Applied Nanotech at a Glance

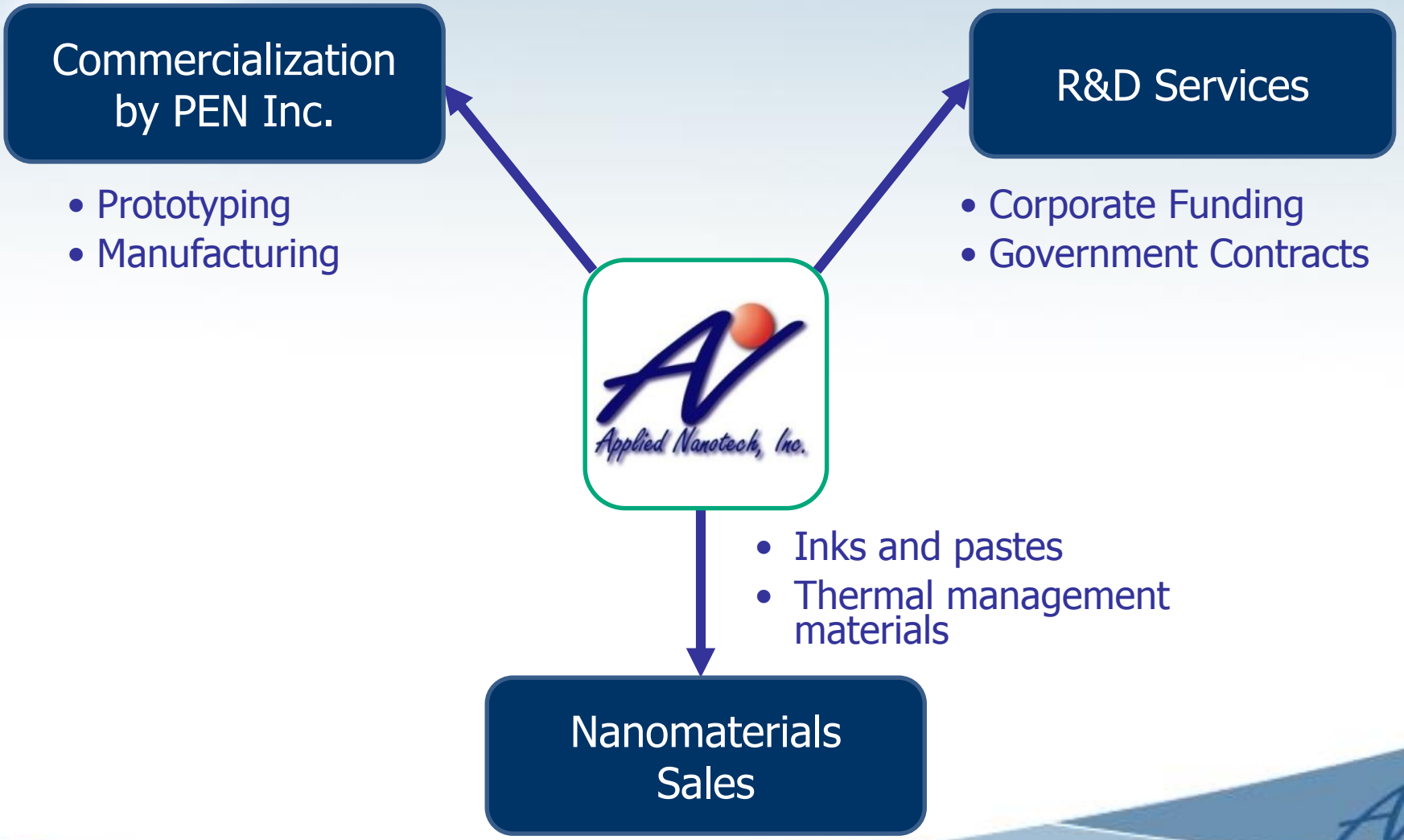
3006 Longhorn Blvd., Suite 107
Austin, TX 78758

Applied Nanotech, Inc.

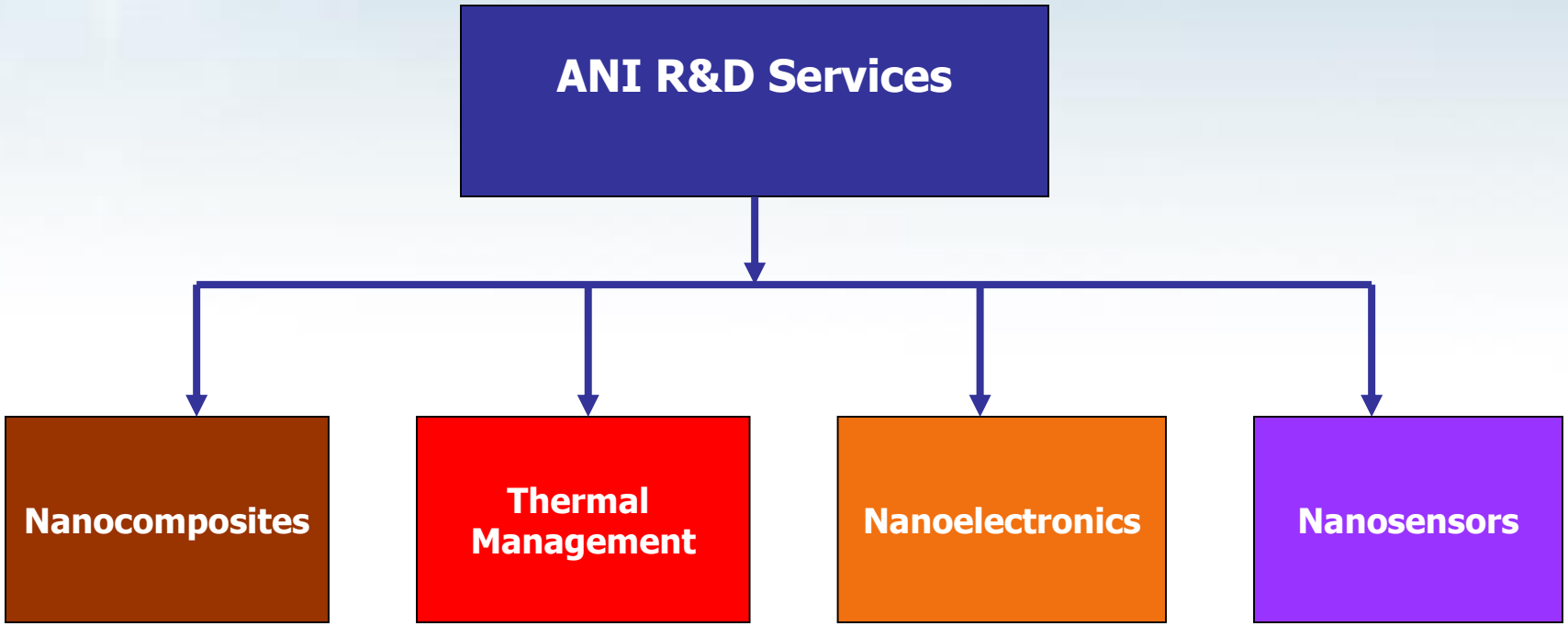
ANI Introduction

- Located in Austin, Texas USA
- Founded in 1988
- Nanotechnology R&D with emphasis in:
  1) Thermal Management
  2) Nanocomposites
  3) Nanoelectronics
  4) Nanosensors
- Three pronged business model:
  1) R&D Services
  2) Product Prototyping for PEN Inc.
  3) Nanomaterials Sales

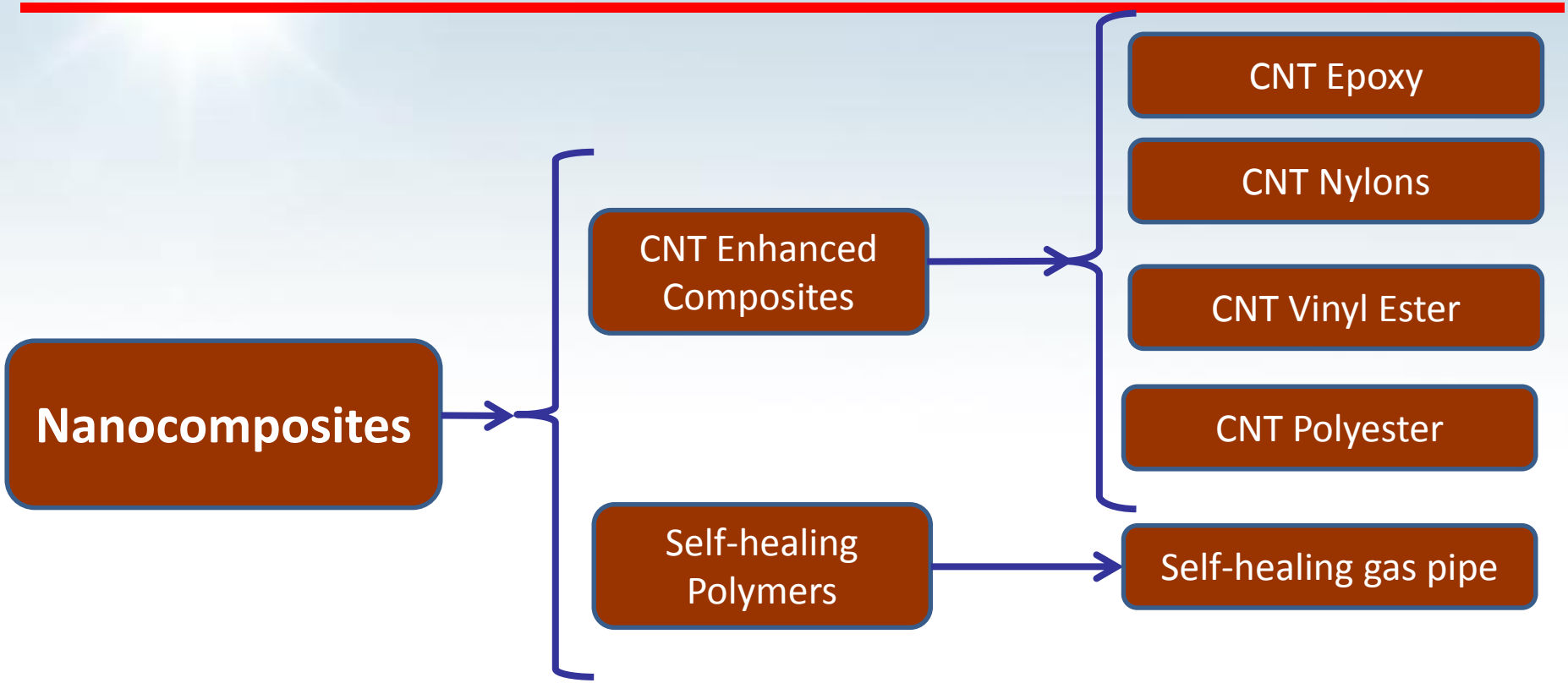
ANI's Business Model



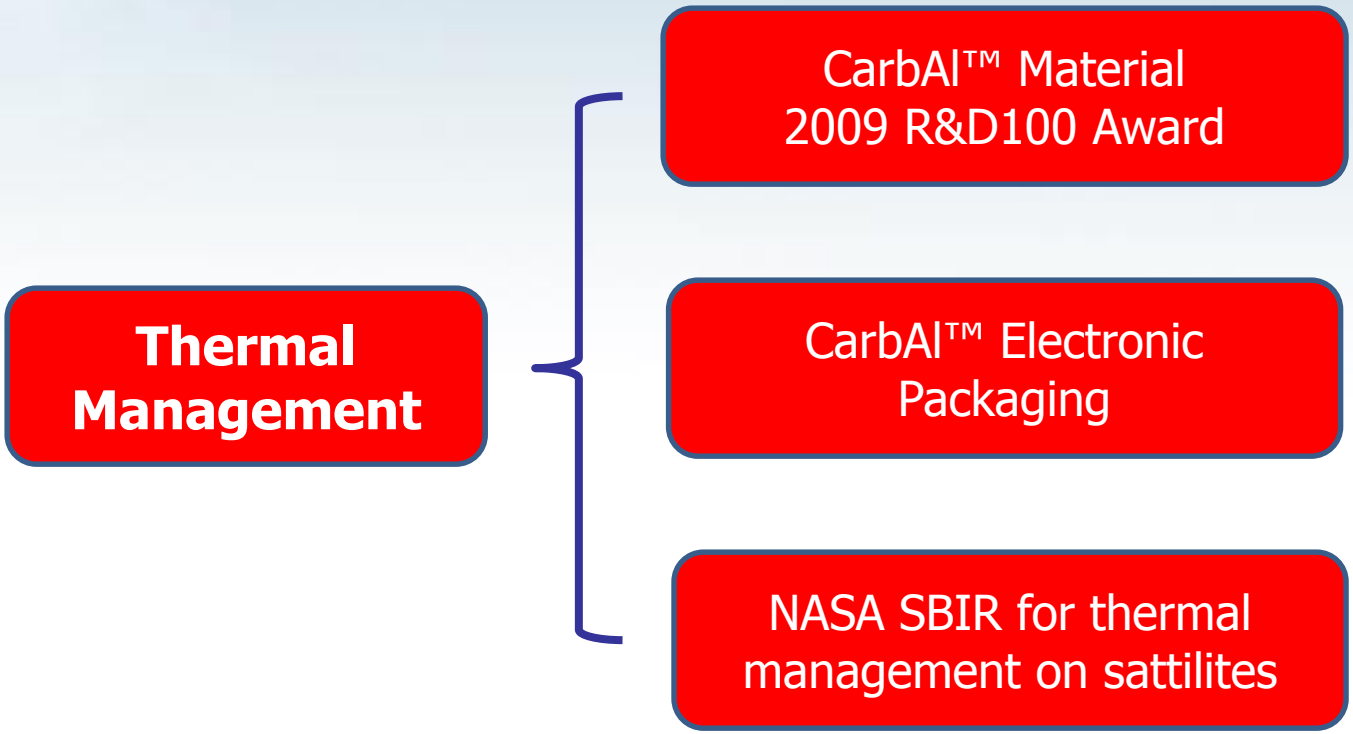
ANI's R&D Divisions



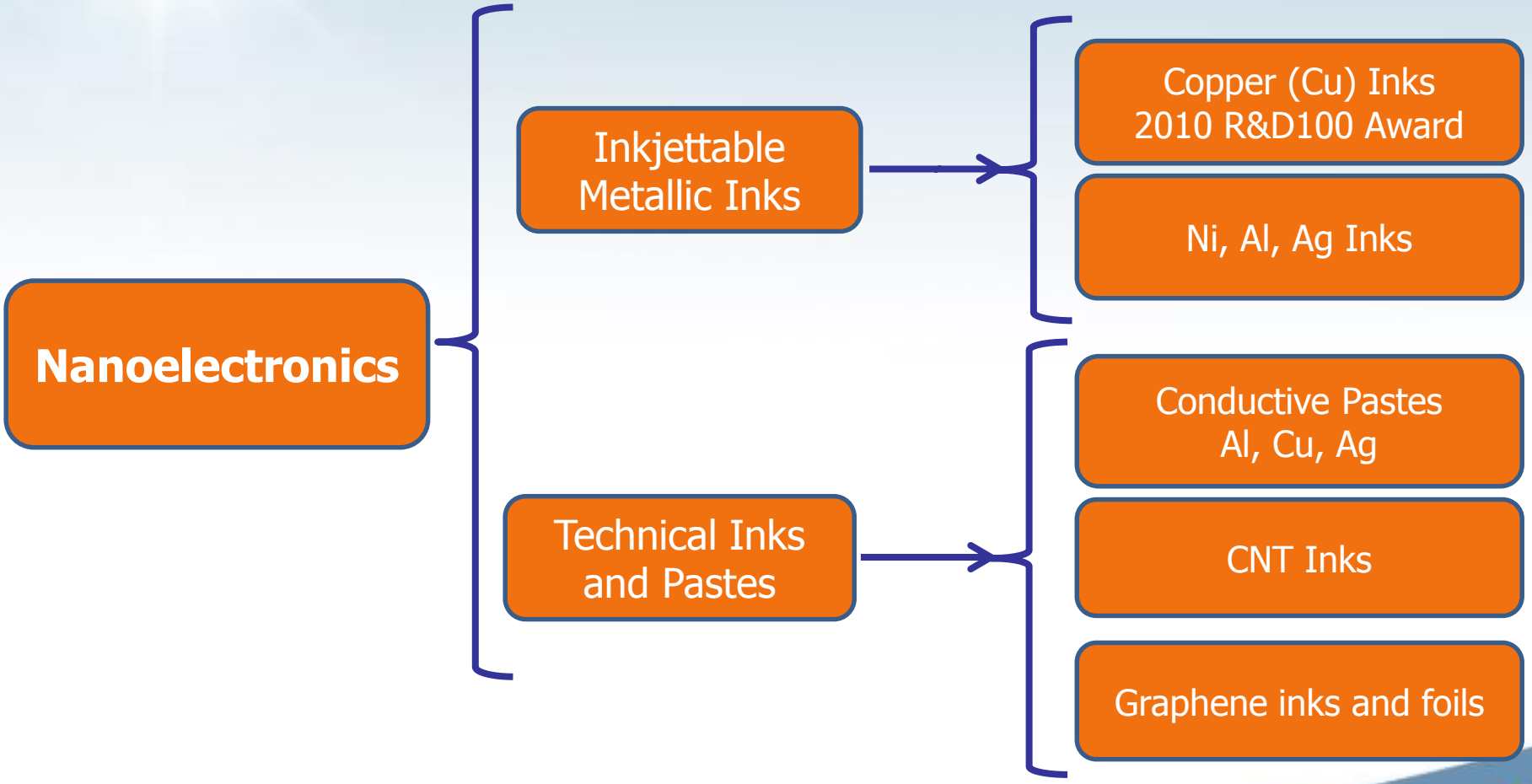
ANI's Nanocomposites Division



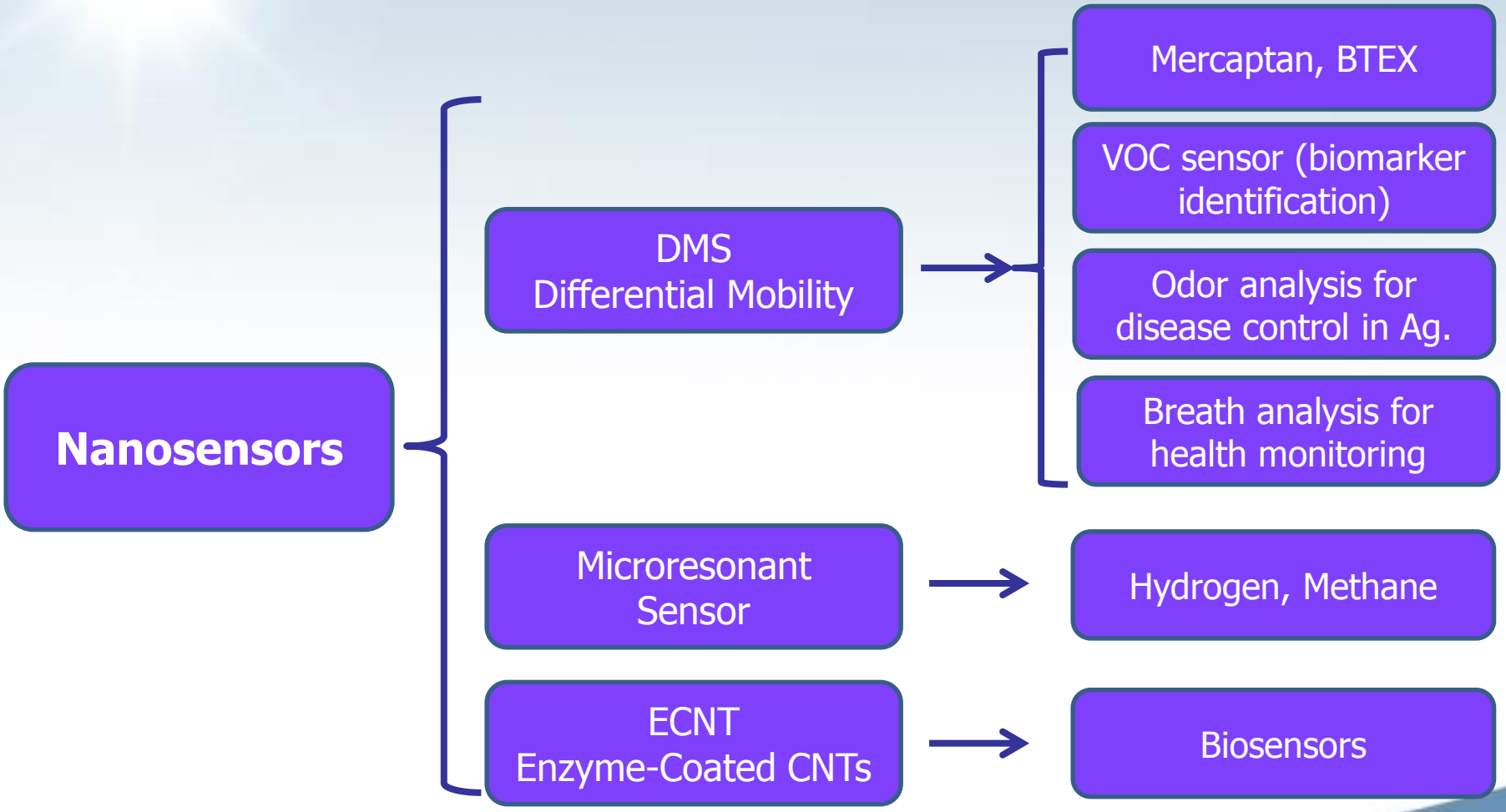
ANI's Thermal Management Division



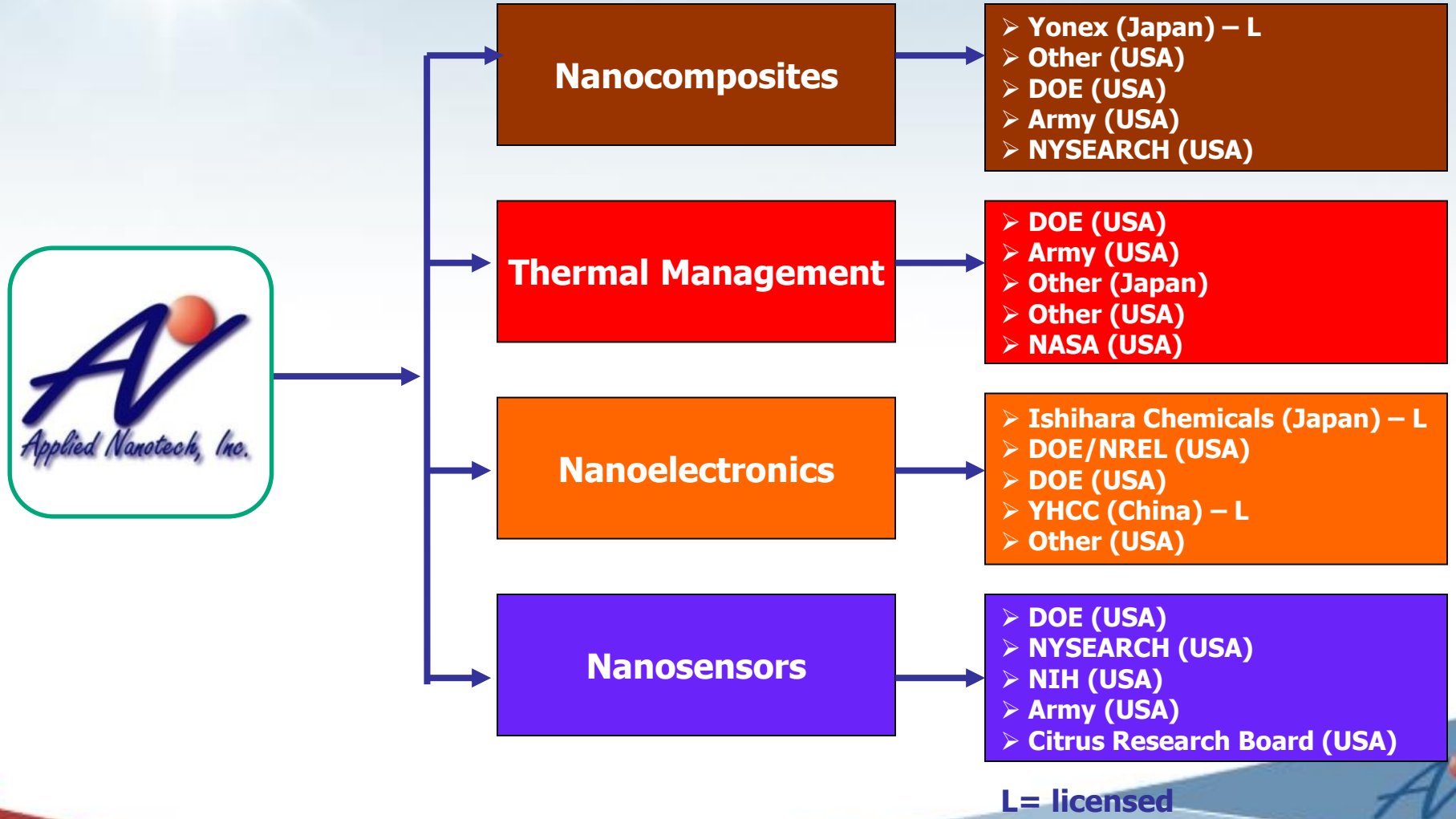
ANI's Nanoelectronics Division



ANI's Nanosensors Division



Recent and Current Funded R&D Activities



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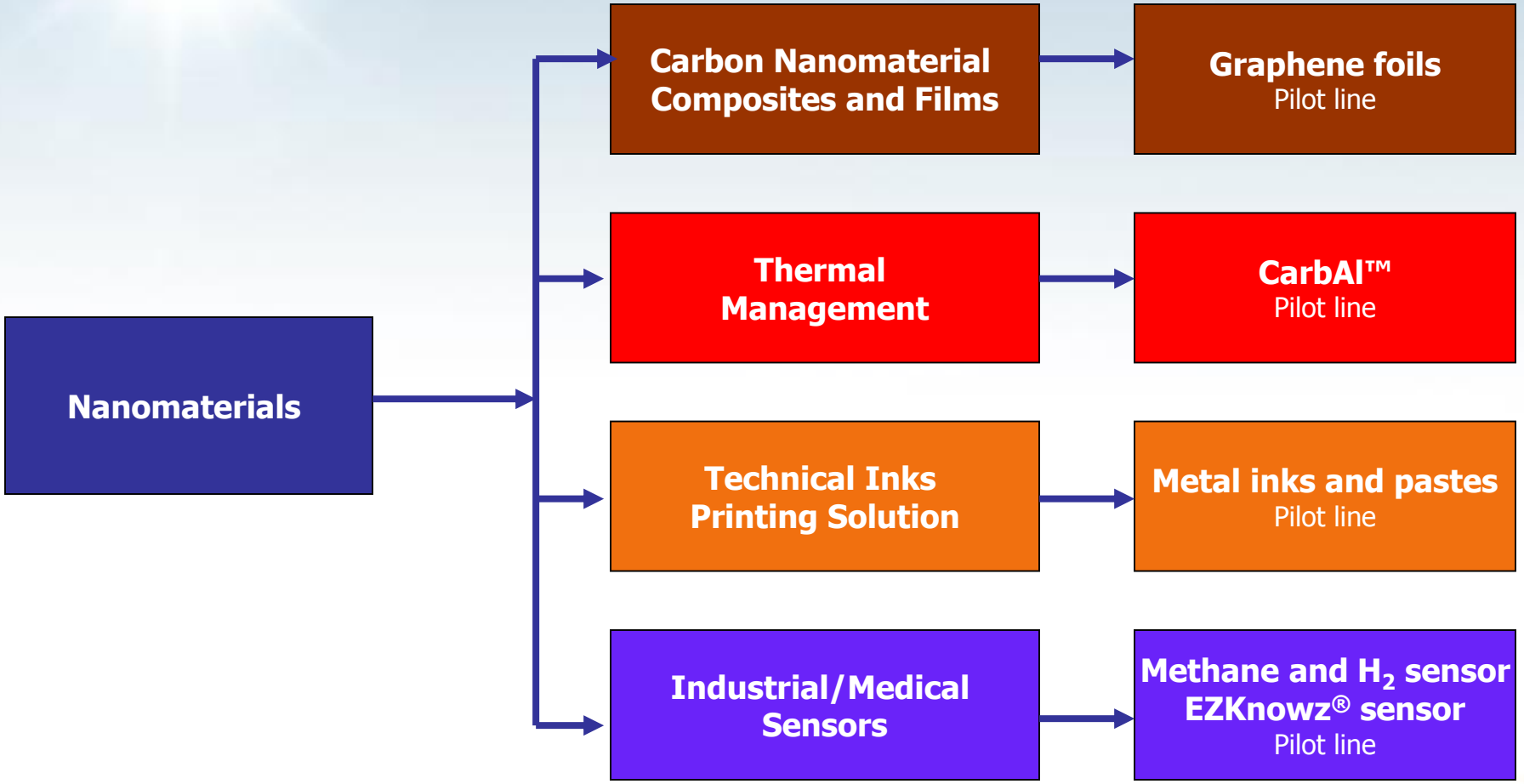
Commercialization at Applied Nanotech



CNT Reinforced Epoxy

Description

CNR-1-250 is a carbon nanotube loaded resin that can be cured at 250°F. The base polymer system is a multifunctional epoxy that contains <2% by weight functionalized carbon nanotubes.

Features

- Improved flexural strength (+45%↑)
- Improved flexural modulus (+20%↑)
- Improved compression strength (+40%↑)
- Improved impact strength (+30%↑)

Application Areas

- Sporting goods and recreation
- Automotive
- Aerospace
- Marine

Complete set of Yonex EZONE golf clubs using ANI's CNT reinforced epoxy technology (Nanopreme™)

Yonex's badminton racquet (brand: VOLTRIC 80) using ANI's CNT reinforced epoxy technology (Nanopreme™)

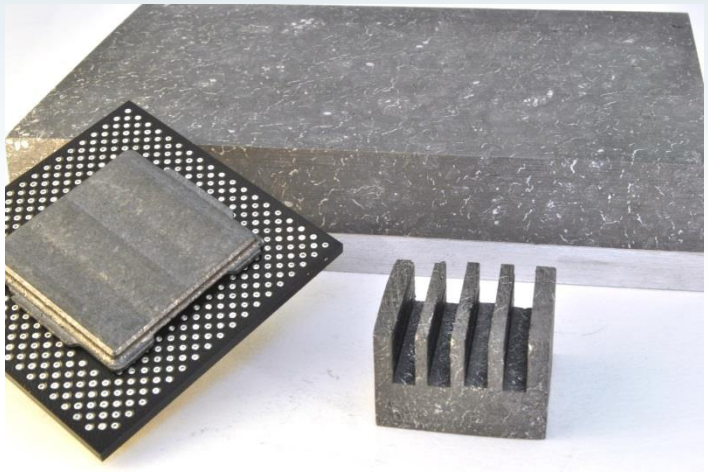
NTM, Nano Thermal Management

The Need

Over 55% of failures in electronic components are due to high operating temperatures.

The Solution

- CarbAl™ has been recognized as one of the 100 most significant product innovations in 2009 by R&D magazine.
- CarbAl™ composite thermal management material has a unique combination of
  - low-density (1.75 – 2.1 g/cm^3)
  - high thermal diffusivity (2.9 cm^2/s)
  - high thermal conductivity (350 - 450 W/mK)
  - low coefficient of thermal expansion (2 x 10^{-6} /K)



CarbAl™

CarbAl™ *is an advanced thermal management material composed of a porous graphitic matrix that is impregnated with a molten aluminum alloy doped with a precise amount of an additive. The resulting material is 80% carbon and 20% aluminum (and other dopants) with greater than 90% filling of the pores.*

Material Properties of CarbAl™

Thermal conductivity: 250-400 W/m-K
CTE: $7x10^{-6}$ /K
Specific heat: 0.75 J/gK
Specific gravity: 2.1 g/cm^3
Bending strength: 40MPa
Young's modulus: 12 GPa

Application Areas

Heat spreaders
PCB substrates
IC packaging
Power Electronics
LED substrates and housing
Concentrated photovoltaics

Production

Overview of manufacturing process for CarbAl™

Step 1: *Pre-heat carbon matrix, pressure mold, and aluminum*

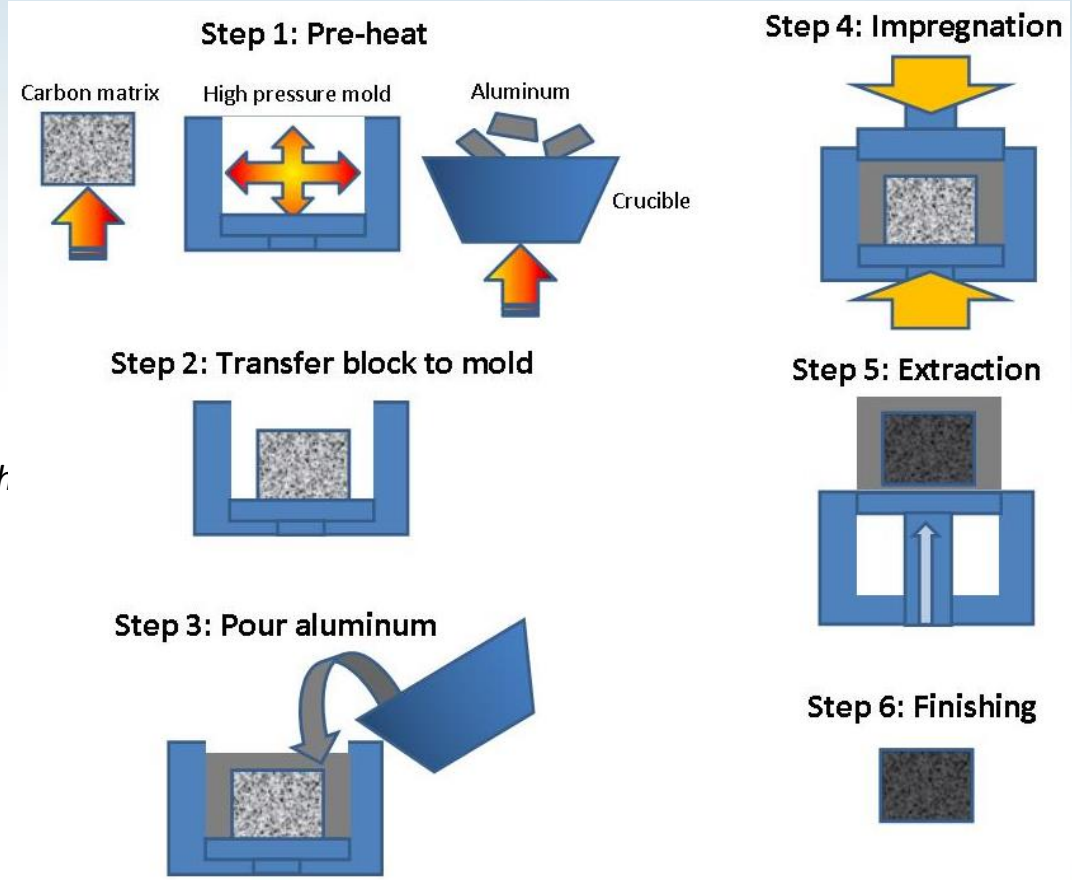
Step 2: *Transfer heated block to heated mold*

Step 3: *Pour molten aluminum doped with additives into mold*

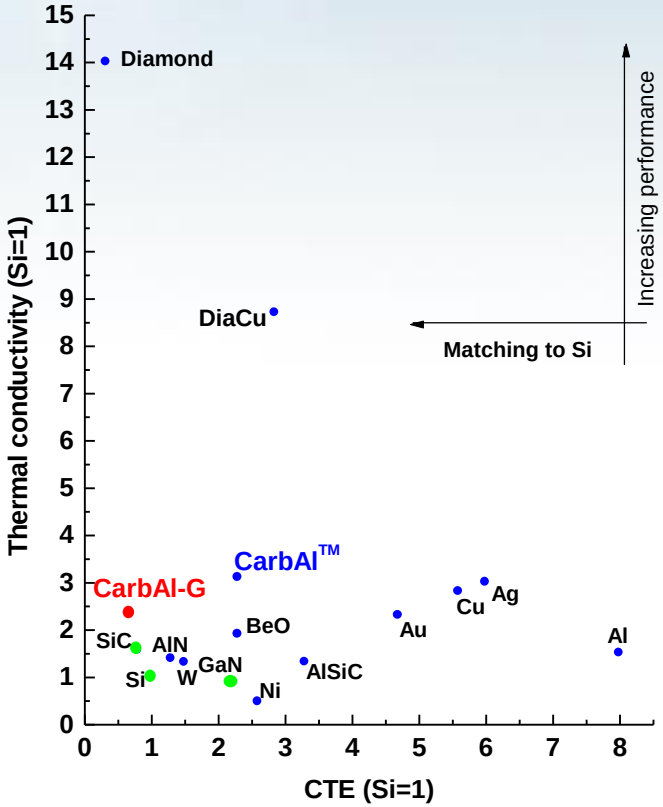
Step 4: *High pressure impregnation*

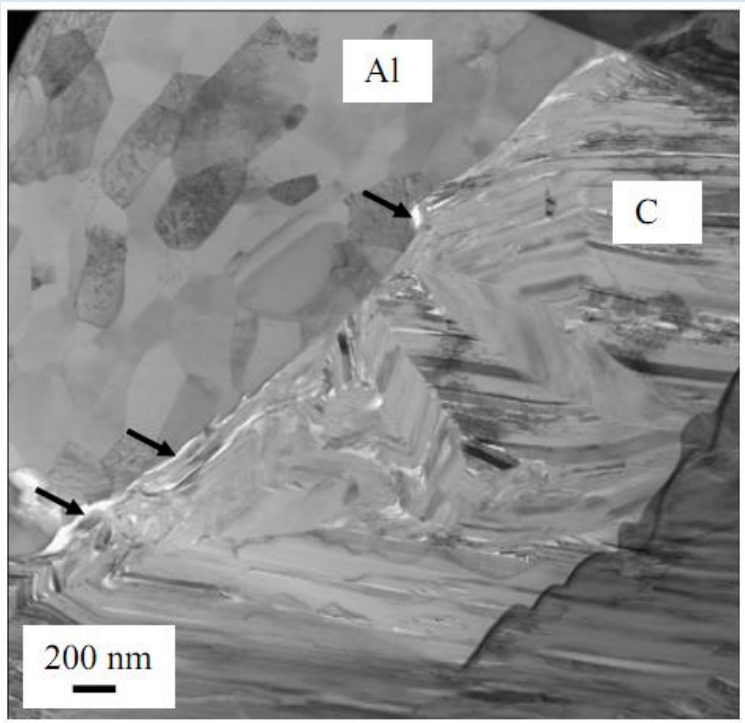
Step 5: *Extract from mold and cooling*

Step 6: *Remove excess aluminum and finish CarbAl block*



CTE Matching to Semiconductors



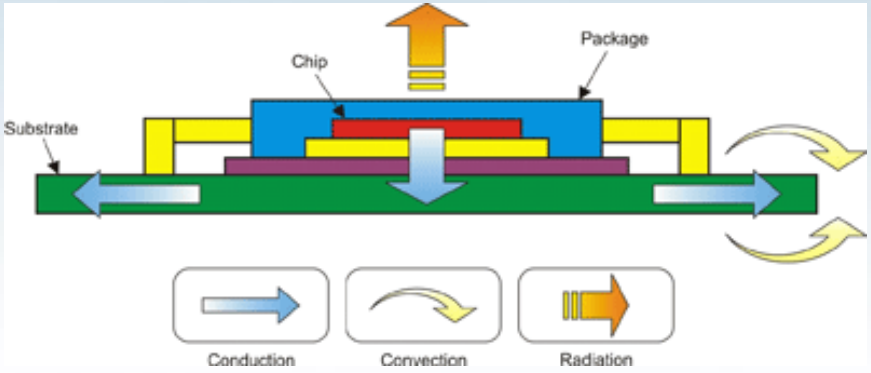


Thermal conductivity versus CTE values

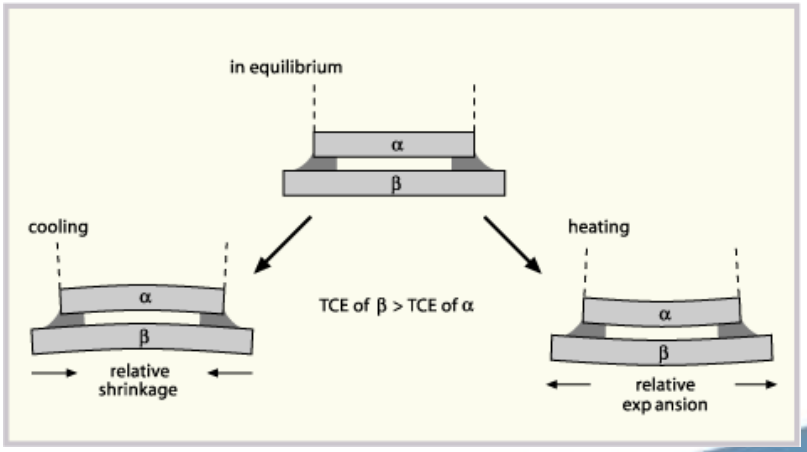
Description of Technology

General Characteristics of CarbAl™

- **High thermal conductivity**
  - Graphitic planes transport thermal energy efficiently away from heat source
  - Rapid spreading of heat from the point of creation to a dissipative heat sink and active cooling



- **Low coefficient of thermal expansion (CTE)**
  - Graphite minimizes thermal expansion for semiconductor applications
  - CTE matched to materials such as silicon, gallium arsenide, and other commonly used materials to reduce stresses introduced by thermal mismatch
  - Lower CTE = less thermal stress



- **Relative Mechanical stability**
  - Aluminum filling provides mechanical support and stability
  - Compatible with standard machining processes

Competition

CarbAl™ is a balance of key performance metrics and material properties with price of material

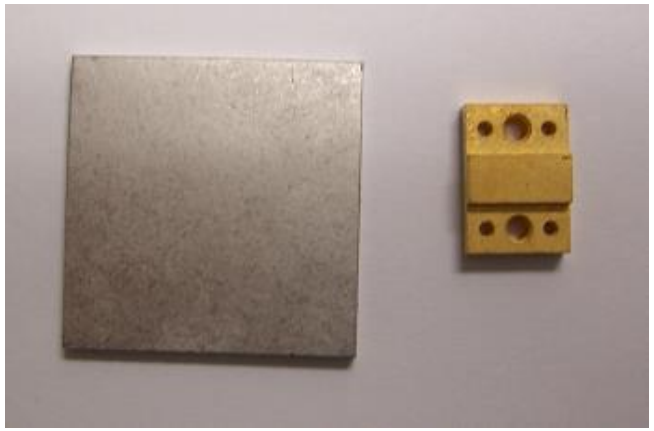
- *High thermal conductivity (amount of heat that can be transferred), 1.5x to 2x of aluminum*
- *High thermal diffusivity (speed of heat spreading), over 3x of aluminum*
- *Low coefficient of thermal expansion (amount of material expansion due to heating) more than 2x better than copper and more than 3x better than aluminum*
- *Good mechanical properties*
- *Lightweight*
- *Price is comparable to copper*

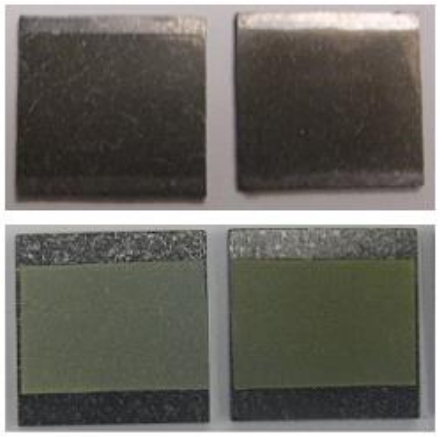
Material	Density (g/cm^3)	CTE (ppm/K)	Thermal Conductivity (W/m-K)	Thermal Diffusivity (cm^2/sec)	Bend Strength (MPa)	Young's Modulus (GPa)	Relative Cost
AlSiC	3	7 - 9	170 - 200	0.88	450	290	$
CuW (10-20% Cu)	15.7-17.0	7 - 8	180 - 200		1172	367	$$$
CuMo (15-20% Mo)	10	7 - 8	160 - 170			313	$$$
Cu	8.96	17.8	398	1.1	330	131	$
Al	2.7	23.6	238	0.84	137 - 200	68	<<$
SiC	3.2	2.7	200 - 270	0.5	450	415	$$
AlN	3.3	4.5	170 - 200	1.47	300	310	$$
Beryllia	3.9	7.6	250		250	345	$$$
Poco Graphite	0.9	1.02	245	-	2.7	-	$$
KFoam	0.48	0.69	220	0.48	2.1	-	$$
CVD Diamond	3.5	1 - 2	500 - 2200	10.5			$$$$$$
CarbAl™-N	**2.1**	**7**	**400-450**	**2.78**	**40**	**12**	**$$**
CarbAl™-G	**1.75**	**2.0**	**180- 400**	**2.9**	**24**	**-**	$

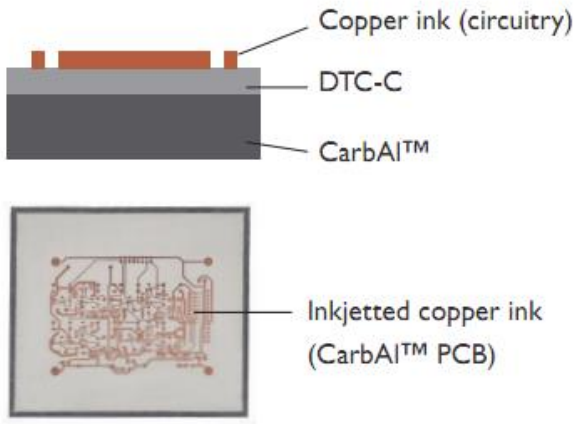
CarbAl Components

Thercobond - Dielectric bonding material with high thermal conductivity

Surface Functionalized CarbAl™				
	Thickness (um)	Breakdown Voltage (V)	Breakdown field (V/um)	Thermal conductivity (W/mK)
Thercobond 1	23	2230	97	1-20
Thercobond 2	35	2480	71	1-20
Plated Ni	50	-	-	20-80
Plated Au	50	-	-	100-300







Ni-B and Au plated CarbAl™

Dielectric layers and circuits on CarbAl™

NASA Phase II Technical Objectives

Phase II NASA SBIR "CarbAl™ Based Thermal Management for Space Flight Systems Applications" Contract No. NNX14CC23C

Applied Nanotech, Inc. (ANI) has developed a thermal management composite material that has a density less than aluminum, thermal properties close to copper and a coefficient of thermal expansion well matched to semiconductor materials.

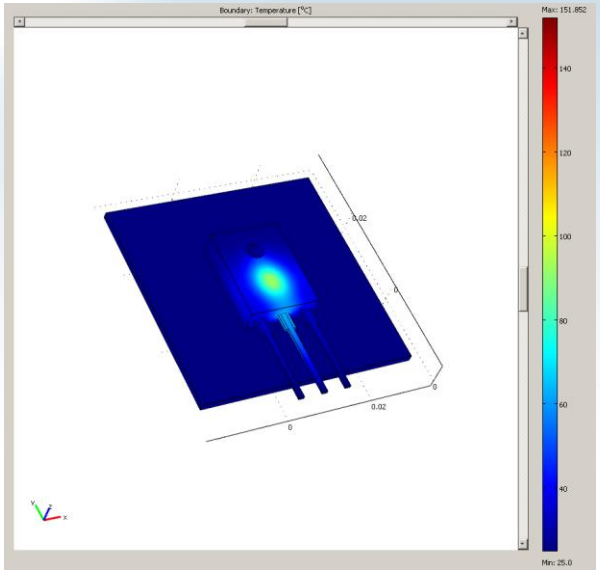
Current TRL level "6" (CarbAl components are sold commercially for non-NASA applications)

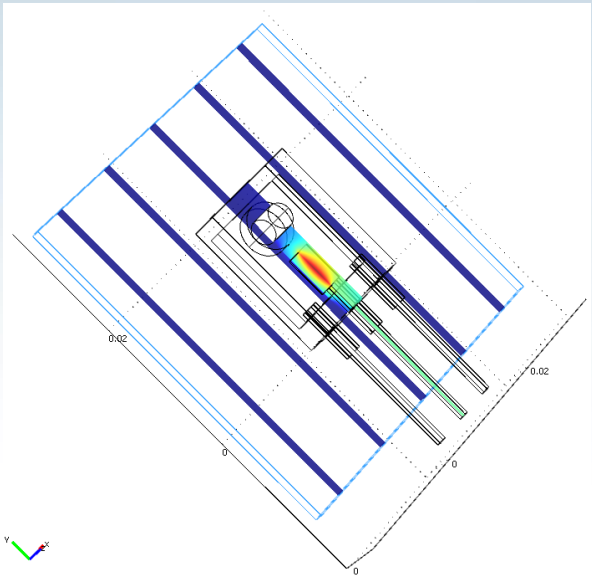
Objective 1: Refine Phase I thermal model for CarbAl-based thermal packaging that encompass specific thermal loads for high power transistors

Objective 2: Fabricate heat sink system for DC power conversion module.

Objective 3: Complete prototype CarbAl™ heat sink system for DC power conversion module.

CarbAl heat sink modeling



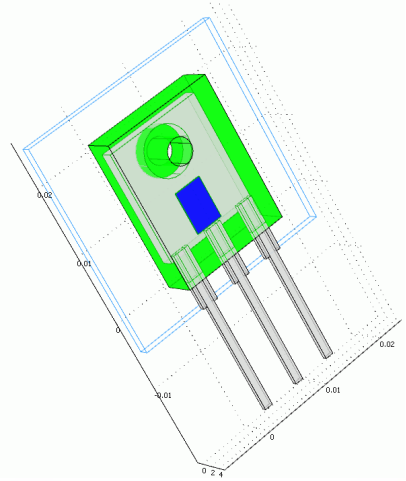


Material	Thickness, mm	k, W/mK	Density, kg/m^3	Cp, J/kg·K
Aluminum	1.5	237	2700	897
CarbAl N	1.5	250/250/400	2100	750
CarbAl G	1.5	200/200/350	1750	690
Mold	3-5	0.84	1200	1200
Spreader	2	301	-	-
Leads	0.6	188	-	-
SiC	0.18; 0.36	149; k(T)	3210	670

CarbAl modeling and Experimental results

Parameter	Specifications
Manufacturer	CREE
Transistor type	SiC MOSFET
Maximum power, W	463
Maximum current, A	90
Max junction temperature, C	150
Max bare die temp, C	150
Die dimensions, mm	4.06x6.44x0.18
Die volume, mm3	4.68
Calculated die Tmax, k=const	***151.9***
Calculated die Tmax, k=k(T)	***146.3***

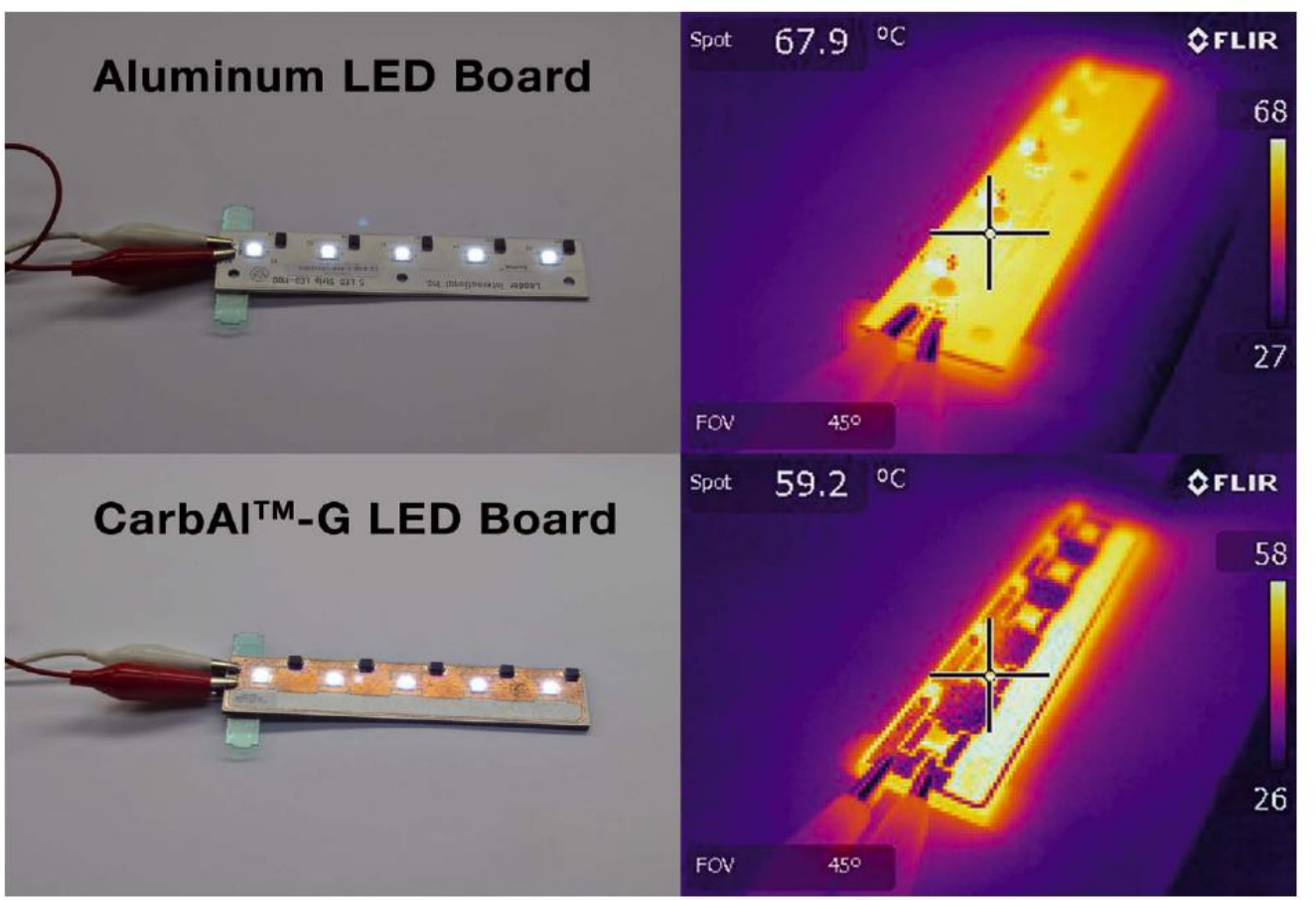
Heat sink material (k)	Max T_{die}, C (CREE)
CarbAl N (250,250,400)	**151.9**
CarbAl N (400,250,250)	161.0
CarbAl G (200,200,350)	154.6
CarbAl G (350,200,200)	167.0
Al (237)	**163.0**



Electric Load Tests:

Load circuit	Gate, V	Drain current, A	Drain power, W	T_{block}, C	T_{chip}, C
Source	24	75	172	28.0	70.6
Source	12	68	255	27.3	85.0
Drain	12	39	565	39.5	122.0

LED CarbAl™ Thermal Packaging

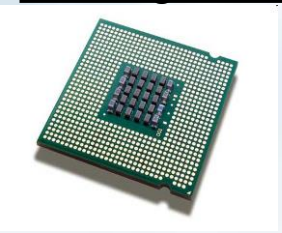


Functionalized CarbAl™ for Various Applications

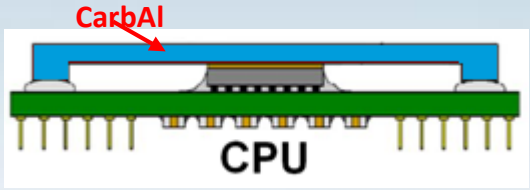
(a) Ceramic dielectric layer on CarbAl™- G.
(b) Polymeric dielectric layer on CarbAl™- G.
(c) Cu plated on CarbAl™-G.
(d) Al layer evaporated on CarbAl™-G.
(e) Anodizes Al layer (insulating Al oxide layer) on CarbAl™-G.
(f) Fully integrated CarbAl™-G with dielectric layers and Cu metallization for packaging 12 LEDs.
(g) CarbAl™-G LED printed circuit board (PCB) using copper on ceramic layer.
(h) CarbAl™-G LED printed circuit board (PCB) using copper on epoxy dielectric layer.
(i) CarbAl™-G printed circuit board (PCB) for multiple LEDs on ceramic having a disc shape.

Military Applications and Market Segments

CPU Integrated Heat Spreaders

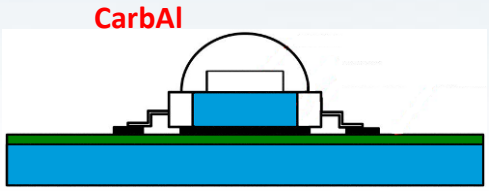


- Removes heat from hot spots on CPU processors for severs, desktops, laptops, mobile devices, and so on.
- Lids for CPU and GPU processors
- Currently use copper and aluminum lids but need better performance and CTE match as processors become faster and consume more power

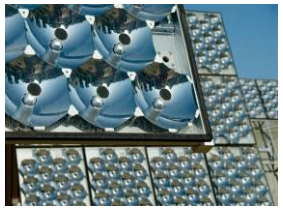


LEDs

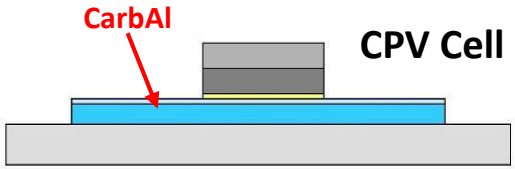
- PCBs and heat spreaders for: General lighting home and industrial, Backlights for LCD TVs, notebooks, and PC monitors, Automotive headlights and traffic signals.



Concentrated Photovoltaics

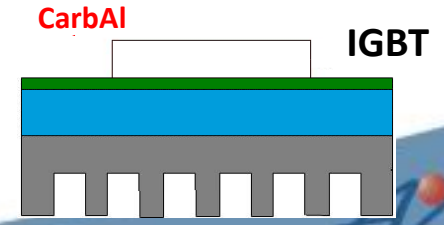


- Focus sun 100x to 1000x onto small photovoltaic cells using mirrors and lenses to increase efficiency up to 50%
- Thermal energy generated must be removed for lifetime and operating efficiency



Power Electronics / IGBTs

- High current power electronics components in automotive, appliances, and industrial applications



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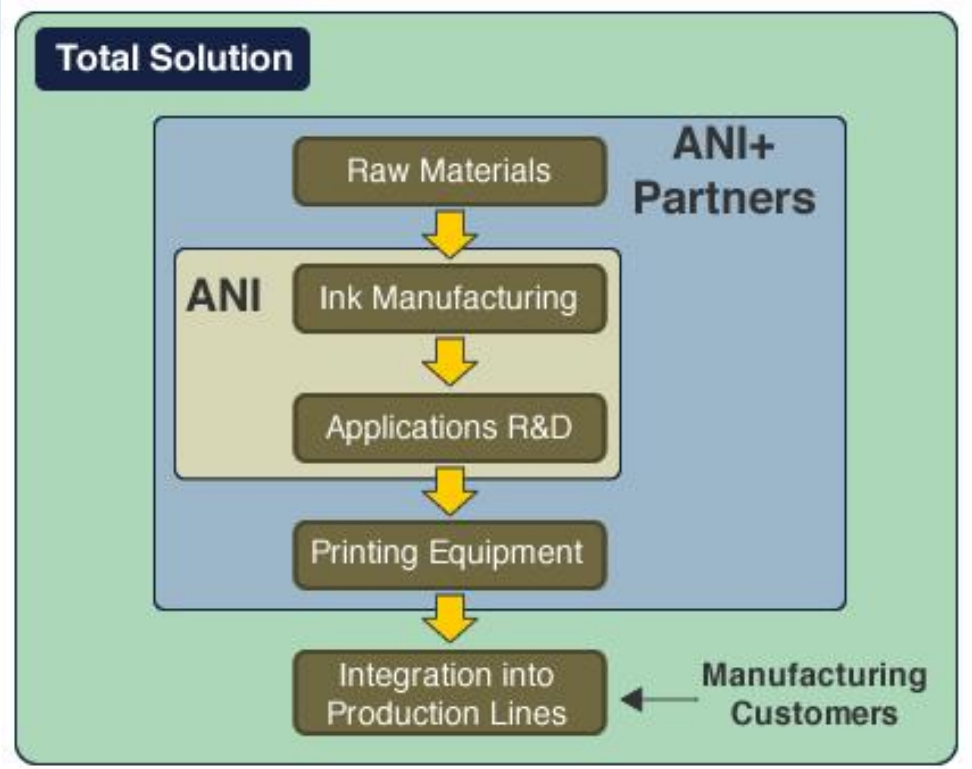
TIPS, Technical Inks Printing Solutions

- Core technologies: technical inks/pastes and nanoparticles
- Focus on printed electronics
- Total solution approach:
  - Raw materials (nanoparticles/chemicals)
  - Ink manufacturing (formulations/dispersions)
  - Applications R&D
  - Printing equipment/processes
  - Integration into high volume production
- Total ink printing solutions are offered in collaboration with strategic partners



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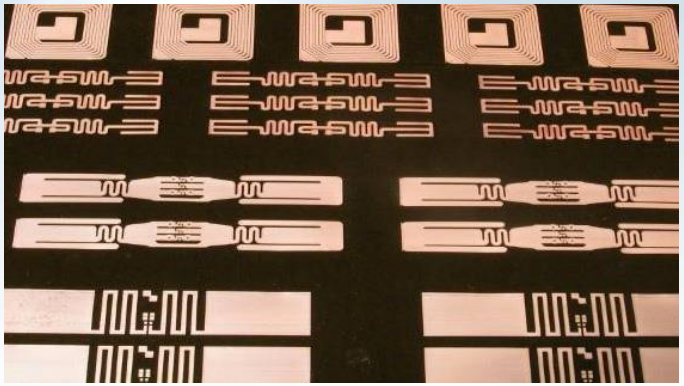
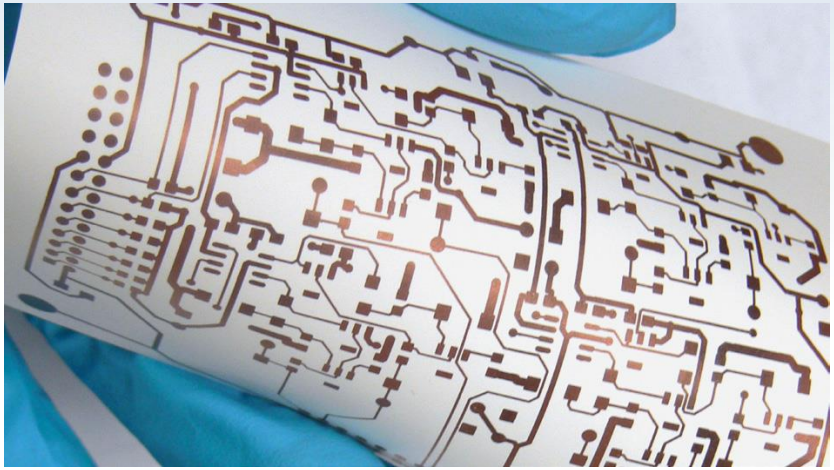
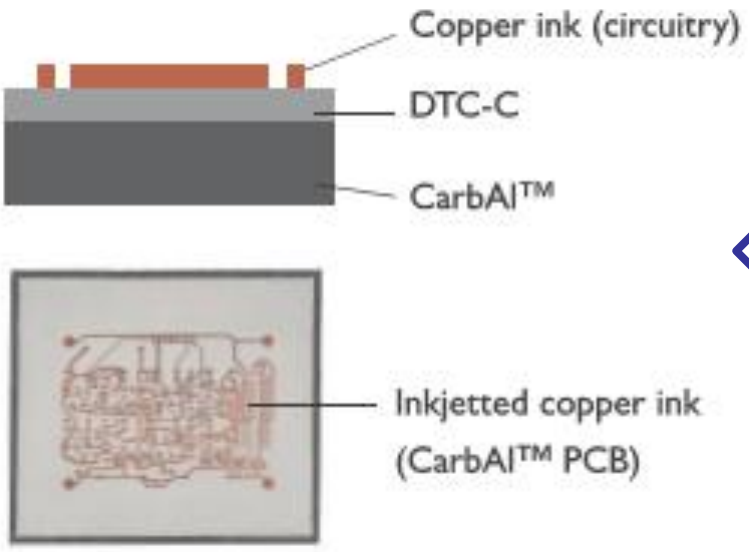


Cu inkjet printed on Kapton

Cu inkjet printed on paper





Cu inkjet printed CarbAl high thermal conductivity material with dielectric that also has high thermal conductivity

EZKNOWZ®
Industrial/Medical Sensors

- Sensors and nanotechnology have a complementary relationship since they both rely upon molecular level phenomena.
- Our sensors have performance advantages for all "3 Ss", namely:
  - Sensitivity,
  - Selectivity,
  - Specificity.
- Our sensor research is looking at critical problems in gas sensing, including:
  - Process monitoring and monitoring of natural gas streams,
  - Homeland security,
  - Health monitoring,
  - Odor and breath analysis,
  - Forensics,
  - Agricultural pathology applications.