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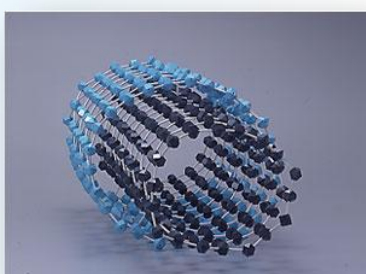
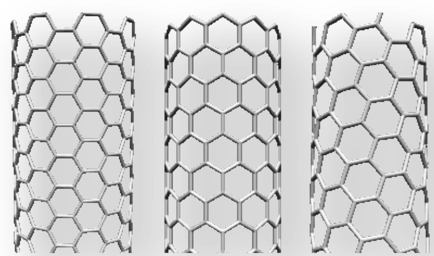
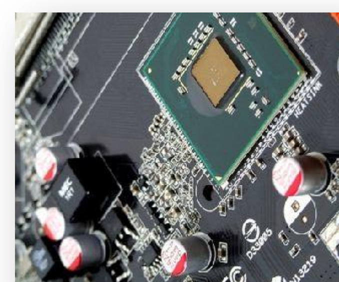
TCi's Application in the Thermal Conductivity Characterization of Nanomaterials

Presented by Adam Harris







AGENDA

- Who we Are?
- Modified Transient Plane Source Method
- Overview of TCi
- NanoMaterials
  - Dispersion and thermal conductivity of carbon nanotube composites
  - Effects of surface-functionalized multi-walled carbon nanotubes on the properties of poly(dimethyl siloxane) nanocomposites
- Comparison to Other Methods
- Q&A

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Non-destructive thermal sensor technology solutions for R&D, production, and QC applications, delivering fast, accurate measurement of **thermal conductivity** and **effusivity** in seconds with virtually unlimited sample size.

Manning Innovation Awards – Prix d'innovation Manning

R&D 100 WINNER

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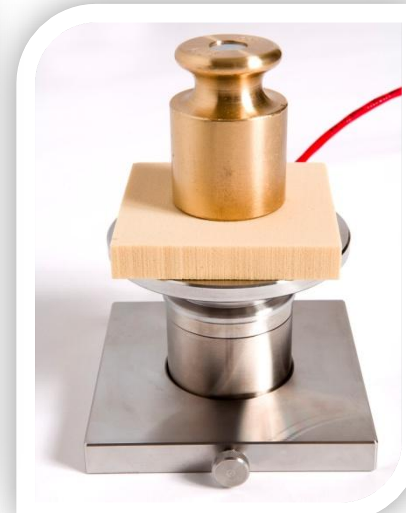


WHAT WE DO

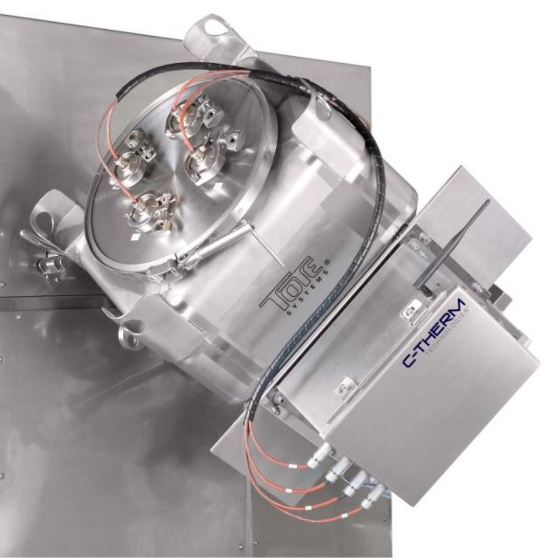
C-THERM PRODUCT LINES

THERMAL CHARACTERIZATION

C-Therm TCi™ Thermal Conductivity Analyzer

Clients include:

- P&G
- Raytheon
- Kodak
- Dupont
- Philip Morris
- US Navy
- Atomic Weapons Est.
- ICI



PHARMACEUTICAL APPLICATIONS

C-Therm ESP™ Effusivity Sensor System

Clients include:

- Patheon
- Wyeth
- BMS
- Astra Zeneca
- Biovail
- USP

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HOW IT WORKS

Wood feels warm

Metal feels cold

Heat always flows from a hot object to a cold object.

Wood is not a good conductor of heat, so it is **slow** to absorb the heat.

Metal has higher **“thermal effusivity”** so the heat from your hand flows into the metal **quickly** - creating the sensation of it being cold.

C-Therm sensors work like your hand, by **rapidly** determining the **rate** of heat flow from one material to another. Like your hands, our sensors **supply** the heat source *and* **detect** the heat flow. They also have no **sample size** issues, and do not destroy the sample being tested.

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HOW IT WORKS

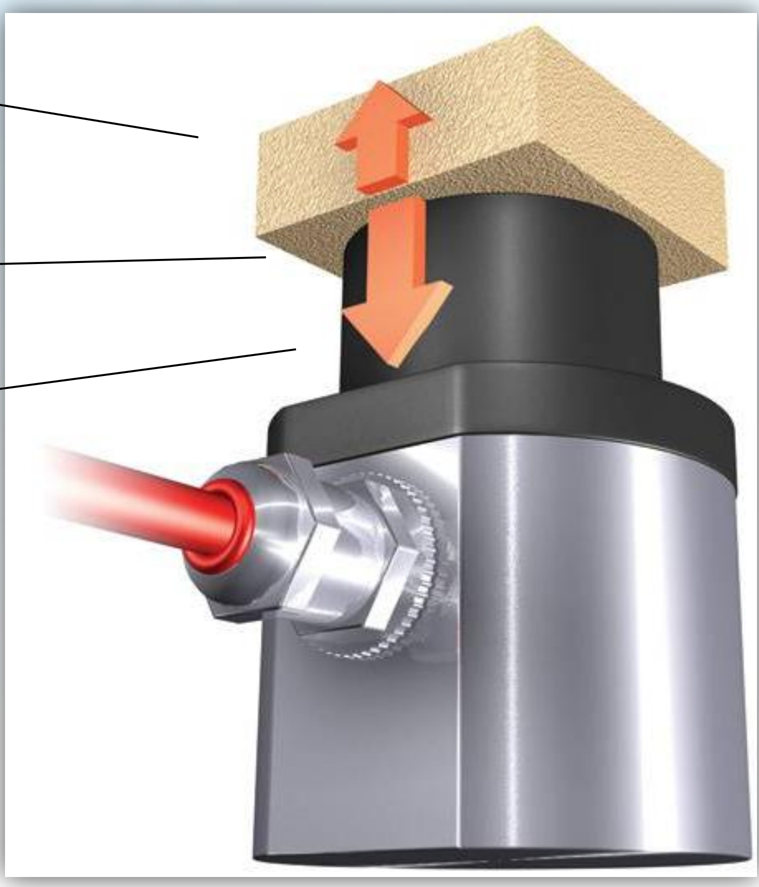
Sample material can be solid, liquid, powder or paste.

A known current is applied to the sensor's heating element, providing a small amount of heat.

The heat provided results in a rise in temperature at the interface between the sensor and the sample – typically less than 2˚C.

This temperature rise at the interface induces a change in the voltage drop of the sensor element.

The rate of increase in the sensor voltage is used to determine the thermo-physical properties of the sample material.



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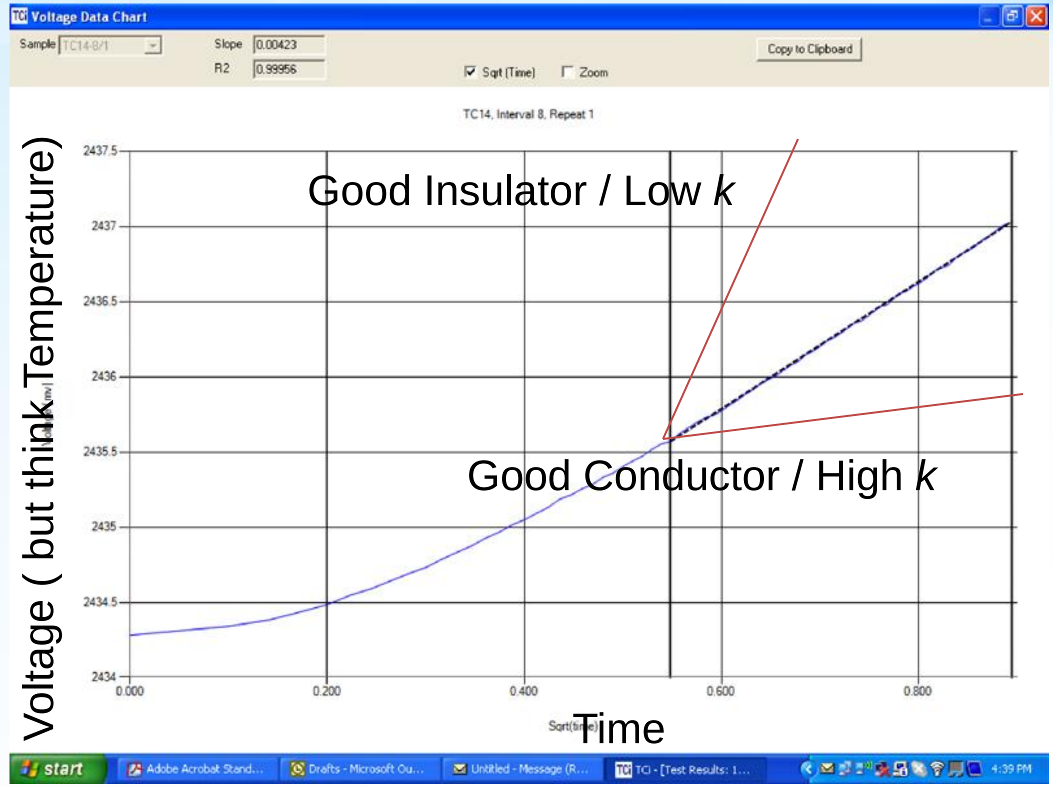
HOW IT WORKS?

The thermal conductivity of the sample material is inversely proportional to the rate of increase in sensor voltage. The change in voltage drop correlates with an increase in temperature at the sensor interface.

The more thermally insulative the material is – the steeper the voltage rise.

Results are displayed on the system's laptop computer in real time.



First 0.3 Seconds: Addressing Contact Resistance, Non-Linear

0.3 – 0.8 Seconds: Within Sample, Linear

OVERVIEW OF TCi™

Fast, Accurate k-Testing
0 to 100 W/mK in 5 seconds

Wide Temperature Range
-50˚ to 200˚C

Easy-to-Use
No calibration required

No Sample Preparation
Unlimited sample sizes

Non-Destructive
Leaves sample intact

Versatile & Modular
Tests solids, liquids, powders & pastes

Highly Flexible
Designed for lab, QC & at-line testing

WHAT DOES IT MEASURE

Thermal Conductivity $= (W / m \cdot K)$

and

Effusivity $= \sqrt{k \rho c_p}$

Where :

k = Thermal Conductivity (W/m • K)

ρ = Density (kg/m^3)

c_p = Heat Capacity (J/kg • K)

It also indirectly measures (calculated) Thermal Diffusivity and Heat Capacity and has user input capabilities to determine Density

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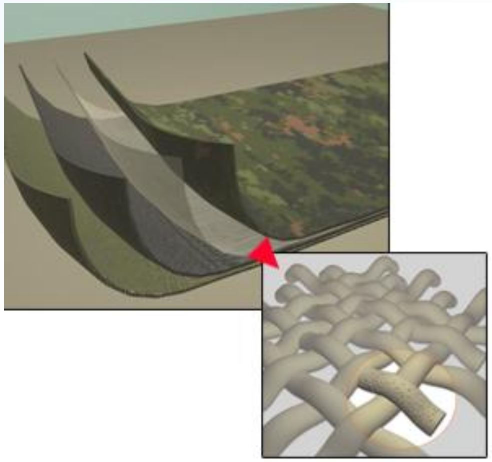
NANOMATERIALS & NANOTECHNOLOGY

The design, characterization, production, and application of structures, devices, and systems by controlled manipulation of size and shape at the nanometer scale (atomic, molecular, and macromolecular scale) that produces structures, devices, and systems with at least one novel/superior characteristic or property.



Source:

Nanomedicine: Nanotechnology, Biology and Medicine

Volume 1, Issue 2, Pages 150-158
R.Bawa, S.Bawa, S.Maebius, T.Flynn, C.Wei

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APPLICATIONS

<u>Medicine</u>

- Diagnostics
- Drug Delivery
- Tissue Engineering

<u>Energy</u>

- Fuel Cells
- Solar Cells (PV)

<u>Elect & IT</u>

- Heat Dissipation
- Memory Storage

Consumer <u>Goods</u>

- Foods
- Cosmectics
- Textiles

+ Many Many More!

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ELECTRONICS – GET THE HEAT OUT!

As electronics get smaller & smaller, the design bottleneck is increasingly heat dissipation. Improving integrated circuit (IC) performance generally requires increased power density, thus generating more heat.

Die attach materials and interconnect devices are often the critical limiting items in the heat flow path out of the IC package. Materials in use today are unsuitable for many of the next generation of high ICs. As a result, challenges exist to meet the design requirements of electrical and thermal conductivity while providing the materials in a format that is easy to use and rapid to install.

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Challenge of Testing the Thermal Conductivity of NanoMaterials

- Limited availability of material
  - Expensive to produce
  - Small limited volume available for characterization
  - Need for non-destructive technique
- Material Format: Liquids
  - Depending on viscosity could be a greater convection challenge

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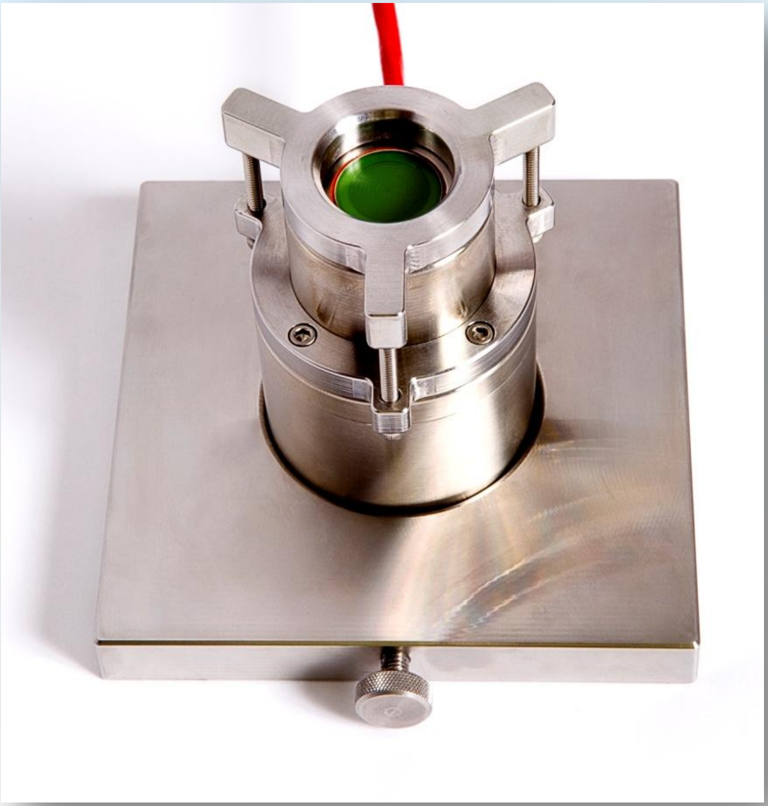
Small-Volume Test Kit (SVTK)



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DISPERSION AND THERMAL CONDUCTIVITY OF CARBON NANOTUBE COMPOSITES

Shiren Wang[a], Richard Liang[b], Ben Wang[b], Chuck Zhang[b]

[a] Department of Industrial Engineering, Texas Tech University, 2500 Broadway, Lubbock, TX 79409, USA

[b]High-Performance Materials Institute, Department of Industrial and Manufacturing Engineering, Florida State University, Tallahassee, FL 32310, USA

Summary

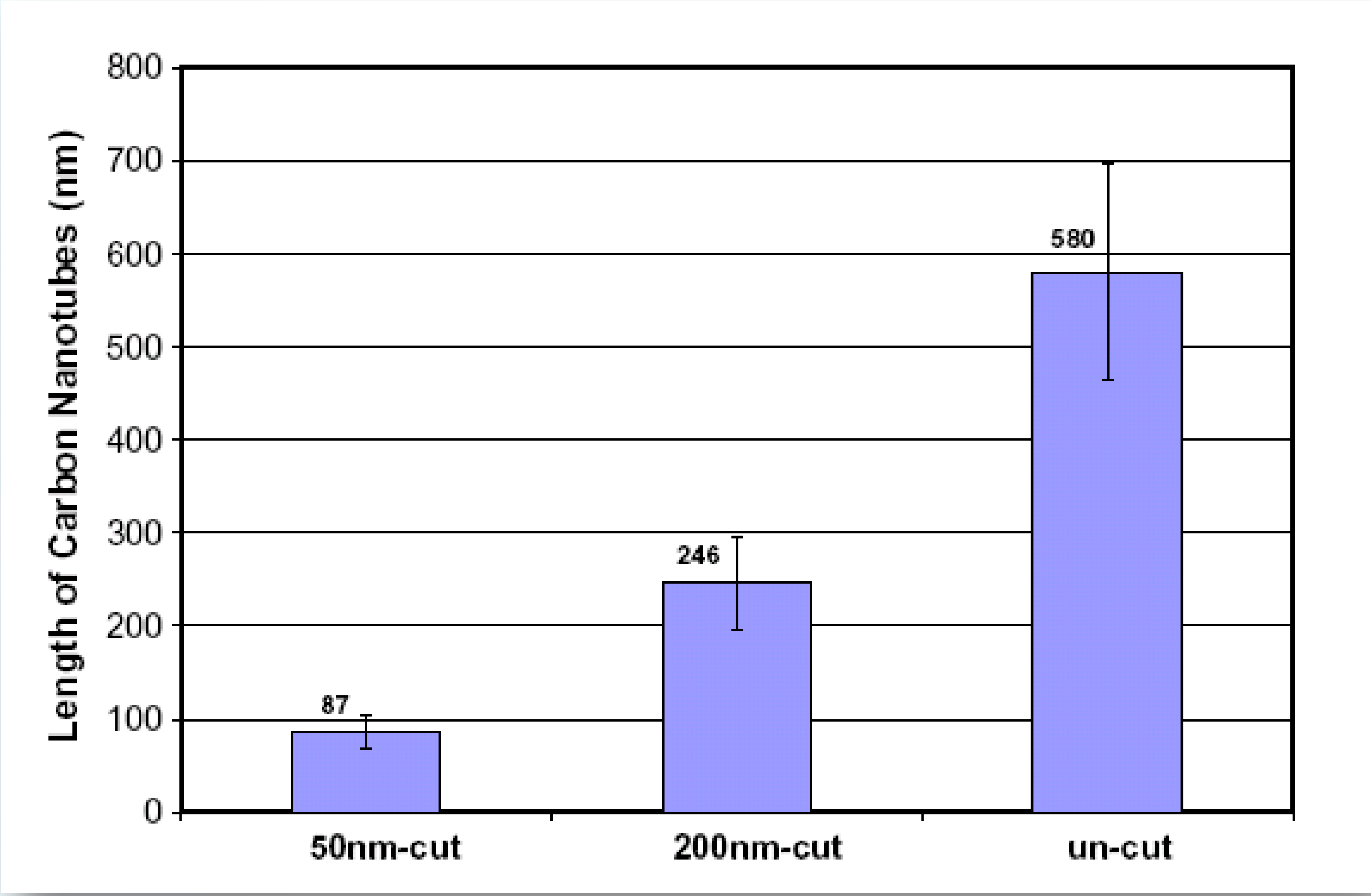
A mechanical method was used to shorten carbon nanotubes (CNTs) for improving dispersion without reducing their thermal conductivity.

Single walled carbon nanotubes (SWCNTs) were mechanically cut to produce short and open-ended fullerene pipes. These shortened SWCNTs were then used in polymer composites.

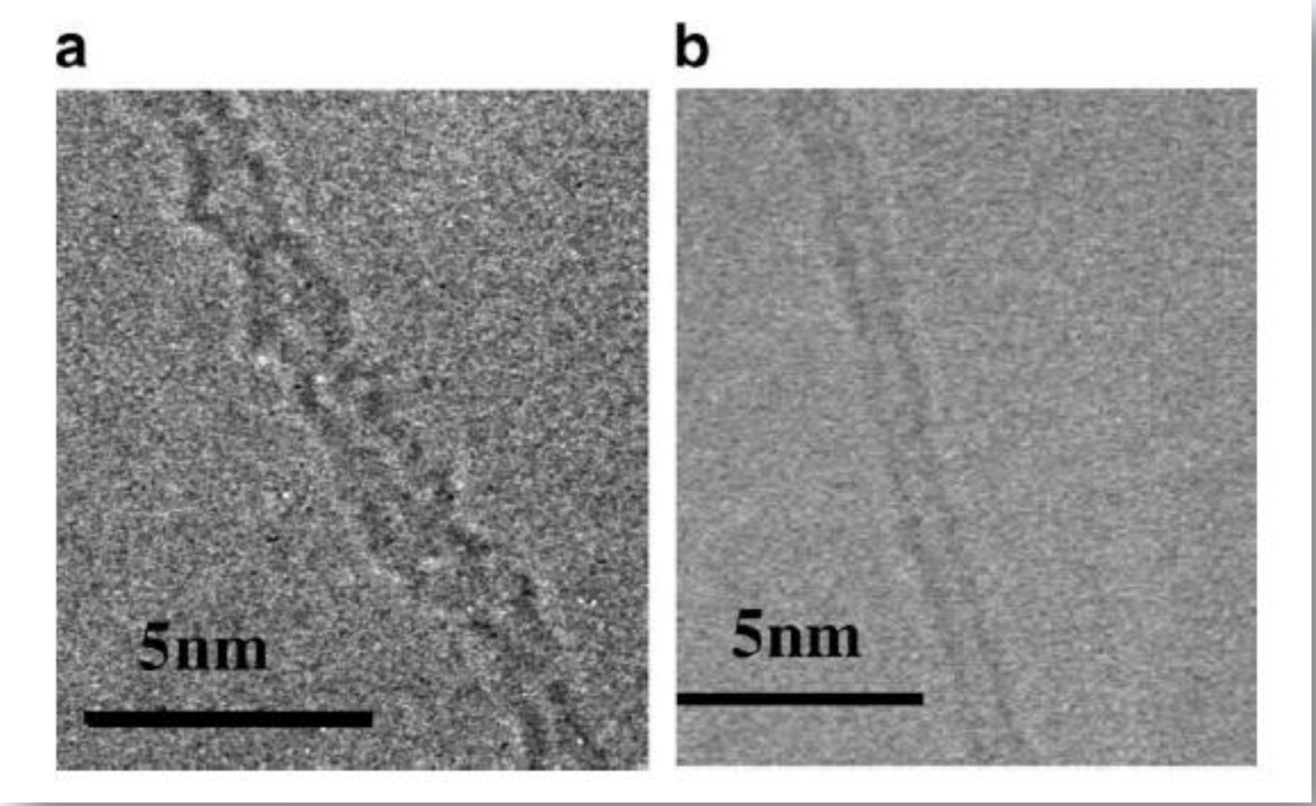
Both atomic force microscopy and scanning electron microscopy characterizations suggested that nanotube shortening significantly improved CNT dispersion.

Thermal conductivity of composites containing short CNTs were found to be much better than those containing pristine CNTs.

Average length of shortened and un-cut SWCNTs

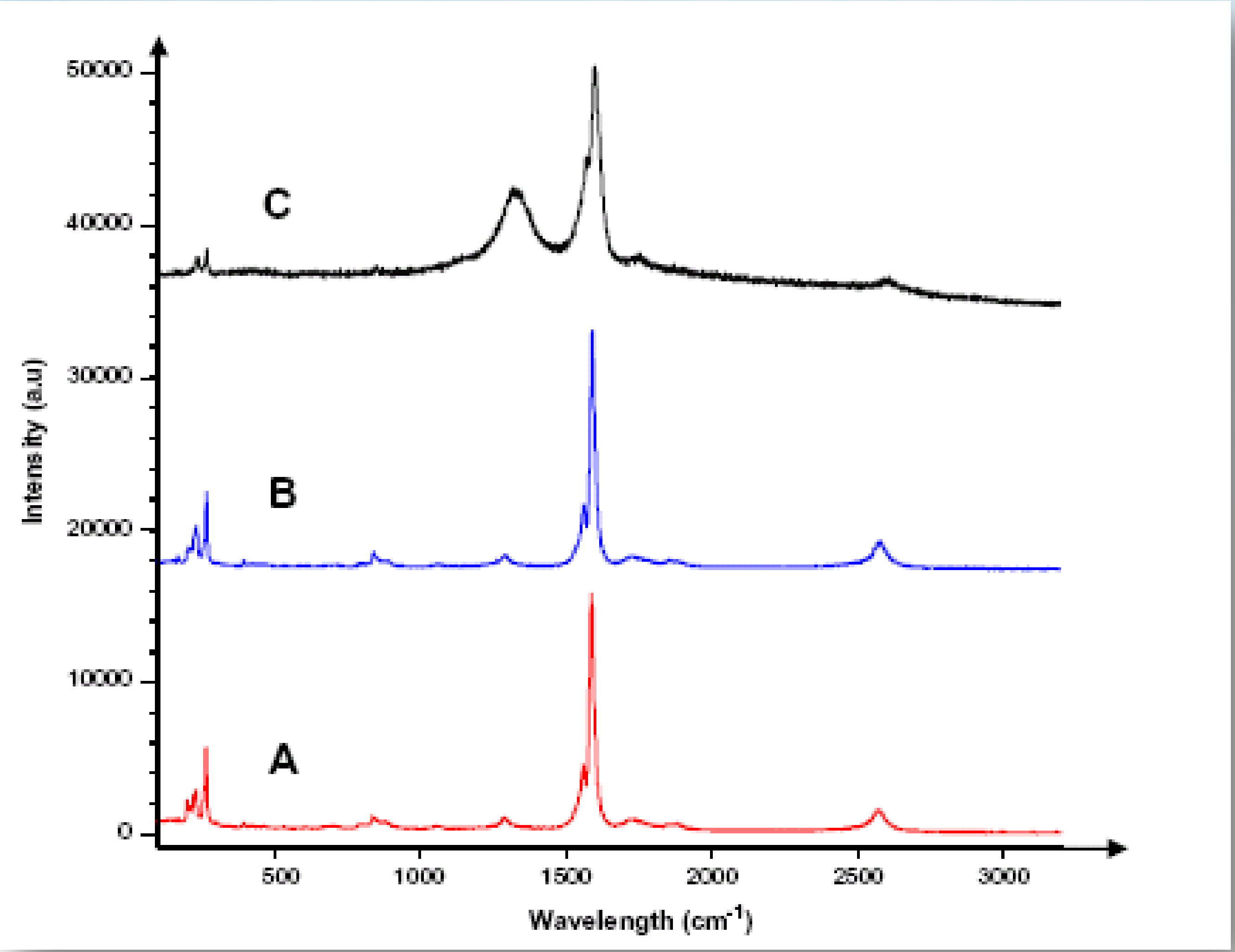


Transmission Electron Microscope (TEM) images of (a) acid-oxidized and (b) microtome-cut SWCNTs



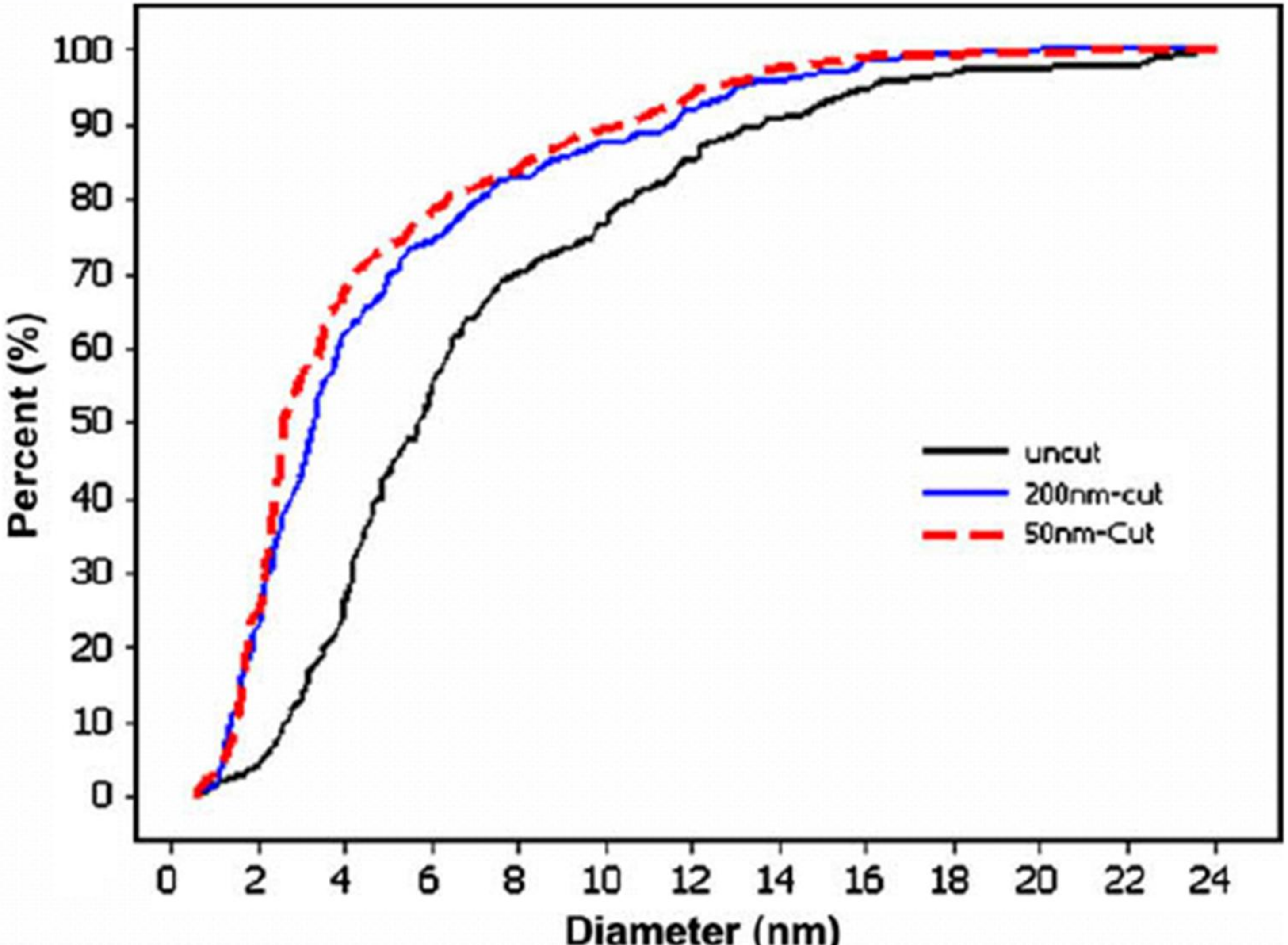
a) Acid-oxidized SWCNT b) mircrotome-cut SWCNT

RAMAN SPECTROSCOPY RESULTS

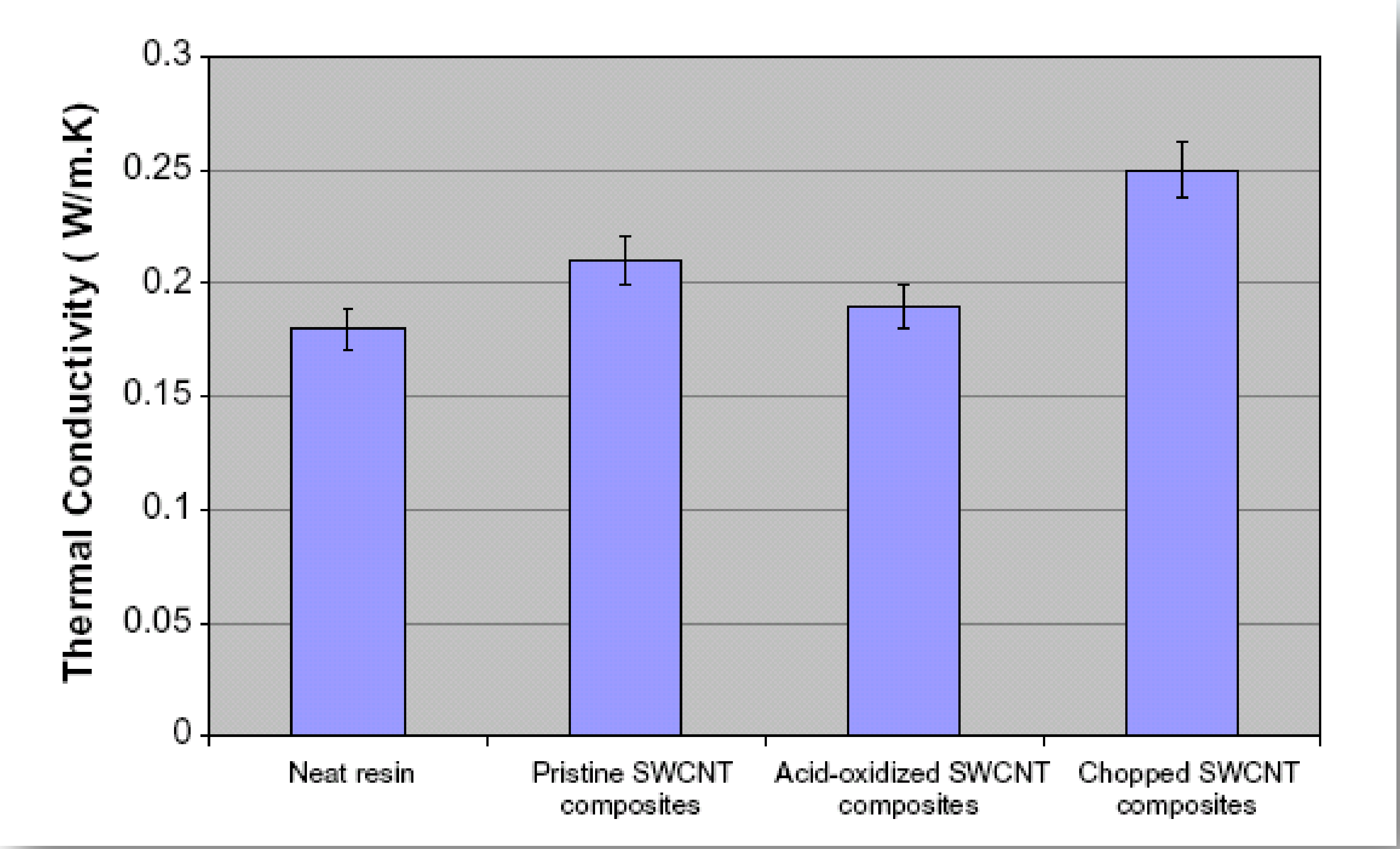


Raman spectroscopy results of SWCNTs. (A) Pristine SWCNTs. (B) Shortened SWCNTs. (C) Oxidized SWCNTs by sulphuric acid

Cumulative % distributions of SWCNT rope diameters in aqueous solution



Thermal conductivity of 0.5 wt% nanotubes integrated composites



CONCLUSIONS

The precise sectioning of CNTs provides an effective way to shorten carbon nanotubes with controlled length and minimum sidewall damage. Shortened nanotubes were found to be easily dispersed into polymer matrices, and then effectively improved the percolation. The minimum CNT sidewall damage and improved percolation in shortSWCNT composites led to an obvious improvement of thermal conductivity.

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EFFECTS OF SURFACE-FUNCTIONALIZED MULTI-WALLED CARBON NANOTUBES ON THE PROPERTIES OF POLY(DIMETHYL SILOXANE) NANOCOMPOSITES

T.P. Chua, M. Mariatti *, A. Azizan, A.A. Rashid

School of Materials and Mineral Resources Engineering, Universiti Sains Malaysia, 14300 Nibong Tebal, Penang, Malaysia

Summary

The effects of surface-functionalized multi-walled carbon nanotubes (MWNTs) on the properties of poly (dimethyl siloxane) (PDMS) nanocomposites are investigated in study.

The surface functionalization of MWNTs is carried out by diphenyl-carbinol functionalization followed by reaction with multifunctional silane, 3-aminopropyltriethoxisilane.

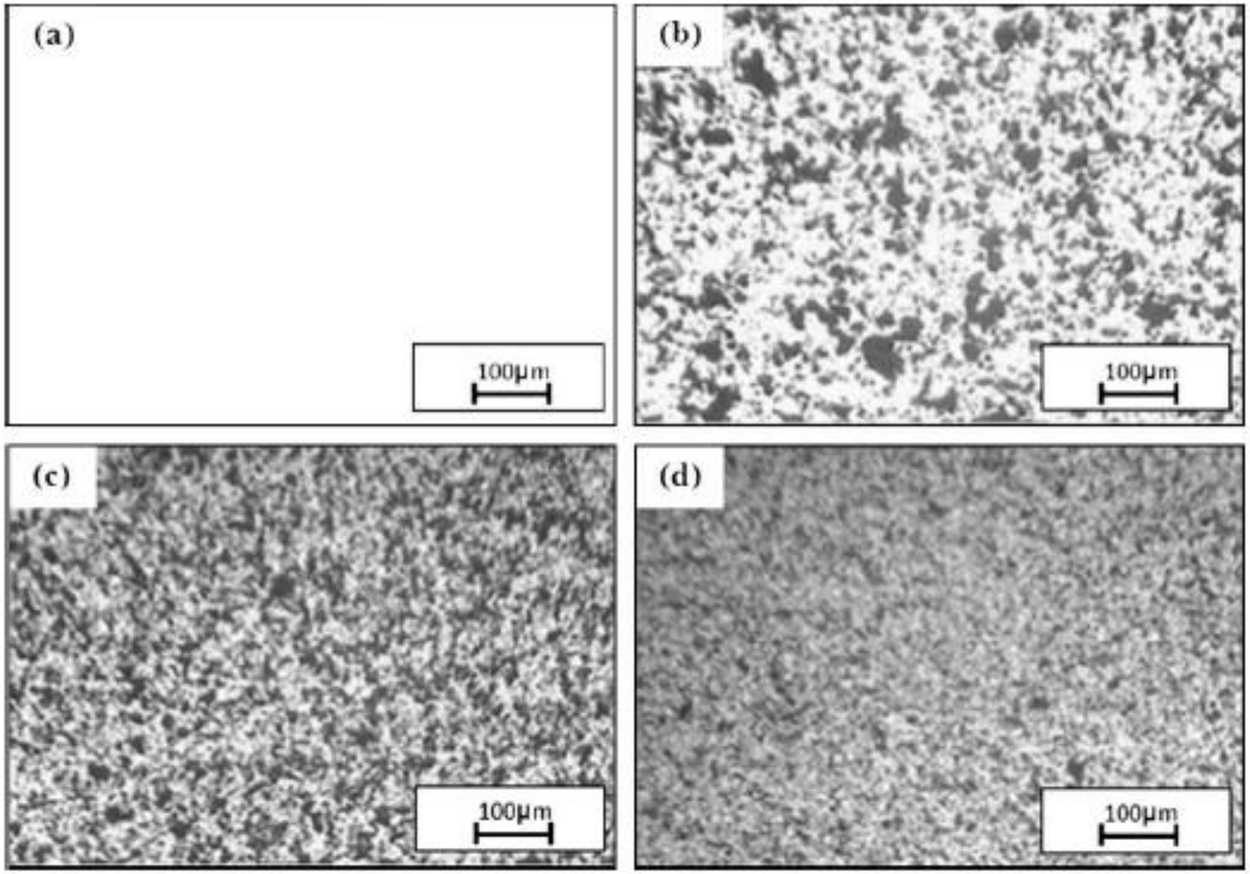
Fourier transform infrared spectroscopy (FT-IR) and energy dispersion spectroscopy (EDS) analysis are used to confirm the presence of diphenyl-carbinol and silane on the surface of the MWNTs.

The effects of the MWNTs' surface treatment on the thermal conductivity properties of poly(dimethyl siloxane)-based (PDMS) nanocomposites are studied with use of the C-Therm TCi Thermal Conductivity Analyzer.

Transmission mode optical microscopy digital images of comparison dispersion of 0.5 vol.% MWNTs in nanocomposites after different surface functionalizations of MWNTs (800X)

Neat PDMS

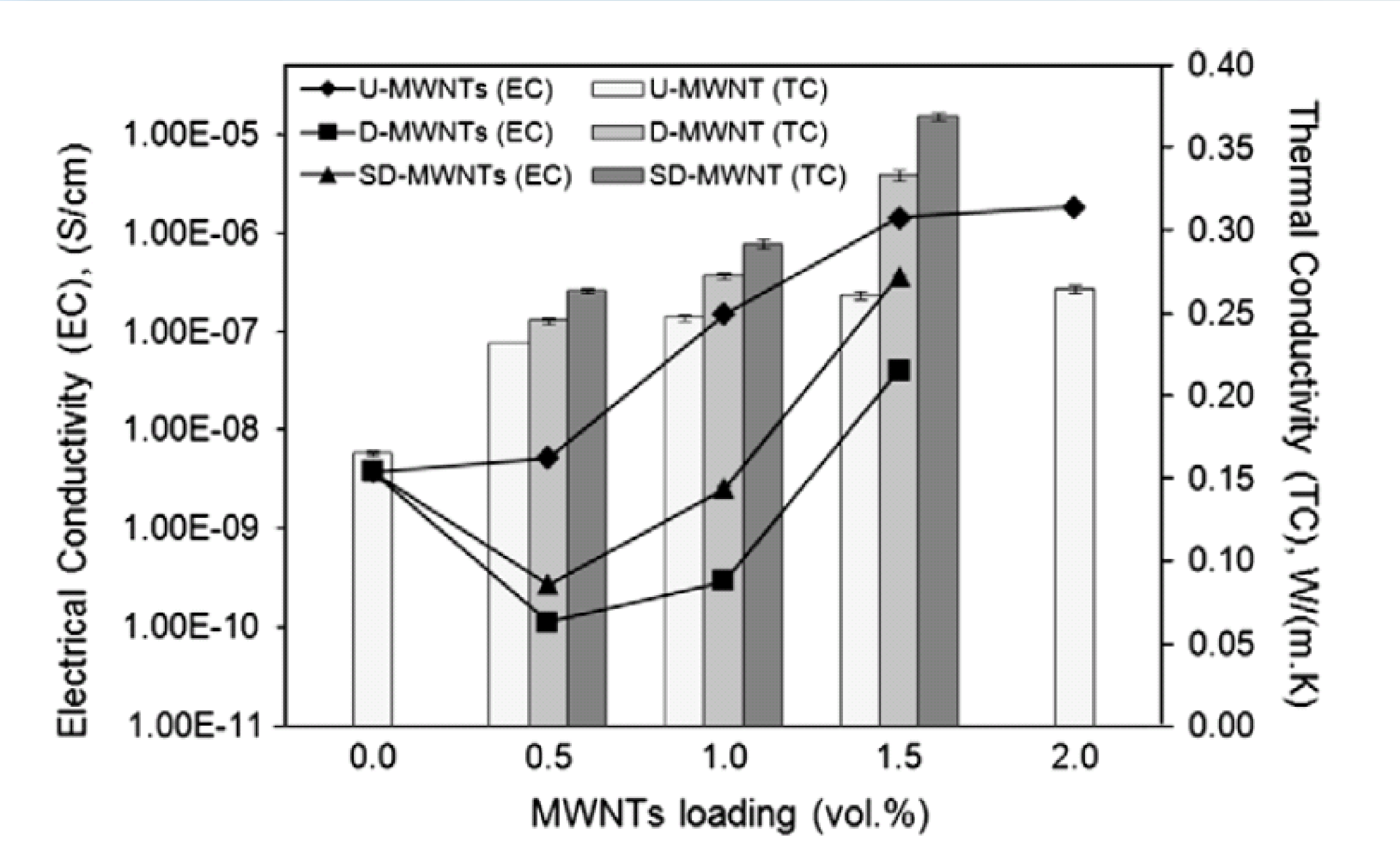
D-MWNTs



D-MWNTs

SD-MWNTs

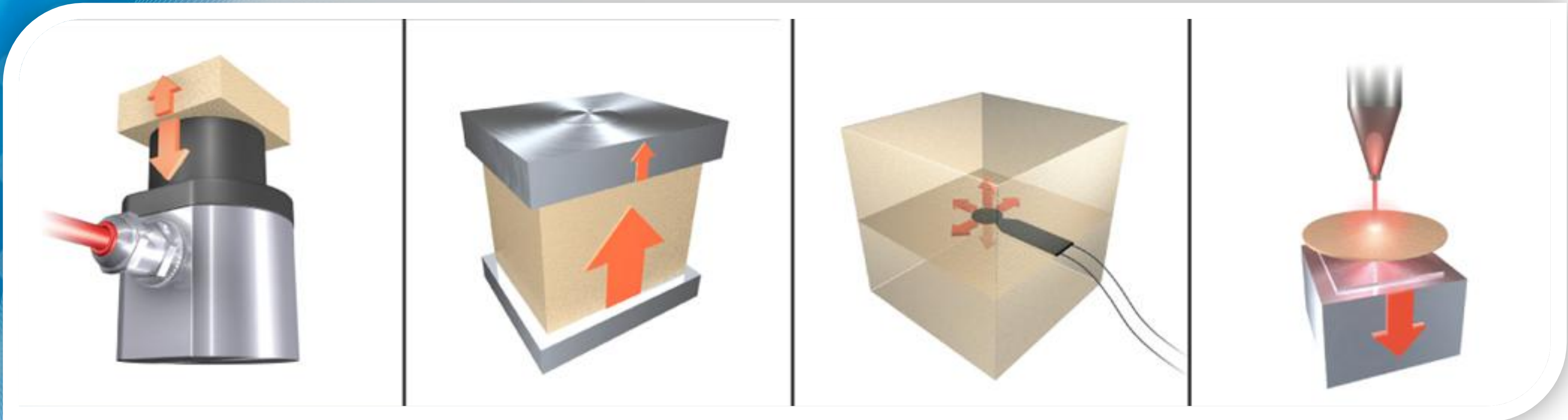
Thermal conductivity and electrical conductivity of MWNT/PDMS nanocomposites



CONCLUSIONS

The results show that the grafting of silane molecules onto diphenyl-carbinol-functionalized MWNTs (SD-MWNTs) improves the dispersion of MWNTs in PDMS; this subsequently enhances the thermal conductivity and dynamic mechanical properties as compared to those containing unmodified (U-MWNTs) and diphenyl-carbinol-functionalized MWNTs (D-MWNTs).

The electrical conductivity of the nanocomposites s shown to decrease due to the wrapping of MWNTs with non-electrical-conducting organic materials.

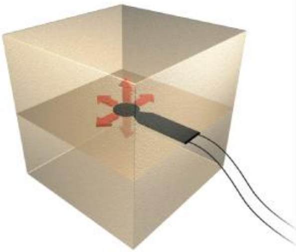
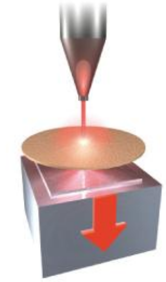


TCi Thermal Conductivity Analyzer

HOW DO WE COMPARE

COMPARISON OF TECHNIQUES

Superior to Other Test Methods[1]:

	 Mathis TCi (Modified Transient Plane Source)	 Traditional Guarded Hot Plate	 Transient Plane Source	 LaserFlash Diffusivity
Sample Configuration				
Minimum	**0.67" diameter (17mm)**	6" x 6" (150 x 150mm)	Two Identical Samples 1" x 1" (25 x 25mm)	0.5" diameter (12.4mm) 0.004" thick (1mm)
Maximum	**Unlimited**	24" x 24" (600 x 600mm)	Two Identical Samples Unlimited	0.5" diameter (12.4mm) 0.004" thick (1mm)
Material Testing Capabilities	**Solids, Liquids, Powders, Pastes**	Solids	Solids, Liquids	Solids

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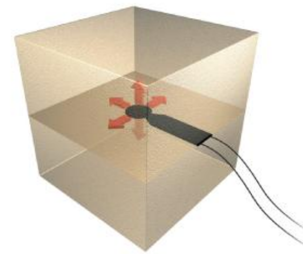
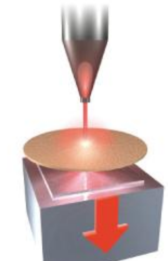
COMPARISON OF TECHNIQUES

Superior to Other Test Methods[1]:

	 Mathis TCi (Modified Transient Plane Source)	 Traditional Guarded Hot Plate	 Transient Plane Source	 LaserFlash Diffusivity
Speed & Flexibility				
Sample Preparation	None Required	Extensive	Some	Extensive
Testing Time	Seconds	Hours	Minutes	Seconds*
Training Time	Minimal	Moderate	Significant	Extensive
Non-Destructive	Yes	No	No	No
Integrated, Downloadable Test Results Database	Yes	No	No	No

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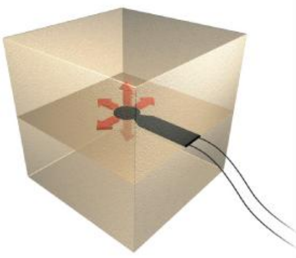
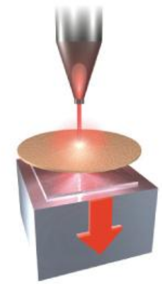
COMPARISON OF TECHNIQUES

Superior to Other Test Methods[1]:				
	 Mathis TCi (Modified Transient Plane Source)	 Traditional Guarded Hot Plate	 Transient Plane Source	 LaserFlash Diffusivity
Range				
k-Range (W/mK)	**0 – 100**	0 – 2	0 – 100 (100 – 500 requires C_p)	0 – 500
Temperature Range (ºF) (ºC)	**-58º to 392ºF** **-50º to 200ºC**	-4º to 392ºF -20º to 200ºC	-148º to 2552ºF -100º to 1400ºC	-148º to 3627ºF -100º to 2000ºC
Pricing	$	$ $	$ $	$ $ $

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WEBSITE: WWW.CTHERM.COM

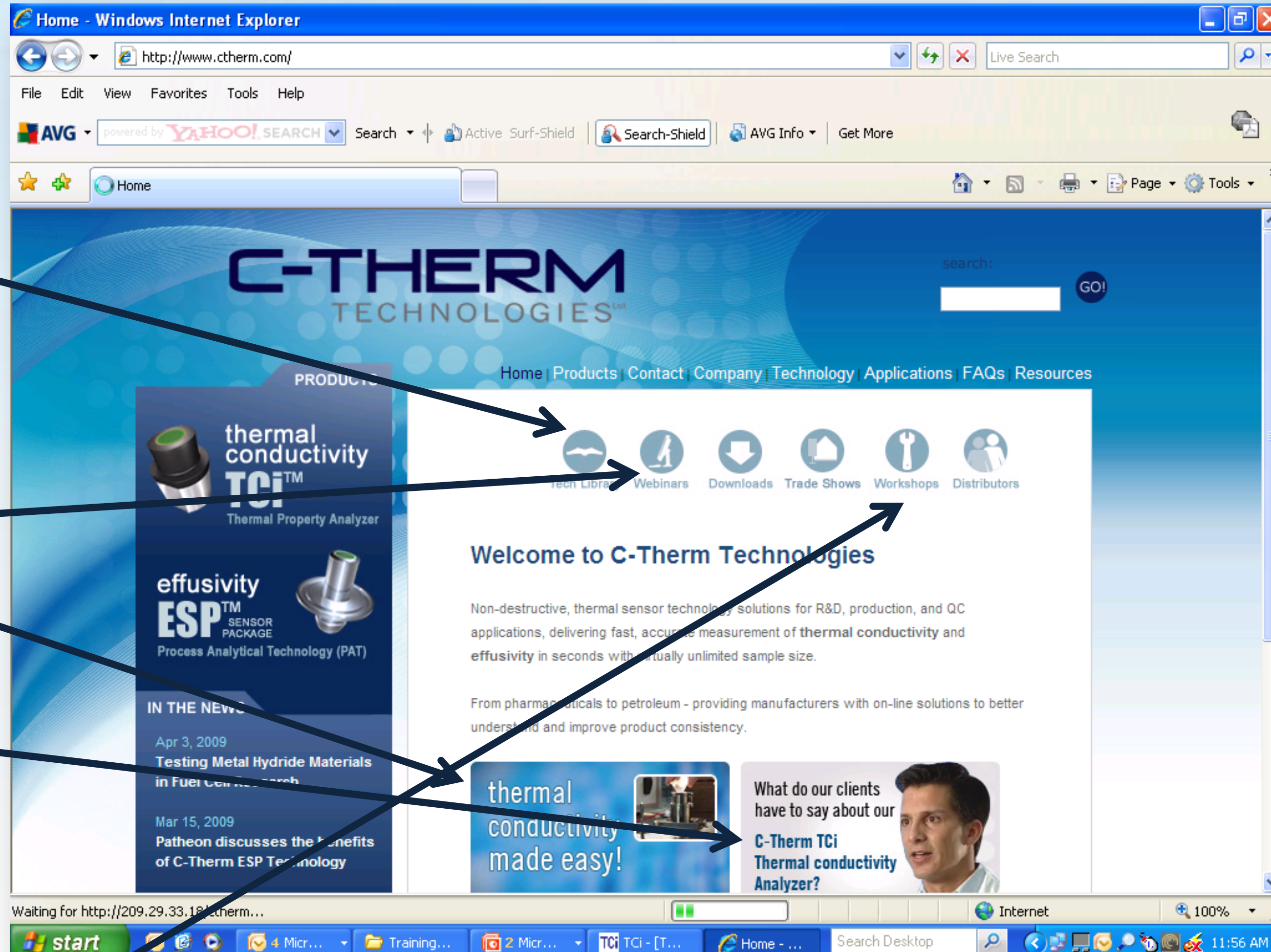
Technical Library Full of Application Notes

Webinar Recordings with Full Audio

Demo Video

Client Testimonials

Upcoming Workshops



QUESTIONS FOR C-THERM?

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THANK YOU!

C-THERM TECHNOLOGIES Ltd.