Suspended Langmuir-Blodgett Film for Surround Gate Transistors

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Abstract:

Transistors with surround gates can carry more current and allow for higher gate efficiency. In suspending a thin Langmuir-Blodgett (LB) film of germanium nanowires across a trench between the source and drain, we can implement a surround gate design by coating the suspended film with high-κ material and sputtering the metal for the gate. In this experiment, we developed the processes, fabricated the transistors, took SEM images and characterized the devices with DC measurements.

Introduction:

A nanowires LB film transistor with only a top gate has a limited channel as the electric field is not uniformly applied to the wire. Accordingly, the performance of the device suffers, since not much current can be conducted through the device. However, with a surround gate design, the applied electric field on the wire is uniform and a full channel can be created, resulting in more current and higher gate efficiency.

In order to realize this design, we developed a process flow that would allow for a high-κ dielectric (HfO_2) coated germanium nanowire film to be suspended over a trench. Then, metal could be sputtered underneath and over the suspended wire, effectively acting as a surround gate for the transistor (Figure 1). For the experiment to be valid, it is critical that film stay suspended throughout the process and the wires form good contact with the source and drain metal.

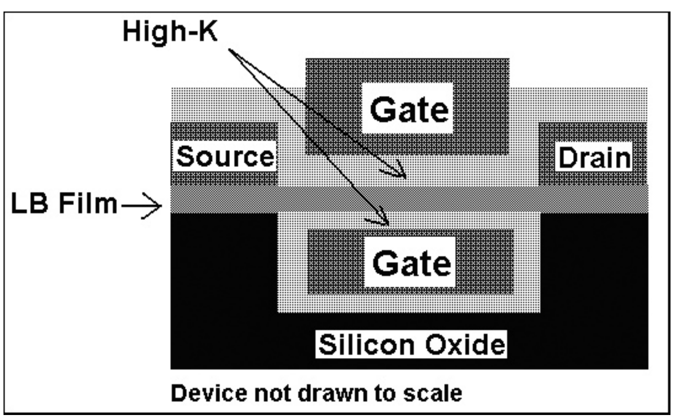

Figure 1: Surround gate design for nanowire film transistor (cross sectional view).

Experiment 1: Non-Suspended Germanium Nanowire Film Transistor

Since the non-suspended film transistors are to be used as reference, we did not fabricate any trenches on the substrate. Following the film transfer, our process was as follows: (a) define the device area with lithography, (b) etch away the excess wires, (c) pattern the source and drain, (d) deposit metal (titanium) for source and drain and liftoff, (e) anneal at 400°C, (f) coat the chip with high-κ material, (g) define the gate area, and (h) sputter the gate metal (platinum).

According to the DC measurements, prior to high-κ coating, the device exhibited p-type characteristics; however, after we coated the wire and sputtered the gate metal, the transistor behaved like an n-type device (Figure 2). We believe that this unexpected change may have been due to the patterning process and the Ti electrodes. Also, the current was much lower than we expected, only in the hundreds of nA range. The low conductance may have been due to the poor quality of the film and transfer process.

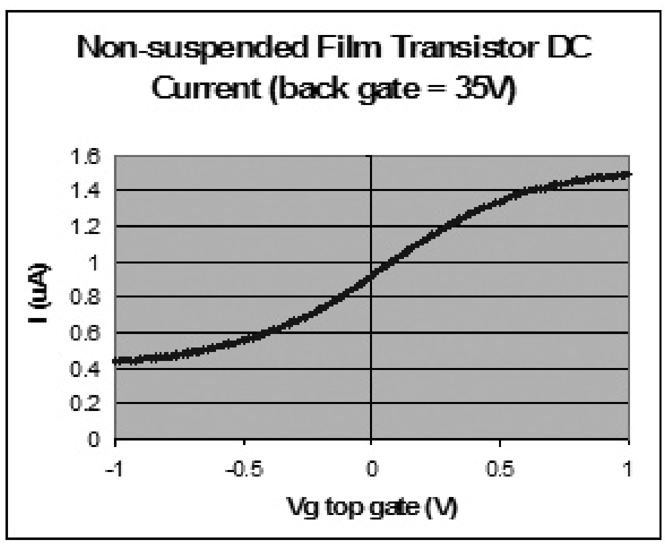

Figure 2: DC current of device with non-suspended film and back gate at 35V.

Experiment 2: Suspended Germanium Nanowire Film Transistor

This experiment used essentially the same process flow as the devices with non-suspending film. However, before the film transfer, trenches with 200 nm depth and 400 nm width are fabricated via e-beam lithography. Therefore, after the film was transferred and excess wires were etched away, the remaining nanowires should be suspended over the trench. Since suspension was a critical requirement for our design, we used SEM images to verify that enough wires had survived through the processes. Furthermore, we took DC measurements of the current between the source and drain to confirm that the wires formed good contact with the metal electrodes.

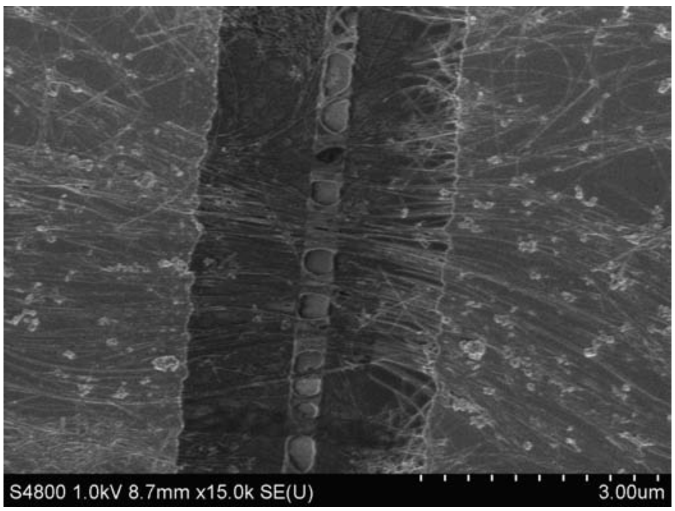

Figure 3: Nanowire film suspended over a trench.

The SEM image shows that most of the nanowires remained suspended over the trenches (Figure 3). However, in some sections, the nanowires were broken, leaving gaps in the trench. Most likely, in these areas, the nanowires were not perpendicularly stretched across the trench; as a result, there were longer suspending sections that were more susceptible to breaking during the fabrication process. Furthermore, the transferred nanowire film was not entirely uniform, resulting in many parts of the chip having no nanowires. Unfortunately, the quality and alignment of the film was a critical factor that we could not control in our experiment. As such, some film breakage occurred, leading to low current conduction.

We have not yet coated the suspended device with high-κ because our first experiment with the non-suspending transistor showed a change from p-type to n-type behavior. Also, we still have current only in the hundreds of nA (Figure 4), not high enough to make a useful device. As such, we need to refine our process before we continue on to the high-κ coating step.

Conclusion and Future Works:

Our experiment in fabricating surround-gate transistors using suspended nanowire film generated interesting results that warrant further investigations.

We have confirmed through SEM images that many nanowires remained suspended over the trench after the processes. However, there are still problems with film breakage, low current, and the change in behavior from p-type to n-type following the high-κ coating and gate metal sputtering. With a different process and higher quality film, we will be able to complete the fabrication of our suspended film transistor and hopefully obtain higher device performance.

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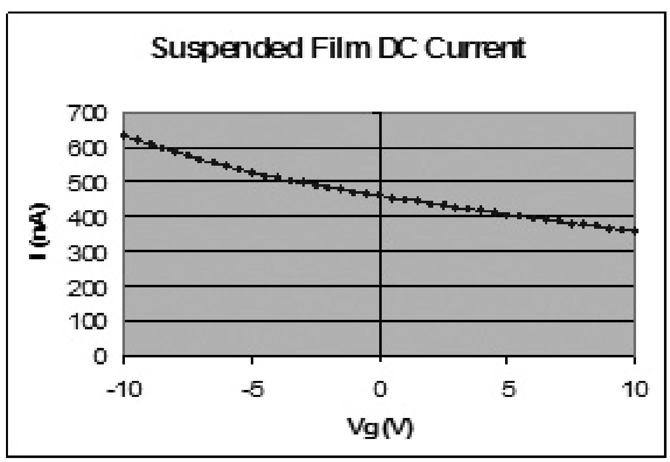

Figure 4: DC current of device with suspended film.