Graphene Transistors for Biological Sensing

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Primary CNF Tools Used: Oxford ALD, graphene furnace, Autostep i-line stepper, Oxford 81

Abstract:

Two-dimensional materials provide a platform for biocompatible yet conformal cellular sensing devices. We report a releasable graphene field-effect transistor fabricated using standard photolithography, and we demonstrate the electrical response of these devices to action potentials from cardiomyocytes and mouse neurons in vitro.

Summary of Research:

Presently, there are numerous methods for single-cell action potential detection, but all struggle to simultaneously obtain high spatial, temporal, and electrical resolution. The use of moveable microscopic graphene field-effect transistors (FETs) has the potential to solve many of these problems.

Since graphene has remarkable voltage sensitivity, the action potential passing through a nearby cell can be easily detected by measuring the current flowing through the device. Moreover, freely-released graphene devices can be manipulated to conform to the cells of interest [1], thereby maximizing the signal recorded in this extracellular measurement. Finally, graphene absorbs only 2% of white light. Its effective transparency allows electrical measurements to be performed simultaneously with numerous imaging techniques, granting high spatial resolution coincident to an electrical measurement of cell action potentials.

We pattern the graphene using standard photolithography techniques. This allows us to play with designs to allow for a more conformal placement on the cell without degrading the electrical responsivity of the device [1]. To prepare these samples, we initially cover our substrate with 20 nm of aluminum oxide (alumina) grown via atomic layer deposition (Oxford ALD), as shown in Figure 1.1. This layer of alumina is a sacrificial layer and will be etched away shortly before the experiment (see Figure 1.3). After transferring graphene, grown via chemical vapor deposition, on top of the substrates, we evaporate 50 nm of gold on top of these samples and pattern it using standard photolithographic processes (exposing with the Autostep i-line Stepper). As shown in Figure 1.2, the final photolithography step is to oxygen plasma etch the graphene into the desired shape (Oxford 81).

After etching away the alumina in hydrochloric acid, the devices, now weakly adhered to the substrate, are placed into the same Petri® dish in which the neural or cardiac cells were cultured. In order to manipulate the devices, platinum-iridium probes were attached to micromanipulators; by forcing these probes into the gold pads, sufficient contact is made to pick up the device. To reduce electrical noise but still allow current to flow, the shafts of the probes were insulated except for a small exposed tip. It is important to note that from the time the alumina is etched away, the devices must remain in fluid; otherwise, we are unable to remove them from the surface and freely manipulate them in space. After picking up a device, it is then placed upon a cell. Experiments are performed in standard cell media,
The electrolyte potential of the media is controlled by a Ag/AgCl reference electrode inserted into the fluid.

An experiment with graphene devices placed on top of cardiomyocytes is shown in Figure 2. As expected, the graphene appears as a mostly transparent sheet stretched between the two gold pads. To monitor the current through the graphene device, a small voltage bias of ~ 100 mV is placed across the device by connecting one of the probes to a battery. We monitor the current flowing through the device using an amplifier connected to either an oscilloscope or data acquisition hardware, depending on our experimental needs.

Successful experiments have been performed with non-released devices (upon which cells are grown) using cardiomyocytes at Cornell and with releasable (free-floating) devices on mouse neurons by collaborators at Oregon State University. The devices used at Cornell were fabricated at CNF, and the cardiomyocytes were cultured by Tyler Kirby, a postdoctoral fellow in the Lammerding lab at Cornell. The resulting data is shown in Figure 3. The neuronal data agrees with the literature [2], yet the cardiomyocyte action potential spike is ~ 100x wider and smaller than anticipated.

Moving forward, we plan to improve our graphene devices to increase the signal-to-noise ratio of our data and improve device-cell contact to capture more of this trans-membrane current. Presently, we are experimenting with device geometries and characterizing a process to put silicon dioxide o-rings between the graphene devices and cells. In doing so, we hope to trap the ions released by the cell during a firing event, thereby increasing the local voltage gating of the graphene. We will also be considering new methods for manipulating our devices with the ultimate goal of performing an electrical measurement in vivo.

References: