nanomakers

Materials booster

Develop, produce & sell
Silicon-based nanopowders that
disruptively improve the
properties of industrial **materials**

Continuous Innovation

Continuous Innovation

- A spin off of cea (2010)
- The technology is protected by several CEA patents, granted with exclusive rights to nanomakers
- which pursued innovating and filed several own patents :

Patent Title	Grant dates	Filing dates
"Method for producing **multilayer submicron particles** by laser pyrolysis" : coated particles **(SiΩC)**	Jun 2015 - Fr Sep 2017 - Eur May 2018 - Cn Jun 2018 - Jp	Jul 2012 - Fr Jul 2013 - PCT
"Submicron particles containing aluminium" : SiCΩAl	Oct 2018 - Eur Apr 2019 - USA	Nov 2013 - Fr Nov. 2014 - PCT
"Method for producing a polymer based material"		Sep 2015 - Fr
nano-Si in batteries		Dec 2017 - Fr
"Valve and sealed container for submicron particles, and method for using same": **Safe Containers** and NanoAirlock valves	Oct 2016 - Jp Jun 2017 - Eur/Fr	Nov 2011 PCT Nov 2012 - Fr
"Suspension system for sub-micron particles in a liquid, and method for using same": Safe Containers external pump system		Feb 2013 - Fr

NM Si 99 Ω C

INNOVATION 2030
CONCOURS MONDIAL D'INNOVATION
Construisons l'avenir en France.

NanoReg2

Project #646221, Funded by the Horizon 2020 Framework Programme of the European Union

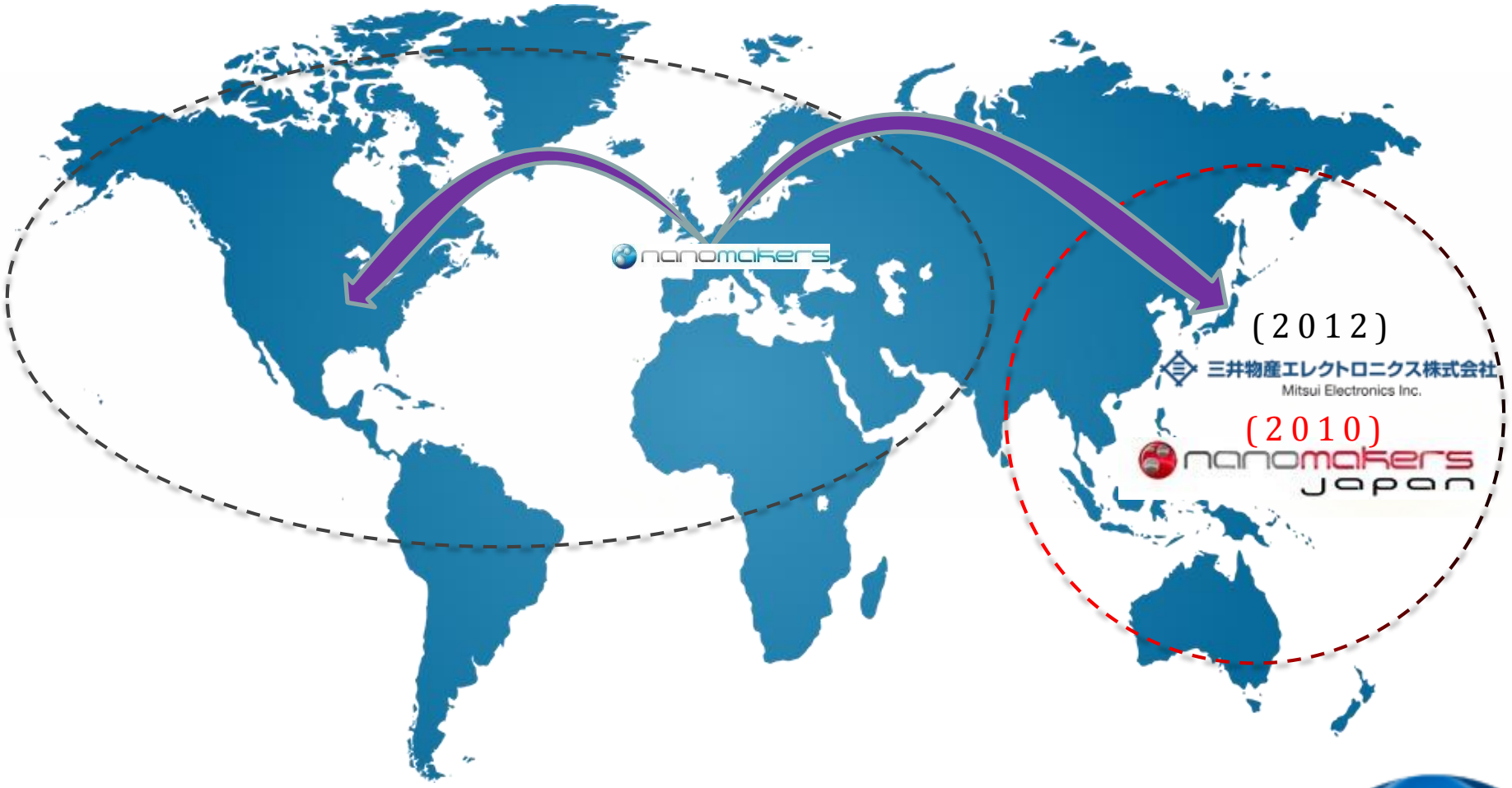
NM SiC 99 Ω A

eit RawMaterials
Connecting matters

Continuous Innovation

nanomakers with & for global partners

*Nanomakers **exports 99%** of its products **outside** of **Europe**.*



Highest quality process & products

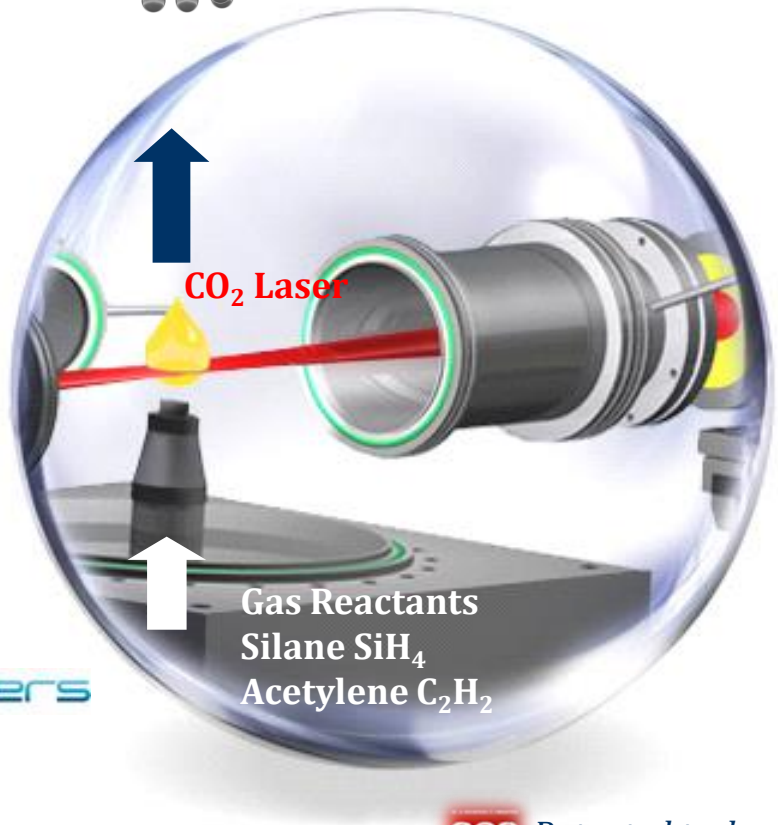
Highest quality process & products

Precise, reliable and secure technology … guarantee of results

Laser pyrolysis process:

1. The laser beam breaks the molecules of gaseous or vapor–phase precursors
2. Nanoparticles start building up abruptly
3. Particle size is controlled by a fast quenching which stops the particle growth

SiC, SiΩC / Si nanopowders



Experience and expertise:

- 33 years of cea know how
- 7 years at pilot scale cea
- +7 years industrial scale nanomakers

cea *Patented technology*

Highest quality process & products

Various value propositions ...

under different forms

SiΩC — NM Si 99 Ω C

Very High Purity
(Available 40nm & 75nm)
internally patented

Si — NM Si 99

Very High Purity
(Available 40nm & 75nm)

SiC — NM SiC 99

Very High Purity
(Available 35nm & 75nm)
Mass deliveries

Value

Free powder

Compacted powder

Suspension

Highest quality process & products

Laser pyrolysis nanomakers … 4 advantages

✧ Homogeneous:

Low particle size deviation.

✧ Pure :

High purity batches, low O2 & metallic content,
(for Si/ SiΩC : **no SiC**)

✧ Reproducible:

Similar particle size distribution, chemical composition from one lot to another.

✧ Customizable:

Size, Surface, Coating

*Our **customers** say* (**Eck Industries** (USA), April 2014):

« First of all the **quality** of the powder received from Nanomakers was very good. The particle distribution was very **tight** and there was no apparent chemical **contamination**. From a practical aspect that means better incorporation into the melt and shorter processing times to get an acceptable particle distribution. I do not hesitate to say the **Nanomakers SiC** is the **best on the market**. »

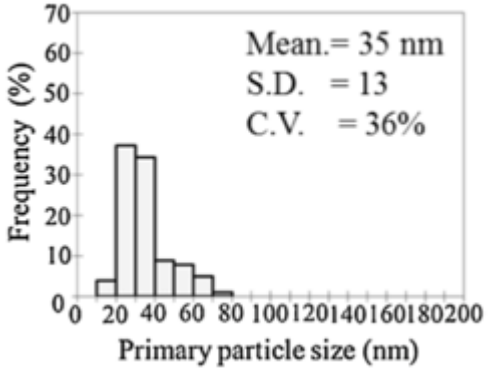
Highest quality process & products

Superior **quality recognized** … by experts :

Kazuya Shimoda of **National Institute for Materials Science (NIMS)**, **Ibaraki** and Takaaki Koyanagi of **Kyoto University**, **Kyoto**

nanomakers **n°1**

- IEST - Institute of Energy Science & Technology Co. Ltd., **Japan**
- Marketech International Inc., **USA**



regarding :

- **Particles size distribution**, and
- **C/Si ratio**, and
- **Impurities content and O2**, and
- **Industrial** production **capability**

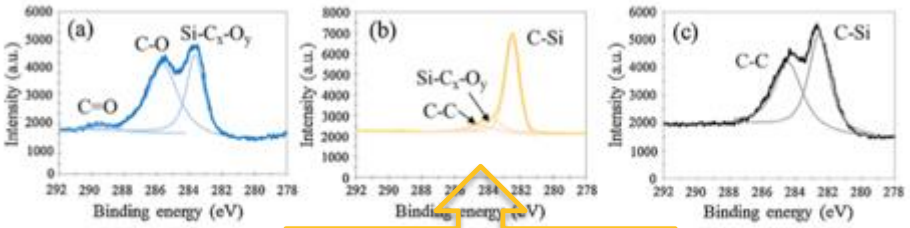


Fig. 7. XPS spectra of C 1s peak for (a) SiCN-1, (b) SiCN-2, and (c) SiCN-3.

nanomakers

In :

« Surface properties and dispersion behaviors of **SiC nano**powders »,
in Colloids and Surfaces A: Physicochem. Eng. Aspects 463 (**Sept. 2014)** 93

An Industrial Company

An industrial company

Industrial production facility in Rambouillet … since 2012

- **10-20 Ton/year**
- Storage & distribution AIR LIQUIDE **for 200+ ton/year**

- **Quality controls**
- Procedures, Material Certificate
- Own control lab
- ISO 9001

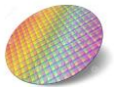
- **« no contact » Strategy**
- For small and big quantities

Creating value for our customers

Creating value for our customers

Applications examples :

- mechanical & chemical **reinforcements, batteries density** etc.




	Semiconductors	Energy Storage	Aerospace	Automotive	Other applications ...	
Targeted end products	**Elastomers** (e.g. **FFKM/FKM**) for **high performance seals**  **marketed**	**Anode material** for **Li-ion batteries**  Marketed soon	**Aluminium alloys** **Nano composite powders for Additive Manufacturing**		**Armouring** 	**Plating** 
Added value proposition	Longer seals **lifetime** & Lower **cost of ownership**	**Doubled** energy density of anode batteries	**Lightweight** structures & parts		**Lighter** protection devices	Increased **abrasion resistance**

Creating value for our customers

High Performance Aluminium

High Performance Aluminium

SiC nano powders … for high performances aluminium alloys

For lighter transportation media

Aeronautics

Spatial

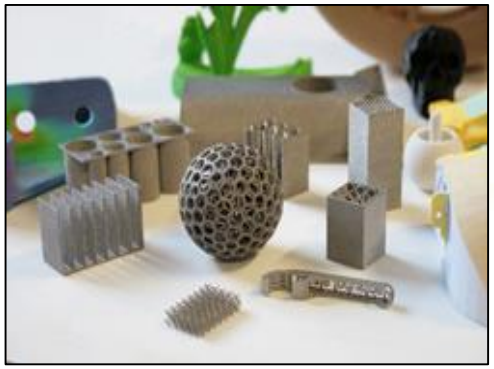
Automotive

Defence

body

Pod of Rafale

Chassis



Additive manufacturing

High Performance Aluminium

SiC nano MMC in aluminium technological choices:

Preferred aluminium grade:

- **A356** already including **7% silicon**

Results (1% wt. loading):

- **Reinforcement** goes into the **grain boundary**
- **Disruptive** improvement in **mechanical performance**
- Significant improvement in **toughness**
- Not compromising the **elongation @ break**
- **Alternative** to **scandium** ?

Dispersion:

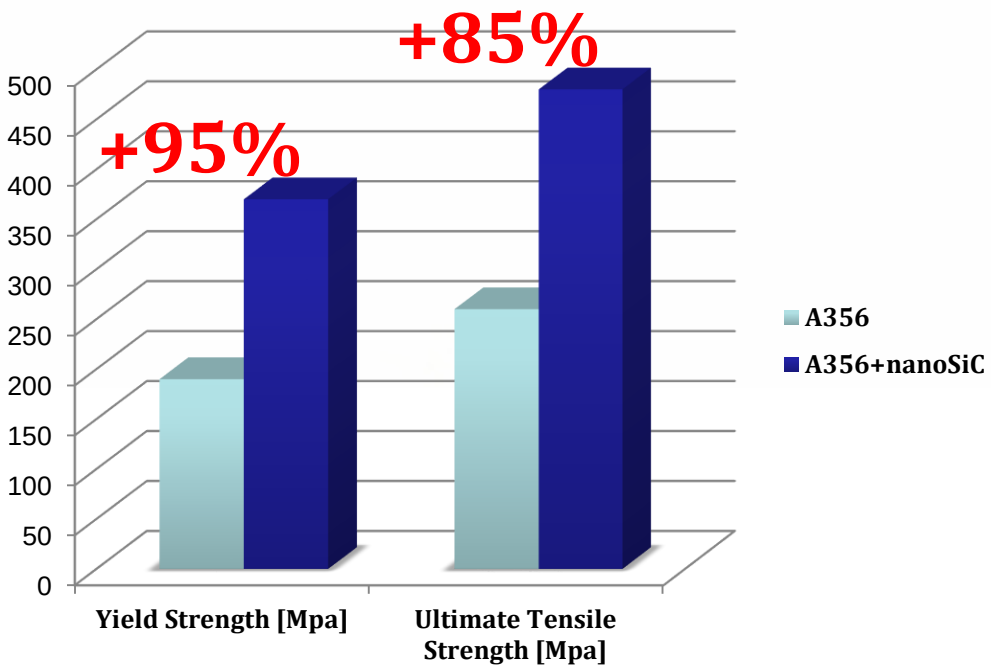
- **Dispersion** is the **key** to obtain improved results : the so-called "**nano-effect**"
- Ultrasonic probe dispersion has proved to be a solution in lab testing

High Performance Aluminium

Reinforcement using 1% wt. of nano SiC

- **Strong** performance improvement for **mechanical properties**
  - Allow part re-design
- **Elongation at break (6-7%)**
  - An improved alternative to existing MMC

- Comparable properties to aluminium 6082 T6
  - Direct casting in replacement of forging.



After T6 thermal treatment (*University of Wisconsin - USA)*

NM SiC as reinforcing agent for aluminum

Possible trials for Foundry:

1. Direct n-SiC dispersion inside melting Aluminum
2. Direct n-SiC dispersion in between solid Al slices/ingots, then melting
3. n-SiC/Al pre-composite manufacturing (powder, shavings, cylinders) then dispersed inside melting Aluminum
4. n-SiC/Al pre-composite manufacturing (powder, shavings, cylinders) then mixed with solid Aluminum, before melting the whole composite

<u>General comments and recommendations:</u>

- Aluminum matrix tested = **AS7G0,3** (or other Al alloys containing around 0 and 10% of silicon)
- SiC % wt. reinforcement = **1%**
- Slow and sequenced introduction of nanoparticles into the vortex generated by mechanical stirring
- Regularly cleaning the surface in order to avoid the formation of an oxide layer that could limit the introduction of nanoparticles in the melt
- Use of sonication to de-agglomerate nanoparticles
- Inert gas degassing to avoid hydrogen introduction and so porosity in the final alloy

NM SiC as reinforcing agent for aluminum

Possible trials for Additive manufacturing:

1. Direct n-SiC blending with Aluminum in a solid-state thermo-mechanical process producing high-deposition rate paste without melting
2. Direct n-SiC blending with Al powder then alloyed/solidified through a selective laser melting process (SLM)
3. n-SiC/Al pre-composite powder manufacturing then blended with Al powder, finally alloyed/solidified through a SLM process

<u>General comments:</u>

- Aluminum matrix = Al alloys containing around 0 and 10% of silicon, or others (**A7075** for example)
- SiC % wt. reinforcement = **1-3%**

<u>Composite basic tests:</u>

Metallography, MEB, Density, Hardness, Yield strength,

Ultimate tensile strength, Elongation at break

HIPERCO Project

Nano-SiC **dispersion** in aluminium alloys **: 3 ways**

① **Melting** alloy : PoC → scaling up
② **Powder** metallurgy
③ **Electrolysis**

Choice = Powder Metallurgy

An eit RawMaterials Connecting matters ***project: High PERformance COmposite***

Technical objectives :

- **Homogeneity** of nano-SiC **dispersion** in the host-**matrix**
- **Powders** characteristics **conservation** along the **process steps**
- **Ceramics-metal interface** quality
- **Improvement** of alloy **performances** (→ **lighthening**)
- Additive **M**anufacturing **efficiency** improvement

HIPERCO Project

An eit RawMaterials Connecting matters ***project***

Project outcomes :

- ✓ Scale-up SiC/Al powder production for additive manufacturing
- ✓ Manufacture parts for aeronautic industry
- ✓ Recycle Al chips into powder for AM

Project Partners:

- ✓ Industry : ZODIAC AEROSPACE, nanomakers, RENISHAW apply innovation™, MECACHROME
- ✓ RTO and academics : cea, KU LEUVEN

To start : January 2018

And Magnesium …

… The + nano effect

>> improving magnesium performance …

Z. Wang et al., Trans. Nonferrous Met. Soc. China 20 (2010), 1029				
Used Technology : Casting, ultrasonic assisted dispersion				
AZ91D alloy composition : 8.94% Al, 0.70% Zn, 0.22% Mn, 0.02% Si, balance Mg	SiC content (wt.%)	YS (MPa)	UTS (MPa)	E@B %
AZ91D Alloy	0	104	174	3.6
AZ91D Alloy+ SiC 50 nm nanopowders	0.5	124 + 19%	216 + 24%	6.6 + 83%

K.B. Nie et al., Materials and Design 36 (2012) 199				
Used Technology : Semisolid stirring assisted ultrasonic vibration + extrusion				
AZ91D alloy composition : 9.07% Al, 0.68% Zn, 0.21% Mn, balance Mg.	SiC content (wt.%)	YS (MPa)	UTS (MPa)	E@B %
AZ91D Alloy	0	90	186	6
AZ91D Alloy+ SiC 60 nm nanopowders	1	198 + 120%	254 + 36%	12 + 100%

nanomakers

> When infinitely small makes a difference :

the « **Nano effect** »