In-Plane Alignment of Carbon Nanotubes using Oblique-Oxide-Deposition

CNF Project # 804-99
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Abstract:
 Preferentially-aligned growth of single-walled carbon nanotubes using oblique oxide deposition is reported. By tilting the surface normal relative to the incident oxide vapor stream, a structured surface results that is conducive to preferentially-aligned chemical vapor deposition growth of carbon nanotubes. Preliminary experimental observations are reported.

Summary:
 Carbon nanotubes (CNTs) have many unique physical properties [1] that spur a lot of current interest. However, before they are of practical use, controlled growth and patterning must be achieved, whereby the size (diameter and length), location (anchor point), alignment (growth direction) and chirality are reproducible for the specific application.

Whereas the diameter [2] and anchor point [3] of CNTs have seen progress in process control, the direction of growth/alignment remains entirely unsatisfactory. Directionality/alignment is a key necessity of any application requiring in-plane nanotube structures.

In this work, we report on a novel method to achieve preferentially-aligned growth of in-plane, single-walled carbon nanotubes using oblique oxide deposition (OOD). With OOD, we are able to structure the surface topography on a nm-scale, prior to conventional chemical vapor deposition (CVD) growth, thereby causing the CNTs to grow in a preferred direction relative to the topography. This method is a powerful one in that multiple and arbitrary directions for CNT growth can be achieved in a single CVD growth run, thereby facilitating the processing of large, complex, networks of organized CNTs.

Obliquely-evaporated films of silicon dioxide have long been known to cause “sympathetic” alignment of liquid crystal molecules [4]. Therefore, might it be possible to utilize OOD to preferentially align CNTs during CVD growth? This was the rational by the first user for conceiving this work.

Following resist-processing, a ~ 0.3 nm-thick iron (Fe) catalyst layer was evaporated (at normal incidence) across the wafer and subsequently lifted off during a 30 min soak in AZ1165.

Following lift-off, the wafers are scribed, cleaved into smaller chips, and readied for CVD growth. During a typical growth run, a quartz tube furnace is raised from room temperature to 700°C at 70°/min while flowing 800 cm³/min of argon. After reaching 700°C, argon continues to flow for a period of 10 min to purge the furnace tube of any remaining oxygen. Following that, for an additional period of 10 min, 800 cm³/min of argon and 150 cm³/min of hydrogen are passed through the furnace tube at 700°C for pre-conditioning. Carbon nanotube growth then ensues for a period of 6 min, during which time 5.5 cm³/min of ethylene (C₂H₄) is added to the Ar and H₂ pre-growth gases. Cool-down at 12°/min with 800 cm³/min of argon completes the process.

Work remains to be done that differentiates between gas-flow alignment and nano-structured alignment using OOD.

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References:
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- Oblique-oxide deposition causes nano-structuring of the surface.
- Carbon nanotubes respond to this surface nano-structure during CVD growth.
- The alignment of carbon nanotubes can be controlled via feedgas flow direction, electric fields, chemical-functionalization and surface nano-structure.
- Work remains to differentiate between these various alignment mechanisms.

Figure 1: AFM image of a 100 nm thick obliquely-deposited oxide film. (The size of the image is 1 x 1 µm²).

Figure 2: SEM of carbon nanotubes grown on the obliquely-deposited oxide layer.