

# 3D Packaging Structure for High Temperature Power electronics

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16/10/14

Introduction

The 3-D structure

Module Manufacturing

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# High Temperature Power Electronics



- ▶ Actuators and electronics close to the jet engine
- ▶ Deep thermal cycling (-55/+225 °C)
- ▶ Long operating life (up to 30 years)



# High Temperature Power Electronics



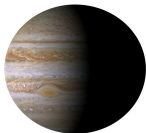
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- ▶ Share the cooling system between electrical and internal combustion engines.
- ▶ Cooling fluid temperature: 120 °C

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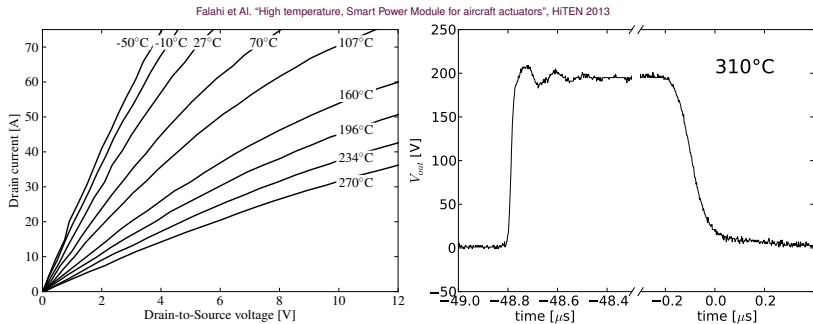
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- ▶ Cooling fluid temperature:  $120\text{ }^{\circ}\text{C}$
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- ▶ Cooling fluid temperature: 120 °C
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- ▶ Nasa mission to Venus: up to 480 °C
- ▶ Mission to Jupiter: 100 bars, 400 °C

# Active Power Devices for High Temperature

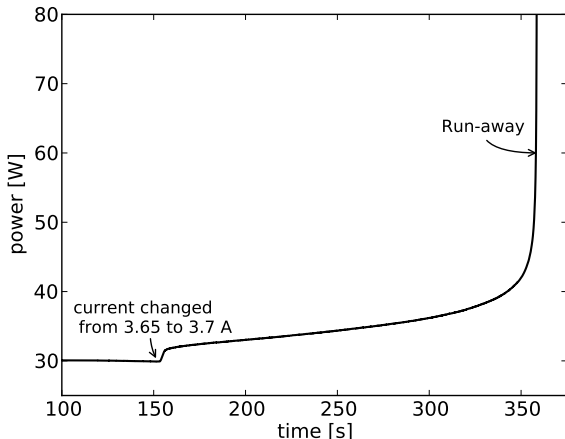


Previous results: SiC JFETs are attractive for  $> 200$  °C operation:

- ▶ rated at 1200 V (or more), several Amps
- ▶ Voltage-controlled devices
- ▶ No reliability issue related to gate oxide degradation

# High Temperature Thermal Management

Buttay et al. "Thermal Stability of Silicon Carbide Power JFETs", IEEE Trans on Electron Devices, 2014



## SiC JFET:

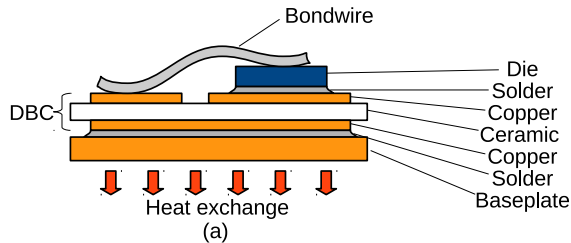
- ▶ 490 m $\Omega$ , 1200 V
- ▶  $R_{ThJA} = 4.5 K/W$
- ▶ 135 °C ambient
- ▶ On-state losses

High temperature capability  $\neq$  reduced cooling needs!

**SiC JFETs must be attached to a low- $R_{Th}$  cooling system.**

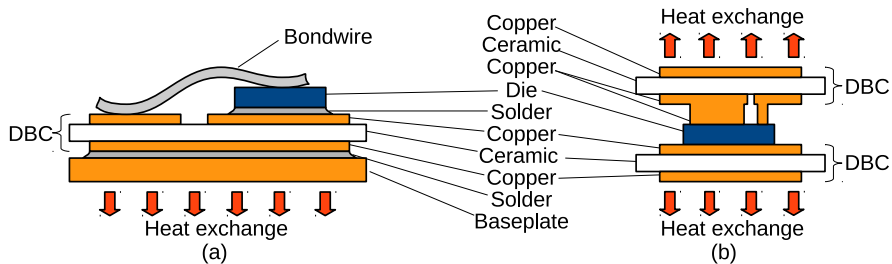


# Double Side Cooling



- ▶ Standard packaging offers cooling through one side of the die only
- ▶ “3-D” or “Sandwich” package: thermal management on both sides
- ▶ Requires suitable topside metal on the die
- ▶ Requires special features for topside contact

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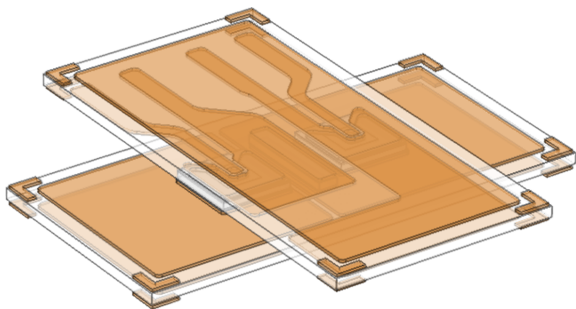
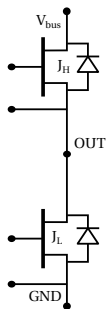
**The 3-D structure**

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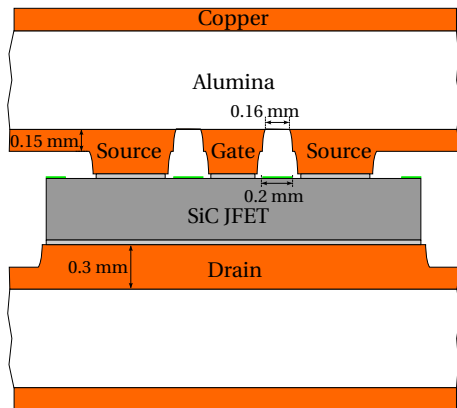


# The proposed 3-D Structure



- ▶ Two ceramic substrates, in “sandwich” configuration
- ▶ Two SiC JFET dies (SiCED)
- ▶ assembled using silver sintering
- ▶ 25.4 mm×12.7 mm (1 in×0.5 in)

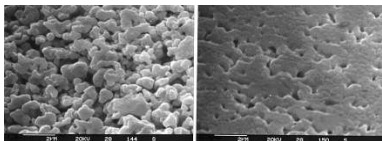
# Ceramic Substrates



Scale drawing for  $2.4 \times 2.4 \text{ mm}^2$  die

- ▶  $\text{Si}_3\text{N}_4$  identified previously for high temperature
- ▶ For development: use of alumina
- ▶ Etching accuracy exceeds standard design rules
- ▶ Double-step copper etching for die contact
- ➔ Custom etching technique

# Bonding Material: Silver Sintering



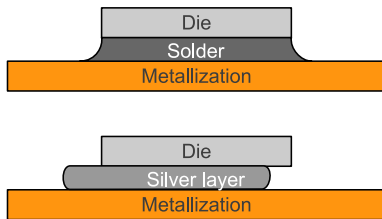
Göbl, C. et al "Low temperature sinter technology Die attachment for automotive power electronic applications" proc of APE, 2006

## Silver Paste

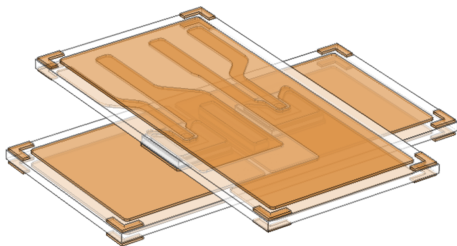
- ▶ Based on micro-scale silver particles (Heraeus LTS-11702P2)
- ▶ Low temperature (240 °C) sintering
- ▶ Low pressure (2 MPa) process

No liquid phase involved:

- ▶ No movement of the die
- ▶ No bridging across terminals
- ▶ No height compensation thanks to wetting

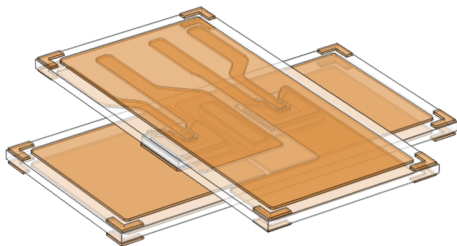


# 3-D Structure: Challenges



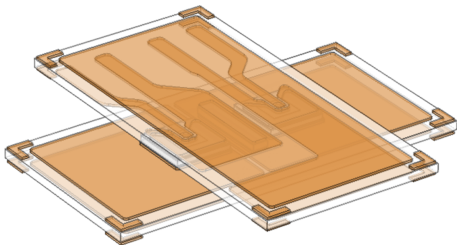
- ▶ Behaviour of silver paste during assembly (bridging, compensation of height differences)
- ▶ High-resolution alignment of parts
- ▶ Etching resolution of the DBC substrates

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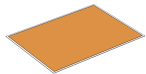
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# Preparation of the Substrates

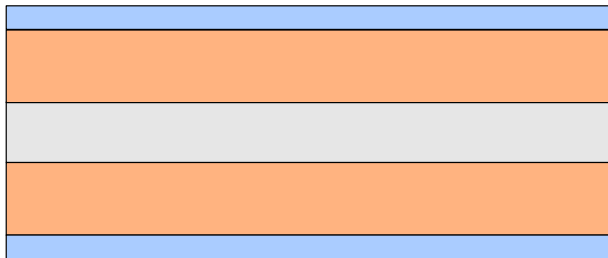
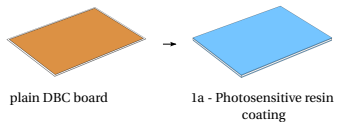


plain DBC board

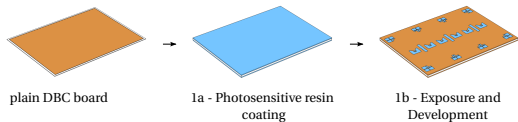




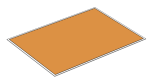
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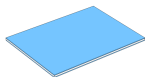
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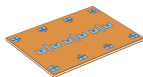
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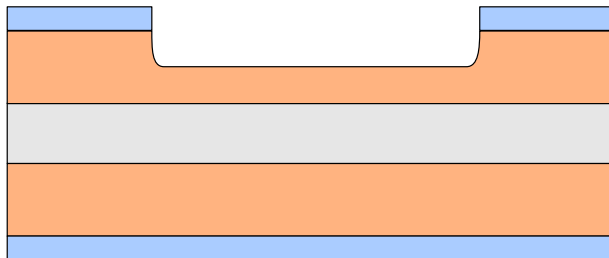
1a - Photosensitive resin coating



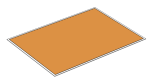
1b - Exposure and Development



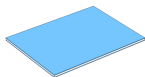
2 - Etching



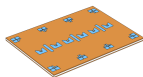
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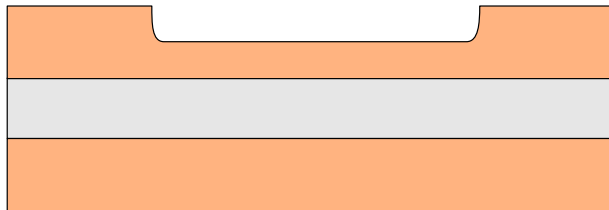
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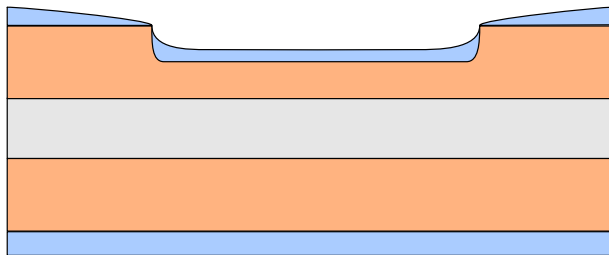
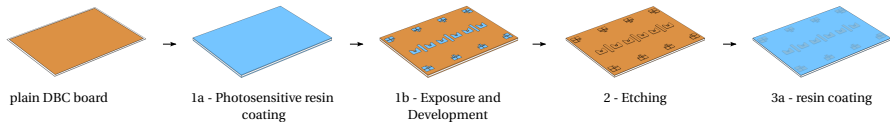
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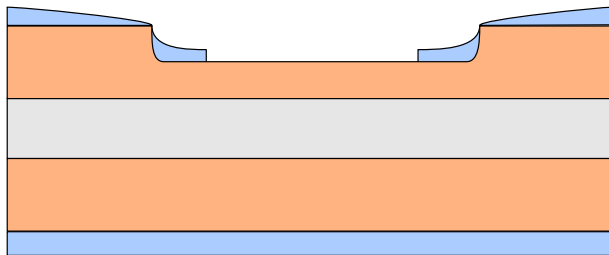
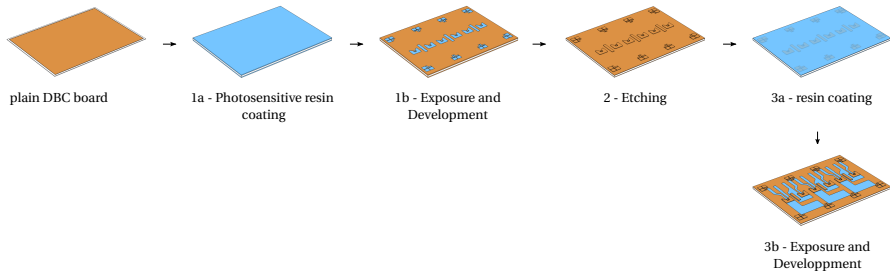
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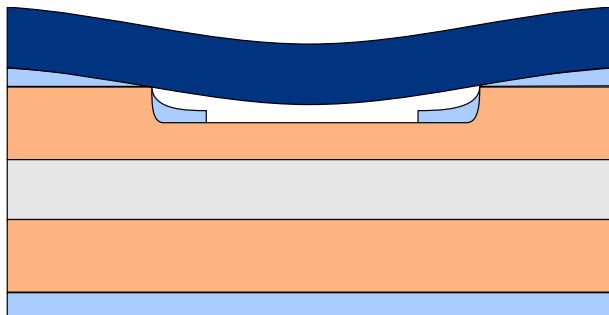
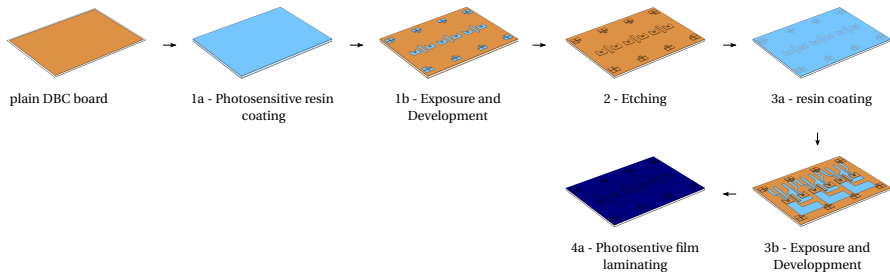
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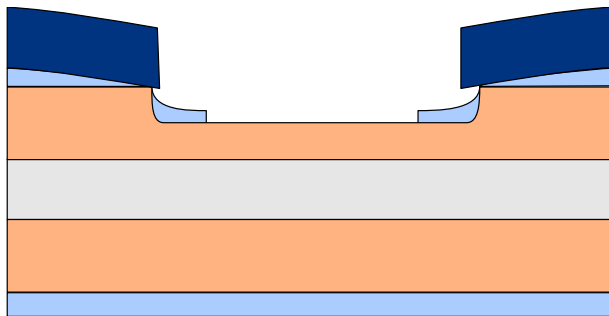
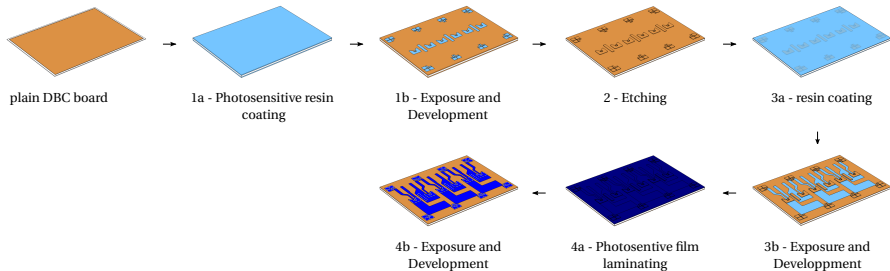
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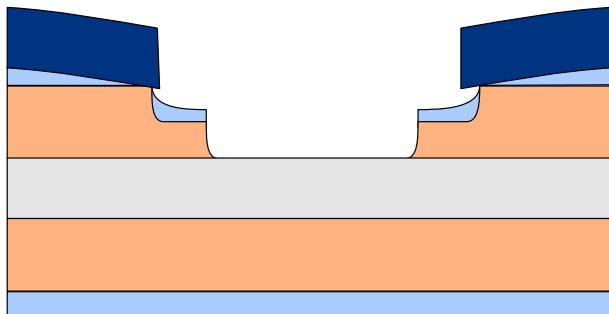
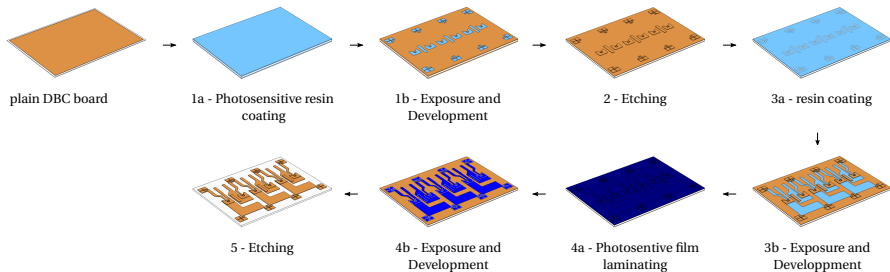


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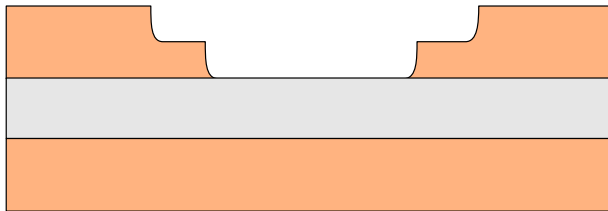
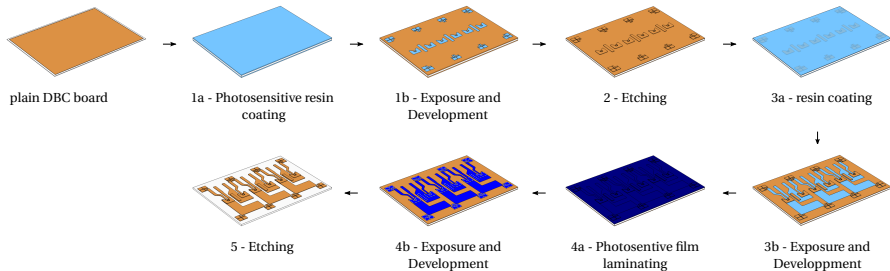




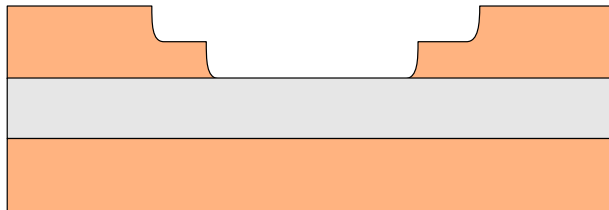
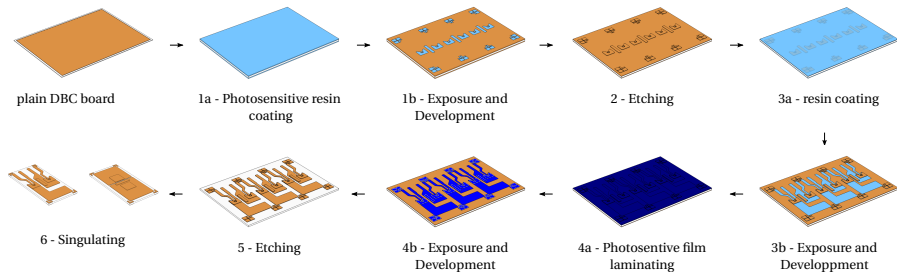
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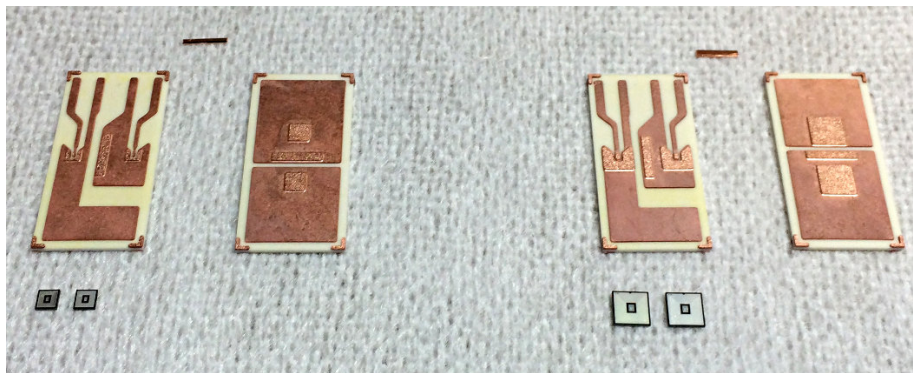
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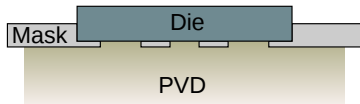
# Preparation of the Substrates



- ▶ Final patterns within  $50\ \mu\text{m}$  of desired size
- ▶ Two designs, for  $2.4 \times 2.4\ \text{mm}^2$  and  $4 \times 4\ \text{mm}^2$  dies
- ▶ Total copper thickness  $300\ \mu\text{m}$ ,  $\approx 150\ \mu\text{m}$  per step

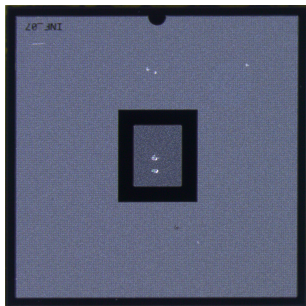
# Preparation of the Dies

- ▶ Standard aluminium topside finish not compatible with silver sintering
- ▶ Ti/Ag PVD on contact areas
- ▶ Need for a masking solution
- jig with locating pockets.

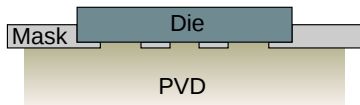


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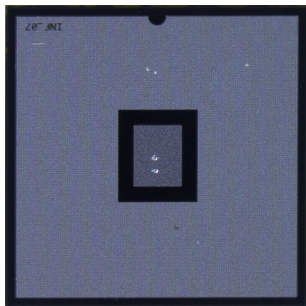
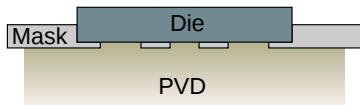


Before PVD

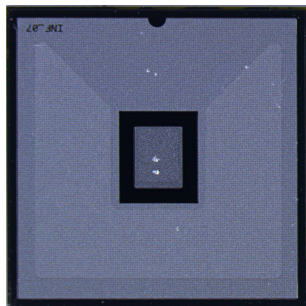


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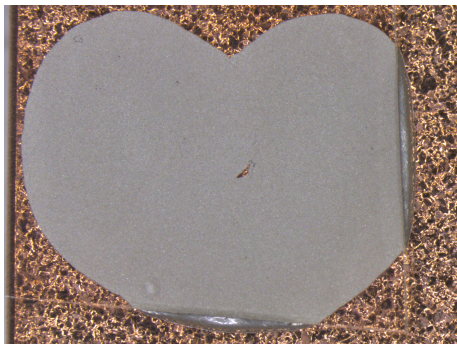


Before PVD



After Ti/Ag PVD

# Sintering process



assembly without drying

- ▶ 30 min Drying step at 85 °C, 30 min sintering at 240 °C.
- ▶ 5 minutes pre-drying before assembly, to increase paste viscosity
  - ▶ use of a glass die to observe paste spreading
- ▶ Sintering under low pressure (2 MPa)



# Sintering process



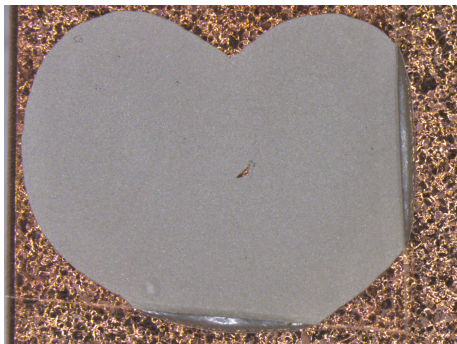
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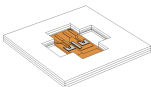
Screen printing

- ▶ Ceramic laser-cut jigs for precise alignment of dies and substrate
- ▶ Two sintering steps using the same temperature profile

# Assembly



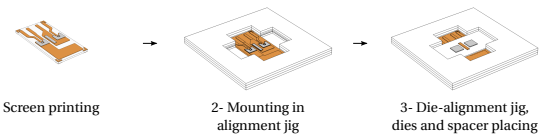
Screen printing



2- Mounting in alignment jig

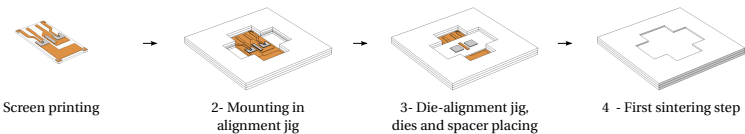
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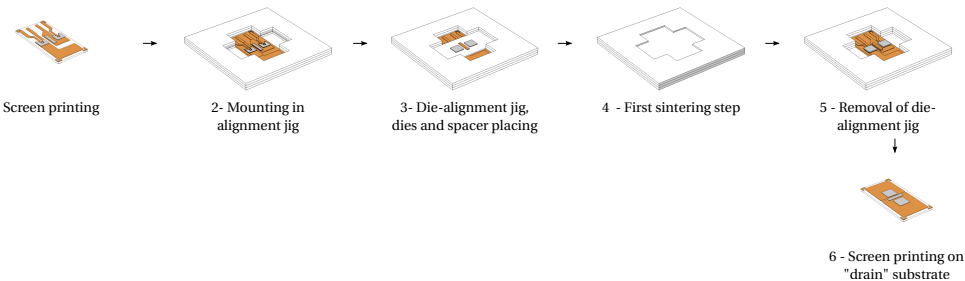
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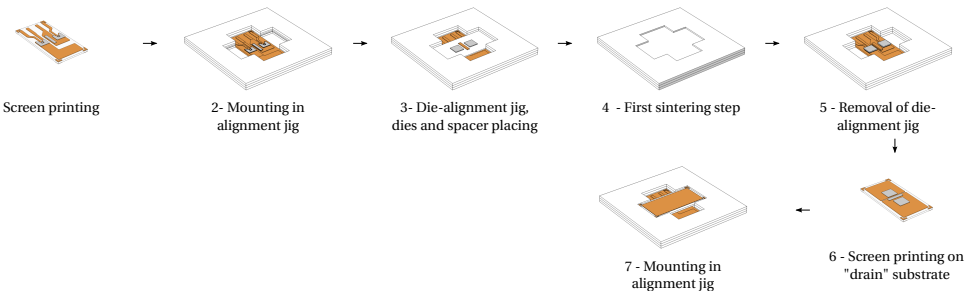
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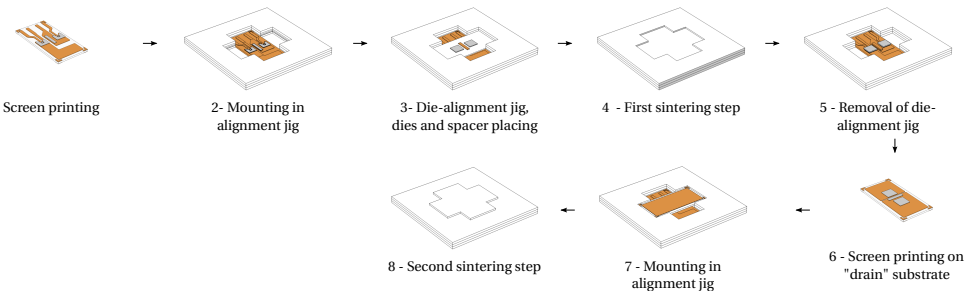


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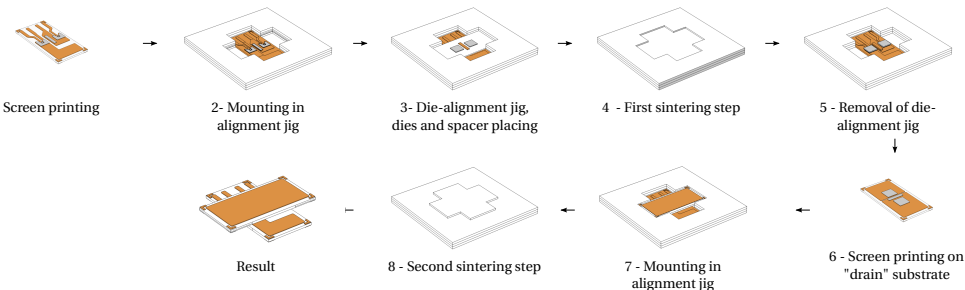
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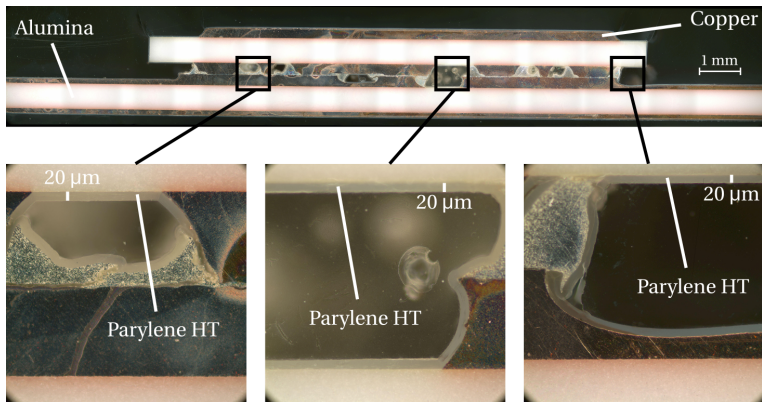
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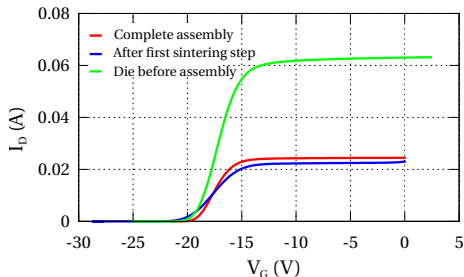
- ▶ Ceramic laser-cut jigs for precise alignment of dies and substrate
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# Encapsulation



- ▶ Tests performed on a “sandwich” without dies
- ▶ Parylene thickness very uniform, including in intricate areas
- ▶ Fluorinated parylenes (HT, VT4, etc.) for high temperature capability

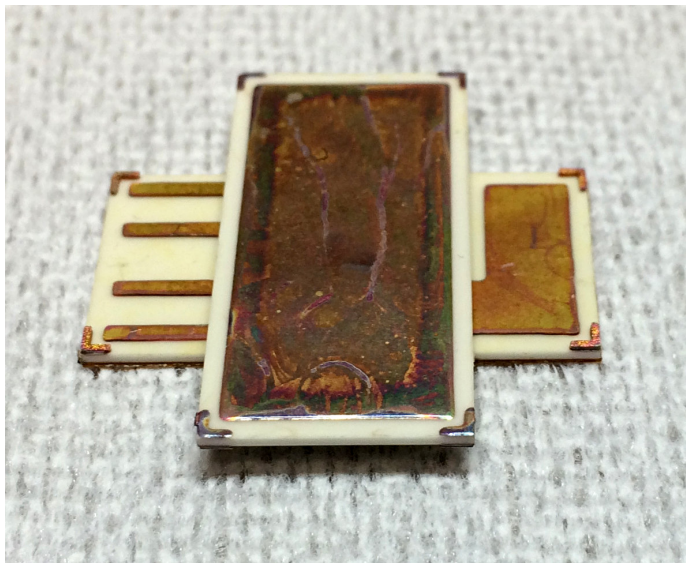




Measured for  $V_{DS} = 10$  mV

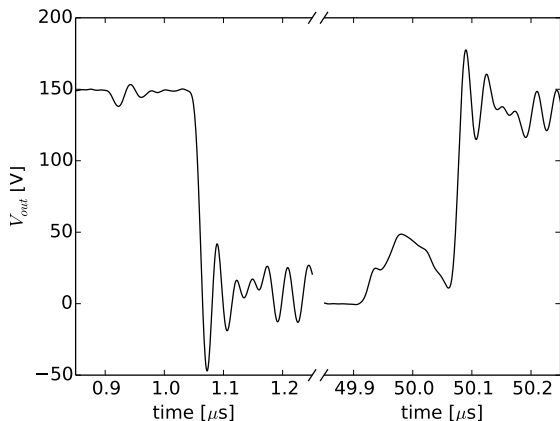
- ▶ Only preliminary tests performed, on a probe station
- ▶ Contact on Gate, Source and Drain of all JFETs
- ▶ No short-circuit between contacts
- ▶ Drop in current probably associated with test probes and oxidation of substrate

# Prototype



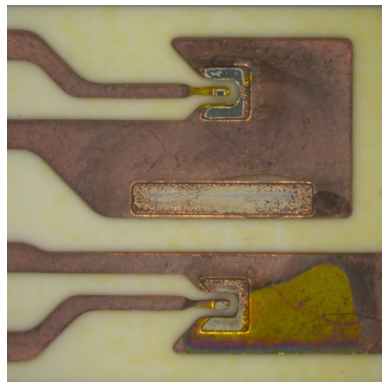
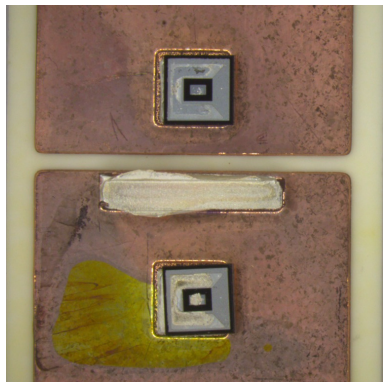
Size:  $25 \times 25 \text{ mm}^2$

# Switching waveforms



- ▶ Tests performed on the smallest dies ( $2.4 \times 2.4 \text{ mm}^2$ ,  $R_{DS_{on}} = 500 \text{ m}\Omega$ )
- ▶  $300 \Omega$  Resistive load, 0.5 A current (no cooling system used)
- ▶ oscillations dues to external layout (and capacitances of the JFETs)

# Limitations of the structure



- ▶ little contact surface compared to size of substrates
- ▶ mechanical stress supported by the dies
- ▶ need for stress relief features



Introduction

The 3-D structure

Module Manufacturing

**Conclusion**

# Conclusion

- ▶ 3D structure using only high-temperature-rated materials;
  - ▶ Should be able to operate continuously at 300 °C, including passivation;
- ▶ Silver sintering is suited to rigid sandwich structures;
- ▶ Proposed etching technique offers satisfying resolution;
- ▶ Package for demonstration of technology, no cooling attempted yet;
- ▶ Next step: design a mechanically robust structure.

# Conclusion

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Thank you for your attention,

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