eryLowICConductivityThresholdInI
Bulk IsotropicSingle-WalledCarbonI
anotube–EpoxyComposites**

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Conducting composites are typically made by embedding conductive particles in an otherwise insulating matrix. The composite particles are typically made from metal, graphene, or carbon nanotubes (SWNTs). The alignment of these particles can be achieved by using an electric field or through the use of a magnetic field. The alignment of the particles in the matrix can improve the electrical conductivity of the composite. However, the alignment of these particles can be challenging, and their alignment is often not uniform. In this study, we investigate the electrical conductivity of a composite made from carbon nanotubes aligned with an electric field. The composite was made by mixing the nanotubes with a polymer matrix and then applying an electric field to align the nanotubes. The composite was then tested for its electrical conductivity.

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lowering[threshold] concentrations.[In] arbon[black] composites[for] example,[the] threshold[an] be[lowered] by inducing[particle] aggregation[28] and[through] the[formation] of[diffuse][or“fluffy”agglomerates.[27] Long, flexible[opes][aligned] multiwalled[nanotubes(MWNTs)][ave] also been used to make[composites] with[threshold][volume][fractions][as][low][as
~ 2 x 10^{-4}]; albeit with[millimeter-scale][inhomogeneities.[29] In
such cases,[as][all][call] composites[the]relationship[between]
particle[aspect][ratio]and[threshold][concentration]becomes[f]-
dicult to predict.[In] SWNT[composites][these] effects[main-
largely] unexplored.[

Here we show how[the] SWNT[length][diameter][aspect][atio]
and[the] spontaneous[formation][of] nanotube[nets][affect]
the conduCtivity[of] bulk[SWNT-epoxy] composites.[We][om-
pare][two][types][of] SWNTs[with] different[mean][aspect][ratio][
and] introduce[two][nanotube-epoxy][processing][methods][that][hibit]
or promote[the] formation[of] networks.[We] observe[conduCtivity][thresholds][at][SWNT][volume][fractions][as][low][as
5.2%+(1.9+0.5)%]x10^{-4}[nearby][times][lower][than][values][quO-
ed][n][previous][eprts][on][SWNT][composites][n][epoxy][ma-
trices.[30] All[conduCtivity][thresholds][all][within][the][semi]-dilute
conduction[“ege”][of][the][rods][but][the][effect][of][nanotube]
aspect[ATIO][on][the][threshold][conduction][is][only][marginal-ly]
explained[by][simple][models][for][ot][percolation][.

T[e][key][to][this][work][s][our][starting][formation][a][l][ute][
0.04%][wt.-%][metastable][dispersion][of][pure][SWNTs][n][c][n][
dimethylformamide(DMF)][SWNTs][remain][well]-dispersed[n][
this][suspenSion][as][solated][SWNTs][and][small][SWNT][bundles][
while][under][sonication][see][Fig.1g][but][slowly][aggregate][
when][sonication][s][turned][off][T][e][absence][of][stabiliz-
ing][and][formation][metastability][permit][networks][to][form][
prior][to][curing][the][low][SWNT][concentration][reduce][aggre-
gation][and][so][enables][us][to][benefit][from][the][gh][aspect][atio][
of][solated][SWNTs][T][e][samples][were][processed][under][a][vari-
ety][of][sonication][conditions][uring][which][time][the][lute][
SWNT/DMF][solution][was][slowly][added][to][the][thermos][
epoxy][es][and][the][DMF][was][allowed][to][evaporate][Con-
tinuous][sonication][produced][more][saged][composites][wh][e][
uptime][of][sonication][prior][to][uring][permitted][net-
works][to][form][T][aken][together][the][use][of][pristine][SWNTs][and][
sonication][allowed][us][to][produce][fairly][omogeneous][ compos-
ites][with][minimal][perturbation][of][the][gh][strength][epoxy][In][-
Terestingly][composites][n][which][nanotubes][were][allowed][to][
reaggregate][exhibit][lower][thresholds][compared][to][more][o]-
mogenized][ones][.

Las[er][oven][Tubes(Rice)][and][HiPco][Carbon][Nano-
technologies(Inc)][SWNTs][were][studied][T][e][nanotubes][were][pur-
ified][to][a][SWNT][ontent][of][>5%][29][ Atomic][force][mi-
croscope][AFM][characterization][showed][that][the][las[er][oven][
(HiPco)][SWNTs][ad][n][average][length][ = 56[8+286][nm][
(166[700][nm][and][an][average][ameter][ de]=1.35[0.15][nm][
(1.1[8.3][nm][These][mensions][over][the][typical][range][of][SWNT][siz-
avail] today][We][found][that][adding][the][SWNT/DMF][solution][slowly][in][small][disegreted][steps][and][allow-
ing][the][DMF][to][vaporate][between][each][step][improved][the][ef-
tiveness][of][the][sonication][Sonication][uring][processing][
tends][to][break][up][transient][SWNT][networks][and][nhibit][the][for-
mination][of][new][ones][Once][the][esired][SWNT][concen-
tation][was][ached][n][the][sonicating][es][as][scribed][above][an]
aliphatic[amine][o]linker[was][stirred][into][the][solution][At][this][sta-
g][the][samples][were][vided][to][two][categories][In][the][first][set][samples][were][placed][into][alcohol][water][bath][to][cure][at][90][°][C][for][30][min][uring][proceed][without][sonication][Here]-
[after][we][ef][to][these][samples][as][non-sonicated][In][the][sec-
ond][set][samples][were][placed][in][the][sonicator][bath][at][80][°][C][

Figure 1. a)–e) Images of composite-SWNTs (volume fraction: 21 & 30%). b) Information about SWNT distribution in the composite-SWNTs and the pristine SWNTs from scanning electron microscopy (SEM) and fractured surfaces. (b, d) (a) InSe-SWNTs and TiO2 composites for different regions and color: (b) SEM images of the same SWNT-epoxy composite-SWNTs (epoxy: white & strips) & appear in the composite-SWNT (epoxy: black) in the right-hand side of the figures. The composite at different positions & are uniformly dispersed & uniformly across the fracture surface & with an enhanced green & yellow color. (d) Dense aggregates & are & present & only & in the composite-SWNT (epoxy: black) in the right-hand side of the figures. The composite at different positions & are uniformly dispersed & uniformly across the fracture surface & with an enhanced green & yellow color. (e) Hexamethyldisilazane-treated TiO2 (epoxy: black) in the right-hand side of the figures. The composite at different positions & are uniformly dispersed & uniformly across the fracture surface & with enhanced green & yellow color. (f) SEM images of the composite-SWNTs (volume fraction: 21 & 30%). (g) SEM images of the pristine SWNTs & the composite-SWNTs from different positions & are uniformly dispersed & uniformly across the fracture surface & with enhanced green & yellow color. (h) Images of the composite-SWNTs (volume fraction: 21 & 30%). (i) SEM images of the pristine SWNTs & the composite-SWNTs from different positions & are uniformly dispersed & uniformly across the fracture surface & with enhanced green & yellow color. (j) SEM images of the composite-SWNTs (volume fraction: 21 & 30%). (k) SEM images of the pristine SWNTs & the composite-SWNTs from different positions & are uniformly dispersed & uniformly across the fracture surface & with enhanced green & yellow color. (l) SEM images of the composite-SWNTs (volume fraction: 21 & 30%).
and were cured under sonication for 30 min. We refer to these samples as “sonicated.” We found that “sonicated” samples were more homogeneous than “non-sonicated” ones. Molding that SWNT networks that were formed during sample processing were successfully spersed.

A series of composite samples with increasing SWNT content is shown in Figure 11. Our SWNT-epoxy composites exhibited a range of microscopic morphologies evident from optical microscopy of thin sections and SEM of fractured surfaces (see Fig. 11). An example of a “non-sonicated” sample is shown in Figures 1a,b. Reaggregation of SWNTs was clearly evident as bright and dark regions on the optical images. These diffuse aggregates were roughly 10 μm in diameter. [SEM] imaging confirmed that nanotube density varied on a similar length scale. Ropes of SWNTs were distributed in a light manner on the fractured surfaces. These clusters were easily spersed by continued sonication just prior to curing. An example of a sonicated “non-sonicated” sample is shown in Figure 1c. (TE) optical and SEM images show that the SWNT distribution was quite homogeneous down to a few micrometers, and although some aggregates were present, their ensity was relatively low. [We suspect the epoxy is self partially stabilizes the suspension once the DMF evaporation facilitates the dispersion. It is important to distinguish the fluorescent features of our “non-sonicated” samples from dense aggregates, which result from a poor initial dispersion.] For example, a sample made from 0.04 wt.% SWNT/DMF suspension is shown in Figure 1c. A substantially larger number of dense aggregates, which presumably existed in the more concentrated starting suspensions, and persisted through processing.

Teflon prepared for the measurements as shown in the inset in Figure 2. [TE] four-point current–voltage (I–V) curves were linear in the range studied, as shown in the same figure. In Figure 3, we show the onduc-

![Figure 3](image) 3. **Conductivity and Volume Fraction**

**Figure 3.** Two-point and four-point I–V curves for a non-sonicated and P90 SWNT composite. 65.80 % SWNT volume fraction shows the typical 8 slope of four-point samples. The inset shows the composite samples molded for two- and four-point conductivity measurements. At a given current, the measured voltage is significantly higher than in the four-point, due to both contact resistance and larger separation between the electrodes. SWNT and HiPco composites as a function of SWNT volume fraction, [φ]. All four sets of composites exhibited a jump in the value of [φ] of 2 to 6 orders of magnitude over a small range, [i.e., a percolation-like behavior]. Near this threshold, we found [φ] = [φ] + ω, where [ω] is the critical exponent. [φ] and [ω] are shown in the figure.
constant background conductivity of the points below the threshold. Axes [a constant that depends on nanotube conductivity and network morphology, and $\theta (\phi - \phi_0) \sin \theta$; the Heaviside step function, such that $\theta(\phi - \phi_0)$ when $\phi = \phi_0$ and $\theta(\phi - \phi_0)$ when $\phi > \phi_0$. Two-point measurements above the threshold were excluded from the fits to avoid systematic errors due to contact resistance.

A least-squares analysis of the fits showed that for each set of composites was strongly bounded by the regions between the glass transition and lowest conduction points. T, $\theta$, exponent ($\tilde{\sigma}$), however, was not well bounded. T, $\theta$, $\tilde{\sigma}$, and the parameter $\gamma$ are summarized in Table 1. Plots of $\log(\phi)$ versus $\log(\phi - \phi_0)$ [5,6] are the nets of Figure 3 show the conductive and insulating states of [5,6].

The volume fraction of each [5,6] set of samples with best-fit [f] [5,6] lines whose slopes provide the best-fit exponent, $\tilde{\sigma}$, [5,6] of lowest measurable threshold was obtained for the non-sonicated sample (see Figure 3). This inhomogeneity $\tilde{\sigma}$ was $\approx 10^{-3}$ for the sonicated samples [5,6] and sonicated MWNTs in epoxy. [5,6] The magnitude of the $\tilde{\sigma}$ value [5,6] that was comparable to some results obtained for MWNTs in epoxy [5,6] is noted over the threshold.

Table 1. Observed thresholds, exponents, and predicted thresholds for each sample set. All numbers were given in 8 terms for SWNT volume fraction.

<table>
<thead>
<tr>
<th>Laser-oven</th>
<th>iPc08</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-sonicated8</td>
<td>Sonicated8</td>
</tr>
<tr>
<td>Threshold &amp; volume fraction ($\rho_x$) 10 $^{-8}$</td>
<td>5.28 $\times$ 10$^{-3}$</td>
</tr>
<tr>
<td>Best-fit exponent ($\tilde{\sigma}$)</td>
<td>2.78 $\times$ 10$^{-3}$</td>
</tr>
<tr>
<td>Dilute/semi-dilute transition ($\rho_d$)</td>
<td>$\times$ 10$^{-1}$</td>
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</table>
latter ratio, our observations do not agree with either model. Another potentially testable prediction is the percolation exponent \( x \), \( xT \) — on without intervals for our [exponent were large] and their best fits ranged from 1.6 (0.5/0.6) to 3.2 (0.5/0.6). [Computer models of conductivity percolation predict a critical exponent value of 2.0.] Other experimental studies of carbon/nanotube composites have found values of \( x \) to be frequently 2.2, 3, 3.5, and 3.9. Additional studies are needed to determine the values of \( x \) for a variety of nanotube structures. In summary, we have developed a methodology to d...
Phthalocyanine IComposites I asHigh-MobilitySemiconductorsI forOrganicThin-Film Transistors**

By Jianzheng Xia, Haibo Wang, Xuanjunc Yan, Jun Wang, Jianwu Shi, and Donghanghao* 

There is a growing research effort in organic thin-film transistors (OTFTs) because organic semiconductors possess numerous advantages, including large-area coverage, easy processing, good compatibility with a variety of substrates, including flexible plastics, and great opportunities for structural modification. These advantages make it possible to form a lot of research on a lot of materials with promising properties, such as gh mobility and on/off ratios. Organic conducting materials with good performance and also being formed by the incorporation of different organic materials have been studied. Also, the mobility of the composites is relatively low. Phthalocyanines (Pcs) are a large family of conjugated molecules with good chemical and thermal stability. Tc is a wide range of applications, including electrical devices, optical switches, data storage, and cells, and OTFs. Our results on OTTFs' aging, source, and drain electrodes sandwiched between organic phthalocyanine (CuPc) and organic phthalocyanine (CoPc) layers reveal that organic semiconductors have different characteristics than organic pure materials. A composite of CuPc/nickel phthalocyanine (NiPc), CuPc/NiPc, n-s copolymers as the active layer n an OTFT n this article. An OTFT n top-contact configuration is schematically depicted in Figure 1. CuPc and NiPc films have been epitaxially grown, and the materials are composed of donor and acceptor units. Representative transfer characteristics are shown in Figure 1 for OTTFs based on CuPc–NiPc (9:1) and films. From the square root of the drain current (Idvs.) vs. gate voltage (Vg), the field-effect mobility (μ) of the saturation regime (μsat) vs. gate voltage (Vg). The field-effect mobility is calculated from the saturation regime data. μ is the reduction of the field-effect mobility relative to the saturation regime mobility [μsat]. μ is attributed to the traps in the organic layer.