrupt switching phenomenon, i.e., SS ~ 0, in Fig.4. Note that the devices characterized in the previous works were with a suspended gate, rather than a suspended channel as the devices featured in this study. Owing to the gradual contact of the suspended NW channel with the gate as explained in Fig.5, the abrupt switching would not be clear.

4. Conclusion

A new TFT structure with suspended NW channels has been proposed and successfully demonstrated. The devices feature a side-gate configuration and suspended NW channels which are formed by striping off a sacrificial oxide layer between the NW channels and the gate capped with a nitride layer. The fabricated devices show hysteresis behavior in the transfer characteristics with a large window of 2.7V. A model considering the gradual contact of the NW channels with the gate due the induced electric force is proposed to describe the experimental observations.

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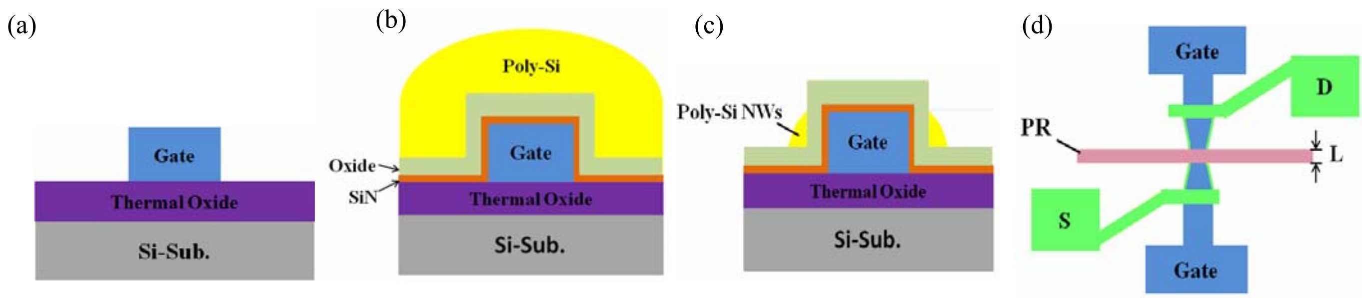

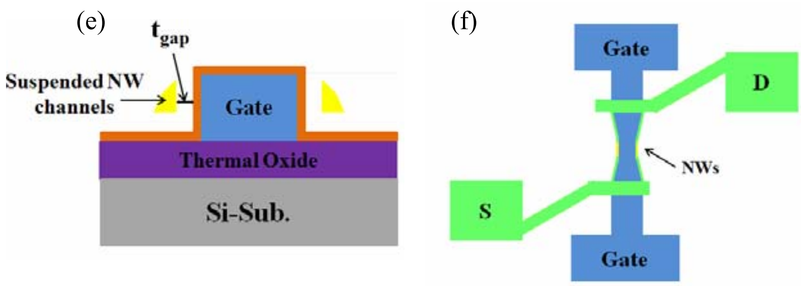

Fig. 1 Key process flows of suspended NW channel TFT.
(a) Bottom gate patterning.
(b) N/O/a-Si films deposition.
(c) NWs formation.
(d) S/D implantation with the masked channel (Top View).
(e) Air gap formation.
(f) Top View of the suspended NW channel TFT.

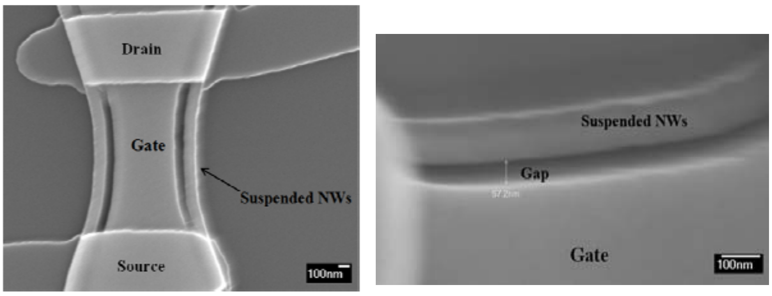

Fig. 2 SEM images of the fabricated suspended NW channel TFT.

	Gate dielectric	Nominal EOT (nm)	SS (mV/decade)	V_{th}(V)
Conventional device	50nm oxide and 25nm SiN	63	1312	5.8
Suspended NW channel device	50nm air and 25nm SiN	208	390	3.62

Table 1. Summary of nominal EOT, SS, and Vth of the conventional and suspended devices (extracted from forward sweeping I-V curves shown in Figs. 3 and 4).

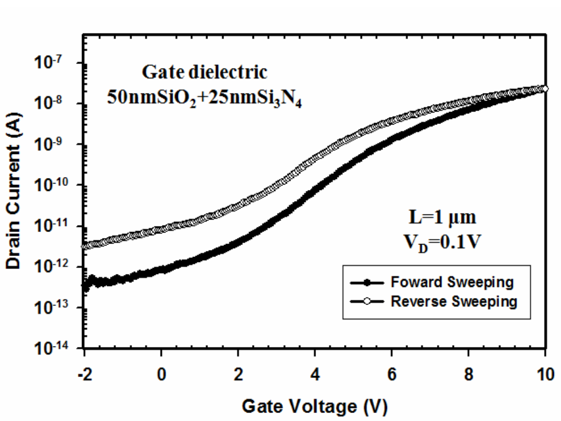

Fig. 3 Transfer characteristics of the conventional (i.e., non-suspended) device with Forward/Reverse sweeping.

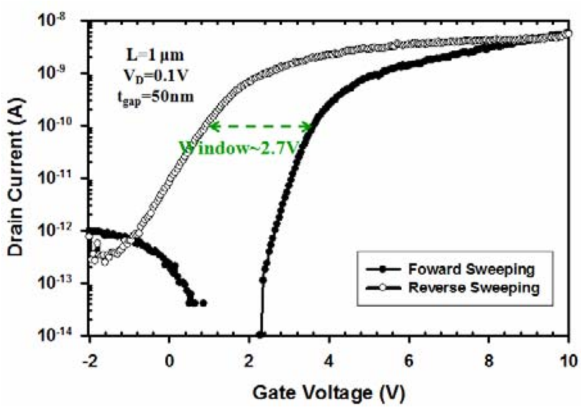

Fig. 4 I_D-V_G hysteresis curves for the suspended NW channel device. ($V_{t\text{-}forward}$=3.62V, $V_{t\text{-}reverse}$=0.93V, $V_{hysteresis}$=2.7V)

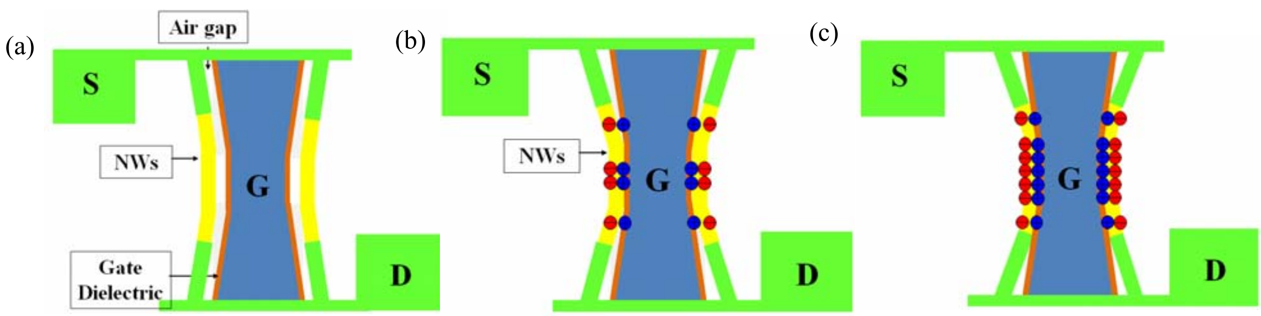

Fig. 5.The operation mechanism of *suspended NW channel* devices. (a) Initial state. (b) (V_G<$V_{t\text{-}foward}$) Not completely turn on. (c) (V_G> $V_{t\text{-}foward}$) Suspended NWs are pulled oward the gate down and the device is turned on.