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

NM Si 99 Ω C

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

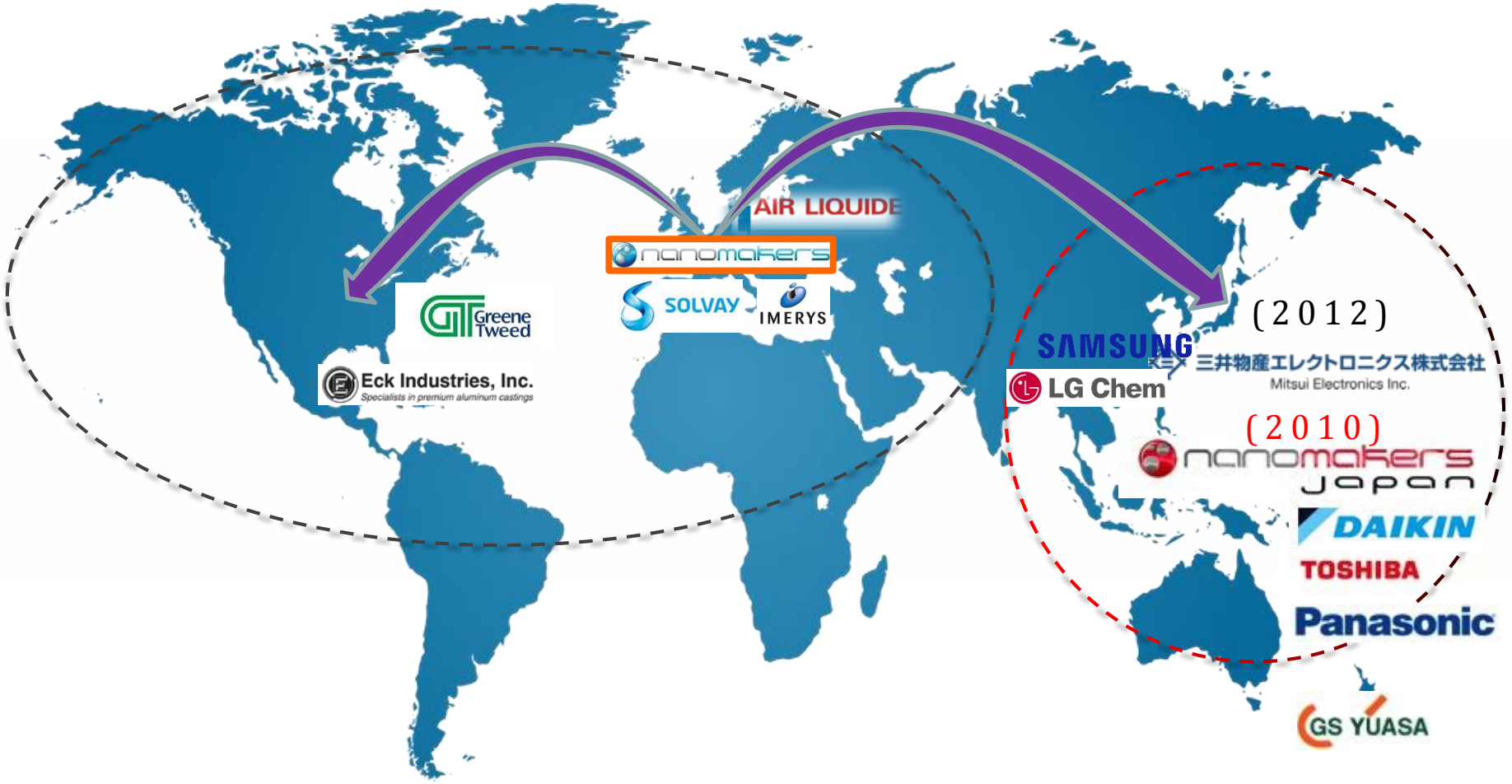
NanoReg2
Project #646221, Funded by the Horizon 2020 Framework Programme of the European Union

NM SiC 99 Ω A

eit RawMaterials
Connecting matters

Continuous Innovation

nanomakers with & for global partners



*For LiB, Nanomakers collaborates with **80%** of the **world Li-ion** battery **market** and particularly with **all** the **technological** and **industrial leaders.** Nanomakers **exports also 99% of its products outside of Europe.***

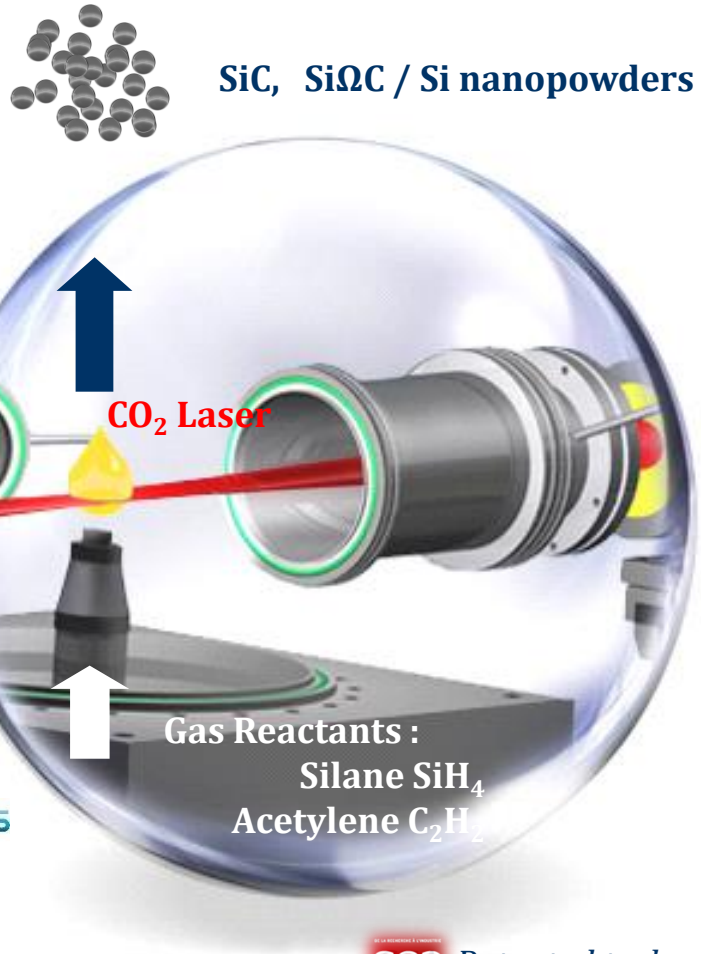
Highest quality process & products

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. **crystals** start **building up** abruptly
3. Particle **size** is **controlled** by a fast **quenching** which stops the particle growth



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

Laser pyrolysis nanomakers ... 4 advantages

Homogeneous :
Low particle **size** deviation.

Strict crystal growth & size control

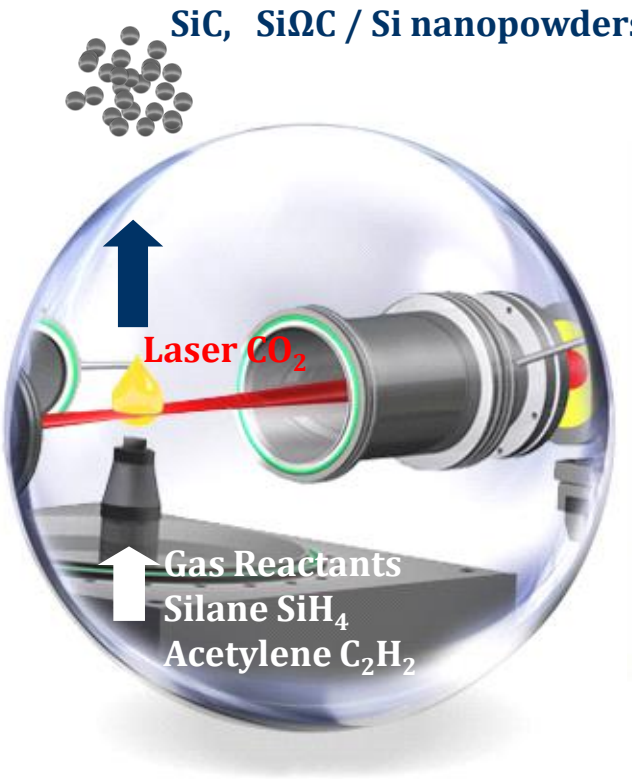
Pure :
High **purity** batches, **low O_2** & metallic content

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

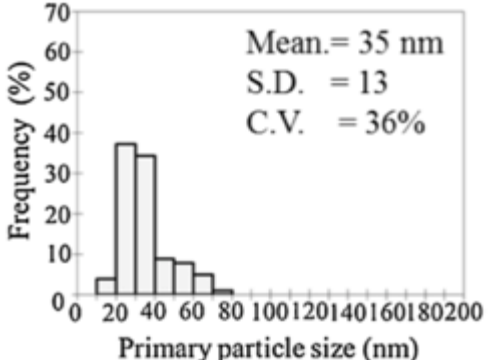
Superior **quality recognized** …

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**



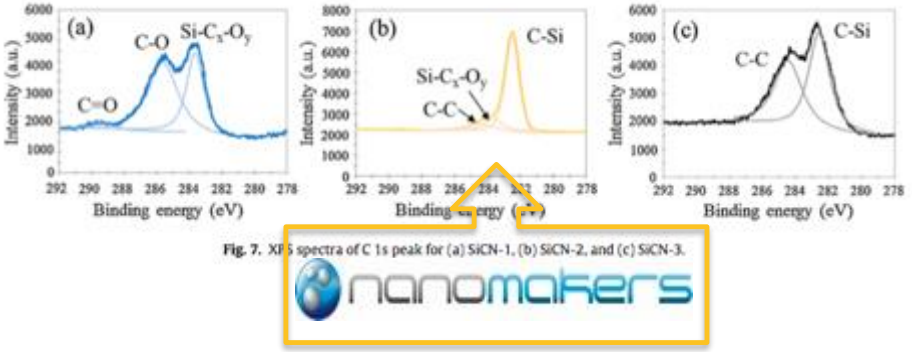


Fig. 7. XPS spectra of C 1s peak for (a) SiCN-1, (b) SiCN-2, and (c) SiCN-3.

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**. »

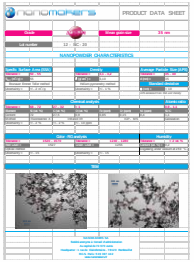
An Industrial Company

An industrial company

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

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

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



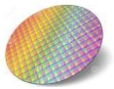
- **« no contact » Strategy**
- for small and larger quantities
- “safe by design”

Creating value for our customers

Creating value for our customers

Applications examples :

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



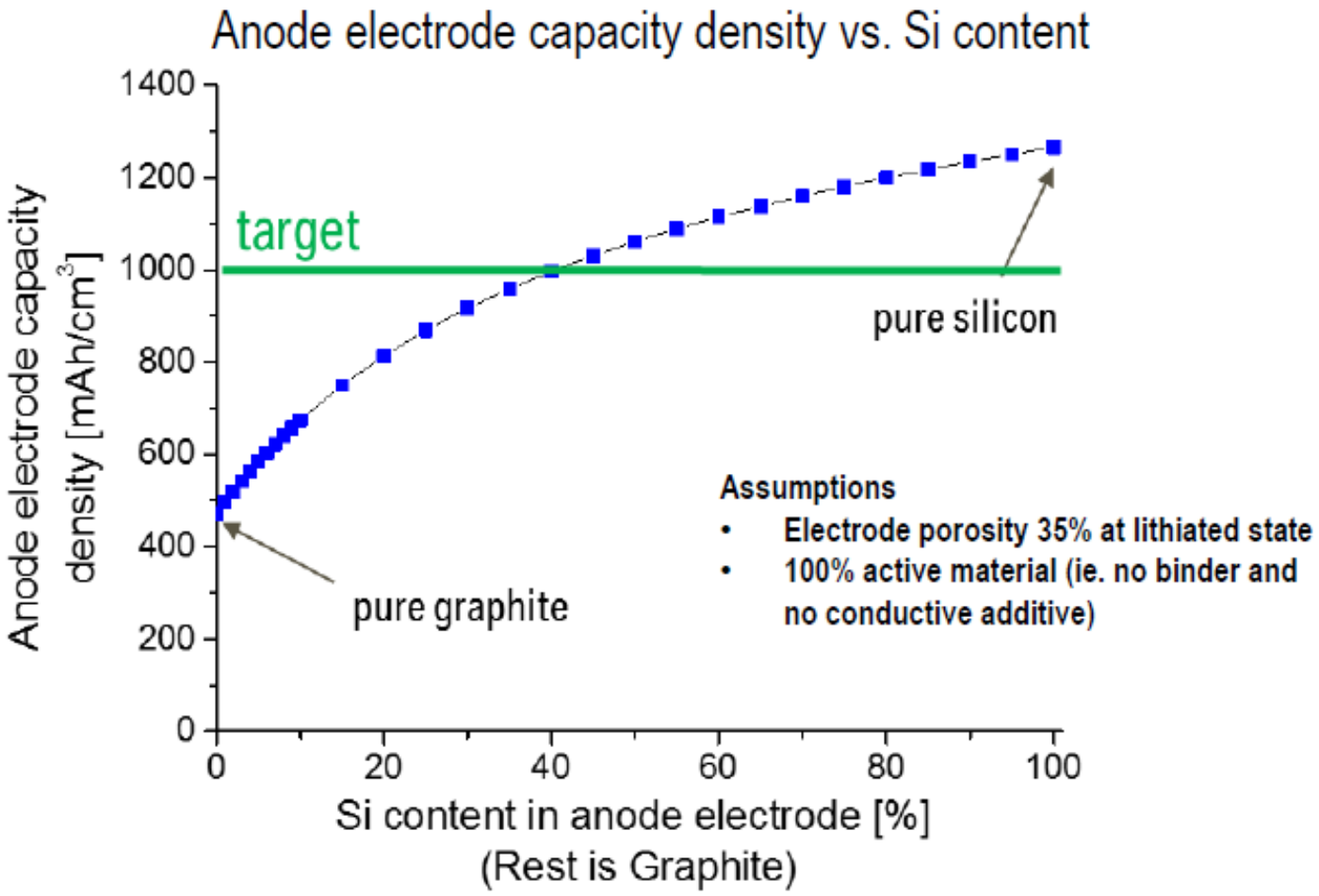

	Semiconductors	Energy Storage	Aerospace	Automotive	Other applications ...	
Targeted end products	**Elastomers** (e.g. **FFKM/FKM**) for **high performance seals**  **marketed**	**Anode material** for **Li-ion batteries**  Marketed soon	**Aluminium alloys** **Nano composite powders for Additive Manufacturing**		**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

Si anodes for Lithium-ion Battery

The industry silicon-based anode consensus

OEMs Intention: **BMW** showed at Battery Japan 2018
30-50% silicon should be suitable for final target.



Market study for Li-ion Battery

Perspectives nano-Si @ 2030 (tpa)

Forecast	2020			2025			2030		
Target markets	**Anode material (ton)**	**Composite Si-C (ton)**	**% Si-C in overall power**	**Anode material (ton)**	**Composite Si-C (ton)**	**% Si-C in overall power**	**Anode material (ton)**	**Composite Si-C (ton)**	**% Si-C in overall power**
EV	62 468	1 750	7%	93 701	7 000	16,6%	109 318	24 500	37,4%
3C	40 000	2 000	5%	55 000	5 500	10%	64 000	21 120	33%
Other niche markets	8 000	1200	15%	12 000	3 000	25%	14 000	8 400	60%
	110 500	4 950					187 318	54 100	

CAGR = 5,5 % (AM) / 27% (Si-C)

Tonnage calculated based on graphite with a capacity of 300 mAh/g and Si-C composite with a capacity of 800 mAh/g

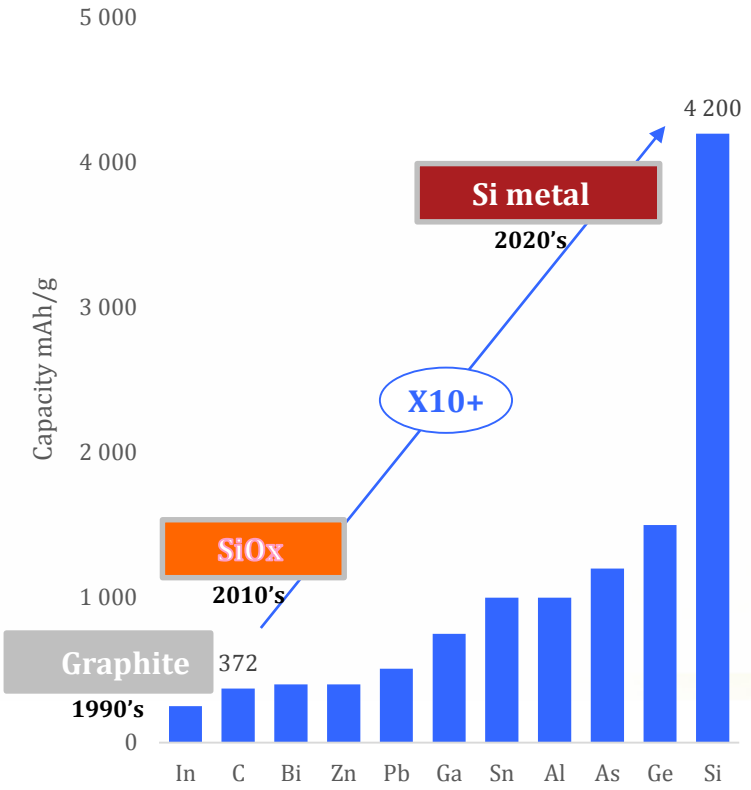
The industry silicon-based anode consensus

WHY ?

- Strong demand for innovation with major R&D efforts aiming at:
  i. **improving density** (autonomy)
  ii. improving **lifetime**
- Technical improvements have mainly taken place on the cathode material so far
- Industry research efforts currently cast on **improving anode capacity** using **silicon** instead of graphite, multiplying energy storage but generating **two major challenges**:

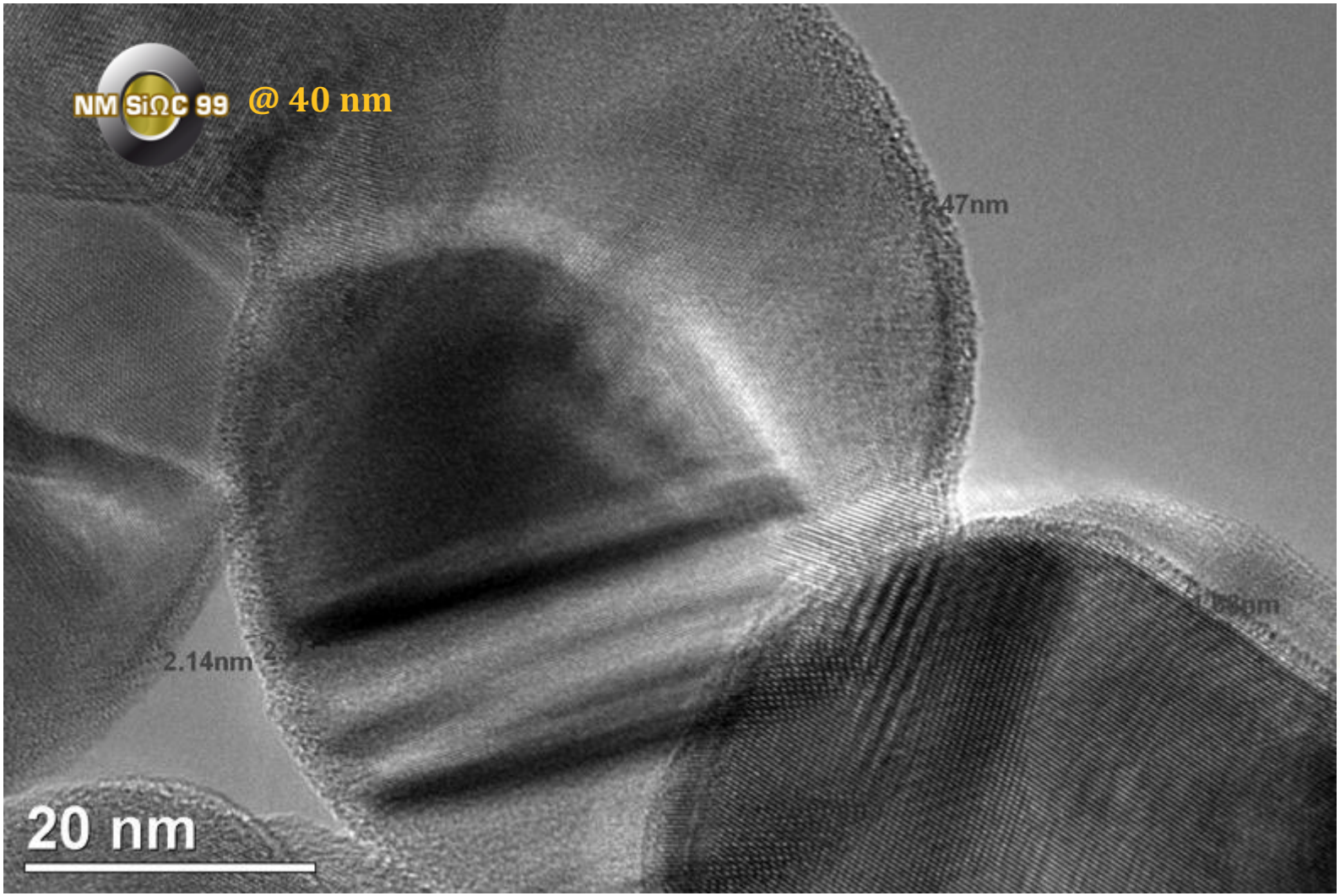
Cracking ***Oxidation***

Silicon performances vs. carbon



*Solving the cracking and oxidation issues are **key enablers** for the **commercialization** of **new generation** Li-ion **batteries : NM SiΩC***

NM SiΩC for high density batteries



NM SiΩC for high density batteries

NM SiΩC99 (intrinsic) **Product Advantages:**

- Our novel nanocomposite **SiΩC overcomes** the **limitations** of
  - pure or non nano Si (**cracking** and **oxidation**)

- **Silicon-**based **particle**
  1. **Homogeneous** particle **size distribution**
  2. **Small** size (**40** nm)
  3. **Low oxygen** content (**< 2%** wt.), **no SiC**, High purity

- **Carbon** shell
  1. **protects Si** from direct **electrolyte** exposure,
  2. **favors** the creation of a **stable SEI** layer, and
  3. improves the **affinity of Si** with most **graphites** and **binders** (CMC, PVDF…).

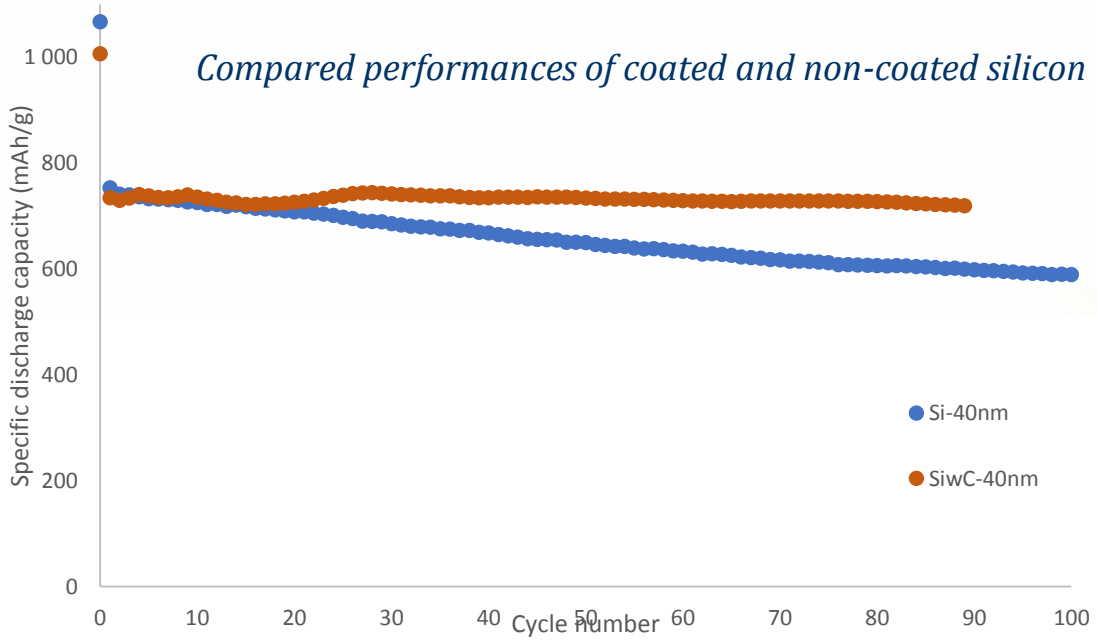
- **Chain like** structure enables **high conductivity** of SiΩC

NM SiΩC for high density batteries

NM SiΩC99 Product Advantages (used in composite) **:**

- Anode performance is improved when using a **structured Graphite/n-SiΩC composite**, which offers significant improvements in both the **gravimetric** and the **volumetric** energy **density** over commercially used graphite.

- Such composites show a **high initial coulombic** efficiency and an **excellent cycling performance**.



NM SiΩC for high density batteries

NM SiΩC99 Product applications:

2 approaches for Lithium-ion Battery application:

1. **Horizon 2020, Liquid type LiB** : Adding NM SiΩC99 to anode materials (SiOx, graphite, etc.) to improve the current anode energy density
   - Mixing nano SiΩC with anode materials,
   - Introducing into existing anode manufacturing process,
   - Improving LiB performances by increasing anode specific capacity

2. **Horizon 2030/40, All Solid State** : Using NM SiΩC99 as main anode material combining with solid electrolyte and solid cathode to make All Solid-State Battery.
   - Multiplying specific capacity of anode by 2-3 (compared with liquid type LiB)
   - Controlled silicon volume expansion: simpler battery design compared to Li metal
   - Providing a safer system for LiB: no dendrite formation, no inflammation if puncturated
   - No “dead Li”
   - Si anode compatible with LiS battery

nanomakers

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