Insulation of a Carbon Nanotube Interface for Retinal Prostheses

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Abstract:

Retinal prostheses are a novel attempt at restoring human vision. We have designed a novel prosthetic device using carbon nanotubes, and attempted to design a passivation layer for the device. We were successful in fabricating a passivation layer using silicon dioxide and silicon nitride films.

Introduction:

Human vision is the result of an electrical signal generated in the retina. Two of the leading causes of blindness, age-related macular degeneration and retinitis pigmentosa, damage the cells responsible for generating this signal, but leave intact the system of cells which delivers the signal to the brain [1]. Retinal prostheses would, in theory, deliver a signal from an imaging device to the nerve system and restore sight.

Instead of using traditional planar electrodes to deliver a signal, our device uses an array of carbon nanotube pillars which would give greater proximity to the retinal nerve system, thus requiring less power and delivering a higher quality signal. To limit the signal at only the desired target neurons, the substrate and the sidewalls of the array must be passivated. Various coatings were tested on the device for passivation, and methods of exposure for signal delivery were attempted.

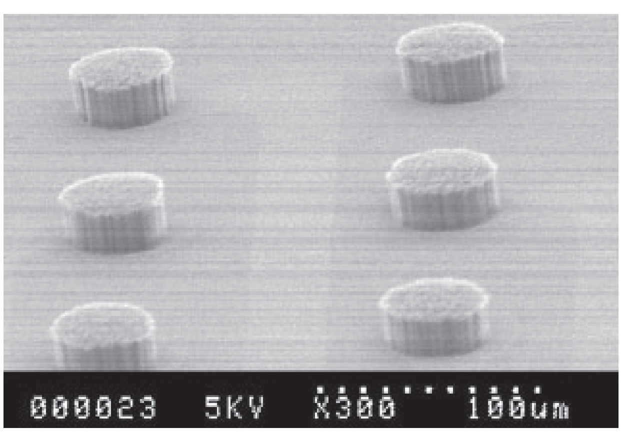

Figure 1: An array of uncoated nanotube pillars.

Fabrication and Experimental Method:

Our prototype device was fabricated on a silicon substrate, covered with 5000Å of SiO_2. A 6 x 6 array of electrodes was deposited on the substrate, consisting of a thin film of polysilicon, an adhesion layer of titanium, and platinum. A lead seed was deposited at the tip of each electrode, and nanotube pillars were grown on the electrodes using a CVD process. The growth conditions were in an environment of 99.8% ethylene at 700°C for 15-30 minutes [2].

Two different types of passivation layers were tested: spin-coated polymers, and PECVD deposited silicon oxide and nitride films. In each instance, the material was deposited and the device contacts were exposed. The arrays were then examined using scanning electron microscopy. We tested the arrays for leakage current by soaking each device in a

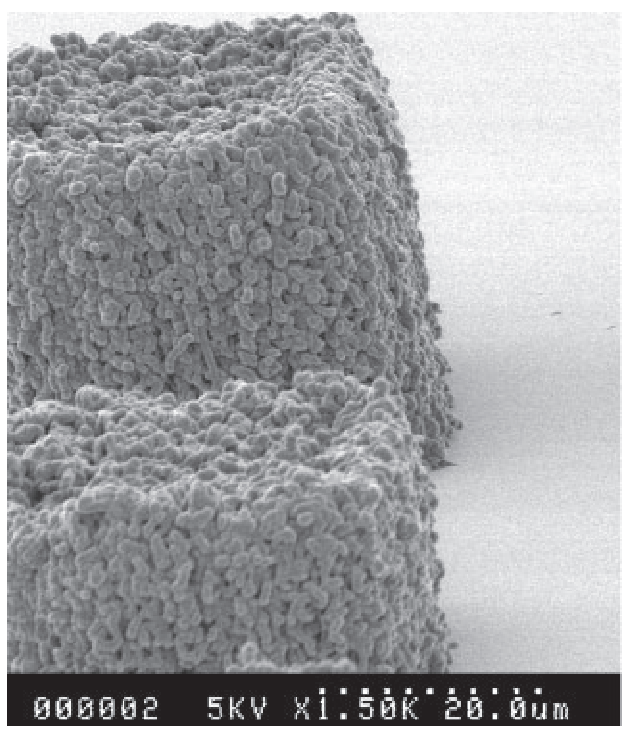

Figure 2: Nanotube pillars coated with 1000Å oxide, 2000Å nitride.

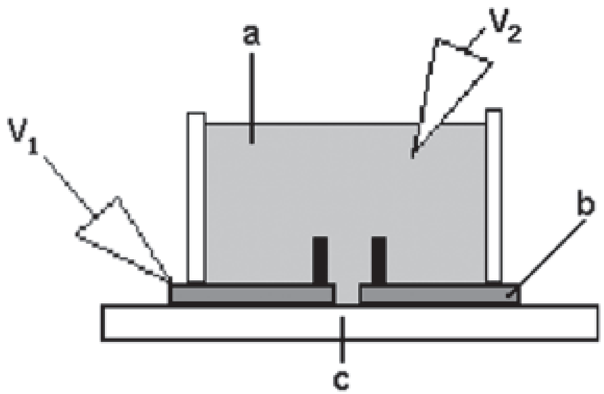

Figure 3: Leakage current testing. (a) Saline solution. (b) Pt electrodes with carbon growths. (c) Silicon substrate.

phosphor-buffered saline solution, and placing a probe on a contact and a Pt counter electrode submerged in solution. Current versus voltage was then measured from zero volts to two volts bias.

An appropriate passivation layer for our purposes must reduce the leakage current emitted by the array by at least two orders of magnitude. Additionally, the layer must be biocompatible, biostable, and hermetic to be compatible with its environment in the retina.

Experimental Results and Discussion:

A number of spin coated polymers were tested on the arrays to test the nanotube pillars' ability to withstand a spin coating. Shipley 3612 and Michrochem SU-8 2007 were deposited, as well as HD Microsystems PI 2556 polyimide. Low viscosity polymers coated the arrays well, while higher viscosity ones ripped the pillars off. Both 3612 and SU-8 successfully coated the arrays; however, neither is biocompatible. The polyimide solution had a higher viscosity and destroyed the device in spin coating.

Two thicknesses of oxide/nitride coatings were tested. The first was 1000Å of oxide capped by 2000Å nitride; the second was 1300Å oxide, followed by 5400Å nitride, followed by another 1300Å oxide. The conditions for deposition of the oxide were a plasma of SiH_4 and NO_2 at 350°C; the conditions for deposition of the nitride were a plasma of SiH_4 and NH_3 at 350°C. Since the deposition is done at a moderately high temperature, there is concern of thermal stress build-up between layers which expand at different rates. The thicknesses of the triple coating are intended to minimize the stress between layers and avoid cracking.

Leakage currents were tested for each coating for biases between zero and two volts, and compared to leakage currents for uncoated nanotube arrays. The 1000Å oxide / 2000Å nitride coating reduced leakage current by approximately two orders of magnitude; the 1300Å oxide / 5400Å nitride / 1300Å oxide coating reduced leakage current by almost three orders of magnitude.

Summary and Conclusions:

Carbon nanotube arrays for retinal prostheses were fabricated, and were tested with various passivating coatings. We have concluded that a sandwich layer of silicon oxide and nitride is appropriate to meet the demands of the device and its intended environment. The thicknesses of the oxide and nitride films were optimized so as to minimize stress within the device surface. A coherent method now needs to be developed so that the tips of the nanotube pillars can be exposed from the passivation layer in order to deliver an electrical signal to the retina.

Acknowledgements:

I would like to thank the Center for Integrated Systems at Stanford and the National Science foundation for their support. I would also like to thank Ke Wang, Jim Harris, and Hongjie Dai for their assistance with this project.

References:

[1] Malini Narayanan Nadig et al. "Development of a silicon retinal implant," Clinical Neurophysiology, 1999, 1545-1553.

[2] Shoushan Fan et al. "Self-Oriented Regular Arrays of Carbon Nanotubes and Their Field Emission Properties," Science, 1999, 283 (5401): 512.

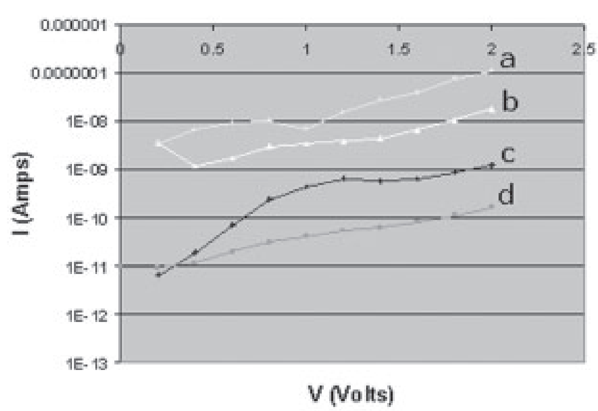

Figure 4: Leakage current data. (a) Uncoated array. (b) 1000/2000Å coating. (c) 1300/5400/1300Å coating. (d) No electrodes (noise).