Carbon Based Nanocomposites and Their Applications

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EMPA

Outline

- Nanotechnology
- Nanomaterials and Characterization
- Nanocomposites for Thermal management Applications
  - Cu-CNTs
  - Al-C60
  - Al-Diamond
- Summary

NANOTECHNOLOGY

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

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)

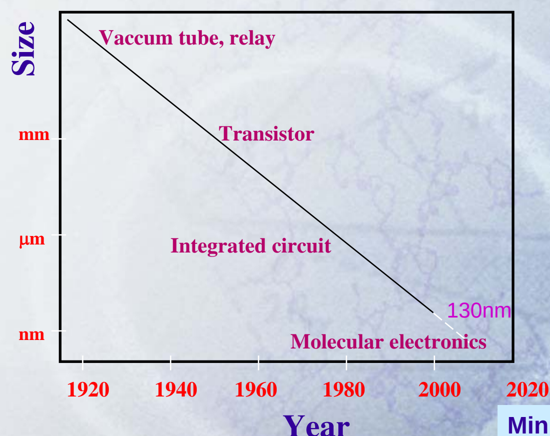
Devices (e.g. sensors)

Systems (e.g. NEMS)

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

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

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



Semiconductor switches

Macromolecules

Molecules

Atoms

Miniaturization

Development of nano-chemistry is the key to realizing the "bottom up" approach to nanoscale electronics

Nanomaterials

Synthesis and Physical Fabrication

- **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, nanograined, micro- and mesoporous and organic-inorganic hybrids

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

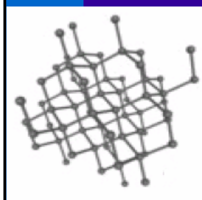
Magnetic Properties – superparamagnetic effect

Surface area to volume ratio
- Surface energy ⇑ – high reactivity
- Al nanoparticles – energetic materials

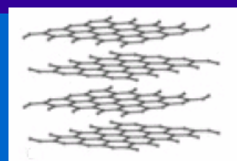
Nanoscale melting temperature
- Nanocrystal – surface energy ⇑ – melting temp ↓
- CdSe (3 nm) nanocrystal melts @ 700 K (1678 K)

New Properties promise new applications

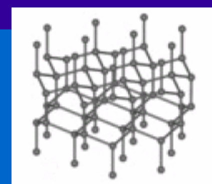
Allotropes of Carbon



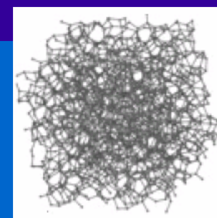
Diamond



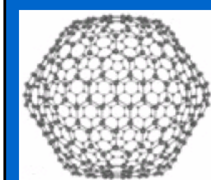
Graphite



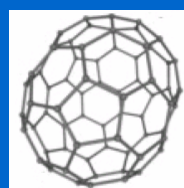
Lonsdaleite



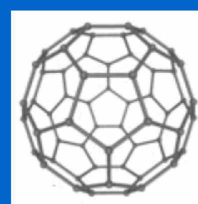
Amorphous Carbon



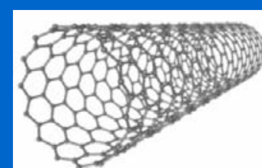
C 540



C 70

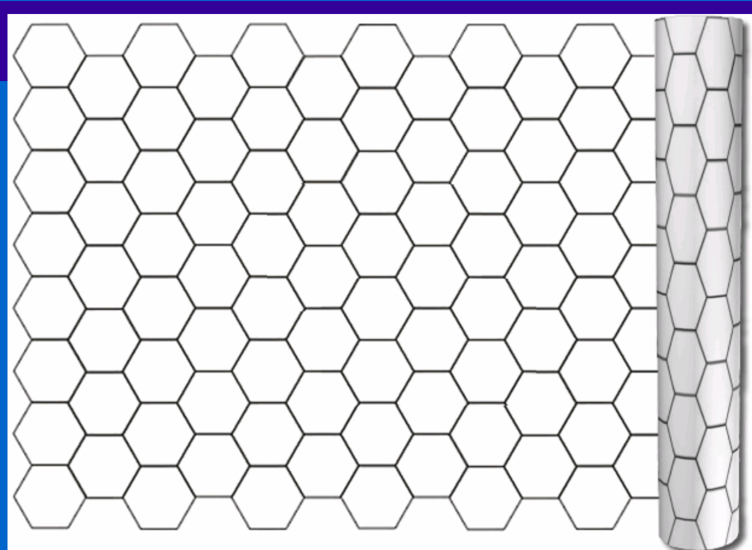


C 60

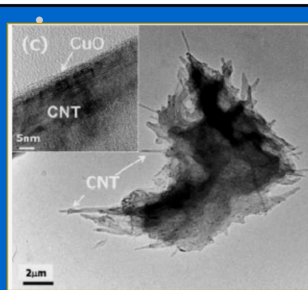


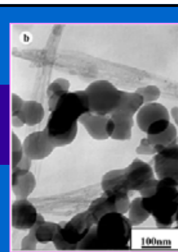
Carbon Nanotube

What is Carbon Nanotube?



ROLLED Graphene Sheet





MMCs
CNT-Al
CNT-Cu
CNT-Co
TiO_2-Al
(In-situ)

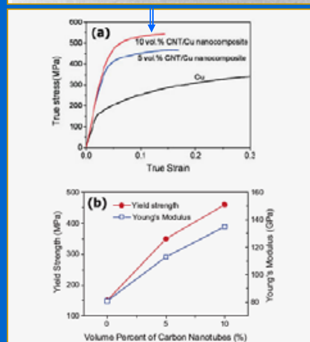


Figure 4. Mechanical properties of CNT/Cu nanocomposites: a) stress-strain curves of CNT/Cu nanocomposites obtained by compressive testing, and b) yield strength and Young's modulus of CNT/Cu nanocomposites with increasing volume percentage of CNTs.

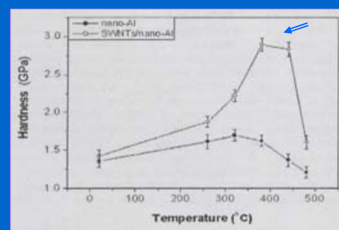


Fig. 3. Hardness of the nano-Al and SWNTs/nano-Al composites consolidated at different temperatures.

R. Zhong, Carbon, 41, 2003, 848

Rice Uni

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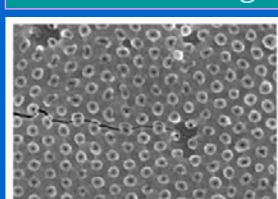
Ref: S.I. Cha et al, Adv. Mat. 2005, 17, 1377

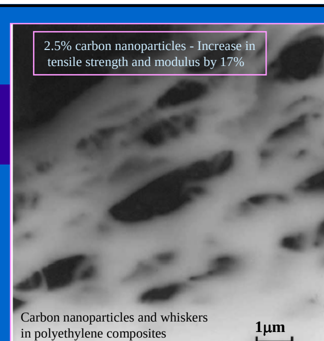
PMCs
Nanotube-Polymers
C nanoparticles-Polyethylene
Nano SiO_2-Polymers
CNT-PMMA

CMCs
CNT-Al_2O_3 Composites
MWNT-SiC Composites
Nanotube-Fe-Al_2O_3
Nanotube-Fe/Co-$MgAl_2O_3$
Nanotube-Co-MgO



CNT-Alumina ordered porous template structure

15. Xia, Z., *et al., Acta Mater.* (2004) 52 (4), 931



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

Carbon nanoparticles and whiskers in polyethylene composites

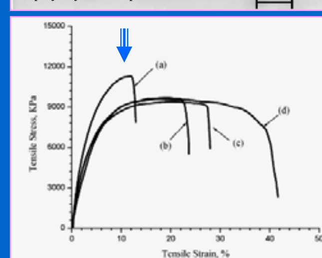


Fig. 7. Tensile stress–strain diagram: (a) Nanocomposites with 0° orientation, (b) nanocomposites with 90° orientation, (c) nanocomposites with powder consolidation, and (d) neat polyethylene.

H. Mahfuz et al, Composites Part A, 35, 2004, 519

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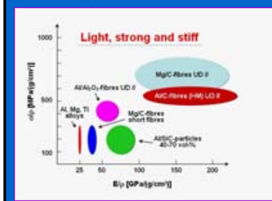

Applications

- Engineering
- Space Defense
- Transport Auto- and Locomotives Naval &Aircrafts
- Composite Materials
- Sports
- Wind energy
- Bridges Structures Buildings

MMCs
PMCs
CMCs

NanoComposites – engineering, multifunctional, biomedical and construction

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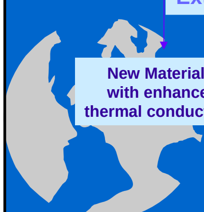
Thermal Management

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

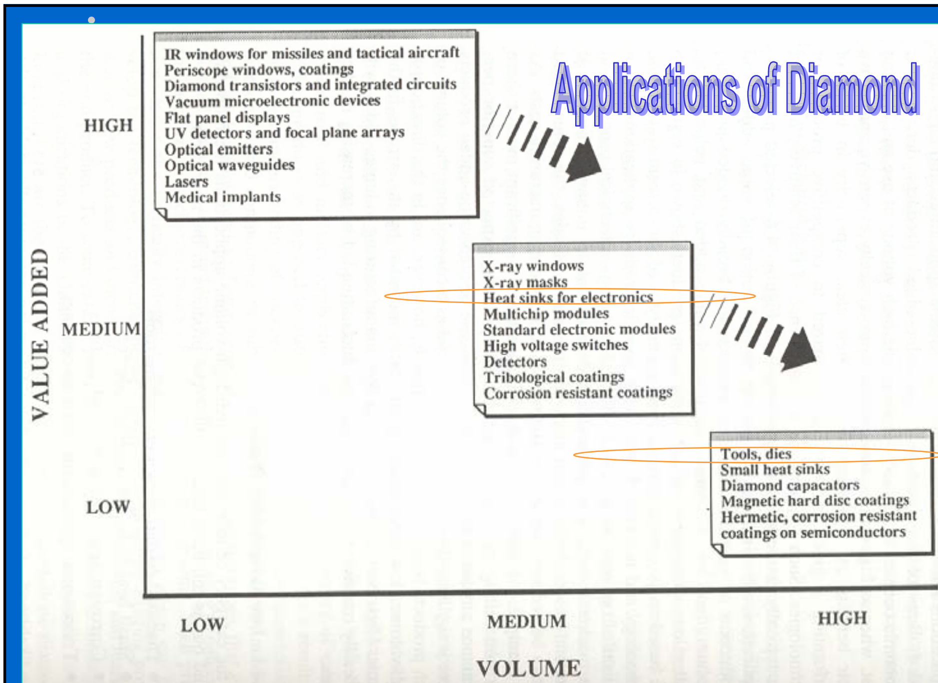


New Materials with enhanced thermal conductivity

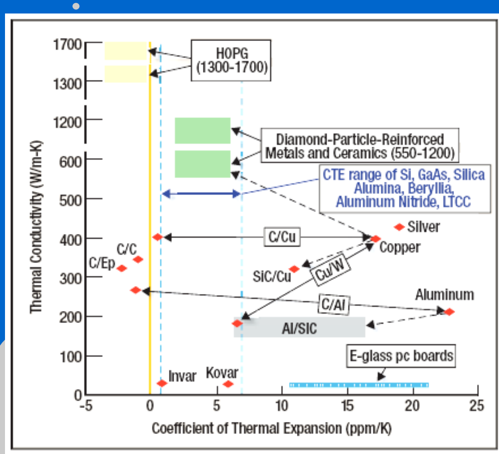
ExtreMat shall push forward the limits in materials technology and will provide and industrialize new knowledge based materials and compounds for to-end and new applications in extreme environments

Insight to processing and characterization of new composite materials

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



Advanced Thermal Management Materials



C. Zweben, Power Elect. Tech. Feb., 2006

Semiconductors, microelectronic and optoelectronic devices

HEAT DISSIPATION
THERMAL STRESSES
WARPING

Thermal Conductivity

First Generation:
<200 W/m-K

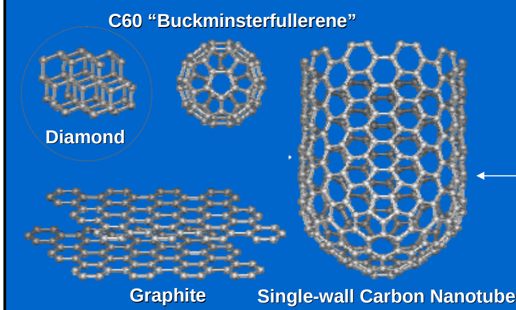
Second Generation:
<400 W/m-K

Third Generation:
>400 W/m-K

Excellent thermophysical props
Reducing cost

- -Servers, notebook computers
- -Plasma display, PCBs
- -Optoelectronic packaging

Composite Matrices - Cu, Ag and Al



Reinforcement
Diamond
Fullerene, C60
Graphite
CNTs

Availability & decline in cost of synthetic diamond

High volume % of reinforcement

Rule of Mixture

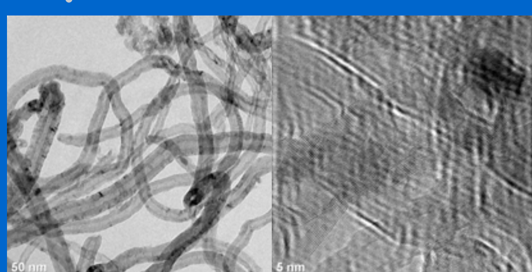
$$\lambda u = \lambda r Vr + \lambda m(1 - Vr)$$

Diamond - λ = 600-2200 W/mK @ 25 °C and CTE = 0.8 x 10^{-6}/K @ 25 °C

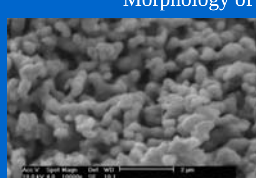
↑ Modulus, Hard, ↑ Thermal Conductivity and ↓ CTE

CNTs – stability & de-agglomeration ?

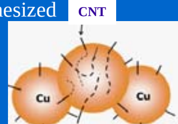
CNT/Cu based Nanostructures



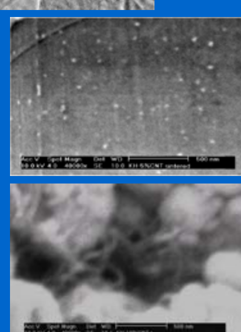
Morphology of MWCNTs



Morphology of synthesized Cu particles



Schematic diagram showing CNT/Cu composite

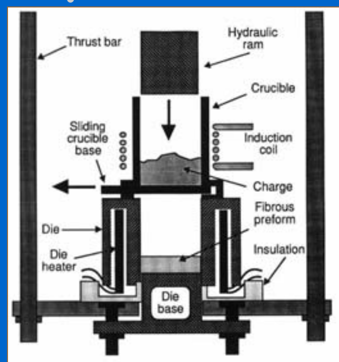


SEM images of sintered composite showing stability of CNT in 5% sample

Synthesis

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

Characterization



Powder Metallurgy (P/M)

Segregation of reinfocement

Fromation of reactive products

Cu-Diamond Composites
- Shock-wave consolidation
- HPHT synthesis

Pressureless reactive infiltration
Lanxide-Process (Al in diamond preform

Al_4C_3

Gas pressure infiltration - better process control but low production rate

SiC coating

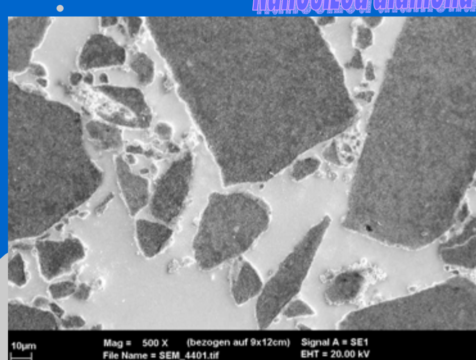
Liquid metal infiltration

Minimum reaction time

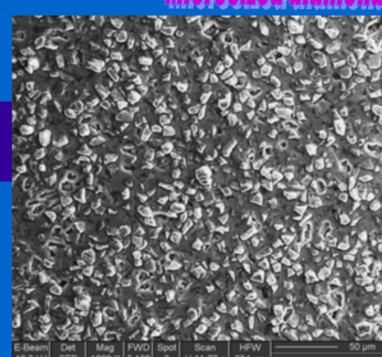
Production benefits

Microstructure

Nanosized diamond



Microsized diamond

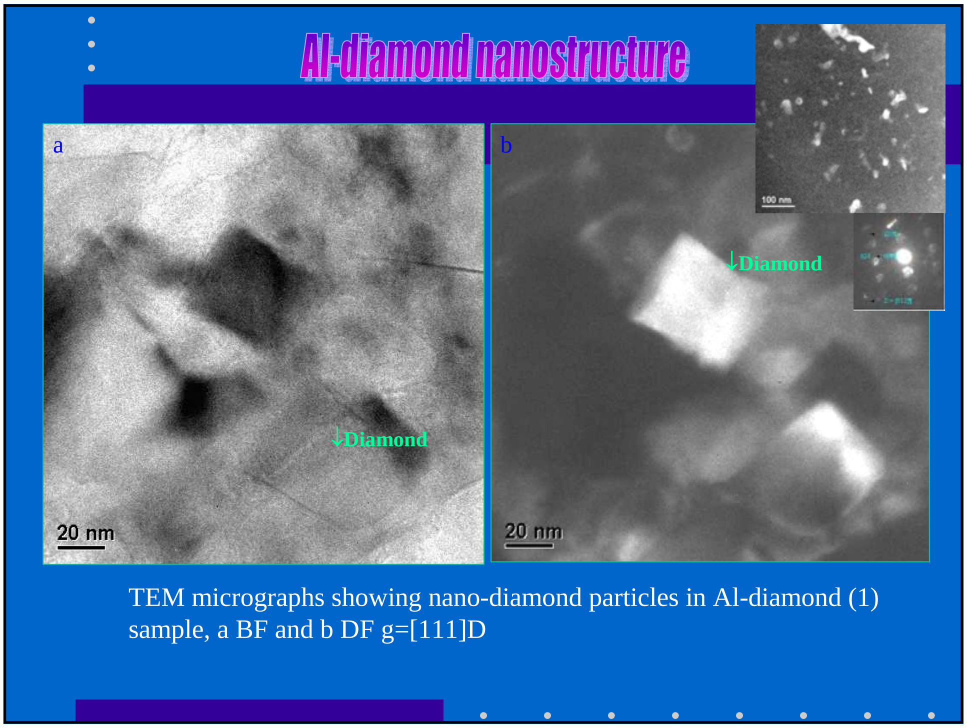


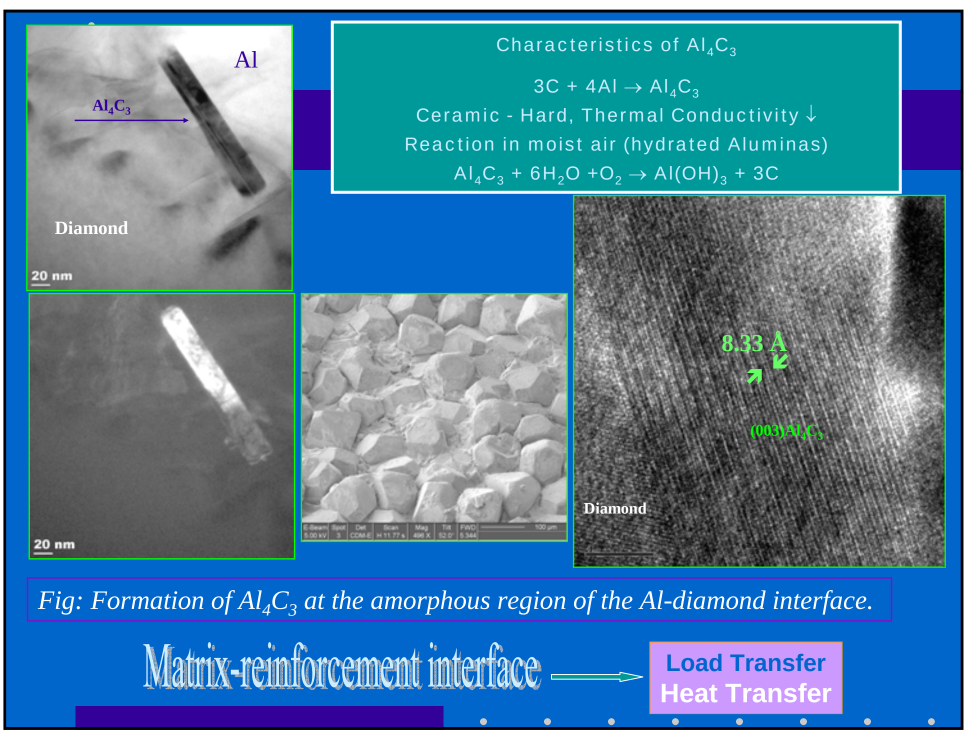
Figures: SEM micrographs showing structure of the Al-diamond based composites.

Interface Examination

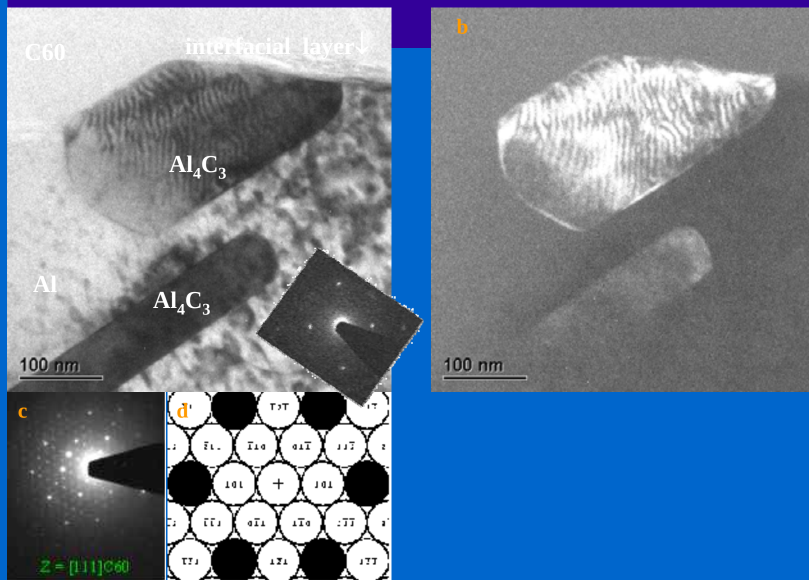
TEM Sample reparation ?

Twin-jet Electropolishing
Microgrinding
Ion Milling


Al-diamond nanostructure
a
b
↓Diamond
↓Diamond
20 nm
20 nm
100 nm
TEM micrographs showing nano-diamond particles in Al-diamond (1) sample, a BF and b DF g=[111]D


Al
Al_4C_3
Diamond
20 nm
20 nm
Characteristics of Al_4C_3
$3C + 4Al \rightarrow Al_4C_3$
Ceramic - Hard, Thermal Conductivity ↓
Reaction in moist air (hydrated Aluminas)
$Al_4C_3 + 6H_2O + O_2 \rightarrow Al(OH)_3 + 3C$
8.33 Å
(003)Al_4C_3
Diamond
Fig: Formation of Al_4C_3 at the amorphous region of the Al-diamond interface.
Matrix-reinforcement interface
Load Transfer
Heat Transfer

- TEM micrographs showing Al_4C_3 at the interface in Al-C60 (4) sample, a BF, b DF g=[011]Al_4C_3, c SADP of C60, d analysis of SADP



Summary

Progress on the production and characterization of carbon based Nanocomposites

Thank you