Suspended Carbon Nanotubes for Opto-Electronic Devices

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Abstract:

Single walled carbon nanotube field effect transistors (SWNT-FETs) have been the subject of much research over the last decade due to their unique electrical properties and small dimensions. In this project, we optimized suspended SWNT-FET structures to provide optimal conditions for small-diameter tube growth (< 1.5 nm), and to provide an even higher performance transistor. We also tried different SWNT growth/application methods, so as to understand which method would best fit a specific device.

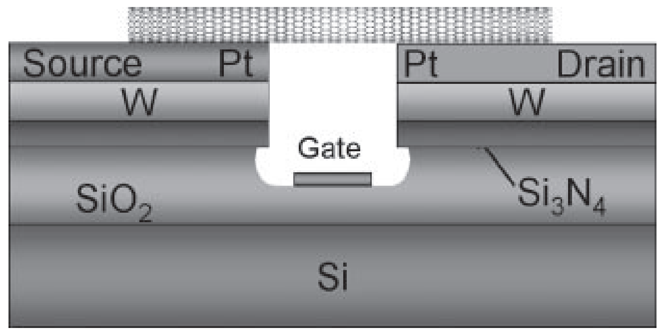

Figure 1: Suspended device structure.

Introduction:

Carbon nanotubes are a few nanometers in diameter, and can serve as metallic or semi-conducting materials. These are key qualities that have caused the SWNT-FET to be of rising interest. Previous groups have been successful in fabricating these SWNT-based field effect transistors, but the full potential of the device has not yet been realized. Our research focused on the improvement of these SWNT-FET structures and nanotube application methods.

Previous structures performed basic photolithography to pattern catalyst islands onto silicon oxide, so as to have a foundation of growth. The silicon oxide is grown on top of a highly doped P-type substrate used for electrostatic doping of the SWNT. A catalyst (cobalt acetate) is spun onto the substrate, and carbon nanotubes are grown from the catalyst. The idea is to get SWNT's to grow from on end of the chip to the other. Two metal electrodes are deposited on top of the catalyst islands to provide electrical contacts for the SWNT. Another structure that is still being researched is the suspended carbon nanotube structure. The entire device is fabricated first, the oxide is etched down in the center to provide a trench, and tubes are grown and suspended over the trench. The nanotube is grown by laying the catalyst, performing the growth, and again relying on an end to end connection of the nanotube which lies on top of the metal electrodes. The metal used on the electrodes is tungsten and platinum. The local gate is also tungsten and platinum. To keep the source, drain, and gate metals from shorting out, a layer of nitride is grown on top of the oxide, and the oxide is wet etched to produce an undercut for the trench as shown in Figure 1. The light emission efficiency from these devices proved to be higher than the light emission from the devices where the SWNT is lying on the substrate. However, such suspended structure is only good for large diameter tube (> 1.5 nm) growth, as it's difficult to grow small diameter tubes (< 1.5 nm) directly on top of metal. The wavelength that the nanotube emits is directly related to its diameter.

Our research not only focuses on optimizing the SWNT-FET device, but also growing smaller diameter tubes (< 1.5 nm) so that the wavelengths emitted will be in our detection range.

Experimental Procedure:

We fabricated a device very similar to the old suspended devices. A local gate was deposited into the trench. Instead of patterning our catalyst islands on top of the metal, we used e-beam lithography to dig a hole in the electrode down to the nitride as shown in Figure 2. The catalyst was then patterned on top of the nitride in an effort to produce small-diameter nanotubes.

The next device uses basic lithography to lay down four electrode pads on silicon. Using e-beam lithography, stems were etched onto the surface, one extending from each electrode. Two stems would lay 60 nm apart. About

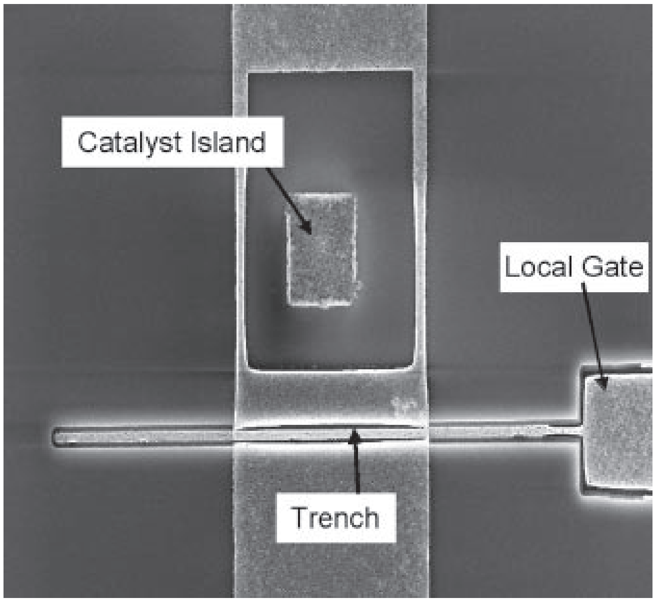

Figure 2: Suspended device with the catalyst island patterned on top of the nitride.

50 nm of gold was deposited on the stems to provide elevation. The idea was to simply stretch a tube across the stems to create a connection by spinning the tubes on the substrate.

Results and Discussion:

Past research found that the metal/catalyst reaction causes small-diameter nanotube growth to be extremely difficult. Thus, the purpose of the device in Figure 2 was to construct the catalyst island as far from the metal as possible. Figure 3 is Raman spectrum data. The G-band occurs at 1600 cm^{-1}, and it's related to the amount of amorphous carbon material that's present at the designated area. The tallest peak is silicon. The radial breathing mode (RBM) peak relates to the yield of carbon nanotubes. Our results showed that we have a lot of carbon nanotubes lying on the catalyst, which is the area of interest that this particular data was extracted from. By taking 250 and dividing it by the RBM number, an estimate of the SWNT diameter can be obtained. We achieved a diameter of 1.1 nm which constitutes as a small diameter tube. Unfortunately through AFM imaging, we saw a very rough nitride surface and no tubes extending from the catalyst, causing the device to be without any connections.

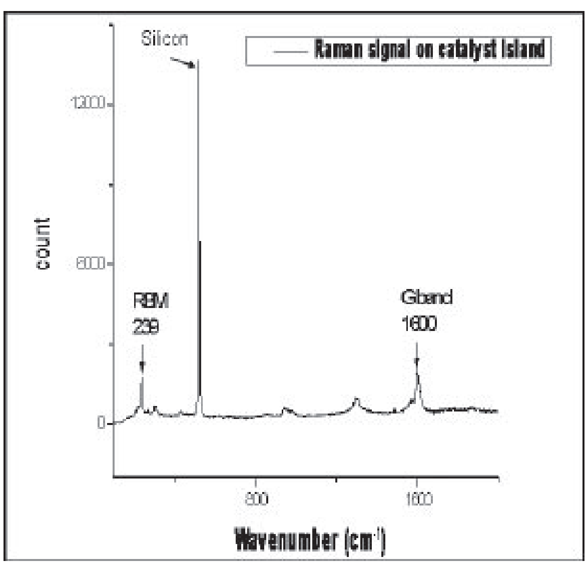

Figure 3: Raman spectrum data of the catalyst island.

The device highlighted in Figure 4 contained lift-off problems. Leaving a device in acetone for 2-3 hours is a normal lift-off procedure. With this device, sonication was absolutely necessary. This was in part due to the thickness of the metal as well as e-beam exposure and development issues. After many attempts at lift-off, we were able to fabricate a successful gold stem device.

Conclusions and Future Works:

We believe that the device in Figure 2 underwent a nitride/SWNT reaction that obstructed the growth of the SWNT's. This reaction will undergo further investigation. The next step for the device in Figure 4 is to have SWNT's spun on to its surface. Electrical and optical data can be taken once a connection is made on the device.

Acknowledgements:

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References:

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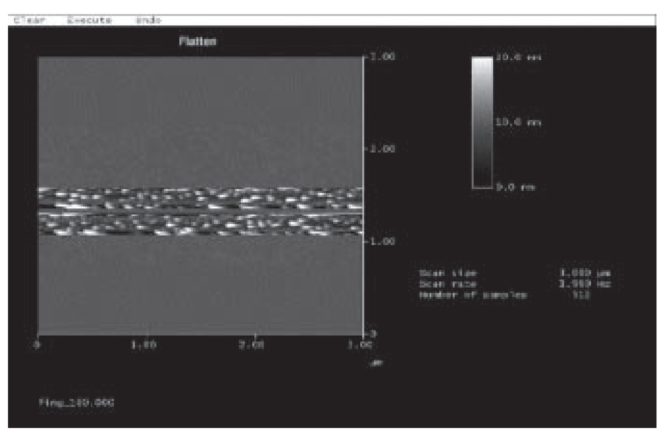

Figure 4: AFM image of a good lift off between the two stems.