FRICIONAL AND ELECTRICAL PROPERTIES OF MULTIWALLED CARBON NANOTUBES

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ABSTRACT

This presentation examines the tribological properties and contact resistance of oriented capped carbon multiwalled nanotube (MWNT) films. Highly anisotropic tribological behavior of MWNT films oriented in mutually orthogonal directions is observed. The average values of coefficient of friction varied from high values ($\mu$=0.795) for vertically aligned nanotubes grown on rigid substrates to low values ($\mu$=0.090) for the same nanotubes dispersed flat on the same substrates. The results were insensitive to humidity, which is in contrast to graphite materials. The multiwalled nanotube layers also had a monotonic decrease in friction coefficient with increased surface temperature in both orientations, having a 32% drop in friction coefficient over a 73°C temperature rise. Preliminary results from contact resistance measurements of nanotube films grown through a porous alumina are investigated as a function of applied static load.

INTRODUCTION

Nanotubes and nanotube films have the potential to be used in solid lubricants as electrically conductive, structurally reinforcing, non-reactive components. The frictional properties of individual nanotubes have been examined by other investigators using atomistic molecular dynamics simulations and atomic force microscopy [1-4]. This investigation experimentally examines the frictional and electrical properties of films of CVD grown nanotubes using a microtribometer that can apply low force loads over an area including hundreds of nanotubes in the contact. Past work on the frictional properties of multi-walled carbon nanotube films showed that almost an order of magnitude variation in friction coefficient can be obtained by varying the orientation of the nano-tubes in the films ($\mu$=0.795 for vertically aligned nanotubes and $\mu$=0.090 for transversely aligned nanotubes) [5]. This work investigates the friction coefficient response to changes in substrate temperature for the same oriented nanotube surfaces. Additionally, the electrical contact resistance for nanotube films is measured using the same tribometer.

EXPERIMENTAL

A multi-walled nanotube (MWNT) sample was grown on a quartz substrate using chemical vapor deposition. A 4% density vertically aligned forest of MWNTs (~50 µm high) was grown normal to the quartz substrate surface. Half of this vertically aligned sample was scraped off, sonicated in acetone and deposited on a new quartz substrate transversely aligned and parallel to the plane of the substrate but unaligned with respect to one another.

The friction coefficient of the two oriented samples was examined as a function of substrate temperature. The linear reciprocating mode of a microtribometer described in [5] was used to evaluate the frictional performance of the samples. Test conditions were a 2 mN normal load, 0.6 mm reciprocation length, 300 µm/s sliding speed, in laboratory air (40% RH). A borosilicate glass lens with a 7.78 mm radius of curvature was used as the pin sample.

The friction coefficient of both the vertically and transversely aligned MWNT samples decreased with increasing surface temperature. Figure 1 shows the friction coefficient of both samples for 100 cycle experiments run at distinct temperatures and unique locations on the films. The friction
coefficient of the vertically aligned samples fell from $\mu = 1.42$ at 27°C to $\mu = 0.42$ at 100°C and the friction coefficient for the transversely aligned sample fell from $\mu = 0.14$ to $\mu = 0.05$ over the same range. Normalizing friction coefficient for both orientations shows the same relative change in friction coefficient as a function of temperature.

A temperature sweep from room temperature to 100°C was also performed under the same experimental conditions on the vertically aligned sample. The temperature dependence was shown to be reversible.

The electrical contact resistance of nanotube films was examined using the indentation mode of the same low-force tribometer. Contact resistance was determined using a four-point measuring technique using an I-V curve for resistance. One sample investigated was a film of carbon nanotubes grown through a porous alumina substrate. Figure 3 shows the contact resistance dropping as a function of applied normal load.

Figure 2 Friction coefficient data collected over 15 cycles of reciprocating microtribometry during a ramp in surface temperature: conditions are the same as figure 1.

The electrical contact resistance of nanotube films was examined using the indentation mode of the same low-force tribometer. Contact resistance was determined using a four-point measuring technique using an I-V curve for resistance. One sample investigated was a film of carbon nanotubes grown through a porous alumina substrate. Figure 3 shows the contact resistance dropping as a function of applied normal load.

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