Field Emission from Carbon Nanotubes

Personnel

G. Sha (A. I. Akinwande and M.S. Dresselhaus)

Sponsorship

DARPA and AFOSR-MURI

Carbon nanotubes are very promising field emitters because of their small tip radii, high aspect ratio, and chemical & mechanical stability. They are capable of producing very high current densities at low operating voltages. However, most of the studies on field emission from carbon nanotubes have focused on two terminal devices, which have limited potential for electronic device application. Thus far, no three terminal devices with gated control have been demonstrated. A gated carbon nanotube device has several distinct advantages over a two terminal one: Three terminal devices have high field factors because of the closeness of the gate. This leads to very high electric field at the tip, and thus they have high emission current densities at low voltages. Three terminal devices are unilateral, have gain and thus can be used in a broad class of electronic devices.

Our process for gated carbon nanotube devices is based on CVD growth of CNTs on silicon substrate using the appropriate catalysts. First silicon tip arrays are fabricated using isotropic etching of silicon and oxidation sharpening. A sacrificial oxide layer and poly-silicon gate are then deposited, followed by the definition of the gate aperture by chemical mechanical polishing. Finally, silicon tips are revealed using oxide etching. After this,carbon nanotubes are grown on the tip surface to form a three terminal field emitter. CVD growth of carbon nanotube is the critical step of our progress. Currently we have achieved CNT growth between catalyst islands on planar silicon substrates. We are now working towards CNT growth along silicon tips and also selective CNT growth based on catalyst patterning.

In order to obtain a good comparison between experimental and theoretical results, we need to know accurately the field factor, which is defined as the ratio of electric field at the tip of emitter to the voltage applied at the gate. We used numerical simulation methods to calculate the field factor by taking into account the actual structure of the field emitter. We applied suitable boundary conditions to our problem space and used finite element methods to solve the Poisson partial differential equation. Field factor β is shown to have excellent power law dependency on tip radius, and the simulation result agrees well with the experiment.

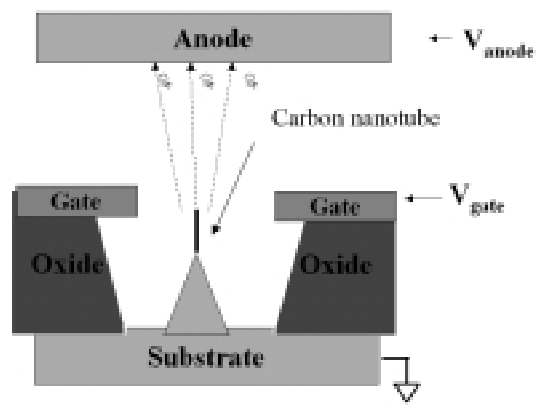

Fig.33: Gated carbon nanotube device diagram

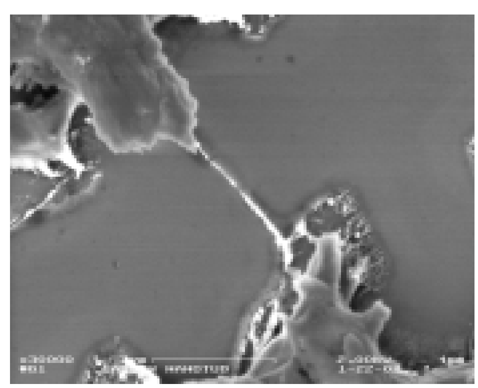

Fig. 34: Carbon nanotubes grew between catalyst islands