nanomakers

Materials booster

Develops, produces & sells **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

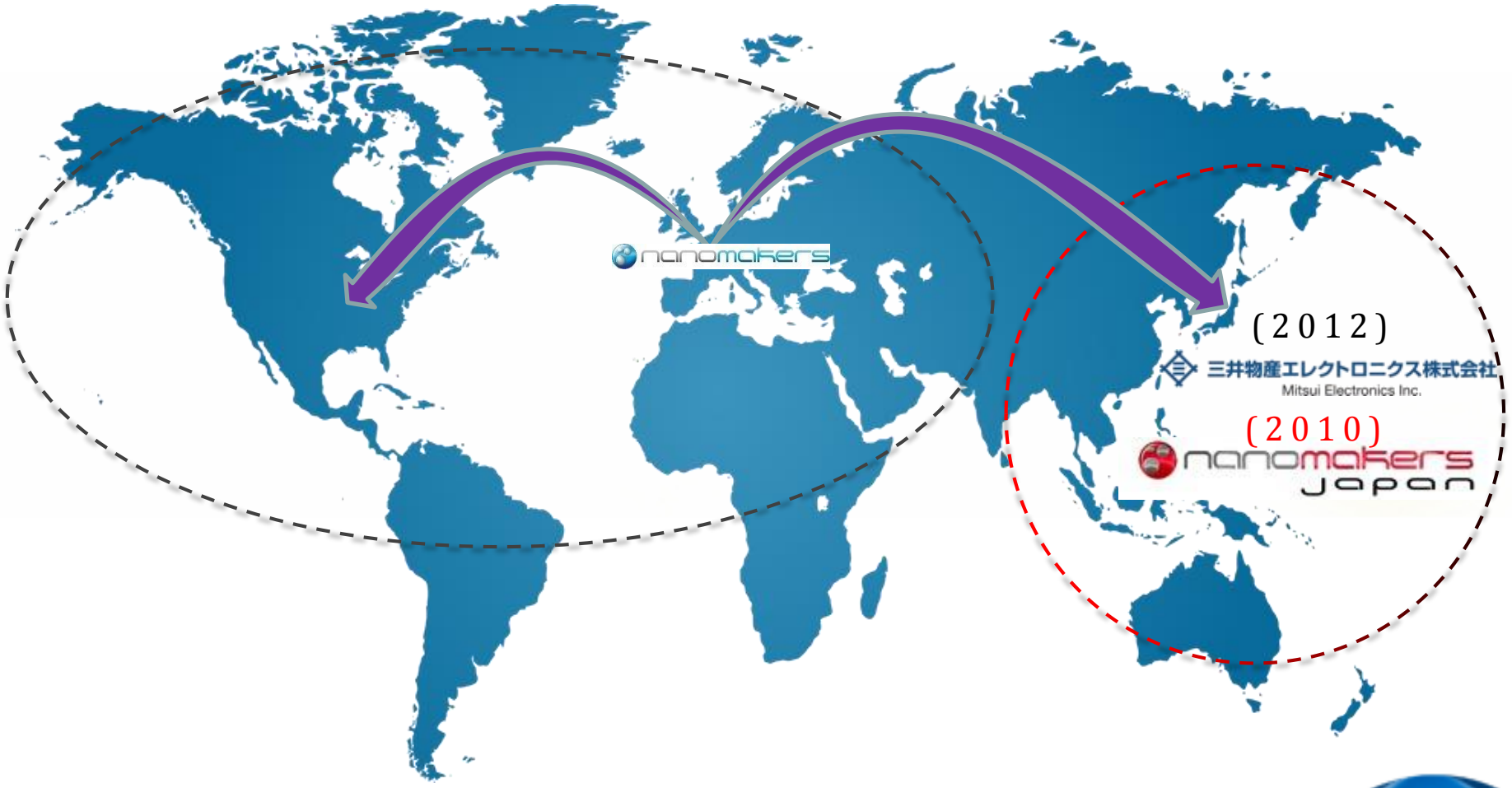
NanoReg2
Project #646221, Funded by the Horizon 2020 Framework Programme of the European Union

eit RawMaterials
Connecting matters

Continuous Innovation

nanomakers with & for global partners

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



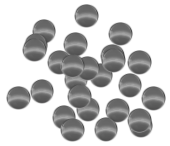
Highest quality process & products

Highest quality process & products

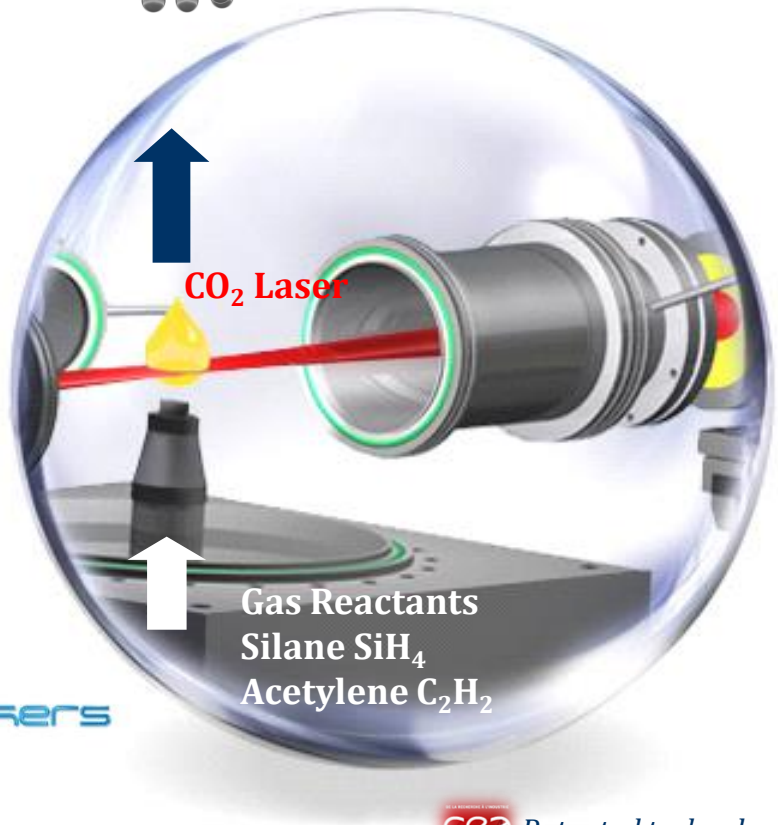
Precise, reliable and secure technology … guarantee of results

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



Patented technology

Experience and expertise:

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

Highest quality process & products

Laser pyrolysis nanomakers ... 4 advantages

Homogeneous :
Low particle **size** deviation.

Strict crystal growth & size control

Pure :
High **purity** batches, **low O_2** & metallic content

Bottom-up process

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

Unique industrial practice

Customizable:
Size, Surface, Coating

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

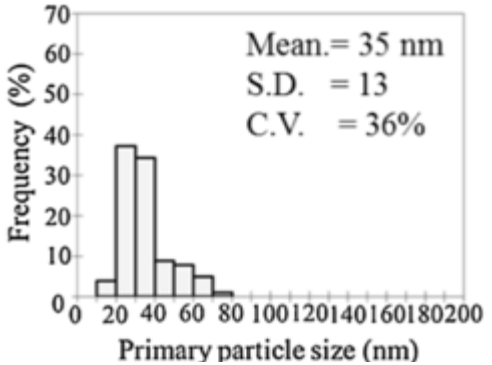
Superior **quality recognized** …

① By ***experts*** : Kazuya Shimoda of **National Institute for Materials Science (NIMS)**, Ibaraki/**Tokyo** and Takaaki Koyanagi of **Kyoto University**, **Kyoto**

nanomakers = # 1 against competitors in **Japan** and **USA**

regarding :

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



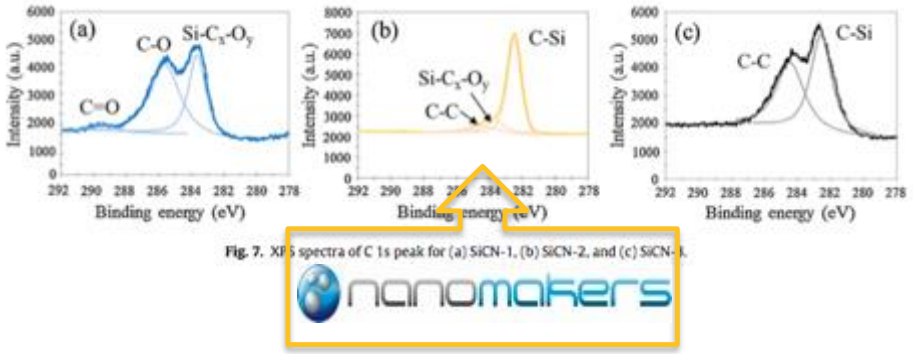


Fig. 7. XPS spectra of C 1s peak for (a) SiCN-1, (b) SiCN-2, and (c) SiCN-3.

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

② And by our ***customers :*** **Eck Industries** (USA) :

« 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**. »

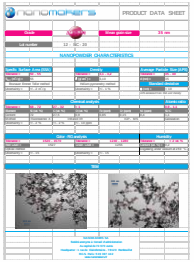
An Industrial Company

An industrial company

Industrial production facility in Rambouillet … since 2012
*(50 km **Paris**)*

- **20 t/year** capacity
- Storage & distribution AIR LIQUIDE **for 200+ t/year**

- **Quality control**
- Procedures, Certificate of Analysis
- Own quality control lab
- ISO 9001



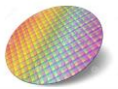
- **« no contact » Strategy**
- for small and larger quantities

Creating value for our customers

Creating value for our customers

Applications examples :

- mech & chem **reinforcement, 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**

Application zoom #1

Ceramics for electronics

Semiconductor market

Semiconductors – Wafer carriers, jigs, etc…

Current market drivers:

Heavier doping for **high power electronics**

→ **higher** process **temperatures**

→ **out of quartz** operating **range**

➔ to be **replaced by** ??

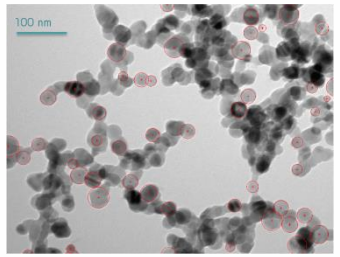
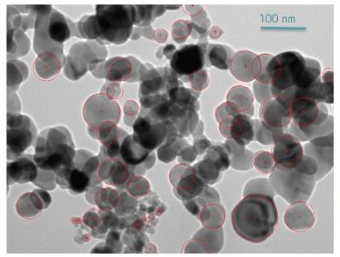
Desired properties of the sintered materials :

- ✓ High **density sintering** ability
- ✓ **Stability** at high **temperature**
- ✓ **Thickness** up to 5mm
- ✓ High **purity** for a **better doping** control

➔ the **sintered nano SiC**, raw material for electronics applications

Sintering with Nano SiC

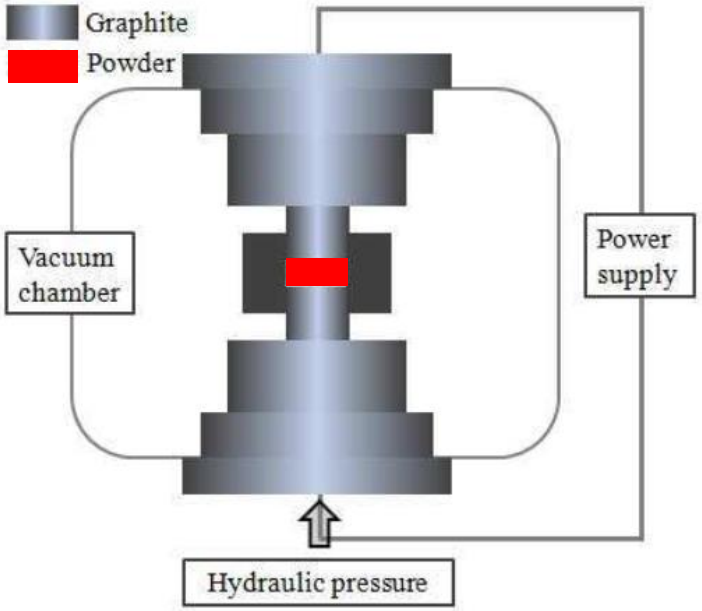
nanomakers typical grade for sintering is **NM SiC 99**

NM SiC 99	Color (Free powder)	SSA (m^2/g)	Density (g/cm^3)	APS (nm)	Stand. Dev. (nm)	TEM
35nm	 Gray	48 - 58	3,1 – 3,2	35 - 40	<10	
75nm	 Light gray	24 - 29	3,1 – 3,2	65 - 80	<20	

Specifications

- Oxygen < 1%
- Moisture content < 1%

Spark Plasma Sintering



Fast growing process → **High** production **rate**

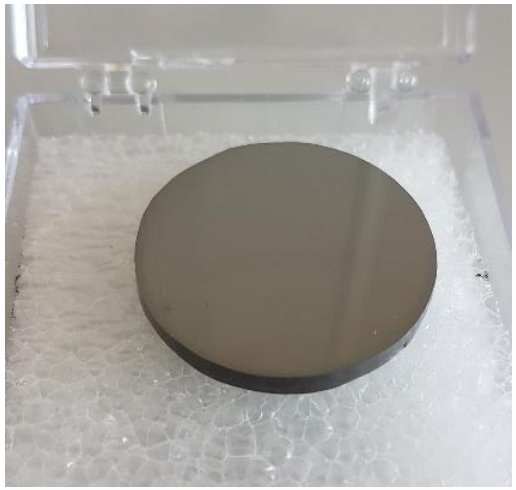
No additive (+ high purity product) → **Contamination-free** parts

Control on the sintering parameters → **Customized parts** properties

Spark Plasma Sintering

Sintered part using **SPS** and **Nanomakers** nano **SiC without** additive

NM SiC 99

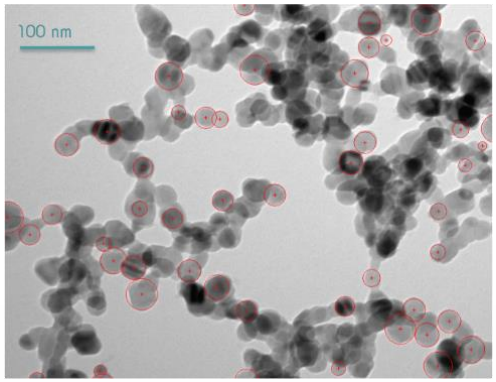


Demonstrator part (Ø 3cm, thickness 3mm)

Nanomakers has reached up to now a **sintering density of 96-99%**, depending on the nature of the nanopowders.

Sintering with Nano SiC

Advantages in sintering NM SiC 99 :



- **Faster** sintering process, **higher** production **rate** and **reduced cost** compared to CVD method
- **Very high** sintering **density without** sintering **additive**

- **Very high** product **purity**, **metallic** traces in **ppm** level
- Resistance to **very high temperatures**

- ***Various*** *sintering* ***methods*** *can be used*

Application zoom #2

SiC ceramics for filtering applications

Filtering membrane

The nano SiC, raw materials for ceramic applications

Potential Applications

Diesel Motor – Particles filters

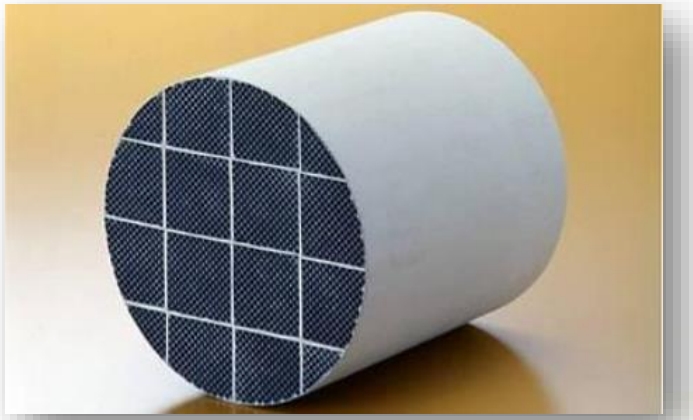
Desired properties of the sintered pieces:

1) High level of porosity
2) Fine porosity
3) High mechanical strength
4) No metallic impurities

Material selection criteria:

1) High Young modulus
2) Fine particles
3) High purity

NM SiC 99



Beurotte, A. *Doctoral dissertation*. Ecole Nationale Supérieure des Mines de Paris, **2011**.

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Our proposal

The nano SiC, raw materials for ceramic applications

Isostatic compression & post treatments

Mixing with an inorganic defluoculant → Isostatic compression (2000bars) → Debinding (500°C) → Natural sintering (2000°C)

Final part

- Open porosity ~ 48%

Application zoom #3

SiC ceramic other applications

Applications for ceramics

The nano SiC, raw materials for ceramic applications

Potential Applications

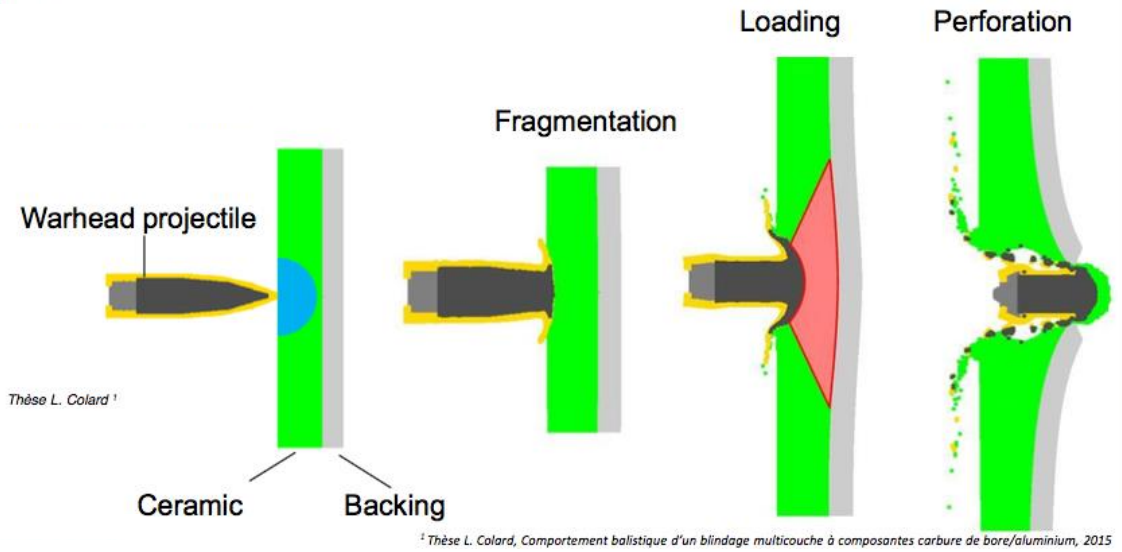
Ballistic protection – Shielding of vests and transportation vehicle

Role of the ceramic:

1) Erode the projectile
2) Limit its penetration
3) Fragment the projectile
4) Distribute kinetic energy

Material selection criteria:

1) Hardness, compressive strength
2) Low density
3) Reasonable cost



[1] Thèse L. Colard, Comportement balistique d'un blindage multicouche à composantes carbure de bore/aluminium, 2015

Applications for ceramics

The nano SiC, raw materials for ceramic applications

Potential Applications

Aerospace – Mirrors and telescope structures

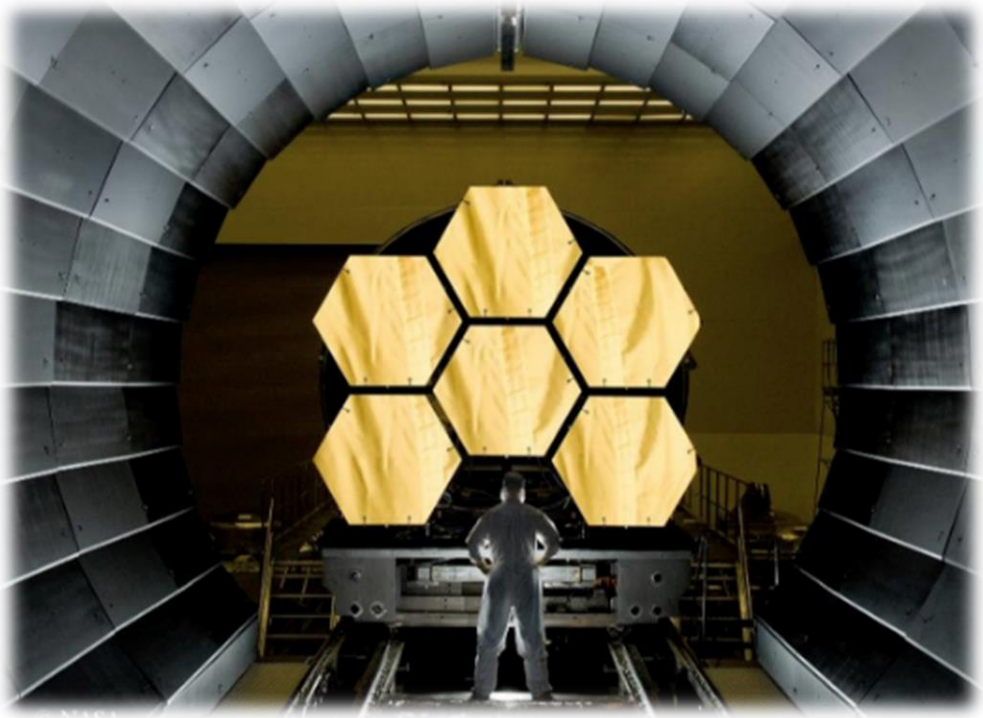
Desired properties:

1) Thermal stability
2) High rigidity
3) Corrosion resistance

Material selection criteria:

1) High Young's modulus
2) Low density
3) High thermal conductivity
4) Low coefficient of expansion

NM SiC 99



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Applications for ceramics

The nano SiC, raw materials for ceramic applications

In conclusion…

Nanomakers capabilities :

- Materials
  - Highly pure SiC nanoparticles
  - Different sizes of nanoparticles
  - Pre-agglomeration of the nanoparticles (granulation)

- Sintering
  - Spark plasma sintering for highly dense parts
  - Isostatic compression for porous parts

THANKS FOR YOUR ATTENTION

nanomakers

When small makes a difference :
the « **Nano effect** »