Improvement of Thermal Dissipation by Nanomaterial addition

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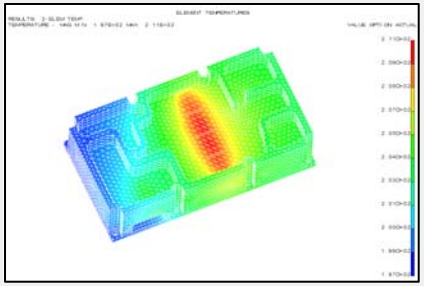
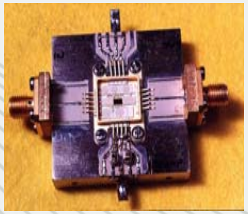
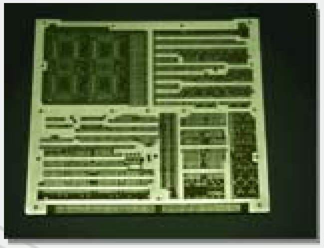
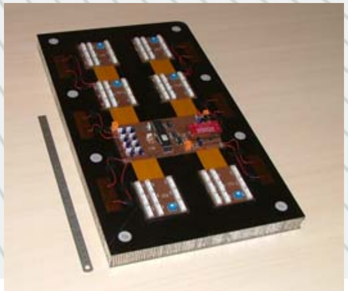
Space thermal packaging materials

- **Chip Level**
  - Nanocarbon based condensators
  - High thermal conductive thin films as DLC or AlN deposition by PVD-Mg and CVD
- **Package level**
  - Aluminium reinforced composites AMC for High dissipative Packaging Ka band amplifiers/ Space
  - GaN wide band gap semiconductors
  - Composite material for packaging Cu-C, CNT,Cu-Diamond
  - Phase Change Materials
  - Microchanels with MMC
  - Thermal conductive adhesives
- **Board level**
  - Metallic Foams heat sinks
  - Integrated heat sinks & radiators (loop heat pipes)
  - PCM multilayer active thermal doublers
  - Thermal conductive composites
- **Rack Level**
  - Multifunctional Racks: CFRP Electronic housings with HT conductive fibers
  - Lightweight alloys









ELECTRONIC INDUSTRY REQUIREMENTS

- Increase of power/packaging density
- Miniaturization: Need for a continuous miniaturization of electronic devices

HEAT DISSIPATION

CRITICAL POINT

- MMIC attachment

Solutions

Solders → High processing temperatures

Adhesives → High percentages of silver(80%)→ Expensive

↓ Mechanical properties

Alternative

Nanomaterials → High thermal conductivity

High surface area to volume ratio

The aim of this study was to conduct research in nanomaterials to be used to dope **adhesives for space conditions** in order to increase their **thermal conductivity**.

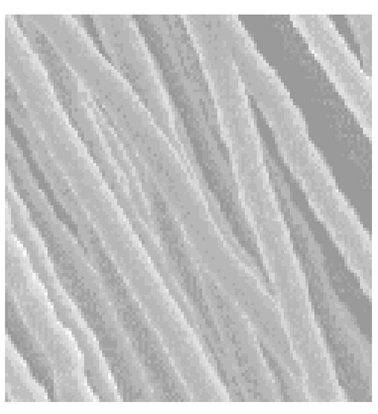
Materials

TWO COMPONENT EPOXY ADHESIVE

Physical properties	
Coefficient of thermal conductivity	0.3 W/mk
Mixture viscosity	9 Pa.s
Shear strength	23N/mm^2
Peel strength	1.5N/mm^2
Tensile strength	47 N/mm^2
Operating temperature	-55ºC to 150ºC
Storage	Room Temperature
Curing cycle	20 min at 80ºC

MATERIAL	K (W/mK)	ρ (kg/m^3)
HYSOL	0.3	1150

Carbon nanofiber (CNF)

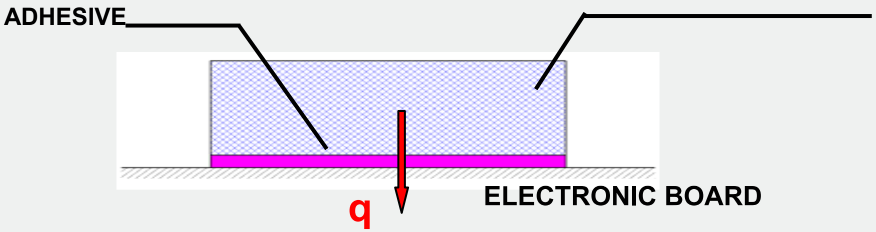


TYPE	Ø (m)	L (m)	K (W/mK)	ρ (kg/m^3)
CNF	1.00E-07	1.00E-04 5.00E-05	1200	2100

Simulation: Finite elements

- Equivalent Thermal conductivity

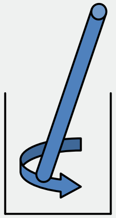
$$q = K_{eq} \cdot \frac{A}{d} \cdot \Delta T \rightarrow K_{eq} = \frac{q}{\Delta T} \cdot \frac{d}{A}$$



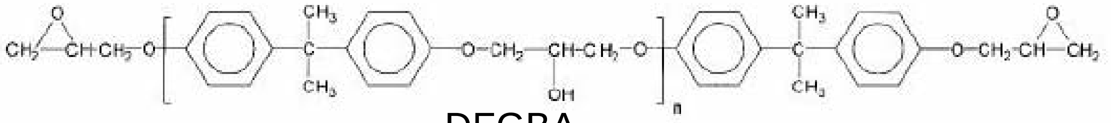
Weight Percentage	Equivalent thermal conductivity (W/mK)
0	0.21
0.1	0.42
0.5	1.23
1	2.22
2.5	5.31
5	10.50
7	14.67
10	21.18
15	32.68
20	44.15
50	129.63

Nanomaterial required to reach the initial objective

CNF dispersion mechanism



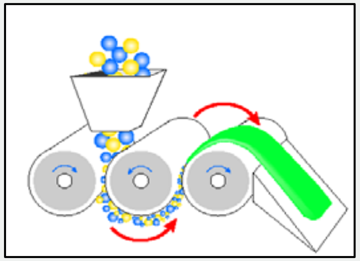
Manual Premix: CNF + Epoxy Part A



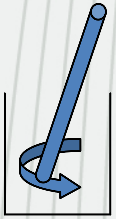
DEGBA

Dispersion device: Three roll mill

Control parameters: Gap and residence time



Hardener Part B

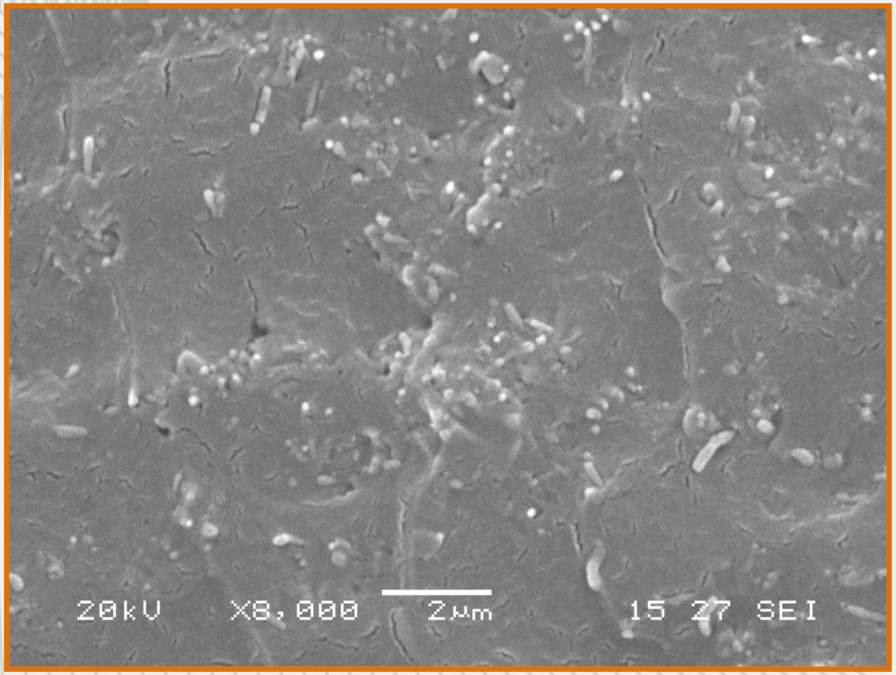


Aliphatic Amine

Defoaming

Curing

Nano-Adhesive



Sample	Laser flash
Hysol	0.30 W/mK (Technical Data Sheet)
Hysol + 2.5wt% CNF	0.27W/mK ≠ 6W/mK

SIMULATION → Ideal conditions

Conductive Network

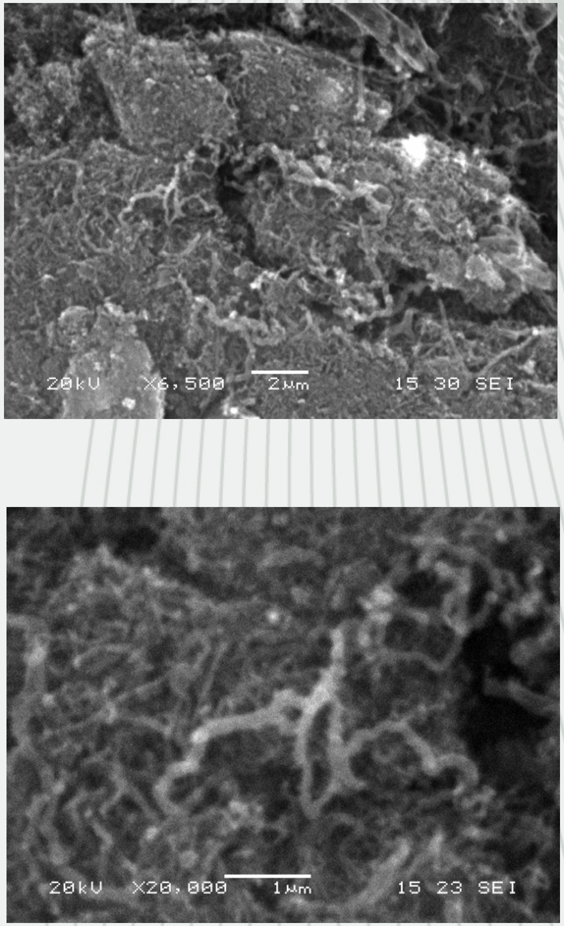
- Lack of dispersion
- No contact between the nanoelements and the electronic component
- No contact between the nanoelemets

Strategies to improve thermal conductivity

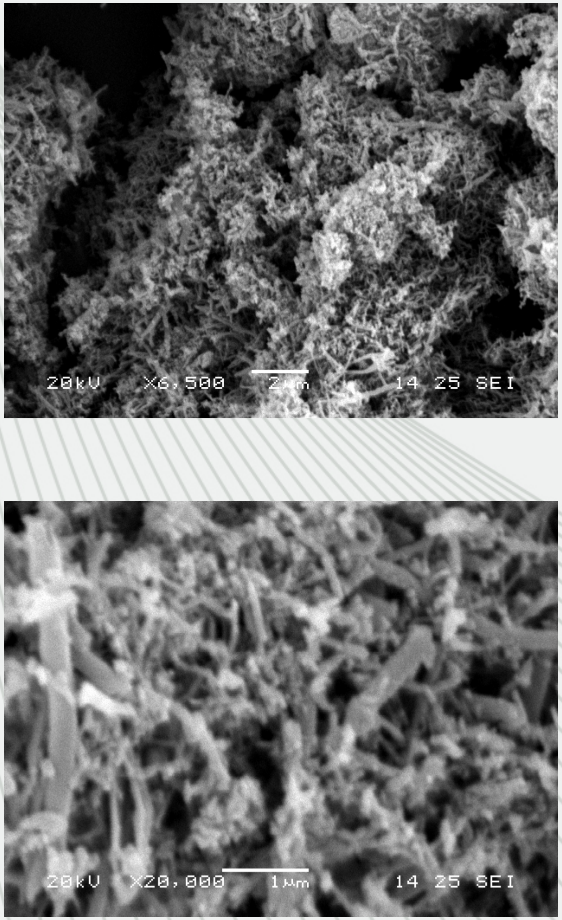
- Heat treated CNF effect (1h at 2800ºC under He atmosphere)
- Synergetic effect between two nanomaterials with different size and shape

Heat treated CNF

GANF

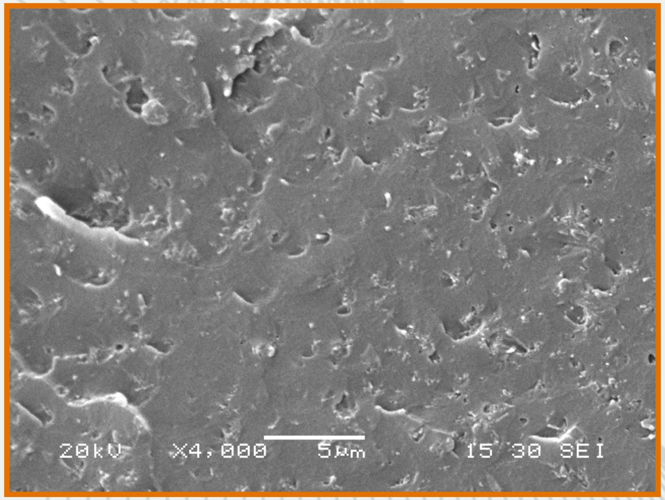


Heat treated GANF (2800°C)

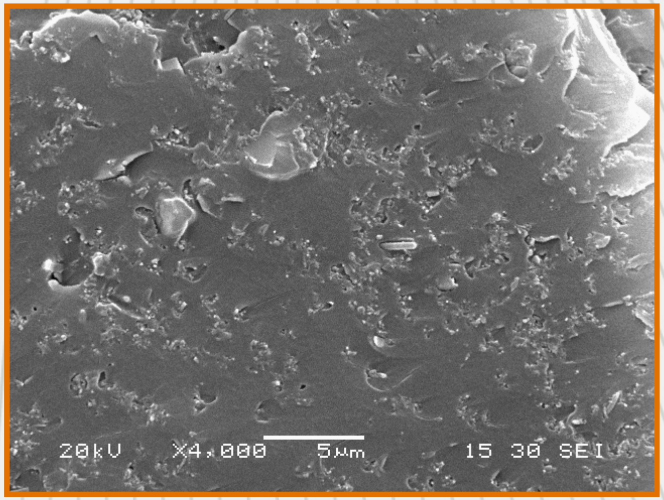


- Graphitization is an effective method of removing defects from CNF:

- Inorganic impurities
- Removed of C-H bonds therefore to reduce the interlayer space.



2.5wt% CNF-G



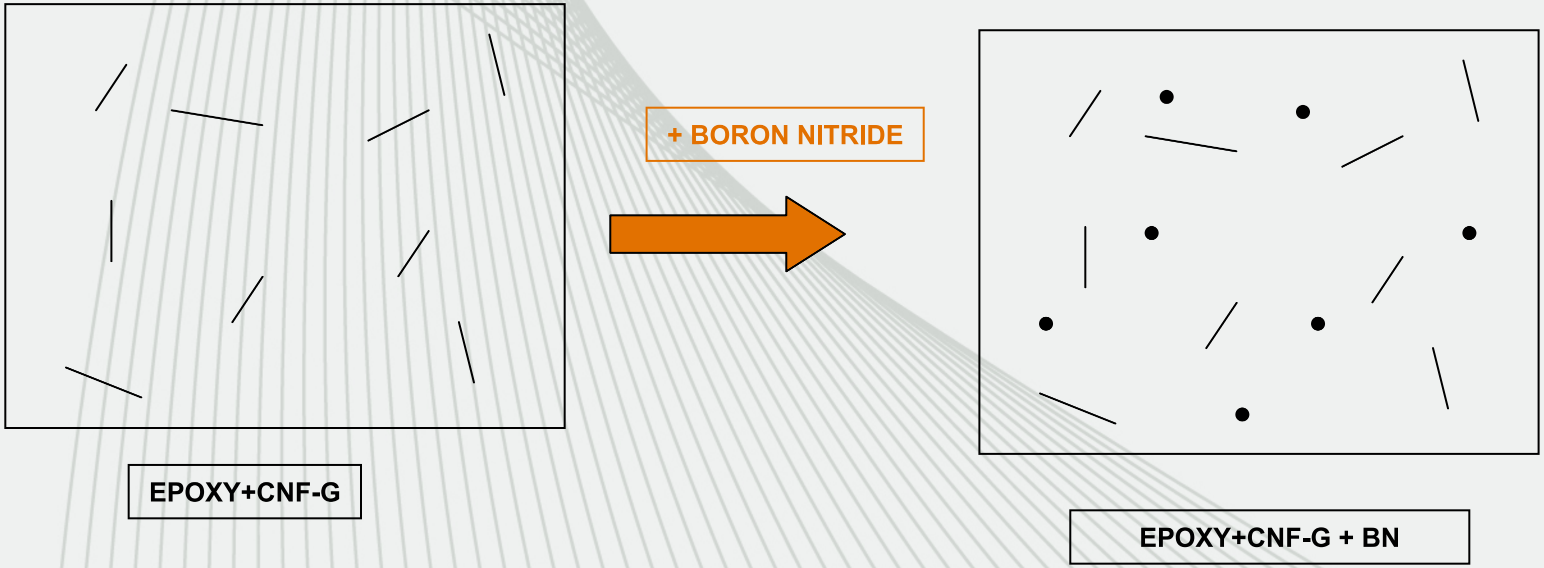
4wt% CNF-G

- ➢ Both samples are homogeneous.
- ➢ Increasing CNF-G concentration the distance among the nanoelements decreases.

Sample	Laser flash (R.T)
Hysol 9483+ 2.5wt% CNF-G	0.27 W/mK
Hysol 9483 + 4wt% CNF-G	0.27W/mK

✓ Graphitization has no effect on thermal conductivity

Synergetic effect



+ BORON NITRIDE

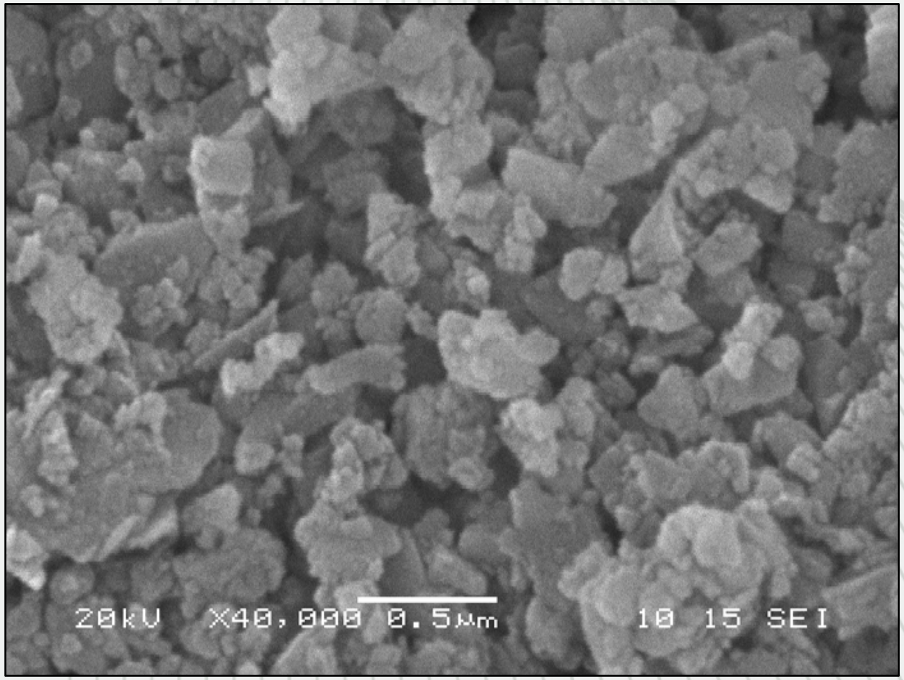
EPOXY+CNF-G

EPOXY+CNF-G + BN

Materials

NANOMATERIAL

- Boron nitride (BN)



Boron Nitride, cubic

Particle size full range: 80-450 nm

Average particle size: 165±15 nm

Specific surface: > 11 m^2/g

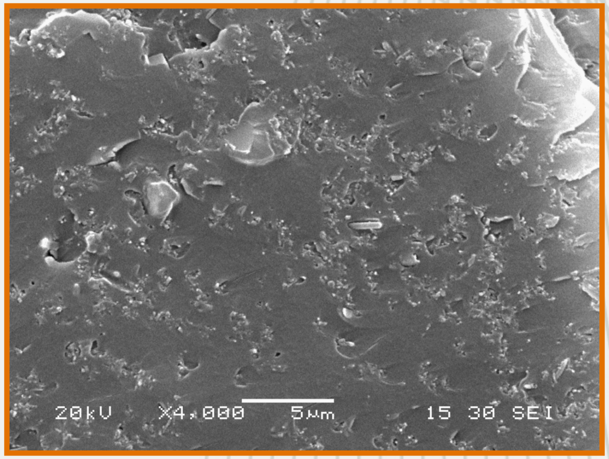
Content of cubic phase: > 99,0 w.%

Thermal conductivity: 600W/mk

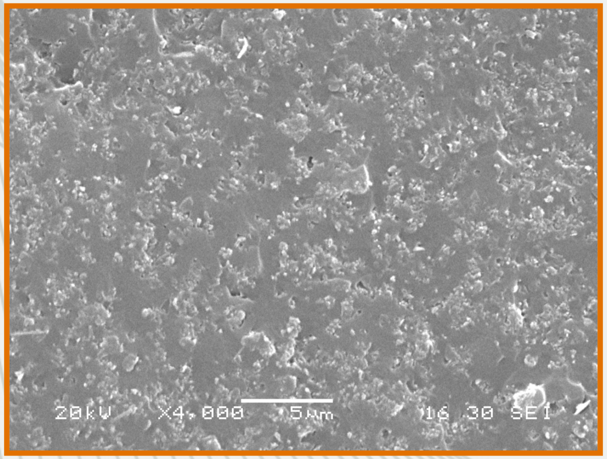
Density: 3,45 g/cm3

- Addition of a second thermal conductive nanomaterial

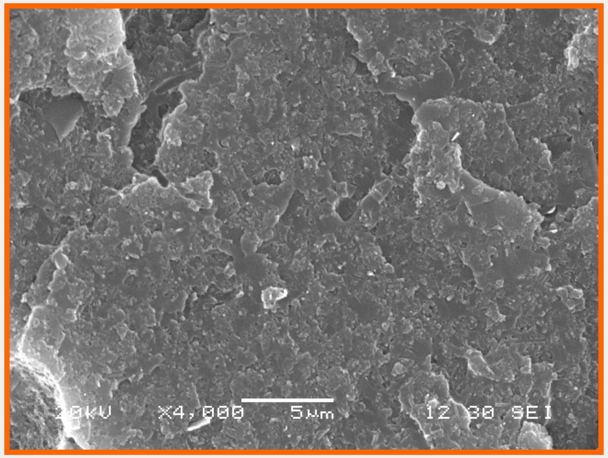
4 wt% GANF-G

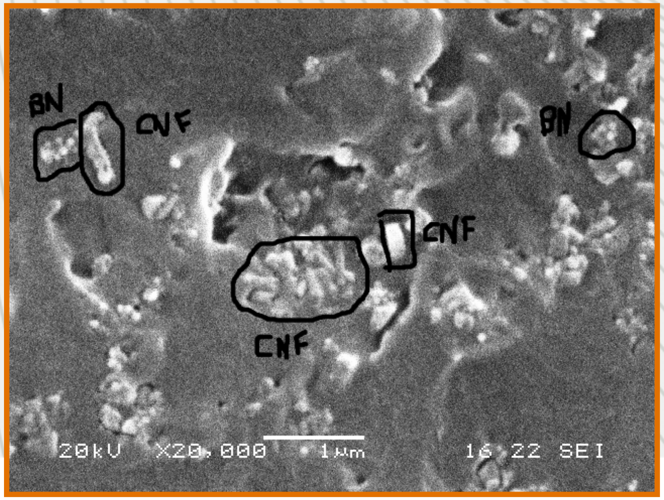


4 wt% GANF-G + 10wt% BN



10 wt% GANF-G + 10wt% BN



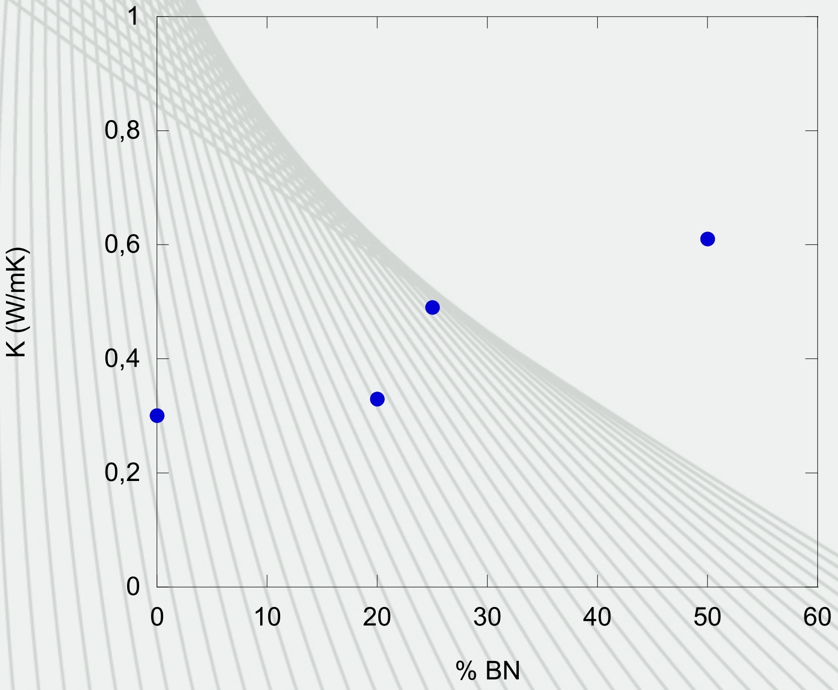


Thermal Conductivity Measurements

Sample	Laser Flash (W/mK)
Heat treated CNF 4wt%	0.27
Heat treated CNF 4wt% + BN 10wt%	0.23
Heat treated CNF 10wt% + BN 10wt%	0.23
Heat treated CNF 20wt%*	-

*Too viscous system

Thermal conductivity at 23°C (Laser Flash)

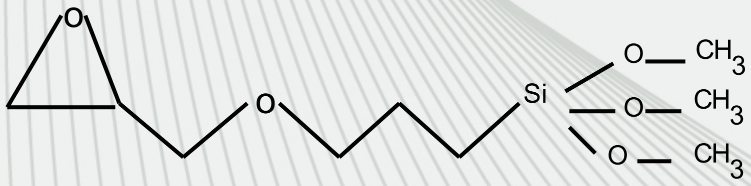


- As BN concentration increases adhesive thermal conductivity increases

Thermal conductivity enhancement strategies

- Compatibility between BN/polymeric matrix interface

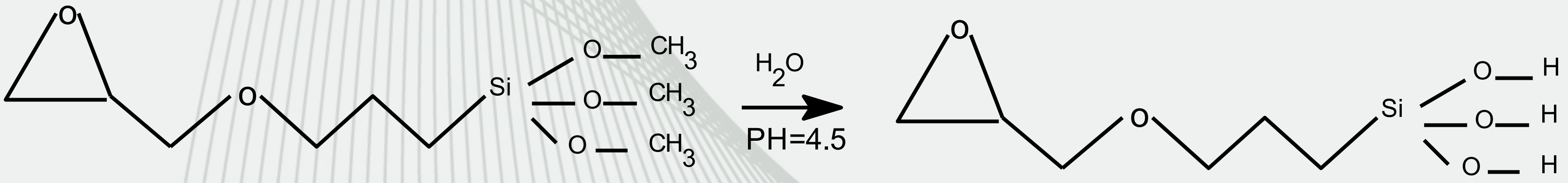
A coupling agent was used:



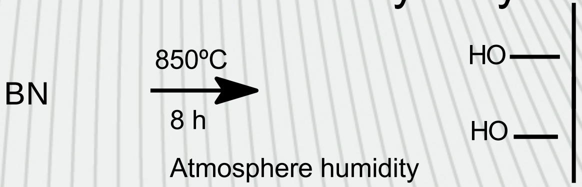
Glycidoxypropyl trimethoxy silane (Z6040)

Modification scheme

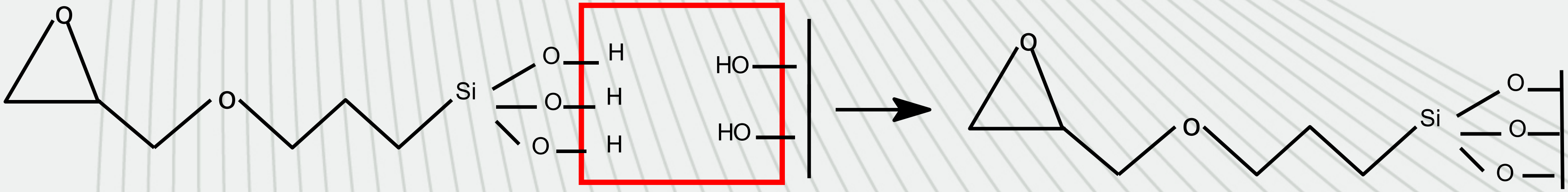
A. Coupling agent hydrolysis (0.5wt%)



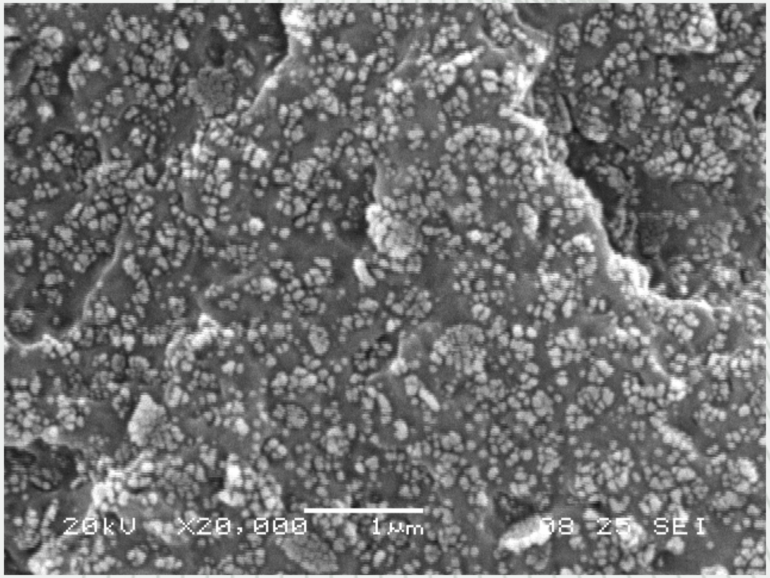
B. BN oxidation and hydrolysis

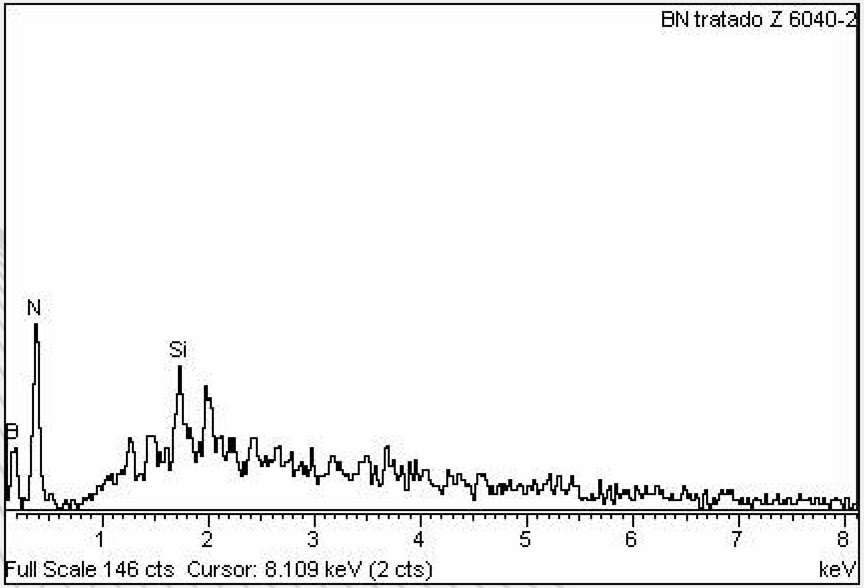


C. Condensation and/or hydrogen bonding



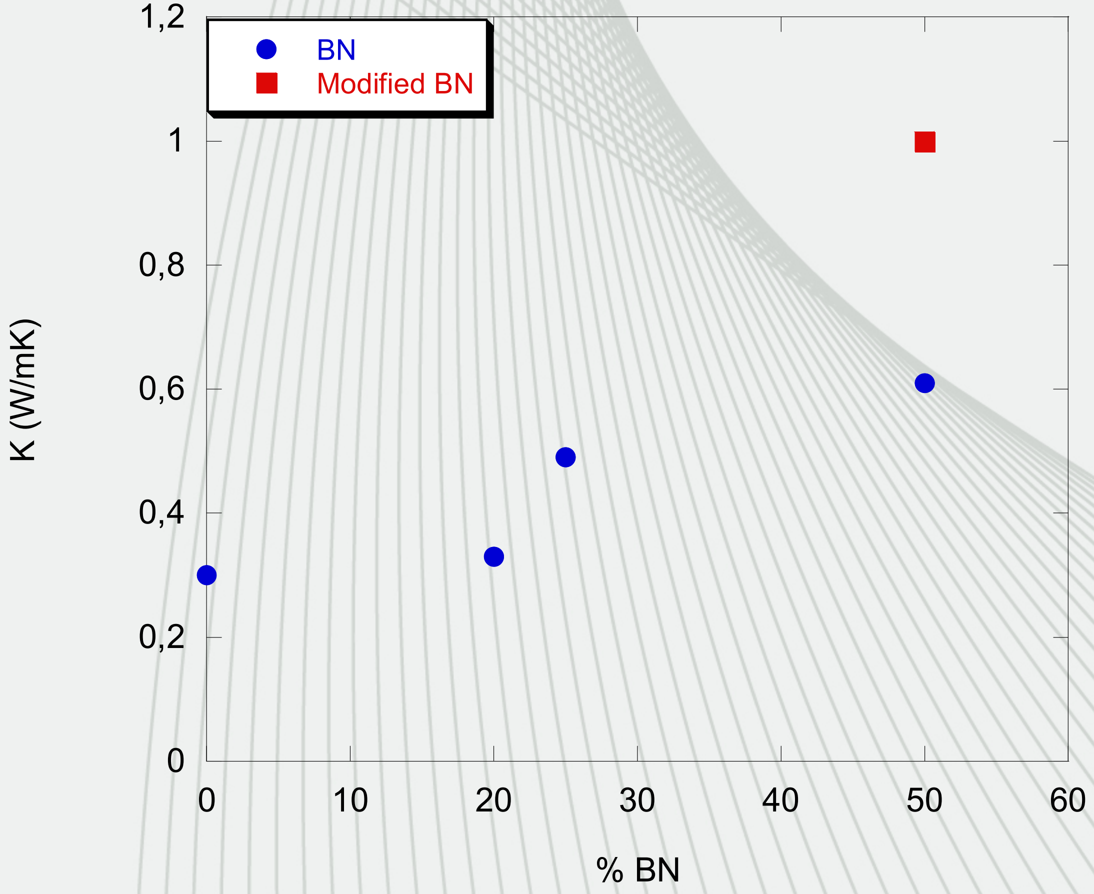
Microstructure and elements analysis





50wt% modified BN

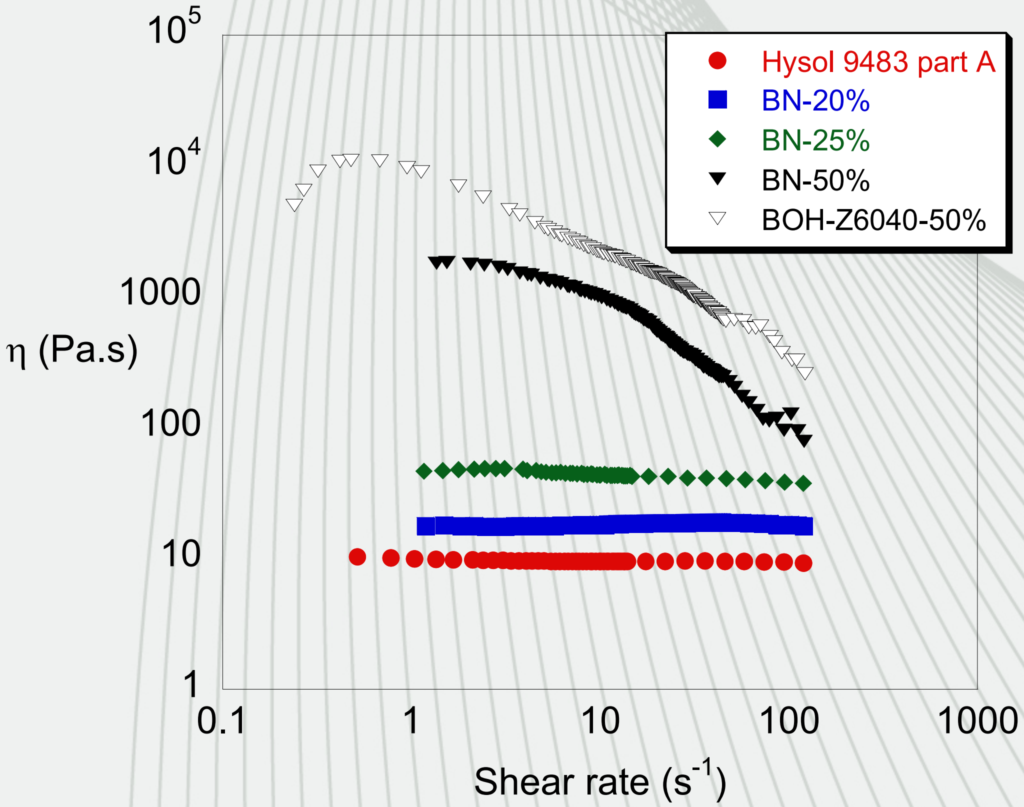
Thermal conductivity at 23ºC



% wt BN	THERMAL CONDUCTIVITY (W/mK)
20	0.33
25	0.49
BN50	0.61
BOH-Z6040-50	1

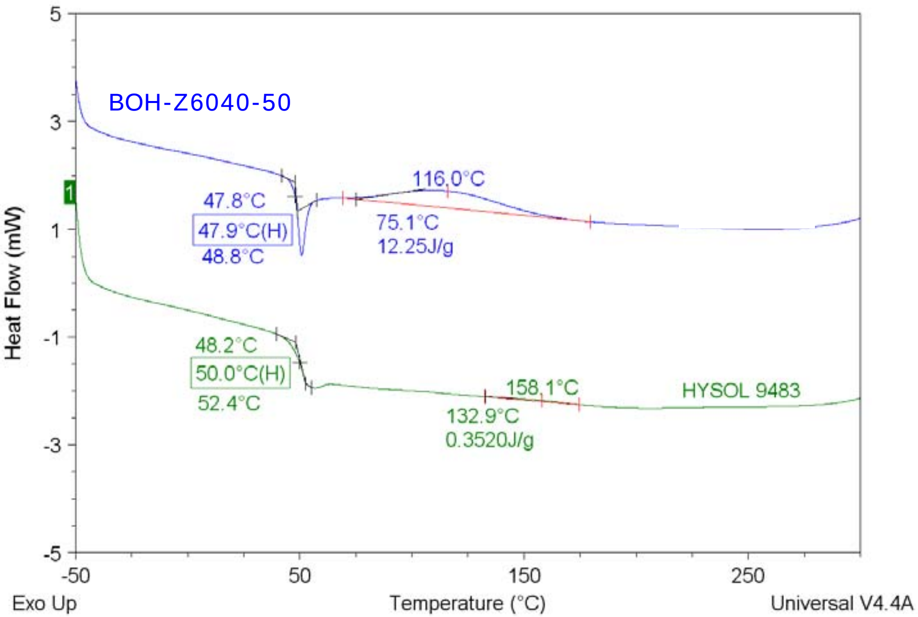
- An improvement on BN/polymeric matrix compatibility increases adhesive thermal conductivity

Adhesive rheological behaviour



- BN-20% and BN-25% present a Newtonian behaviour (shear rate independent).
- BN-50% presents shear thinning
- The surface modified composite (BOH-Z6040-50%) present the highest shear viscosity. This could be because interfacial bonding between the nanomaterial and the epoxy resin becomes stronger when the BN surface is modified.

Glass transition temperature by DSC



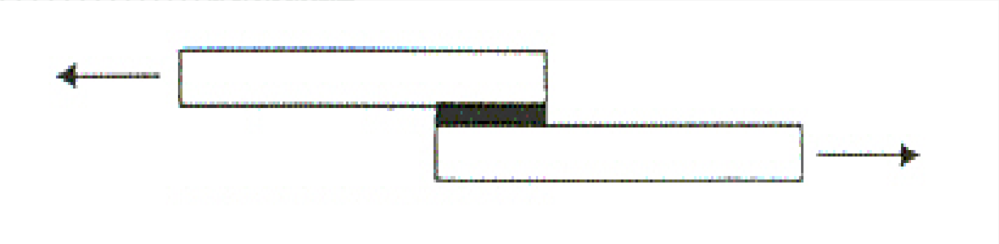
- Both samples show similar Tg,
- The presence of BN has no effect on the curing mechanism

Sample	Tg (ºC)
Hysol 9483	48
BOH-Z6040-50	48

- DSC at 10ºC/min from -50 to 300ºC

Joint strenght

- Joint strength test were performed according to ASTMD 1002



- Aluminium sheets (100×25 mm2) were used as adherends. Single-lap adhesive joints were prepared by bonding the aluminium sheets together with the adhesive (12.5×25×0.1 mm3)

- The adhesive thickness were controlled by using teflon.

Shear strenght

Sample	Strength (MPa)
Hysol 9483	5.3 ± 0.6
BOH-Z6040 50%	6.1 ± 1

Test Vehicle

- P-Channel lateral MOSFET
- Manually dispensed via syringe
- 250µm Al Ultrasonic wire bonding
- Hermetically sealed

Test	Result
Electrical test BUZ905	Electrical functionality confirmed
Die Shear MIL-STD-740 test method 2017-2	No shearing below 2.5Kg
Thermal cycle MIL-STD-740 test method 1051	20 temperature cycles (-55ºC to 150ºC, ramp time<1min; soak time <15min)
Die Shear MIL-STD-740 test method 2017-2	No shearing below 2.5Kg
Acceleration MIL-STD-740 test method 2006	No structrual and mechanical weaknesses (20000g/min in the Y1 direction)

- All devices passed electrical test after thermal cycling, vibration and acceleration

Thermal impedance MIL-STS-750 Test method 3161.1

- Lead tin solder: 0.8ºC/W
- Comercial epoxy silver loaded: 7ºC/W
- Nanoadhesive: 16.8ºC/W

R=1/KL/A

- Comercial epoxy silver loaded: 2.5W/mK
- Nanoadhesive: 0.96W/mK

Conclusions

✓ To control adhesive thermal conductivity a combination of different parameters must be taken into account; BN concentration, dispersion degree and polymeric matrix/BN interface compatibility.

✓ Epoxy adhesive thermal conductivity increases from 0.3W/mK to **1W/mk** under the experimetal conditions.

✓ This thermally conductive adhesive could acomplish the specifications in terms of mechanical properties and dispensing methods.

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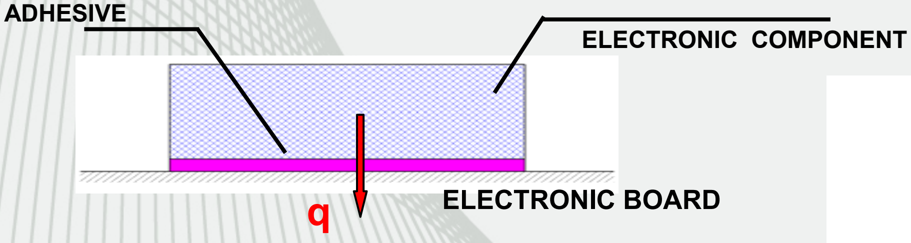
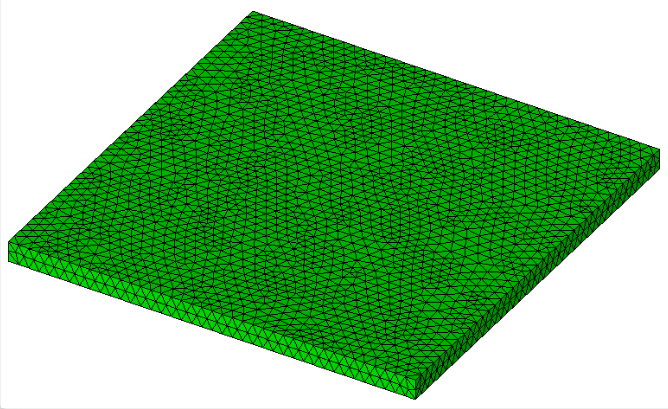
Final adhesive properties

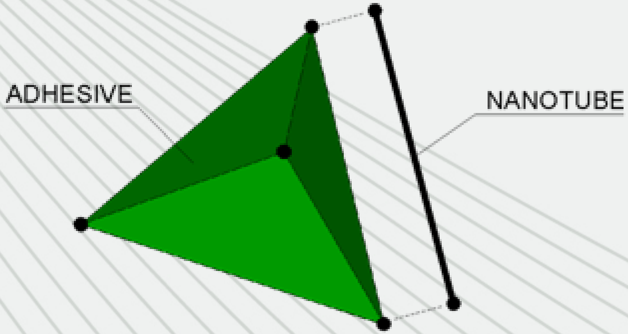
Properties	
Thermal conductivity (W/mk)	1
Viscosity (cps)	80.000-100.000
Tg (ºC)	48
Joint strength (MPa)	6.1

Modelling. Finite Element Methods





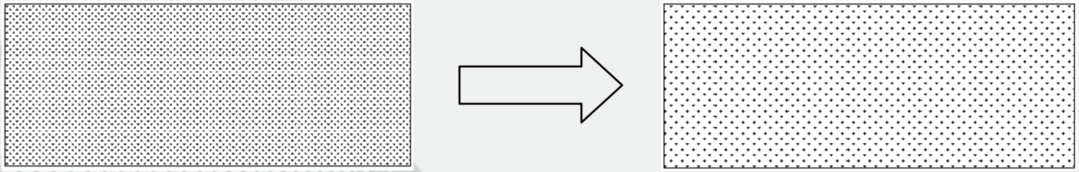
1. Mesh the model with commercial software
   - Take into account the nano-material length
2. Export the mesh topology to an ASCII file
3. Add randomly the nanoparticles to the original mesh trough THERDISS in house developed software
   - According to the weight percentage
   - According to the properties of the nanomaterials
4. Establish the boundary conditions trough THERDISS
   - Surface temperatures
5. Solve the case with commercial software
   - The program calculates the heat flow q
6. Calculate the equivalent thermal conductivity by,



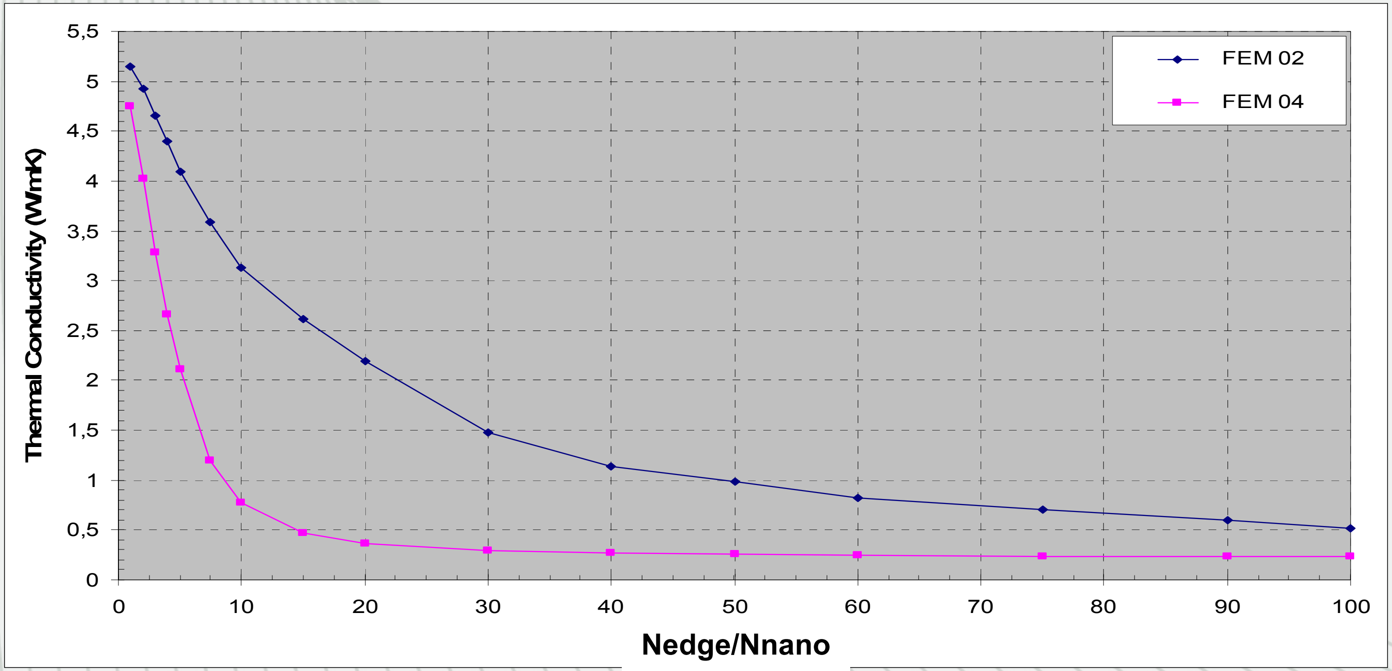
$$q = K_{eq} \cdot \frac{A}{d} \cdot \Delta T \rightarrow K_{eq} = \frac{q}{\Delta T} \cdot \frac{d}{A}$$

Influence of lack of dispersion on the thermal conductivity

?????



Nedge Nnano	K (W/mK)	
	FEM 02	FEM 04
1	5,15	4,75
2	4,93	4,02
3	4,66	3,29
4	4,39	2,66
5	4,09	2,12
7,5	3,59	1,20
10	3,13	0,77
15	2,61	0,47
20	2,19	0,37
30	1,48	0,30
40	1,14	0,27
50	0,98	0,26
60	0,82	0,25
75	0,71	0,24
90	0,59	0,23
100	0,52	0,23

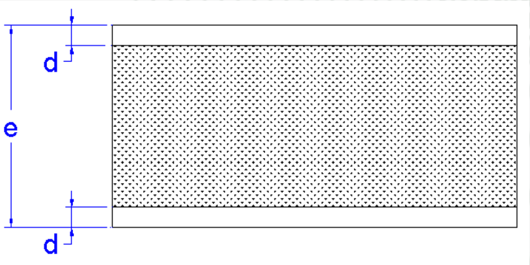


- Conductive network not good enough

TN2100: Nanocomposite development

Influence of no contact on the thermal conductivity

NO CONTACT BETWEEN THE NANOELEMENTS AND THE ELECTRONIC COMPONENT

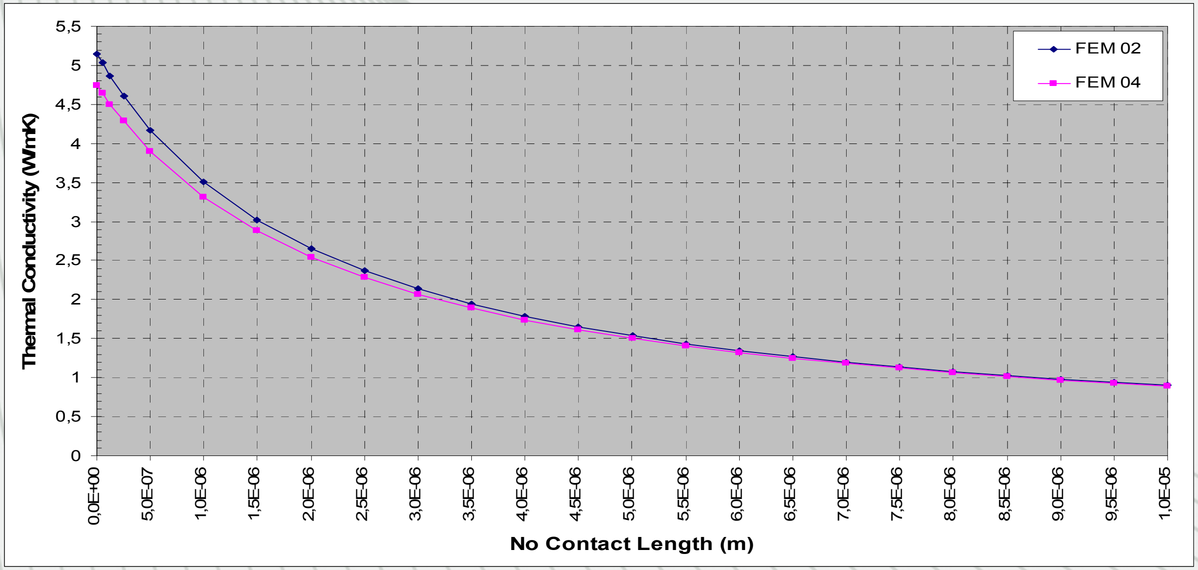


Adhesive

Doped Adhesive

Adhesive

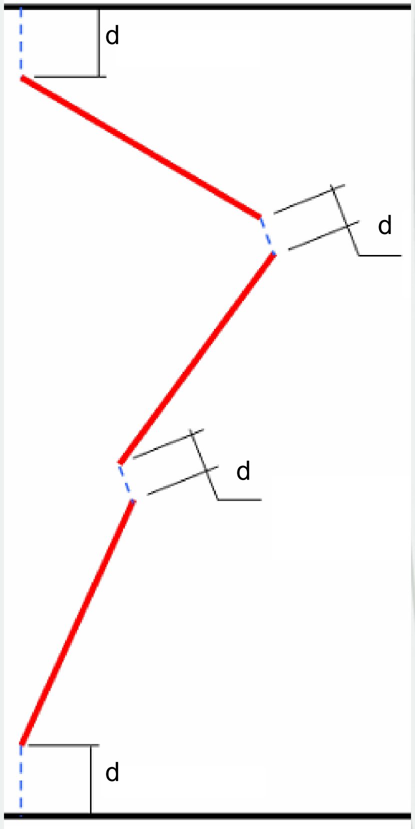
d (m)	K (W/mK)	
	FEM 02	FEM 04
0,00E+00	5,15	4,75
1,00E-06	3,50	3,31
2,00E-06	2,65	2,55
3,00E-06	2,14	2,07
4,00E-06	1,79	1,74
5,00E-06	1,54	1,50
6,00E-06	1,35	1,32
7,00E-06	1,20	1,18
8,00E-06	1,08	1,07
9,00E-06	0,98	0,97
10,0E-06	0,90	0,89

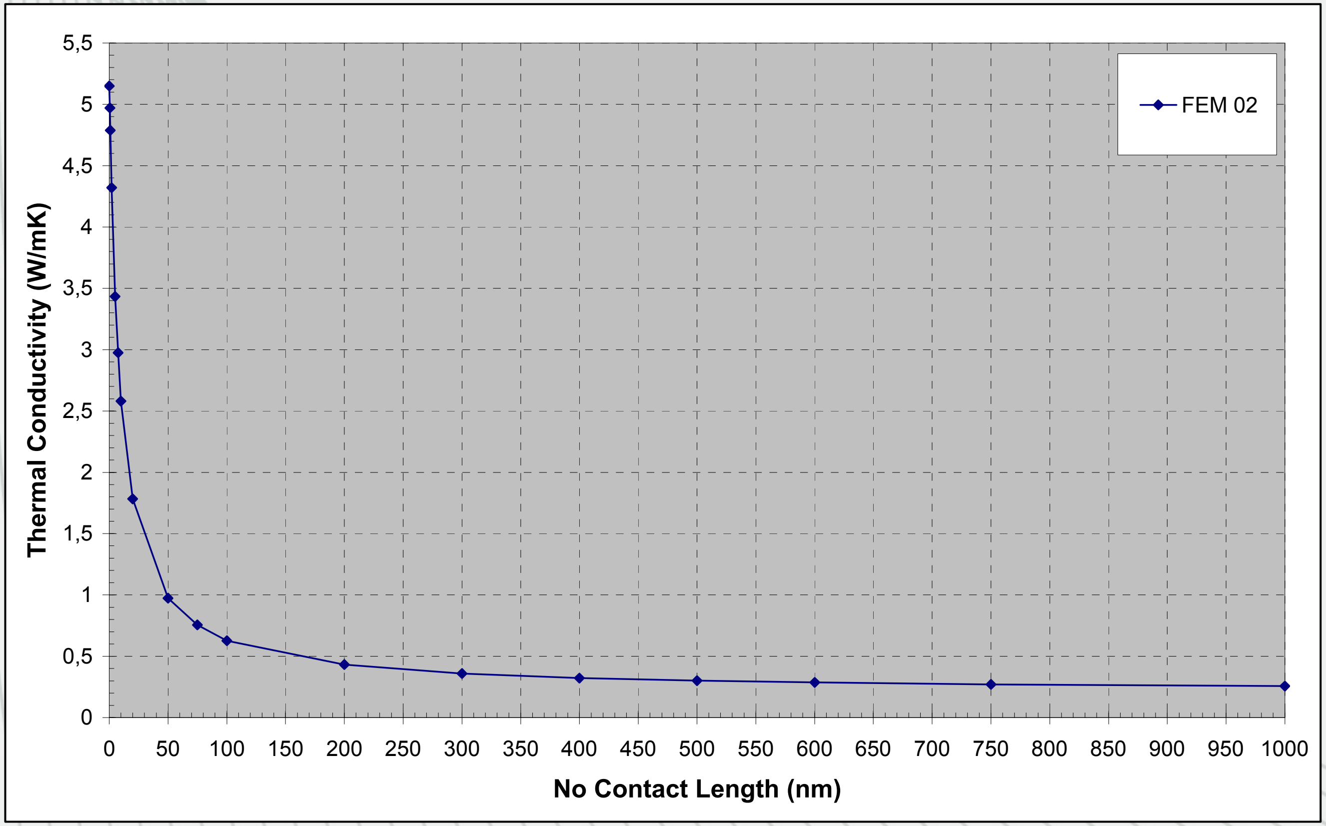


- Conductive network not good enough

Influence of the no contact on the thermal conductivity

NO CONTACT BETWEEN THE NANOELEMENTS





- Conductive network not good enough