Optimization of the manufacturing process of macro and nano structures for power modules' interconnection

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Thomas DIAS[1], Bojan DJURIC[12], Vincent BLEY[1], Olivier DAGUT[1], Julien MORAND[2], Jean-Pascal CAMBRONNE[1], Stefan MOLLOV[2]

[1]Université de Toulouse;
UPS; INPT; LAPLACE;
118 rte de Narbonne – Bât. 3R3
CNRS; LAPLACE;
F-31062 Toulouse France

[2]Mitsubishi Electric
R&D Centre Europe
1, allée de Beaulieu CS 10806
35 708 RENNES CEDEX 7
France

Outline

- Introduction
- Concept of the interconnection
- Current profiles experiments
- Conclusion and outlook

Introduction

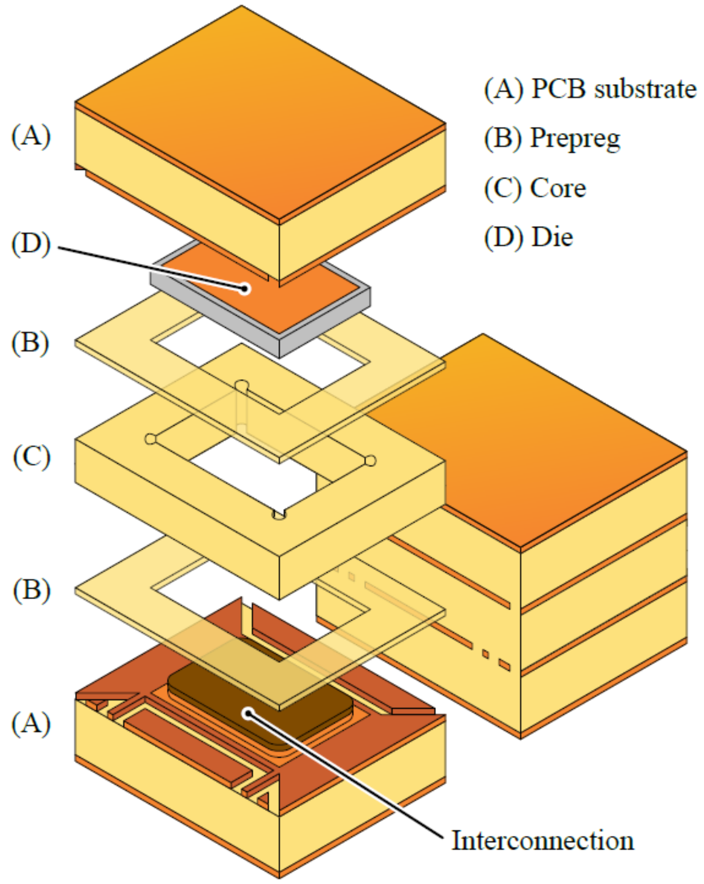
Increasing power density of converters has been a great challenge in the last years:

Wide Band Gap switches:

- Faster switching times => need to decrease stray elements ;
- Higher Tj => Higher ΔT and various CTEs combined with cyclical stresses => need to increase reliability ;
  - Packaging improvement via 3D integration.
    - PCB-embedding technology by micro-vias could suffer of cracks due to cyclical stresses.

=> Alternative interconnection by macro and nano structures

Concept of the Interconnection



Assembly schematic

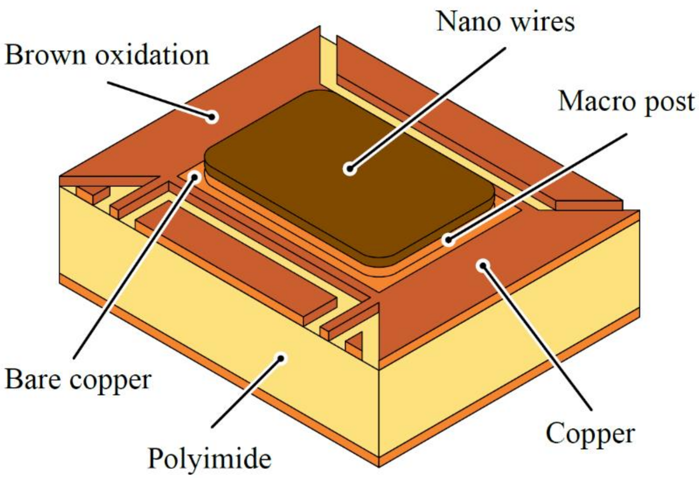
The proposed solution consists of:

- Interconnecting the die, on each side, by a PCB substrate with macro and nano structures ;
- Manufacturing by electroplating process.

Challenge of the innovative interconnection :

- Maximizing contact surface with die ;
- Z-axis control.

Concept of the Interconnection



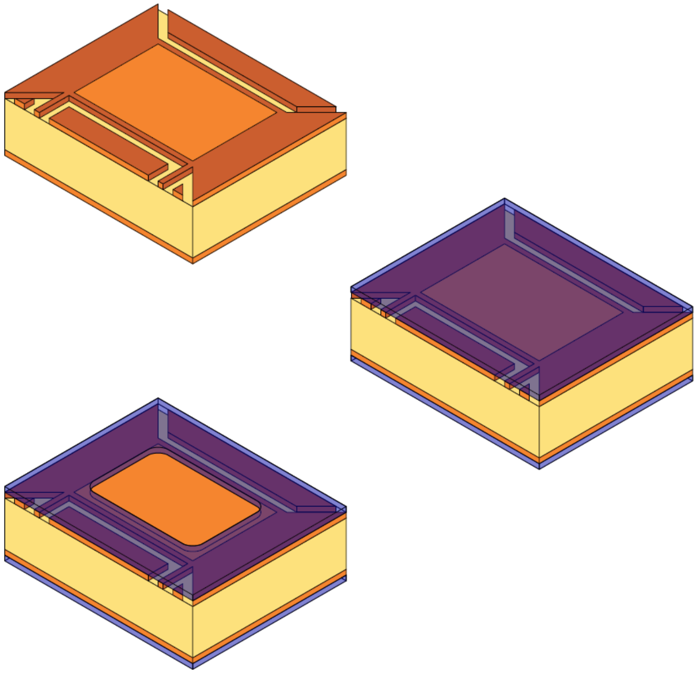
Interconnection schematic

Advantages of this interconnection :

- Full copper structure ;
- Double sided thermal management possible ;
- Expected to be flexible ;
- Use of typical PCB production line equipment.

The objective of this work was to make the process industrially viable.

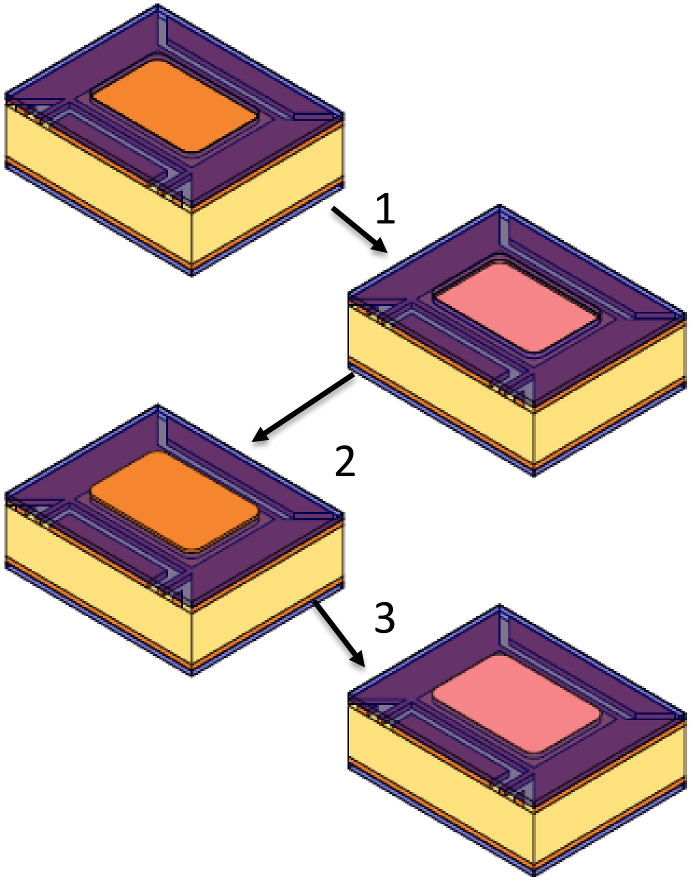
Concept of the Interconnection



Assembly schematic

1. Dry film (42 µm) applied, on both sides, all over the PCB substrate ;
2. Opening to get the interconnection's shape ;
3. Deposition on the working area :
   - Electrolytic bath ;
   - Pure copper counter electrode.

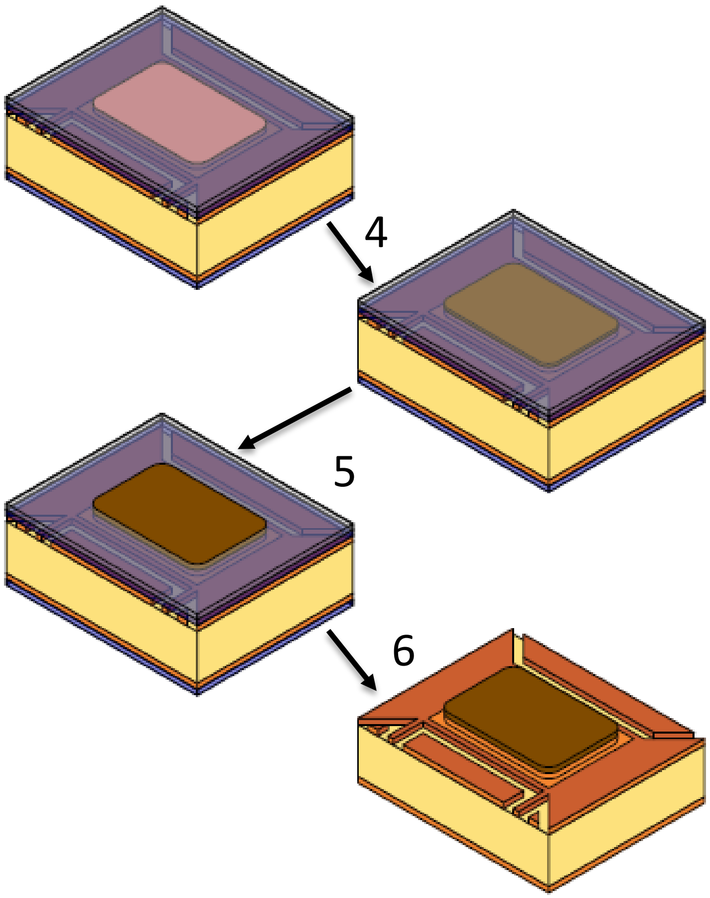
Concept of the Interconnection



Schematic of manufacturing steps

1. Copper electro-etching ;
2. Macro post electroplating ;
3. Levelling of the macro post ;

Concept of the Interconnection

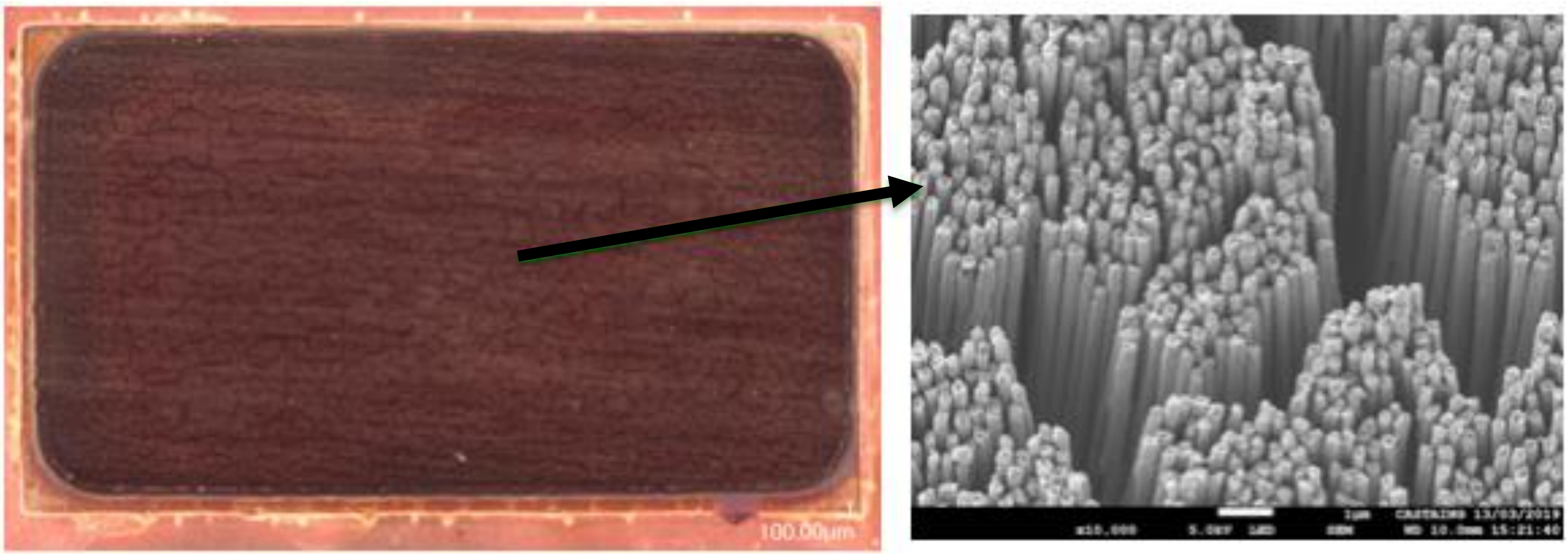


Schematic of manufacturing steps

1. Copper electro-etching ;
2. Macro post electroplating ;
3. Levelling of the macro post (electro-etching) ;
4. Nano wires electroplating with pressed anode ;
5. Membrane filling with distanced anode (electroplating) ;
6. Dry film and membrane removal.

Concept of the Interconnection

Resulting macro and nano structured interconnection after the manufacturing process:

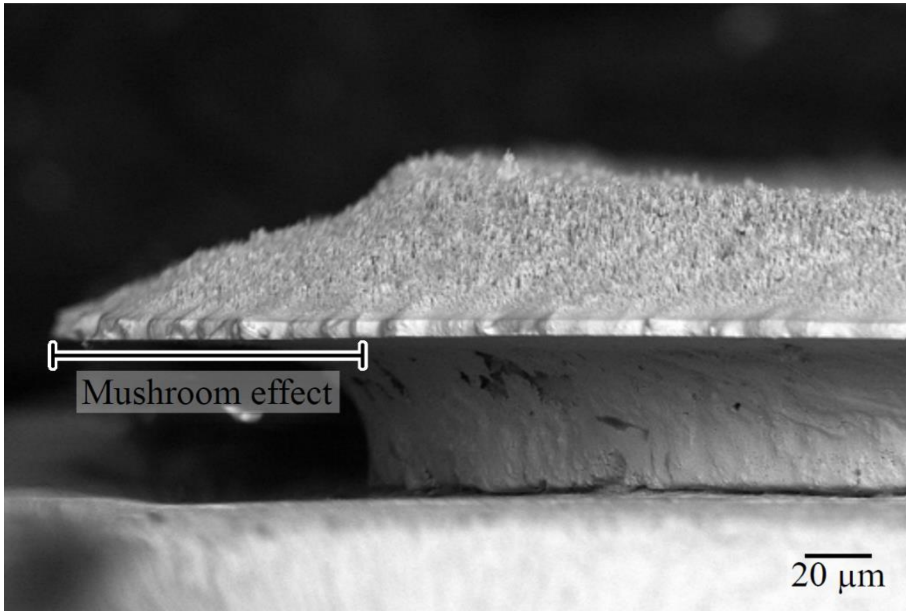


"Nano forest" digital microscope image & SEM acquisition

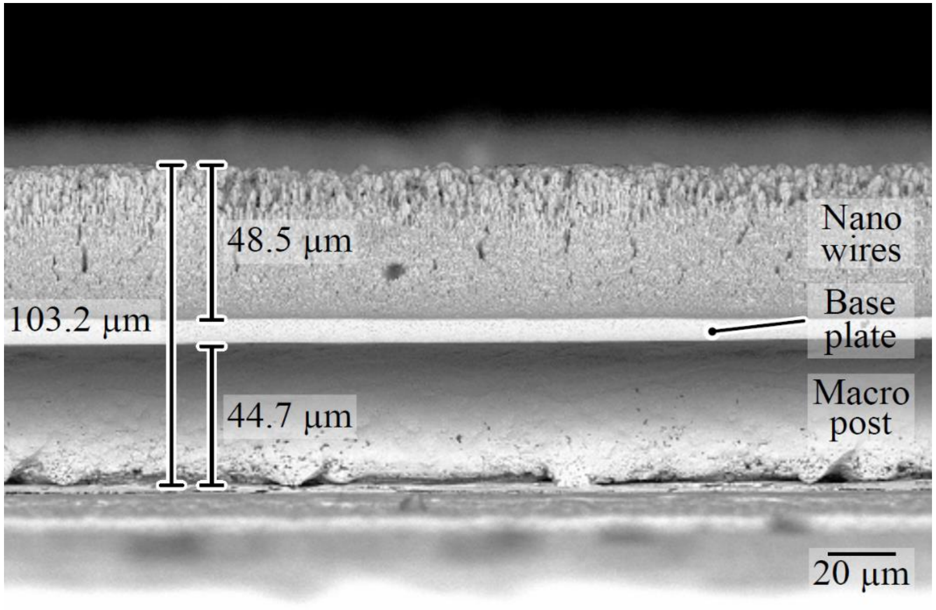
- Around 50% density of nano wires all over the macro post
- 200 nm Diameter wires

Concept of the Interconnection

Side view of the resulting macro and nano structured interconnection after the manufacturing process:



Mushroom effect



Side view of the interconnection

100 µm interconnection is achieved, with a "baseplate", "mushroom" and border effect

Concept of the Interconnection

Manufacturing process challenges :

- Short manufacturing time ;
- Repeatability of the process : standardized procedure and control methods ;
- High homogeneity of the nano structures in terms of height.

Current experiments

The key elements of this process:

- Deposition step by distanced anode is crucial for homogeneity ;
- Average current determines deposition rate (µm/s):

$$\frac{h}{\tau} = \frac{V_m I}{nFS}$$

- Current waveform crucial for homogeneity :
  - Fast pulses => same deposition rate on the whole surface ;
  - Longer pulses => promote deposition on areas closer to the anode.

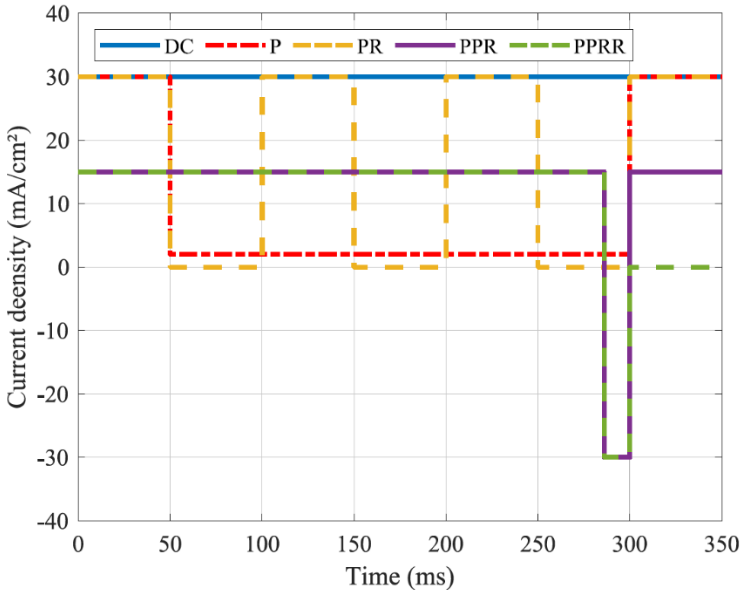
Height: h (µm); average current: I (A); Duration: τ (s); Molar volume: Vm (μm^3/mol); Electrode area: S (μm^2); Number of electrons involved: n; Faraday's constant: F (C/mol)

Current experiments

Different parameters can be adjusted:

- Forward current density ;
- Reverse current density ;
- Presence of relaxation ;
- Periods of the different steps.

Wave	P	PR	PPR	PPRR
Pulse	X	X	X	X
Relaxation		X		X
Reverse			X	X

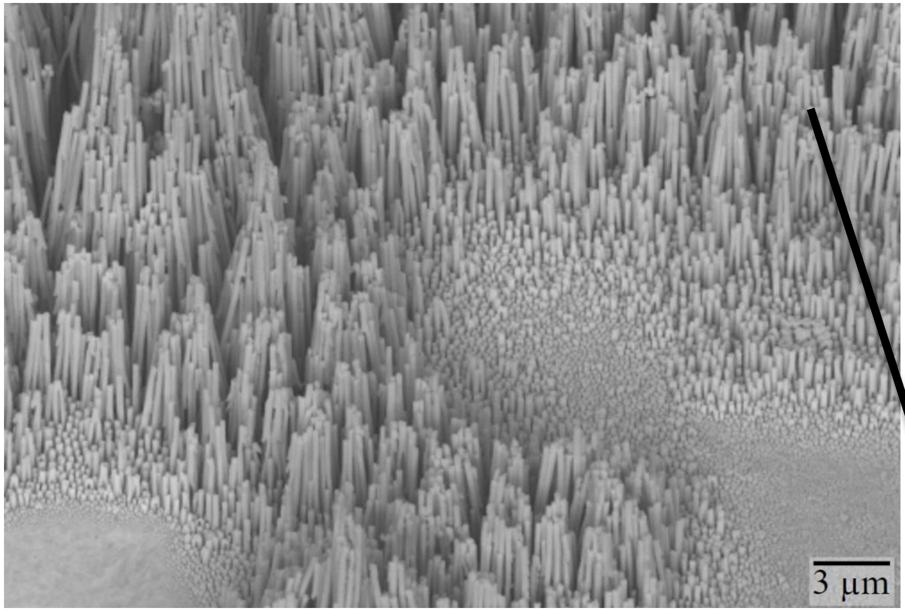


Summary of the profiles used

Profiles experimented:

- Pulsed (P) ;
- Pulsed Relaxed (PR) ;
- Periodic Pulse Reverse (PPR) ;
- Periodic Pulse Reverse Relaxed (PPRR).

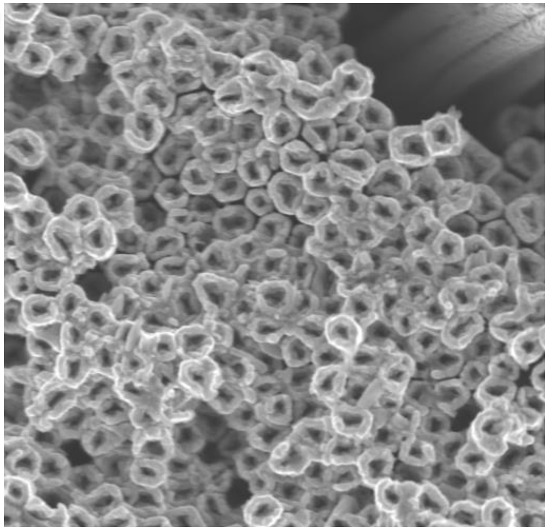
Current experiments - DC



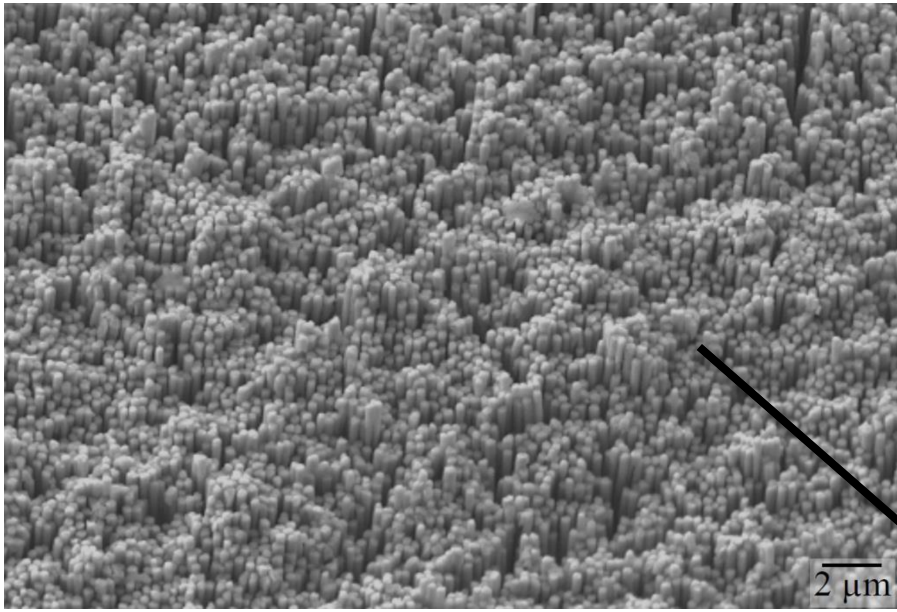
SEM acquisition of the DC deposition

30 mA/cm² current density, following manufacturer's recommendations.

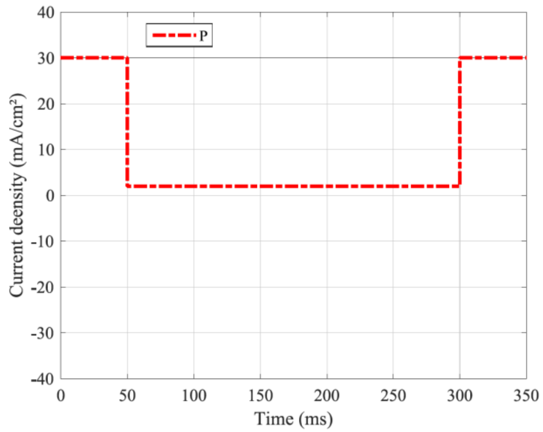
- Fast deposition : 1h30
- NW's height difference: 100 µm
- Mushroom effect: 200 µm
- Hollow section



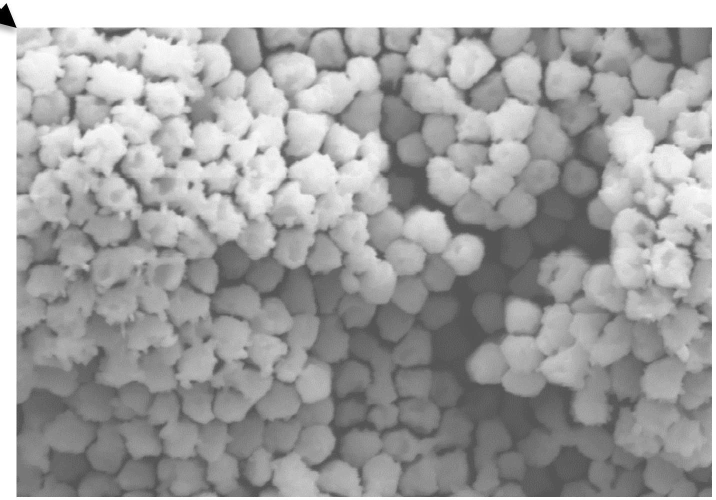
Current experiments - P



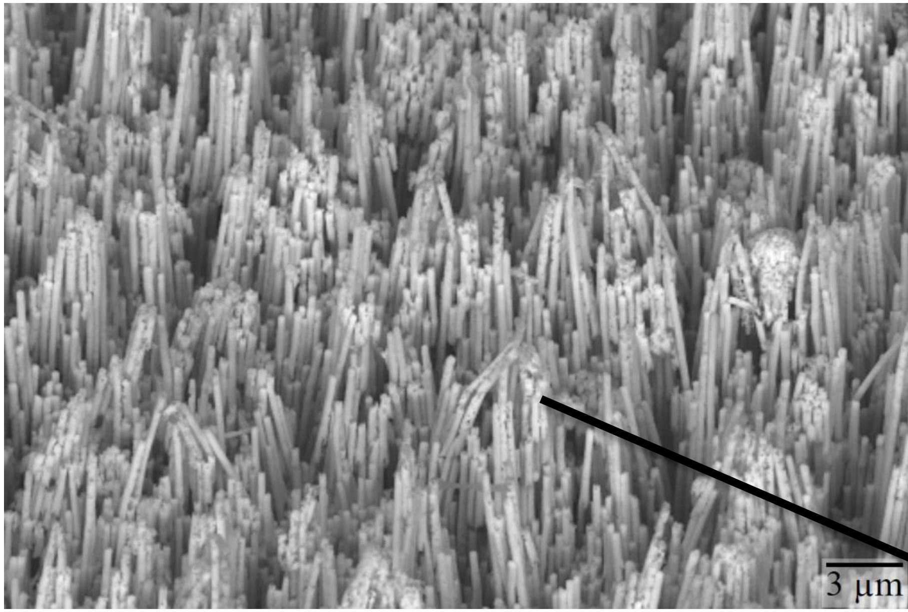
SEM acquisition of the Pulsed profile



- Long deposition time: 6h53;
- Low NW's height difference: 1 µm ;
- Mushroom effect: 20µm ;
- No defects.

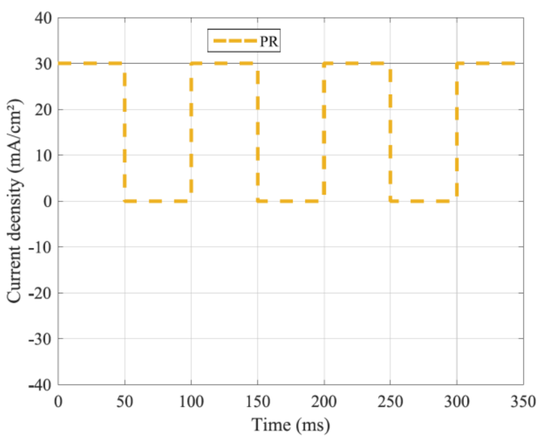


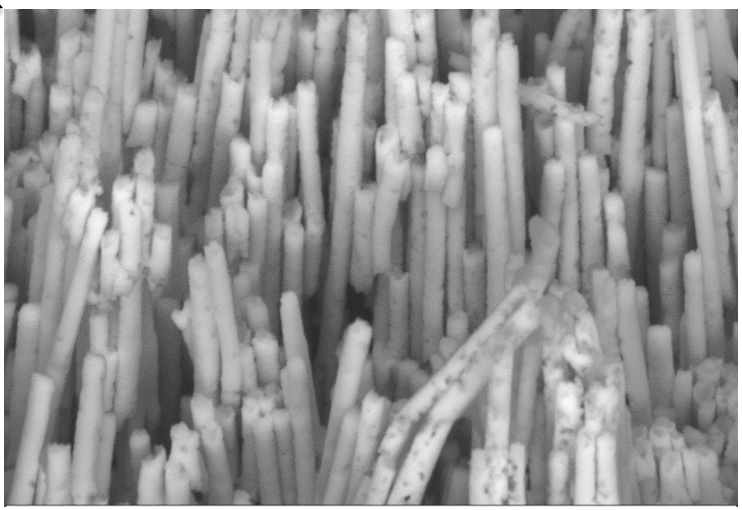
Current experiments - PR



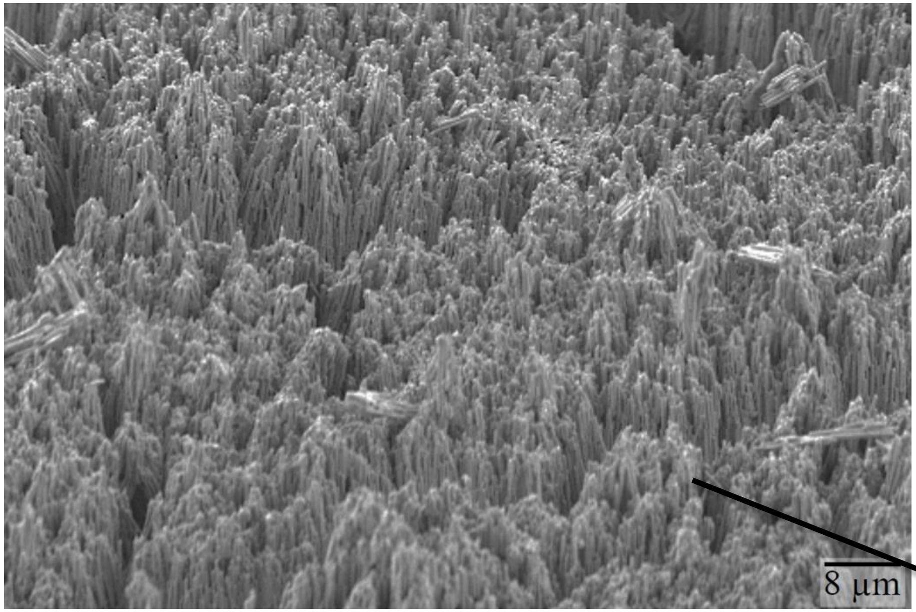
- Short deposition time: 3h ;
- "High" NW's height difference: 6 µm ;
- Mushroom effect: 20µm ;
- Weak wires.

SEM acquisition of the PR deposition

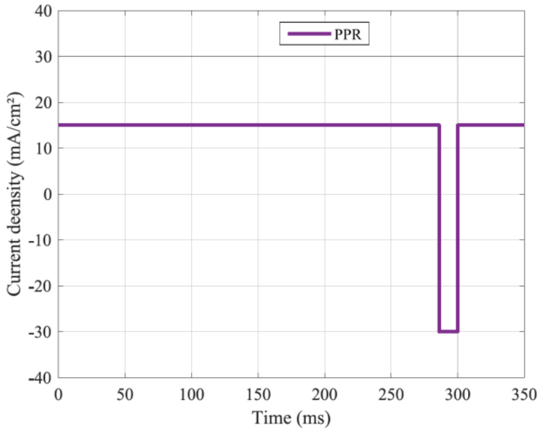




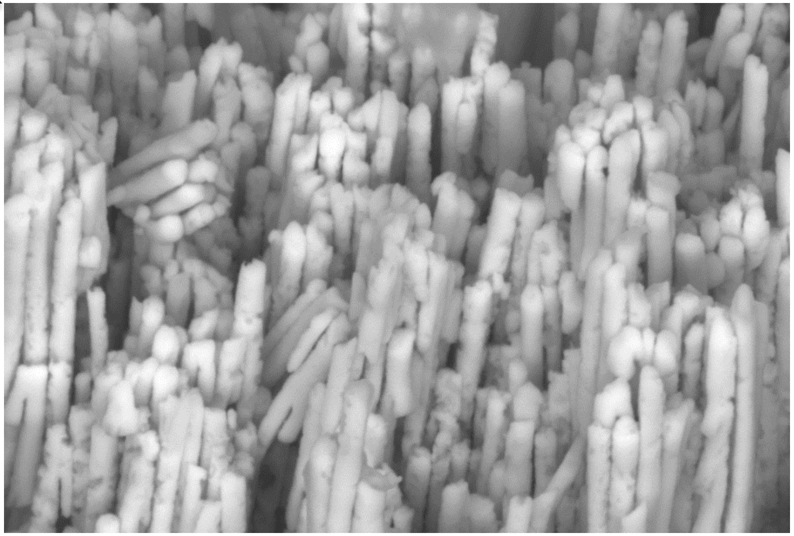
Current experiments - PPR



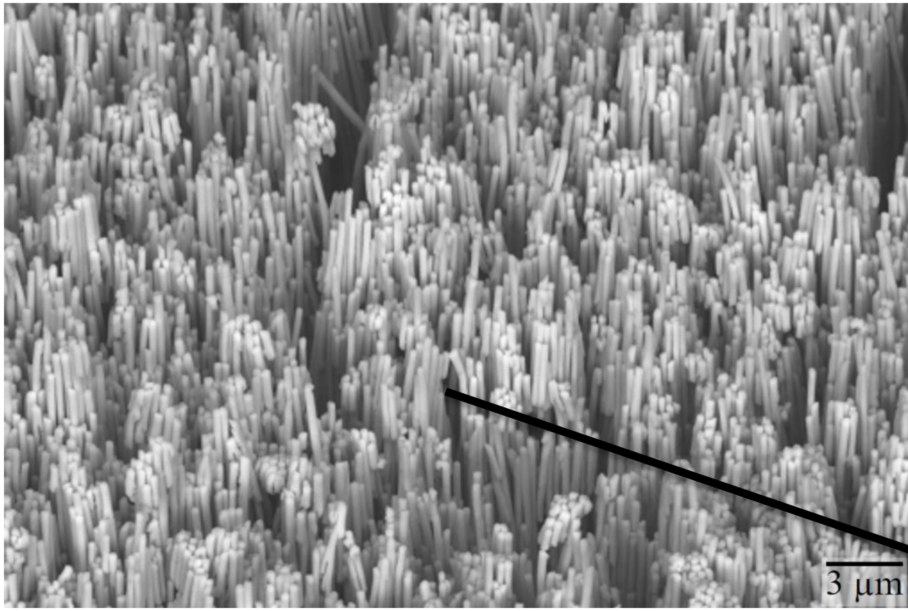
SEM acquisition of the PPR deposition



- Short deposition time: 3h30
- “High” NW’s height difference: 10 µm ;
- Mushroom effect: 40µm ;
- Small border effect.

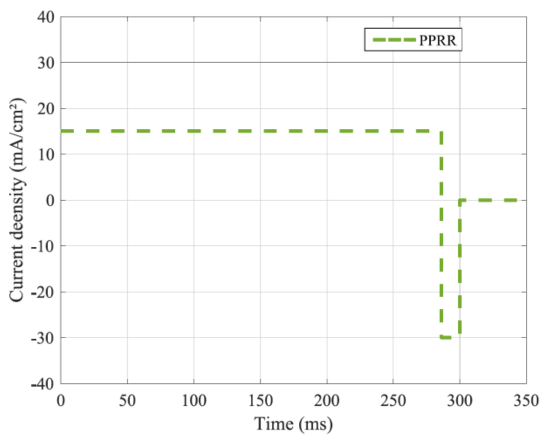


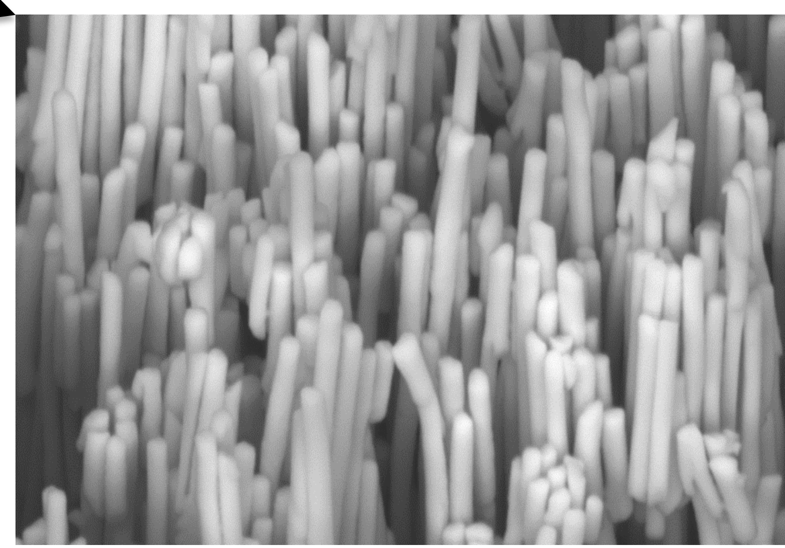
Current experiments - PPRR



- Deposition time: 4h ;
- Low NW's height difference: 2 µm ;
- High mushroom effect: 100µm ;

SEM acquisition of the PPRR deposition





Conclusions

- The process has been standardized, with high repeatability ;
- Some profiles are better suited for homogeneity, while others for precision on the electroplated area (less mushroom effect) ;
- The current profile has a high influence on the characteristics of the nano wires.

Outlooks

- Comparison of profiles with the same average current density ;
- Work on the process itself to avoid the macro post and mushroom effect ;
- Use of electropolishing to increase the homogeneity of the surfaces.

Thank you for your attention.

Any questions?

thomas.dias@laplace.univ-tlse.fr
b.djuric@fr.merce.mee.com
vincent.bley@laplace.univ-tlse.fr
j.morand@fr.merce.mee.com

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