Neurotransistors for Biomedical Technology

A.J. Menezes and V. J. Kapoor
Biomedical Nanotechnology Research Center, MS#309
The University of Toledo, Toledo, OH 43606

In a neurotransistor, a neuron is placed into contact with the dielectric gate of the oxide-semiconductor field effect transistors. The action potentials generated by the neurons can modulate the source-drain current of the FET. This device can be used to obtain noninvasive recordings of neuronal activity of the brain. In addition, an array of neuron transistors can be fabricated to obtain information about the activity of neuronal networks. Neurons on the gates of these transistors grow processes called dendrites, which can form synaptic connections with other neurons within the network. These neurons can be capacitively stimulated and the resulting action potentials can be recorded from the neurons throughout the entire network.

The fabrication of neurotransistors is achieved by silicon integrated circuit technology. Transistors with dimensions L x W), 5 x 100, 10 x 100, 16 x 30 and 20 x 100 microns are used. The source and drain regions were contacted by diffused lines 8mm long and 80um thick. Contact pads of dimensions 1mm x 1mm are placed at the end of the diffused lines. Masks were designed using AutoCAD.

N-type silicon wafers with a resistivity of 5 – 8 ohm-cm are cleaned using the standard RCA technique. A 10000 A thick layer of silicon dioxide is grown using wet oxidation at 1100 C and serves as a diffusion mask. Photolithography techniques are used to open the source drain regions in the oxide. A layer of phosphorosilicate glass is spun on which serves as a dopant (p-type) source. The dopant is driven in at 1100 C for 15 minutes in a 5% O_2/ N_2 environment. The gate region is opened using photolithography and etching with buffered hydrofluoric acid solurion. A 200 Å thin gate oxide is grown using dry O_2 with N_2 bubbling through TCE solution at 1000 C. Contact regions are opened using photolithography and etching with BOE. Aluminum is deposited by photolithographic patterning (lift off) technique for contacts formation. Deposited aluminum contacts are sintered at 475 C for 15 minutes in a N_2 atmosphere.

Two types of neuron cells were examined using the neurotransistors. First were neurons dissociated from the ganglia of the leech, Hirudo Medicinalis. Leeches obtained from Leeches USA were kept in artificial pond water in a refridgerator. The ganglia were dissected in Leech Ringer(115 mM NaCl, 4 mM KCl, 1.8 mM $CaCl_2$, 10 mM Glucose, 10 mM HEPES solution adjusted to pH 7.4 with NaOH) under a stereo microscope. Neurons were dissociated from the ganglia in Leibovitzs L-15 medium supplemented with 2% Fetal Bovine Serum, glucose(6mg/mL) and gentamycin(0.1mg/mL). Ganglia in supplemented media were opened using a fine forceps. Neurons were maintained in an incubator at 21 C for a day. The cells were then centrifuged and replaced with Leech Ringer solution. The cells suspended in Leech Ringer were placed on the gate of the neurotransistor.

The second kind of cells were murine neuroblastoma cells (N1E-115, American Type Cell Collection) are cultured in standard media mist consisting of 50 ml DMEM, 5 ml fetal bovine serum, and 5.0 ml streptomycin. The media is changed every three days and cultures are maintained in a sterile incubator at 37 C under a humidified atmosphere containing 95% O_2/5% CO_2. Upon reaching confluence, the cells are detached from the flask with the addition of 0.05% trypsin, pelleted, washed and re-suspended in serum-free media to eliminate any trypsin residue. The suspended cells are plated onto glass cover slips or transistor arrays, and are maintained in serum-free media for at least 4 days to promote differentiation into functional neurons. Cells were found to adhere to the silicon-di-oxide substrate (wafer).

The current-voltage characteristics as well as electrical recordings of action potentials at room temperature demonstrated the feasibility of using neurotransistors for biomedical nanotechnology especially for investigation of animal brain. The animal model will thus allow the investigation of neural activity for the human brain.