Carbon Based Nanocomposites and Their Applications

Fazal Ahmad Khalid
Pro-Rector
GIK Institute of Engineering Sciences and Technology
Topi, NWFP, Pakistan
(Khalid@giki.edu.pk)

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Outline
Nanotechnology
Nanomaterials and Characterization
Cu-CNTs
Al-C60
Al-Diamond
Summary

Nanocomposites for Thermal management Applications
NANOTECHNOLOGY

- Nanotechnology is the art of manipulating matter at the nanometer scale to create novel structures, devices, and systems.

Some Areas of Applications:
- Catalysts
- Coatings
- Energy storage
- Electronics
- Pharmaceutical and diagnostics

Nanotechnology promises to be the key technology for next 2-3 decades. The potentialities look exciting, but the exploration has just begun.

Structures (e.g. materials)

Devices (e.g. sensors)

Systems (e.g. NEMS)

* 1 millimeter = 1,000 micrometers;
  1 micrometer = 1,000 nanometers

Source: "Nanotech: The Tiny Revolution" (November 2001); AtomWorks

Development of nano-chemistry is the key to realizing the “bottom up” approach to nanoscale electronics.

Vacuum tube, relay

Transistor

Integrated circuit

Molecular electronics

Size

Year
Nanomaterials

- Zero-Dimensional
  - Nanoparticles (oxides, metals, semiconductors and fullerenes)

- One-Dimensional
  - Nanowires, Nanorods and Nanotubes

- Two-Dimensional
  - Thin films (multilayers, monolayer, self-assembled and mesoporous)

- Three-Dimensional
  - Nanocomposites, nanograin, micro- and mesoporous and organic-inorganic hybrids

Synthesis and Physical Fabrication

Nanomaterials - Size-Dependent Properties

- Chemical Properties - reactivity, catalysis
- Thermal Properties - melting temperature
- Mechanical Properties - strength, adhesion and capillary force
- Optical Properties - absorption and scattering of light
- Electrical Properties - tunneling current
- Magnetic Properties - superparamagnetic effect

Surface area to volume ratio
- Surface energy $\uparrow$ - high reactivity
- Al nanoparticles - energetic materials

Nanoscale melting temperature
- Nanocrystal - surface energy $\downarrow$ - melting temp $\downarrow$
- CdSe (3 nm) nanocrystal melts @ 700 K (1678 K)

New Properties promise new applications
Allotropes of Carbon

- Diamond
- Graphite
- Lonsdaleite
- Amorphous Carbon
- Carbon Nanotube

What is Carbon Nanotube?

ROLLED Graphene Sheet
MMCs
CNT-Al
CNT-Cu
CNT-Co
TiO₂-Al
(In-situ)

Carbon nanoparticles and whiskers in polyethylene composites

2.5% carbon nanoparticles - Increase in tensile strength and modulus by 17%

CMCs
CNT-Al₂O₃ Composites
MWN-SiC Composites
Nanotube-Fe-Al₂O₃
Nanotube-Fe/Co-MgAl₂O₃
Nanotube-Co-MgO

Nanotube-Polymers
C nanoparticles-Polyethylene
Nano SiO₂-Polymers
CNT-PMMA


Ref: S.I. Cha et al., Adv. Mat. 2005, 17, 1377
R. Zhong, Carbon, 41, 2003, 848
Composite Materials

Engineering

Space Defense

Wind energy

Bridges

Structures

Buildings

Sports

Transport

Auto- and Locomotives

Naval & Aircrafts

MMCs

PMCs

CMCs

NanoComposites - engineering, multifunctional, biomedical and construction

"Thermal management is one of the Key concerns in diverse fields such as Microelectronics and Space Technology"

ExtreMat Project

Insight to processing and characterization of new composite materials

Approach to transfer the attractive physical properties of diamond to bulk engineering components

ExtreMat shall push forward the limits in materials technology and will provide and industrialize new knowledge based materials and compounds for to-end and new applications in extreme environments

New Materials with enhanced thermal conductivity
Advanced Thermal Management Materials

Semiconductors, microelectronic and optoelectronic devices

HEAT DISSIPATION

THERMAL STRESSES

WARPING

Thermal Conductivity

First Generation:
<200 W/m-K

Second Generation:
<400 W/m-K

Third Generation:
>400 W/m-K

Excellent thermophysical props
Reducing cost

Servers, notebook computers
Plasma display, PCBs
Optoelectronic packaging

First Generation:
<200 W/m-K

Second Generation:
<400 W/m-K

Third Generation:
>400 W/m-K
**Composite Matrices - Cu, Ag and Al**

**Reinforcement**

Diamond Fullerene, C60 Graphite CNTs

High volume % of reinforcement

Rule of Mixture

\[ \lambda_u = \lambda_r V_r + \lambda_m (1 - V_r) \]

**Availability & details in respect of various matrices**

- **C60 “Buckminsterfullerene”**
- Diamond
- Graphite
- Single-wall Carbon Nanotube

**Modulus, Hard, Thermal Conductivity and CTE**

- Diamond: \( \lambda = 600-2200 \, \text{W/mK} \) at 25\(^\circ\)C and CTE = \( 0.8 \times 10^{-6} / \text{K} \) at 25\(^\circ\)C

**CNTs – stability & de-agglomeration?**

**CNT/Cu based Nanostructures**

**Synthesis**

- CNTs dispersion in ethanol
- CNTs and Copper acetate monohydrate mix
- Drying (100 \(^\circ\)C) and calcination (320 \(^\circ\)C) of mix
- Reduction of copper oxide
- Uniaxial Cold compaction
- Sintering at 900 \(^\circ\)C

**Characterization**

- SEM images of sintered composite showing stability of CNT in 5\% sample
- Characterization

**Morphology of synthesized Cu particles**

**Morphology of MWCNTs**
Figure: SEM micrographs showing structure of the Al-diamond based composites.

Interface Examination

TEM Sample preparation?
Twin-jet Electroplishing
Microgrinding
Ion Milling
TEM micrographs showing nano-diamond particles in Al-diamond (1) sample, a BF and b DF g=[111]D

Fig: Formation of Al₄C₃ at the amorphous region of the Al-diamond interface.

Characteristics of Al₄C₃

3C + 4Al → Al₄C₃
Ceramic - Hard, Thermal Conductivity ↓
Reaction in moist air (hydrated Aluminas)
Al₄C₃ + 6H₂O +O₂ → Al(OH)₃ + 3C

Load Transfer
Heat Transfer
TEM micrographs showing \( \text{Al}_4\text{C}_3 \) at the interface in Al-C60 (4) sample. a BF, b DF \( g=(011)\text{Al}_4\text{C}_3 \), c SADP of C60, d analysis of SADP.

Summary

Progress on the production and characterization of carbon based Nanocomposites
Thank you