LAPLACE-ENSEEIHT, Toulouse, France, April 24-26, 2019
International Workshop on Integrated Power Packaging 2019

AEROSOL JET PRINTING PROCESS FOR SEMI-EMBEDDED POWER ASSEMBLY

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Outline

1. Context & Background & Objectives
2. Aerosol Jet Printing Process
   i. Description
   ii. Strategy
3. Printed layers characterization
   i. Optical and electrical analysis of the deposit layers
   ii. Shear tests
4. Switching cell fabrication & characterization
   i. Devices selection
   ii. Switching cell design and fabrication
   iii. Electrical characterizations
5. Conclusion & Future works

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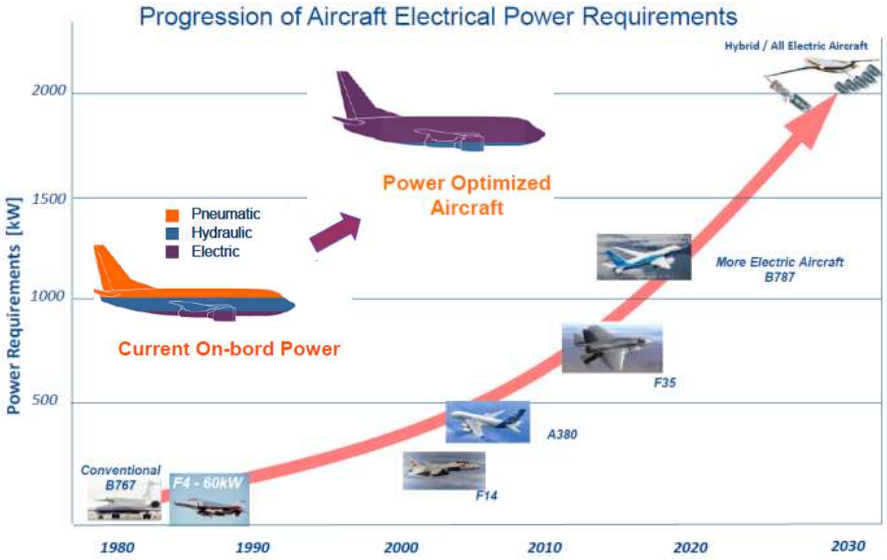
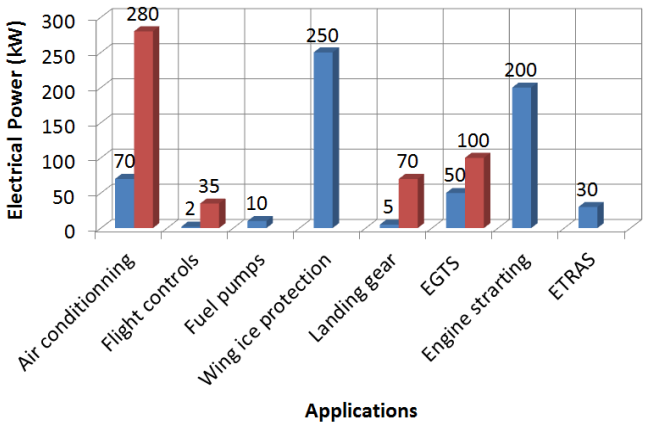
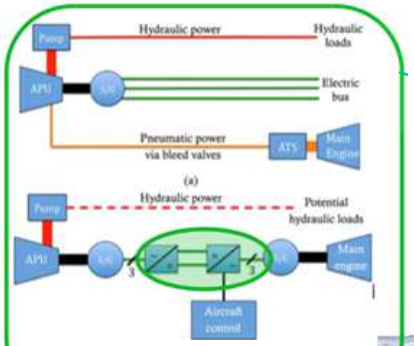
Context - Background - Objectives

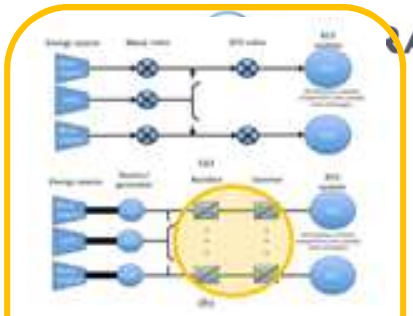






Auxiliary Power Unit

- THSA
- RUDDER
- ELEVATOR
- S/G APU
- *PAC APU*



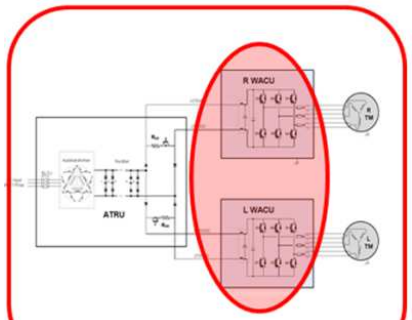
Environmental control system

- AILERON
- FLAP
- SLAT
- WIPS
- SPOILER

- *EPS*
- ESN
- ECS

- THROTTLE LEVER
- SIDE STICK
- CABIN DOORS
- CABIN

- THRUST REVERSE
- *HYDRAULIC POWER SYSTEM*
- MAIN ENGINE START
- *DEGIVRAGE NACELLE ?*



Electric Green Taxiing System

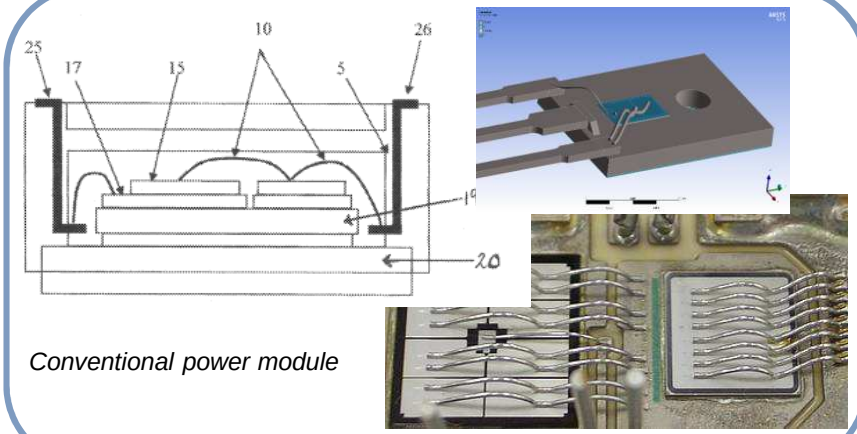
- MLG BRAKING SYSTEM
- *E/R MLG*
- *MLG DOORS*
- *CARGO DOORS*
- *EGTS*

- *NOSE STEERING*
- *NLG DOORS*
- *E/R NLG*

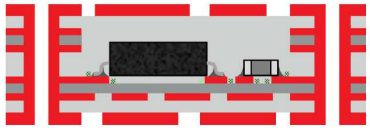
Context - Background - Objectives

- ➢ From 2D to 3D power assemblies

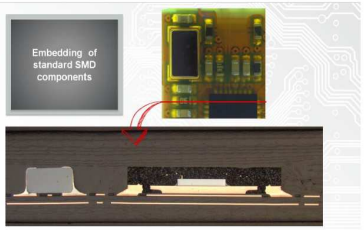
- ↑ embedded devices
- ↑ electrical perf.
- ↑ power density
- ↑ reliability
- ↑ design complexity

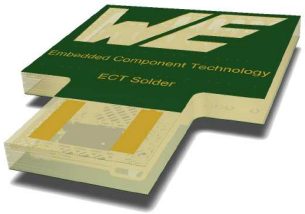


Conventional power module

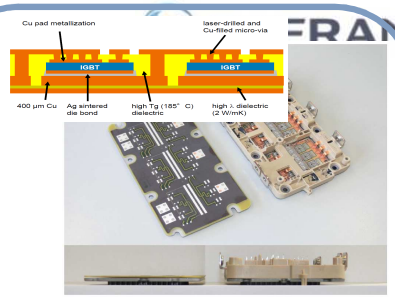


embedding advantages
- ➔ high miniatrisation
- ➔ protection of components and solder joints
- ➔ short signal paths
- ➔ improved heat dissipation

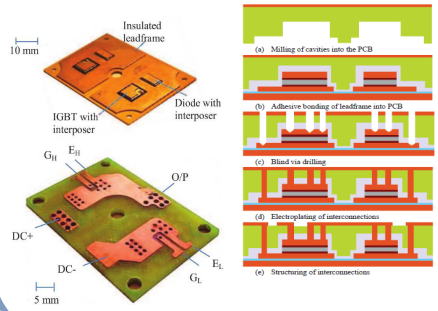




Source : Wolf et al., 2014

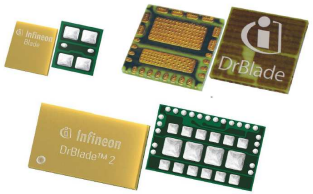


Source : Ostmann et al., 2016

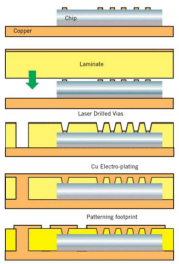


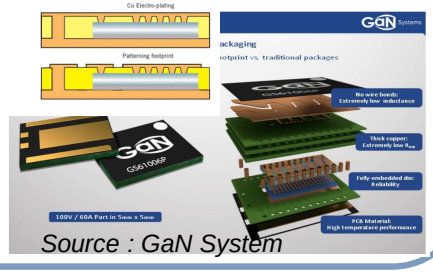
Source : Sharma et al., 2018

BLADE Packages
- ➔ embedded MOSFET / Driver
- ➔ manufacturing on PCB format

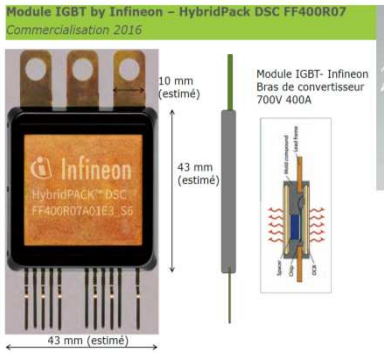


Source : Infineon

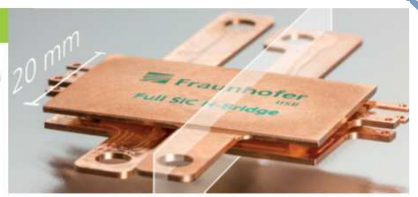




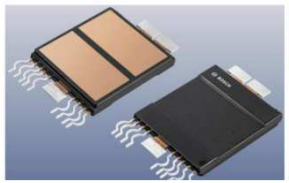
Source : GaN System



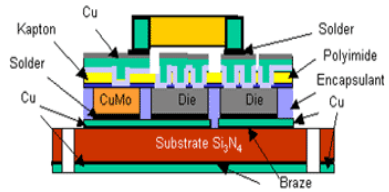
Source : Infineon

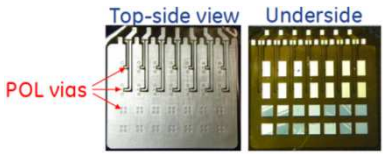


Source : Fraunhofer



Source : Bosch





Source : General Electric

Context - Background - Objectives

- Evaluation of the **Aerosol Jet Printing** process
- Semi-embedded approach (less complex) : an alternative to embedded technology approach
- Low to medium power converters using Si and GaN power devices
- Several advantages
  - *Integration of power electronics on **non-planar substrate***
  - ***Form factor** depending on the substrate and not on the assembly itself*
  - *Possibility to use **various nature of materials***

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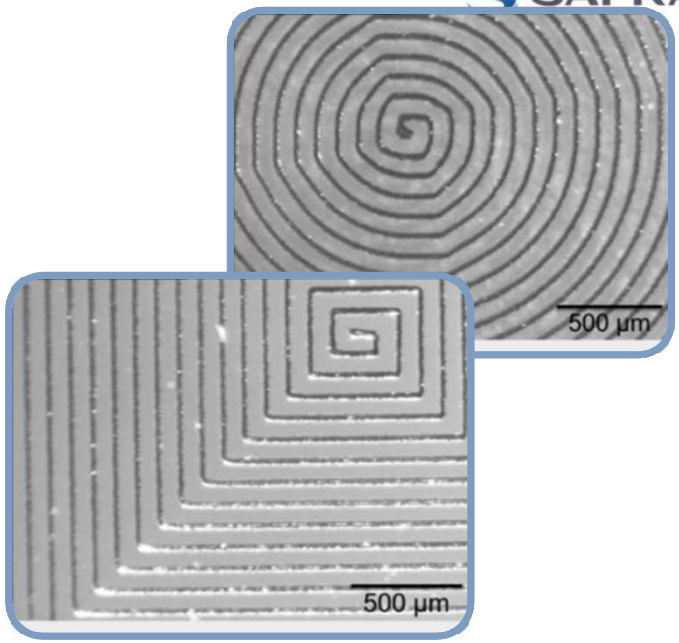
Aerosol Jet Printing Process : description



Source : CTTC

Principle

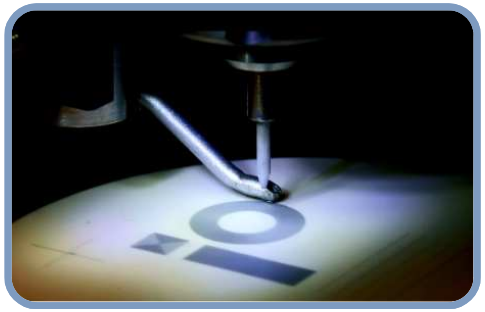
- Direct deposition of aerosolized ink by nozzle on substrate

Materials and post-treatment

- Inks loaded with ceramic, metallic or polymer particles
- Post process: drying, curing, UV, thermal, IR…

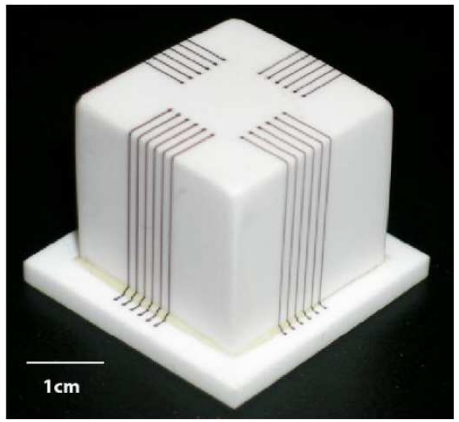
Advantages

- High precision
- Simple post process
- Adapted for inks of higher viscosity
- Printing on non-planar substrates
- Multi-material

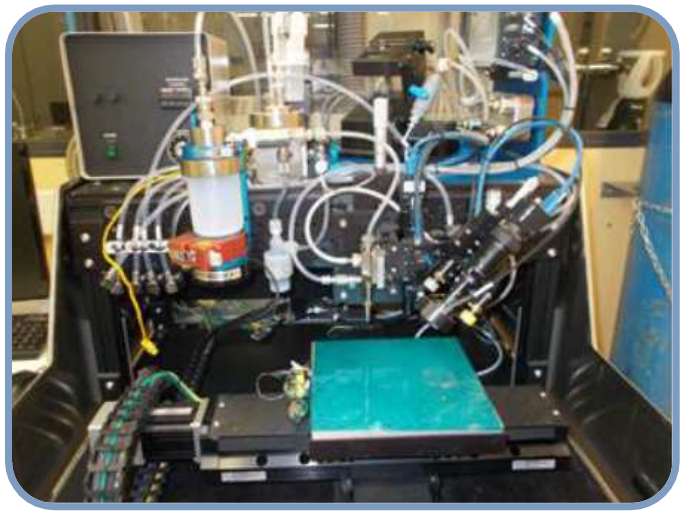


Limitations

- Rather low thickness (1µm to 10µm)
- Small size of powders (1-2 µm)



Aerosol Jet Printing Process : equipment



OPTOMEC Aerosol Jet 200

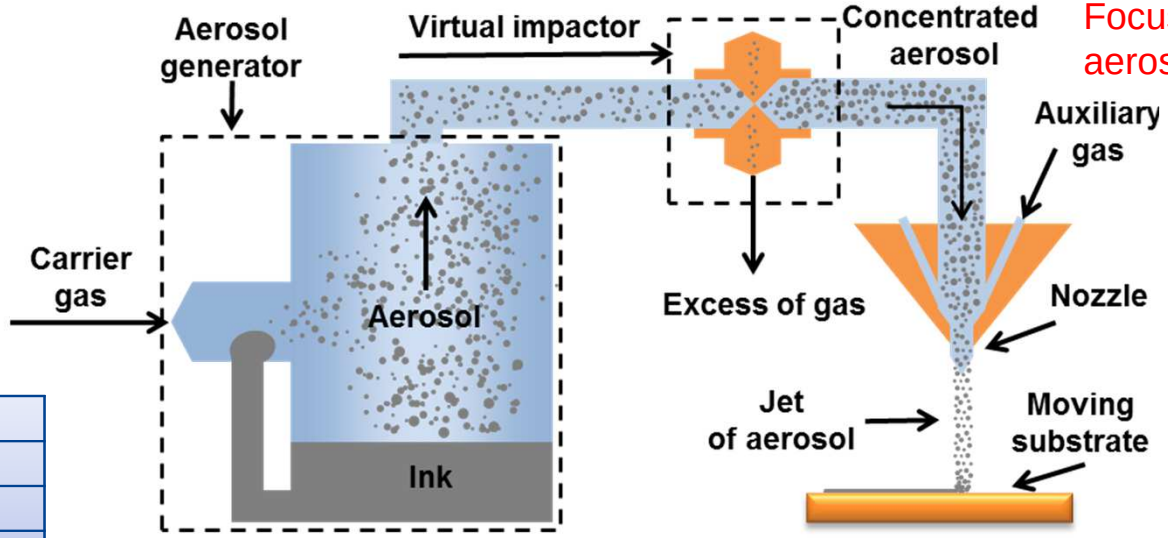
Parameters	Properties
Nozzle diameter*	100 -300 µm
Drop volume	0.001 – 0.005 µl
Line width**	10 – 50 µm
Ink viscosity	0.7 – 1000 cP
Stand-off distance	2-5 mm

** updated to 800µm for large lines*

*** up to 500µm width with 800µm nozzle*

Virtual impactor:
- Reducing aerosol quantity
- Selecting thinner droplets

Auxiliary gas:
Focusing the aerosol jet



Nozzle :
- Fine one to thin designs
- Wide one for surface covering

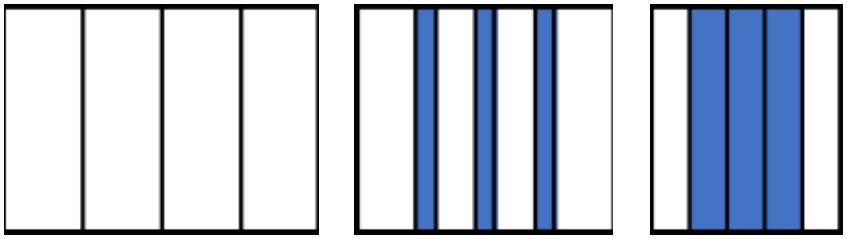
Aerosol formation :
Pneumatic or ultra-sonic

Stand-off distance :
From 2 to 5 mm

Aerosol Jet Printing Process : strategy (1/2)

- Multi-layer using silver ink
  - Layer thickness from 1µm to 10µm
  - > 50µm requested

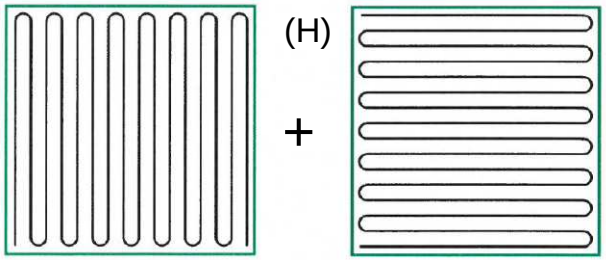
- Overlap



0% 25% 50%

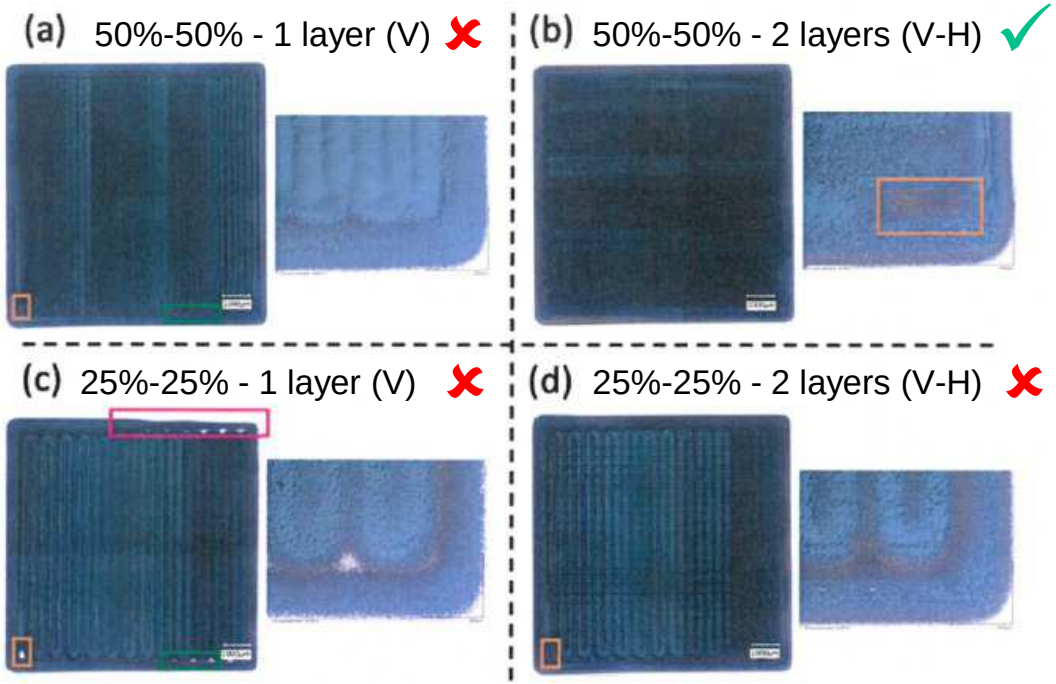
- Printing directions

(V) (H)



= 2 printed layers ←→ 1 Effective layer (E-layer)

Glass substrate



- Quiet good results
- 500µm printed width
- Overlap 50%-50%
- 2 layers (V-H)
- 2-4 min to cover 1mm^2

SAFRAN

Aerosol Jet Printing Process : strategy (2/2)

➢ Curing conditions

Tests	Curing temperature (°C)	Duration (min)
#1	150°C	60
#2	180°C	60
#3	165°C	60
#4	150°C	30
#5	180°C	30
#6	165°C	30
#7	150°C	120
✓ #8	180°C	120
#9	165°C	120

Line (repeatable process)
500µm width / ~3µm thick

- Pre-heated substrate (>25°C) to start drying layers
- Overlap 50%-50%
- 2 layers (V-H)
- 8 E-layers before cleaning and curing
- Fired 120min at 180°C to evaporate the solvent and the additives
- Reference point for nozzle positioning

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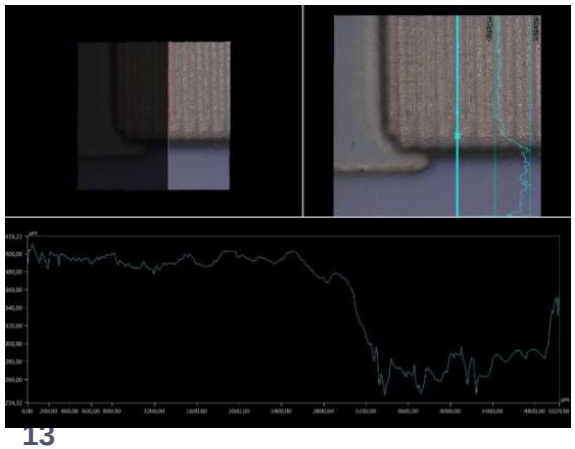
Printed layers characterization : analysis (1/2)

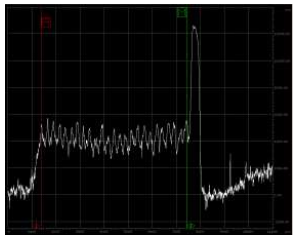
- Step Roughness

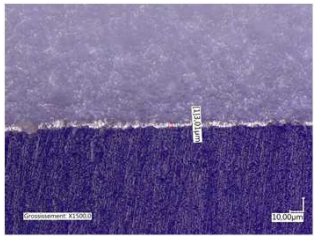
Keyence VHX8000



~120µm thick
with
32 E-layers

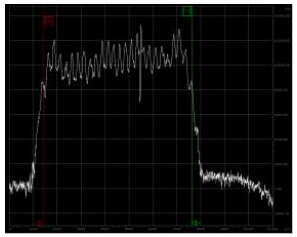
2 E-layer + curing

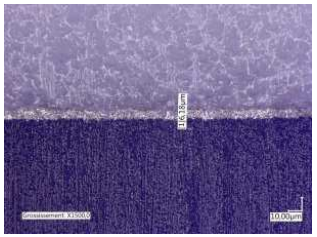




Width : 3.01µm
Thickness : 4.157µm
Roughness : 0.497

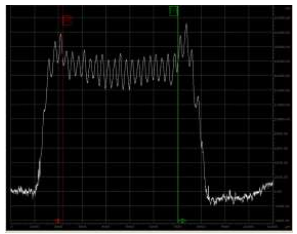
4 E-layers + curing

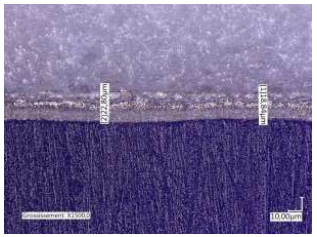




Width : 6.18µm
Thickness : 10.288µm
Roughness : 0.773

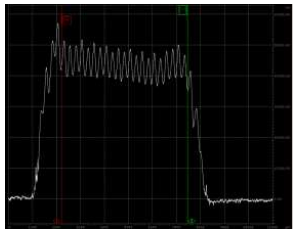
8 E-layers + curing

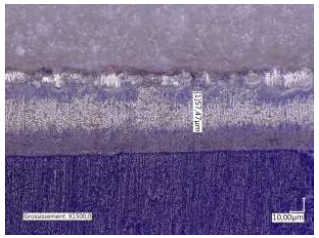




Width : 22.8µm
Thickness : 16.864µm
Roughness : 1.168

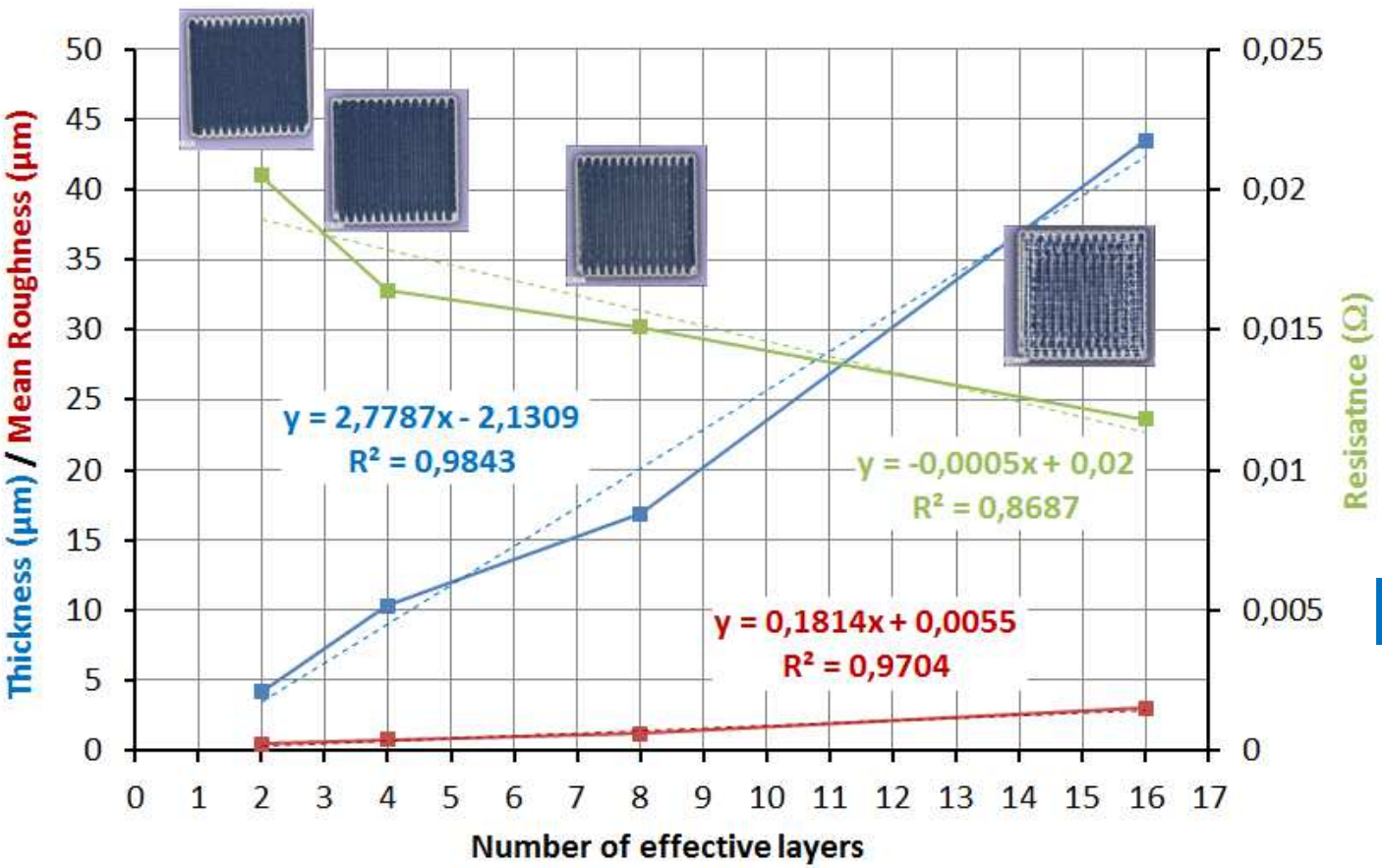
16 E-layers + 2 curings



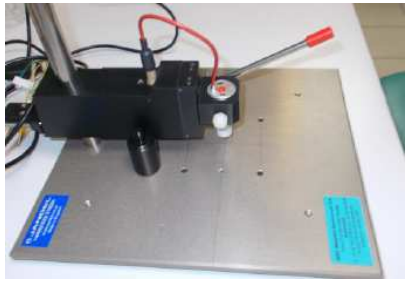


Width : 57.47µm
Thickness : 43.5µm
Roughness : 3.025

Printed layers characterization : analysis (2/2)



➢ Electrical characteristics

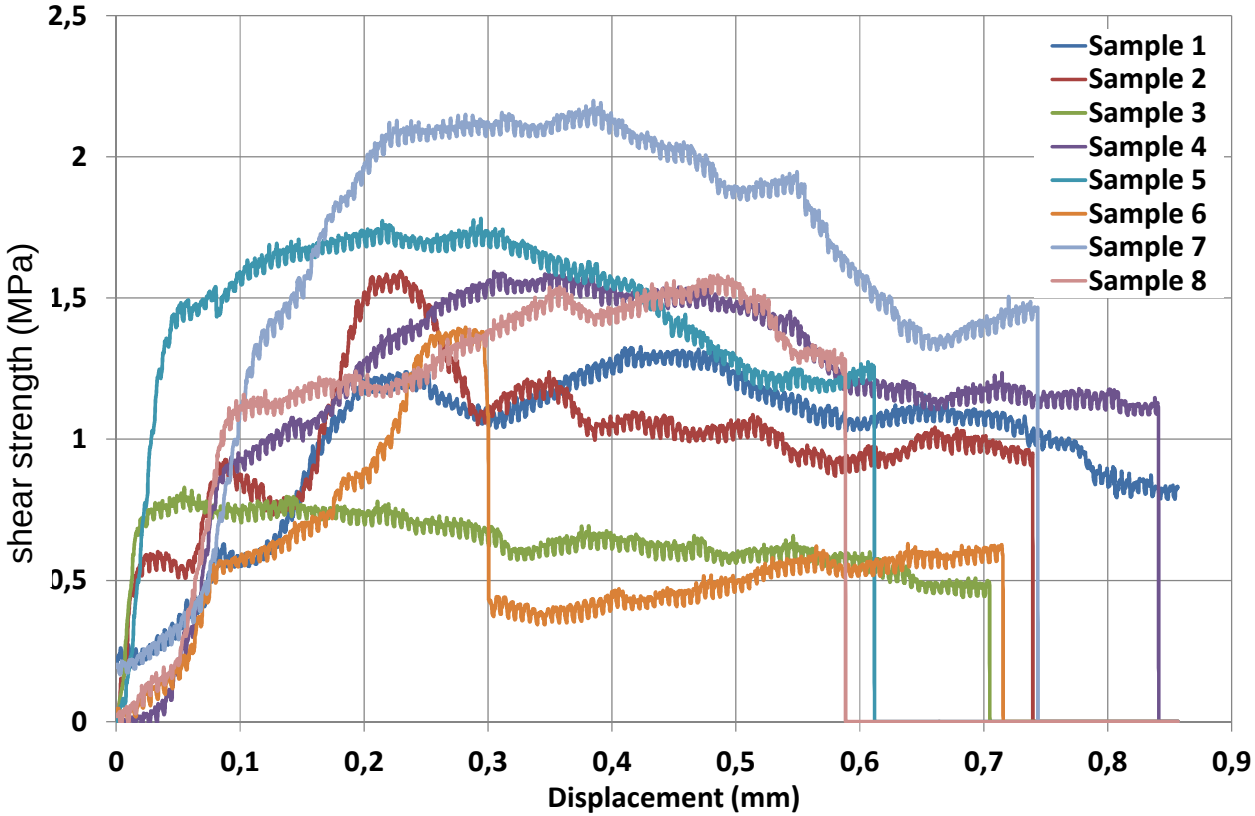


4 probes resistance measurement (Jandel)

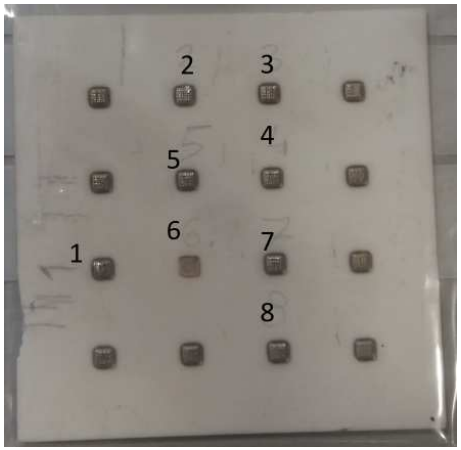
↑ Number of layers
- ↑ thickness
- ↓ electrical resistance
- ↑ roughness

32 E-layers to reach ~120µm

Printed layers characterization : shear stress

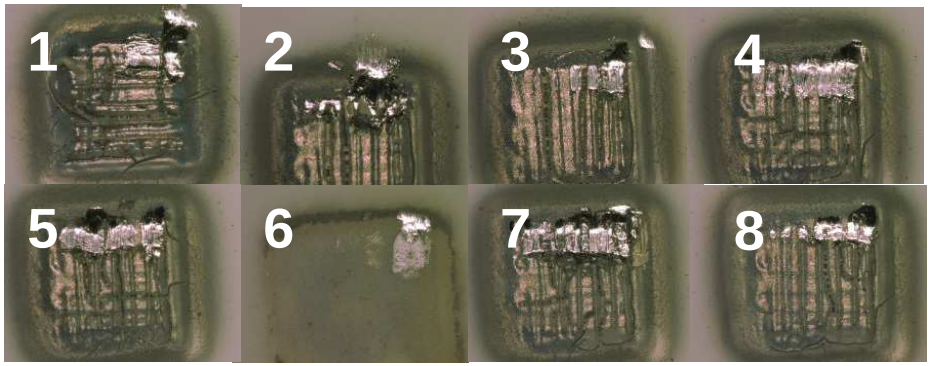


➢ 8 tested pins



Pin : 2mm x 2mm x 200µm

INSTRON Modèle 5548



- Difficulty to carry out the tests (>300µm requested)
- #6 shows a shear strength of 1.4 MPa (>5MPa)
- Need of complementary tests (peel test)

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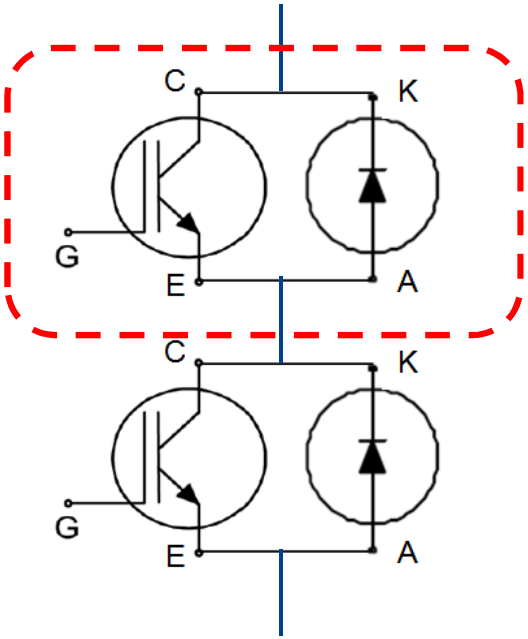
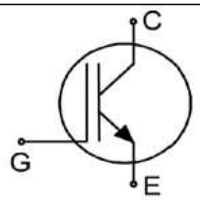
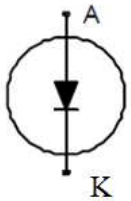
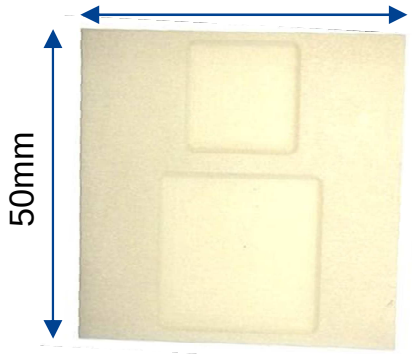
Switching cell : devices selection

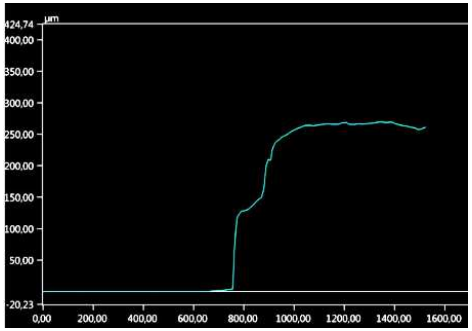
- Schematics
- Dice from Infineon
- AlN substrate



Transistor	Diode
	
IGC99T120T8RL	*IDC51D120T6M*
1200V / 100A	*1200V / 100A*
	
9.5mm x 10.39mm x 115µm	*7.00mm x 7.30mm x 110µm*



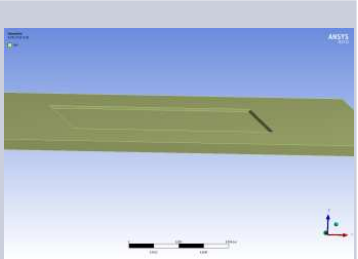
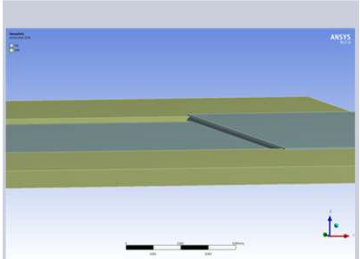
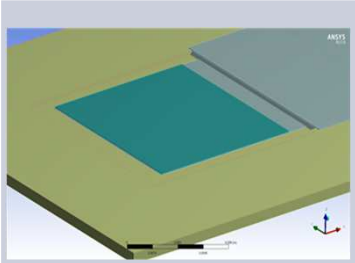
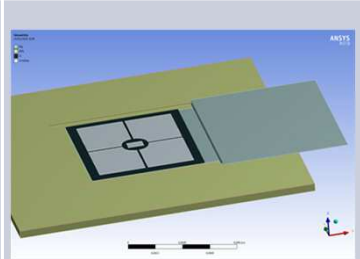
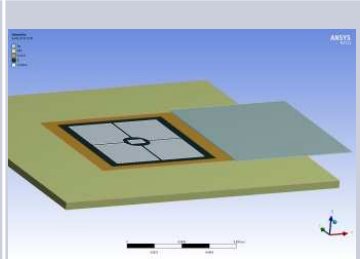
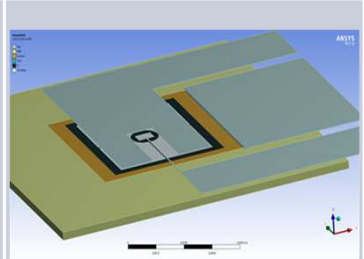
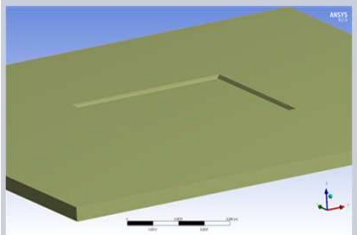
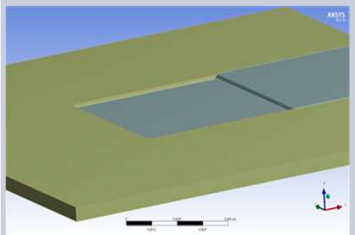
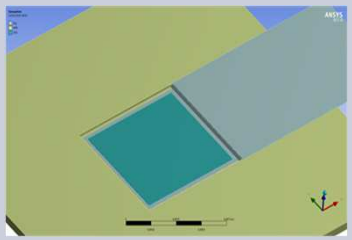
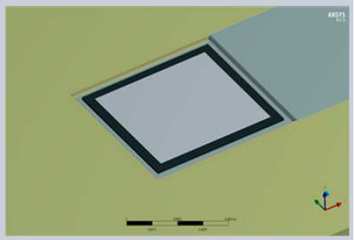
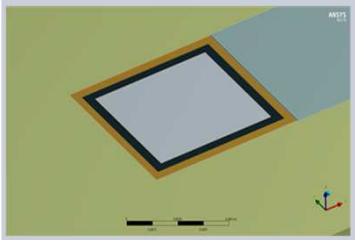
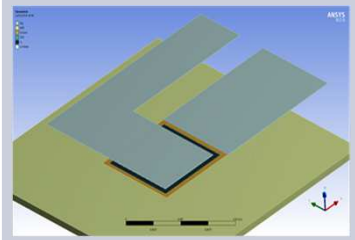
2 cavities



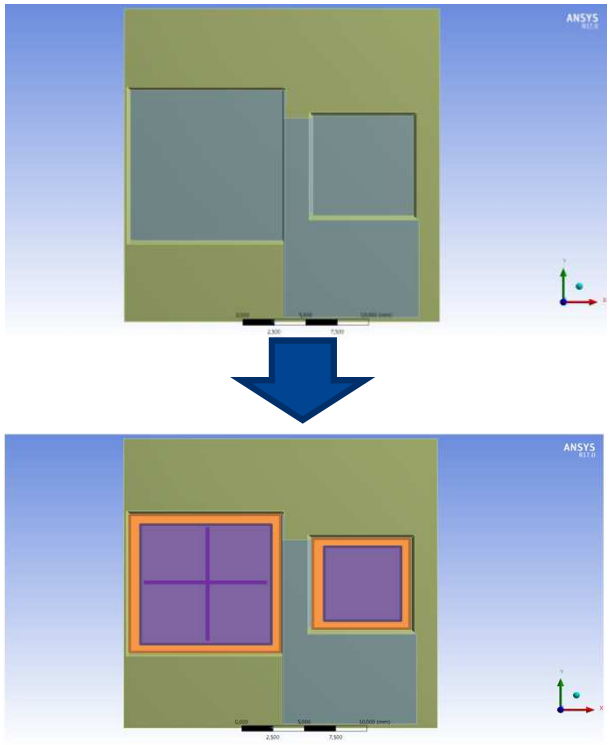
~270µm depth cavity

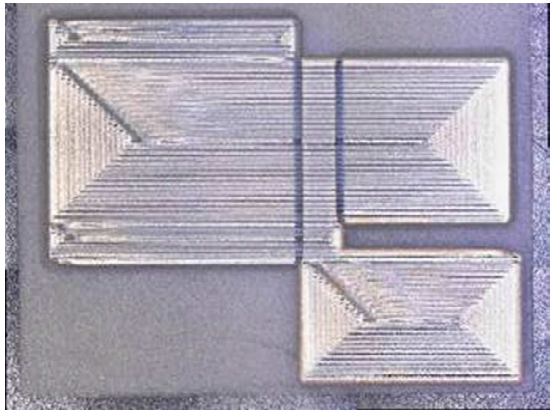
SAFRAN

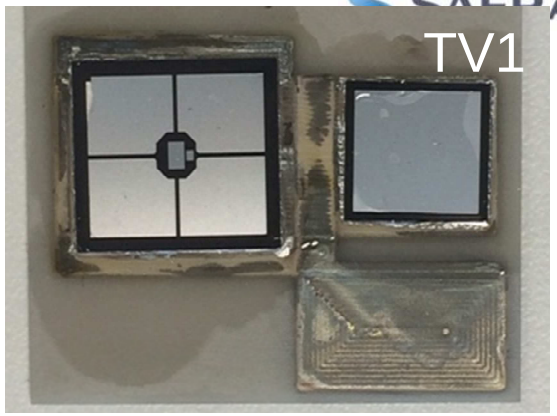
Switching cell : design of the transistor side and diode side

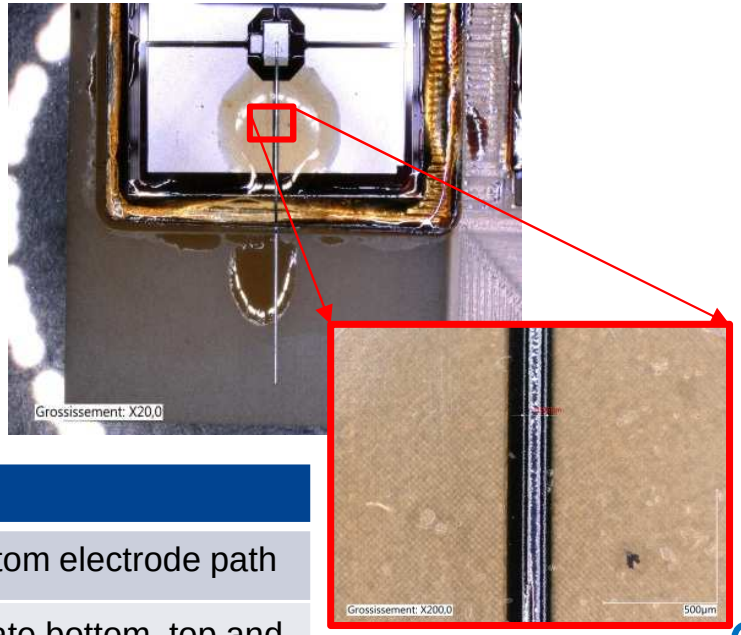
	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
Transistor						
	270µm depth, 12mmx12mm surface ceramic cavity machining	Bottom power electrode 100µm silver ink deposit	50µm SnAgCu preform	115µm transistor die positioning and brazing	Epoxy resin Structalit® 5810 deposit + curing @ 160°C	Top power electrode 100µm silver ink deposit covering the epoxy isolator
Diode						
	270µm depth, 8mmx8mm surface ceramic cavity machining	Bottom power electrode 100µm silver ink deposit	50µm SnAgCu preform	110µm diode die positioning and brazing	Epoxy resin Structalit® 5810 deposit + curing @ 160°C	Top power electrode 100µm silver ink deposit covering the epoxy isolator

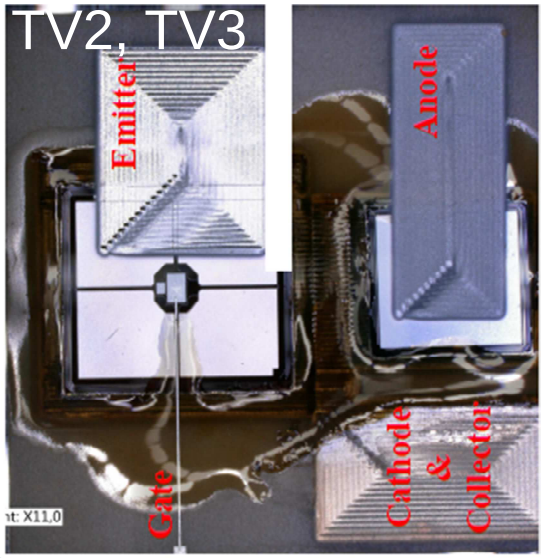
Switching cell : fabrication











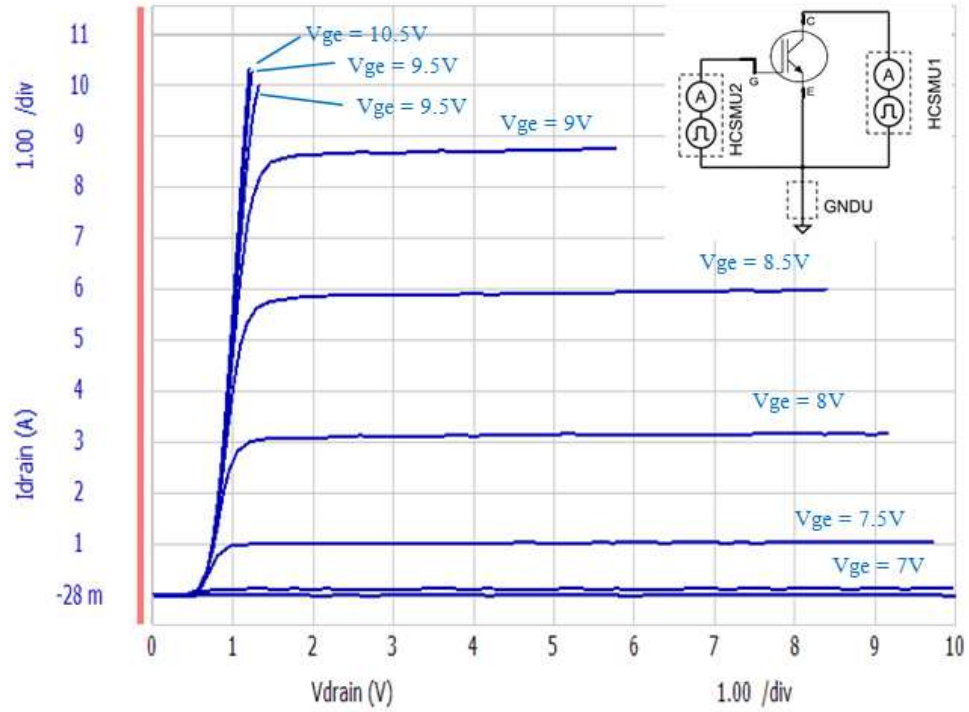
✘ Degradation of the resin

TV	Purpose of each TV
TV1	I-V characteristics to evaluate the bottom electrode path
TV2, TV3	Double pulse characteristics to evaluate bottom, top and gate electrode path

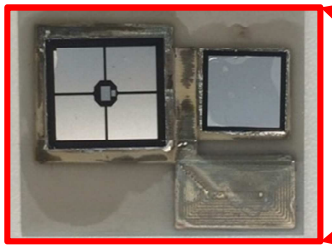
Switching cell : static electrical measurements

➢ I-V output characteristics of IGBT (@25°C)

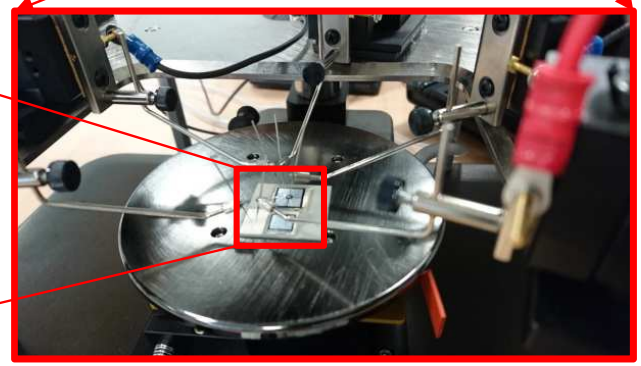
$V_{CE} \in [0 – 10]V$
$I_C \in [0 – 10]A$
$V_{GE} \in [7 – 10,5]V$



KEYSIGHT B1505 + probe station



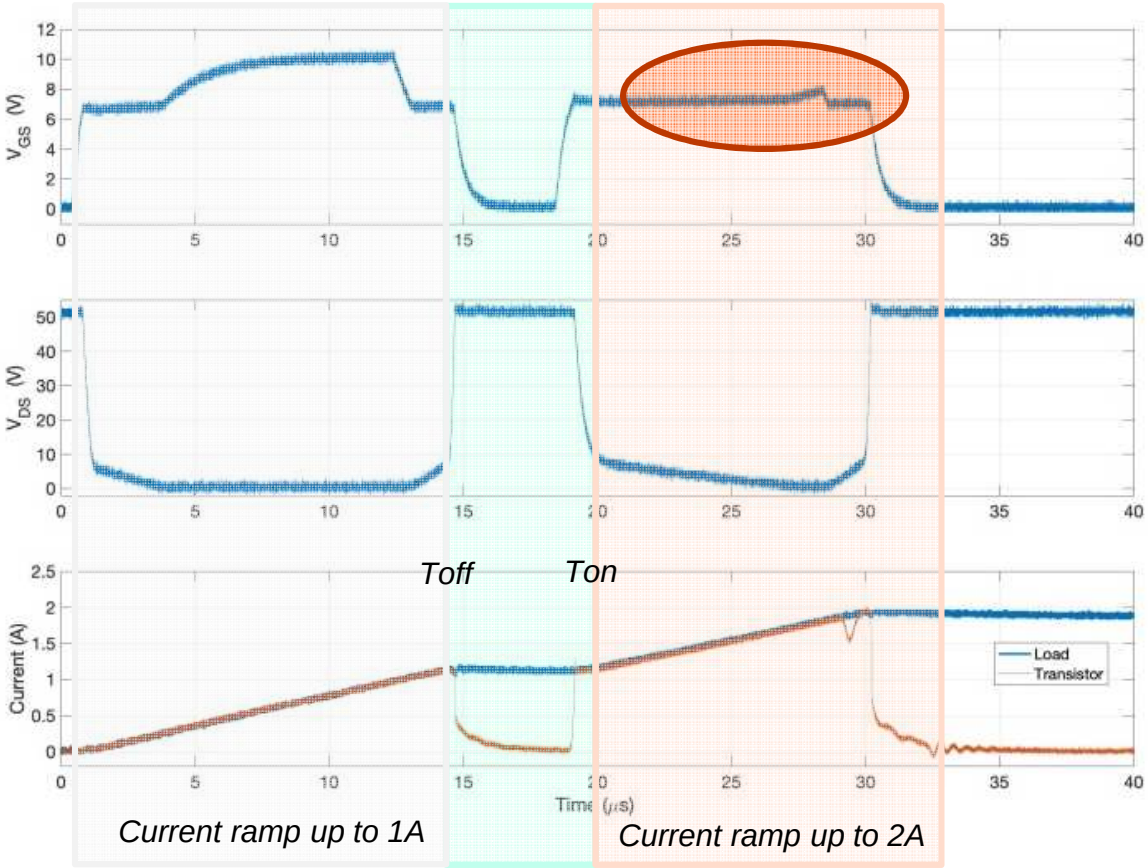
TV1

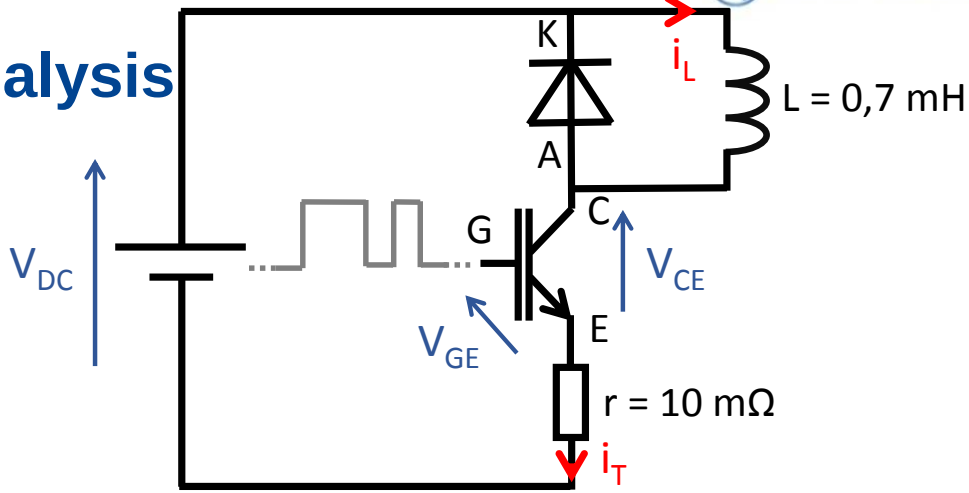


✓ bottom electrode path

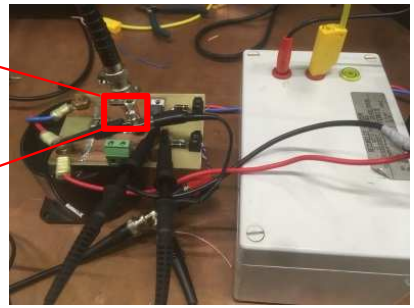
Switching cell : dynamics electrical analysis

- Double pulse switching test @ 50V / 1A & 2A





TV2, TV3



- ✓ bottom electrode path
- ✓ gate electrode path
- ✗ top electrode path

Failure analysis on-going

Outline

1. *Context & Background & Objectives*
2. *Aerosol Jet Printing Process*
   i. *Description*
   ii. *Strategy*
3. *Printed layers characterization*
   i. *Optical and electrical analysis of the deposit layers*
   ii. *Shear tests*
4. *Switching cell fabrication & characterization*
   i. *Devices selection*
   ii. *Switching cell design and fabrication*
   iii. *Electrical characterizations*
5. **Conclusion & Future works**

Conclusion

- Aerosol Jet Printing process has been evaluated and shows promising results as semi-embedded approach for power devices (low to medium power)
- Possibility to use non planar substrate

Future works

- Failure analysis of the 1st run
- Improvement : resin choice and deposit + process optimization for thickness
- Reliability : behavior of the silver layers on epoxy resin and evolution of the stacking layers microstructure under ageing
- Design a full low power converter

Thank you for your attention