

# Design and Manufacturing of a Double-Side Cooled, SiC based, High Temperature Inverter Leg

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15/5/14

Introduction

The 3-D structure

Silver migration

Module Manufacturing

Conclusion

Introduction

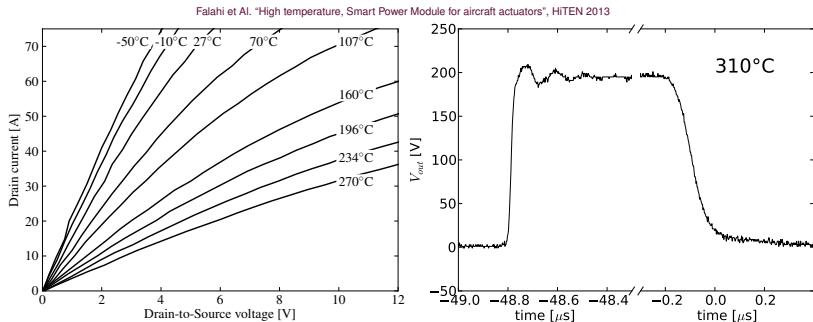
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# Active Power Devices for High Temperature

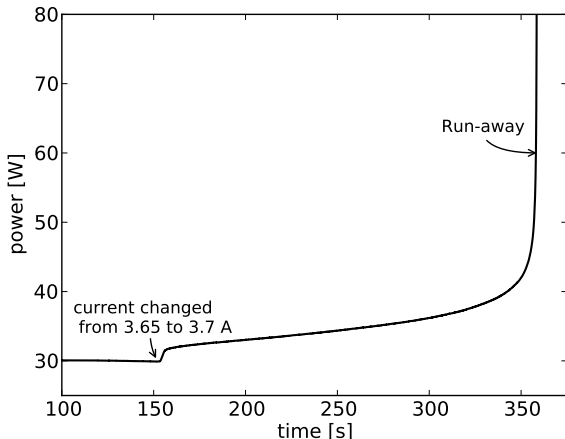


Previous results show that SiC JFETs are attractive for  
> 200 °C operation:

- ▶ 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



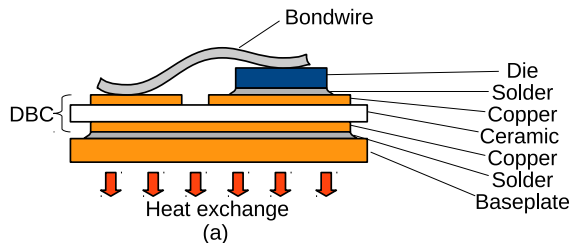
## SiC JFET:

- ▶ 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.**

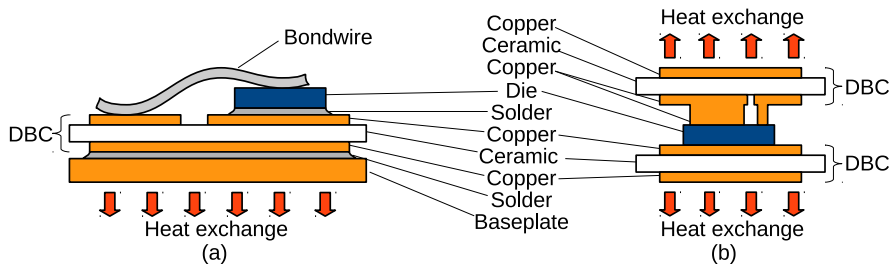


# Double Side Cooling



- ▶ Standard packaging offers cooling through one side of the die only
- ▶ “3-D” or “Sandwich” package performs 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**

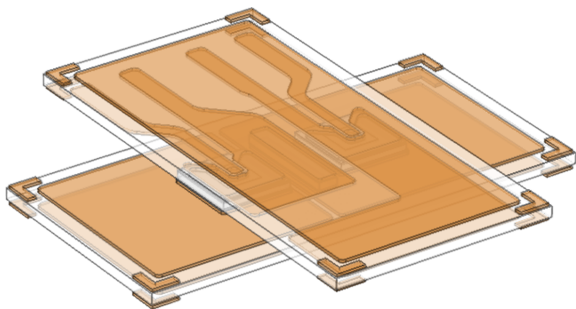
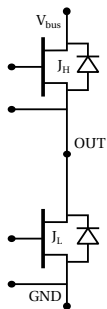
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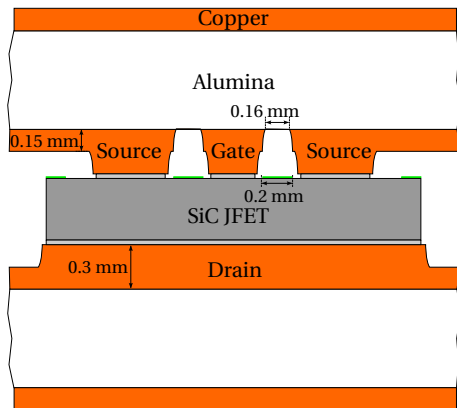


# The proposed 3-D Structure



- ▶ 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)

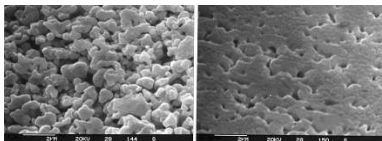
# Ceramic Substrates



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



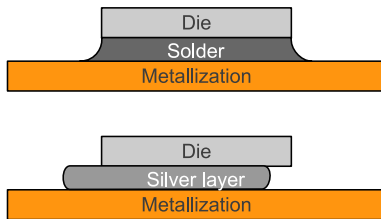
Göbl, C. et al "Low temperature sinter technology Die attachment for automotive power electronic applications" proc of APE, 2006

## Silver Paste

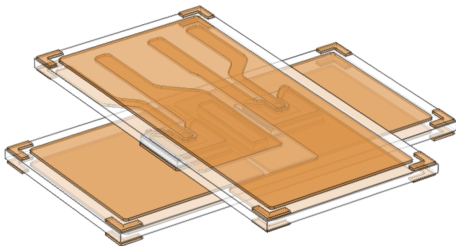
- ▶ Based on micro-scale silver particles (Heraeus LTS-117O2P2)
- ▶ Low temperature (240 °C) sintering
- ▶ Low pressure (2 MPa) process

## No liquid phase involved:

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

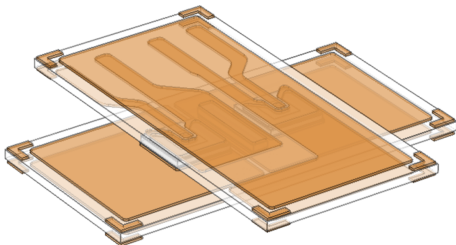


# 3-D Structure: Challenges



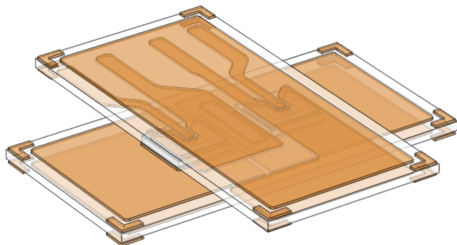
- ▶ Behaviour of silver at high temperature (risks of migration)
- ▶ Behaviour of silver paste during assembly (bridging, compensation of height differences)
- ▶ High-resolution alignment of parts
- ▶ Etching resolution of the DBC substrates

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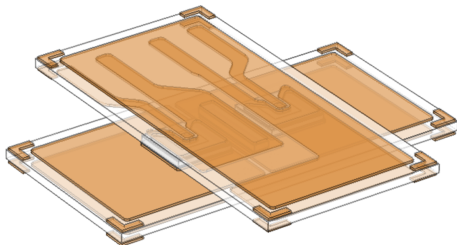
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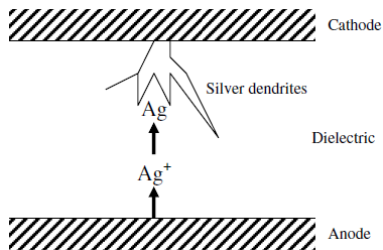
**Silver migration**

Module Manufacturing

Conclusion



# Causes of Silver Migration



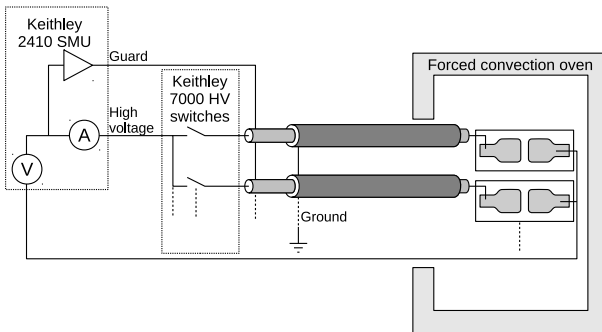
Source: Yang S et al. Initial stage of silver electrochemical migration degradation. *Microelectron Reliab* 2006;46(9):1915–21.

Silver atoms can migrate due to simultaneous presence of:

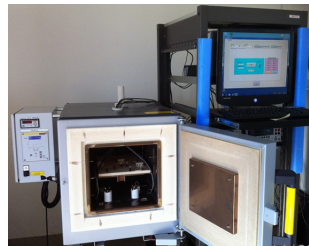
- ▶ High Temperature
- ▶ Oxygen/moisture
- ▶ Electric field

**Silver will then form filaments across the potential differences, causing short circuits!**

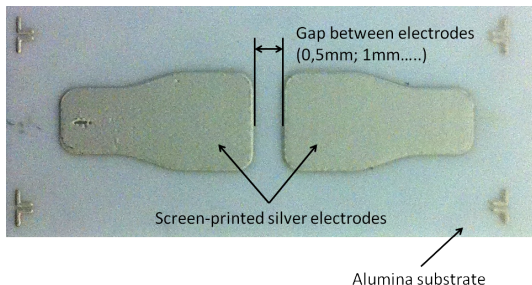
# Characterization Test Bench



- ▶ Up to 10 samples biased and monitored simultaneously
- ▶ 1100 V max biasing,  $< 10$  nA accuracy
- ▶ Tests performed at 300 °C

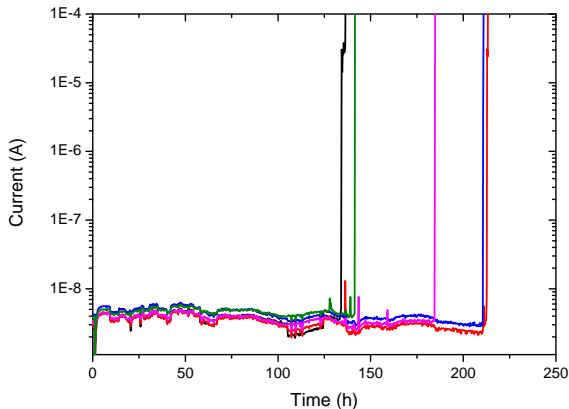


# Test Vehicles

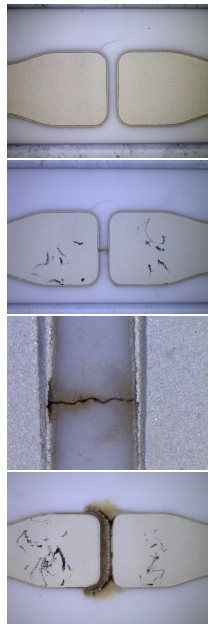


- ▶ Silver paste stencil-printed on alumina, and sintered
- ▶ Various gaps investigated: 0.5, 1, 1.5, 2 mm
- ▶ Test of vehicles:
  - ▶ Un-protected
  - ▶ Protected with a 20  $\mu\text{m}$  layer of parylene HT
- ▶ 5 samples for each configuration

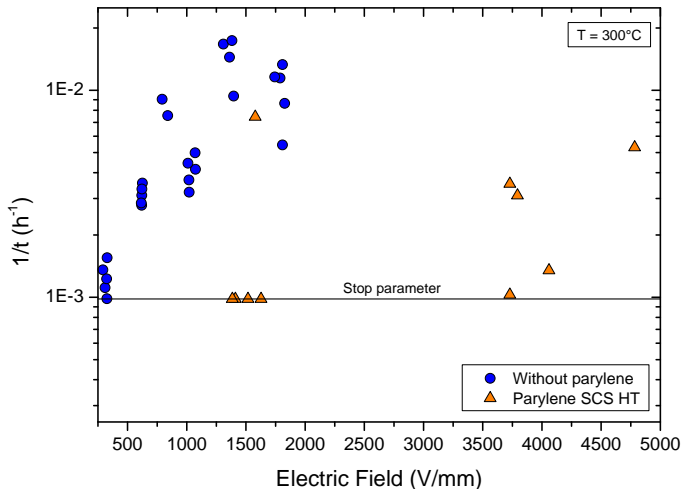
# Results – Un-coated samples



- ▶ Leakage current remains negligible until short circuit
- ▶ Large differences between similar test vehicles:
  - ▶ shape of the silver migration
  - ▶ time before failure



## Results – 2



- ▶ time before failure short without encapsulation (100–1000 h)
- ▶ Strong increase with parylene HT protection
- ▶ Tests stopped after 1000 h if no migration occurred

# Conclusions on High Temperature Operation of Silver-Sintered Joints

- ▶ Silver migration is an issue
- ▶ It should be evaluated on a more representative test vehicle (silver used for die attach only)
- ▶ Parylene HT is a good way to slow down migration
- Parylene HT will be used in the 3-D structure.

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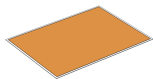
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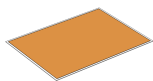
# Preparation of the Substrates



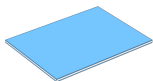
plain DBC board

- ▶ 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

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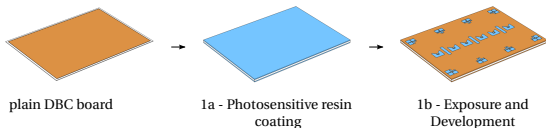
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1a - Photosensitive resin coating

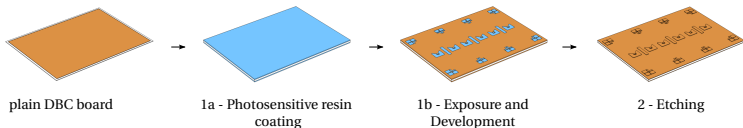
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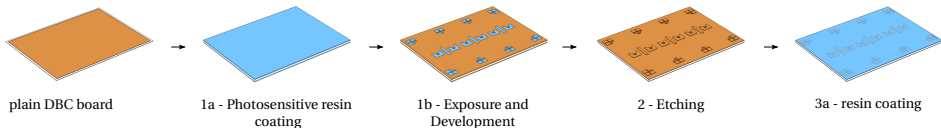
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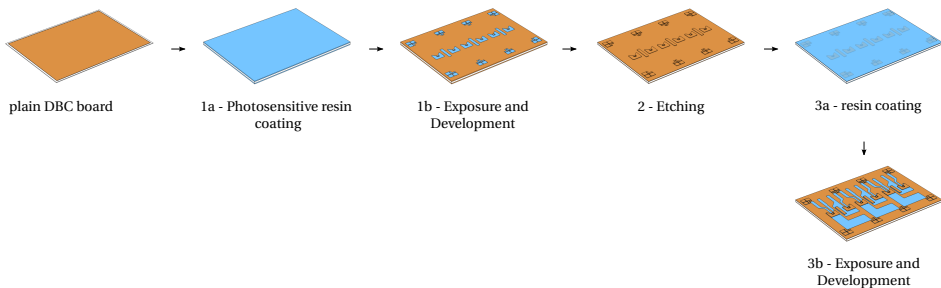
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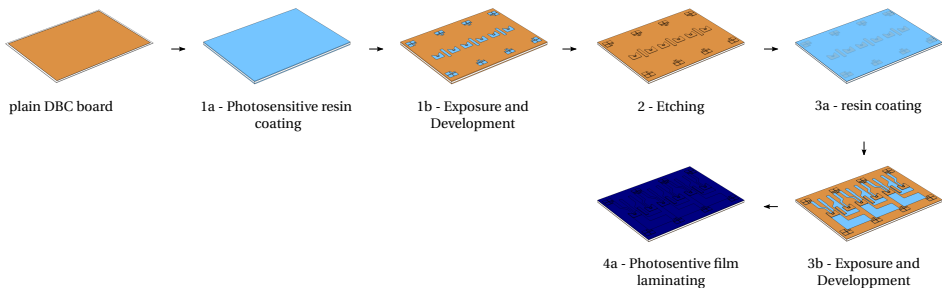
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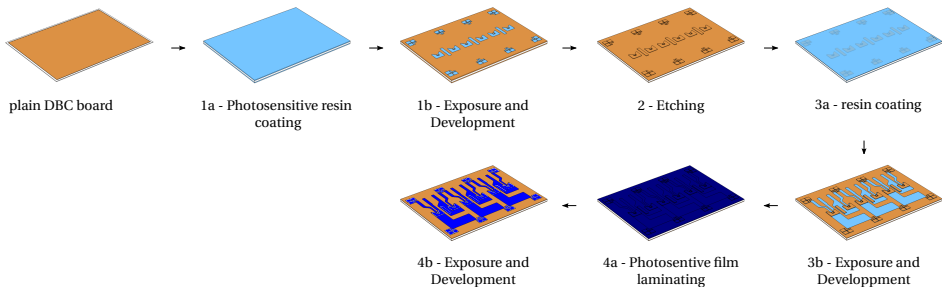


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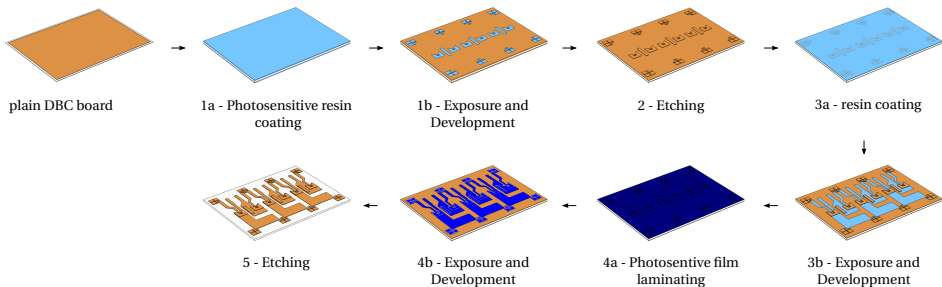
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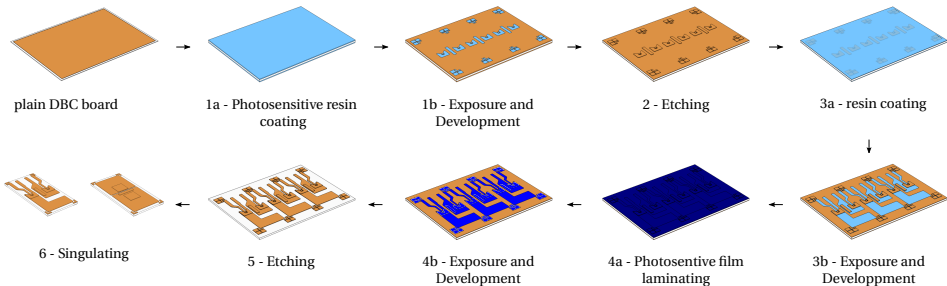
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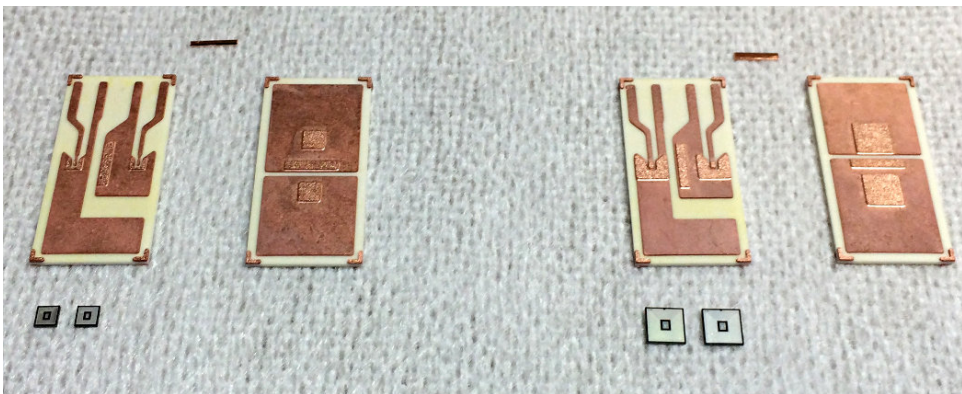
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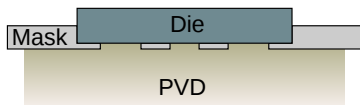
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- ▶ Ti/Ag PVD on contact areas
- ▶ Need for a masking solution
- jig with locating pockets.

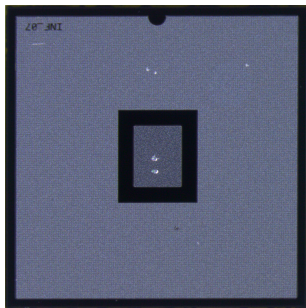
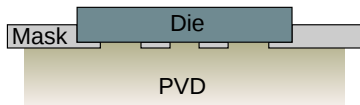


Before PVD

After Ti/Ag PVD

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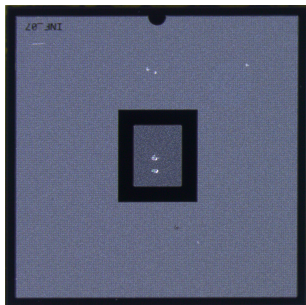
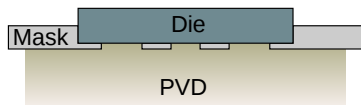


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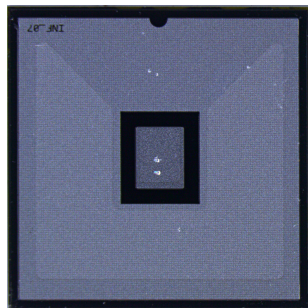
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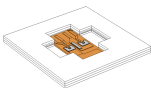
Screen printing

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

# Assembly



Screen printing



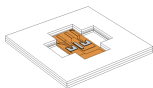
2- Mounting in  
alignment jig

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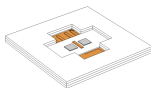
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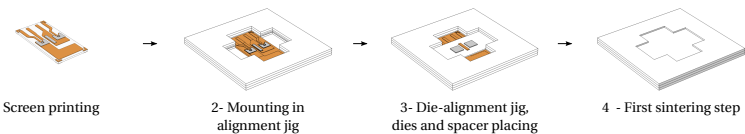
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3- Die-alignment jig, dies and spacer placing

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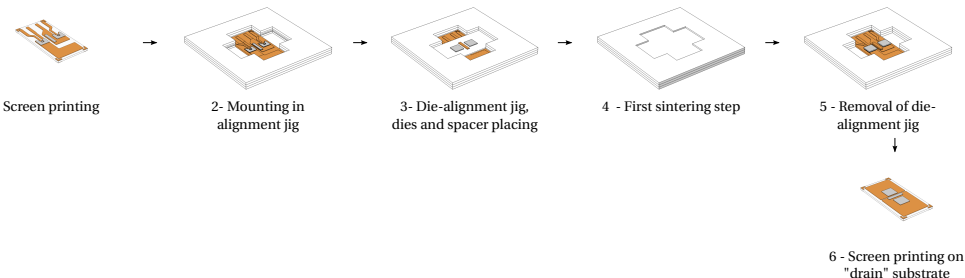
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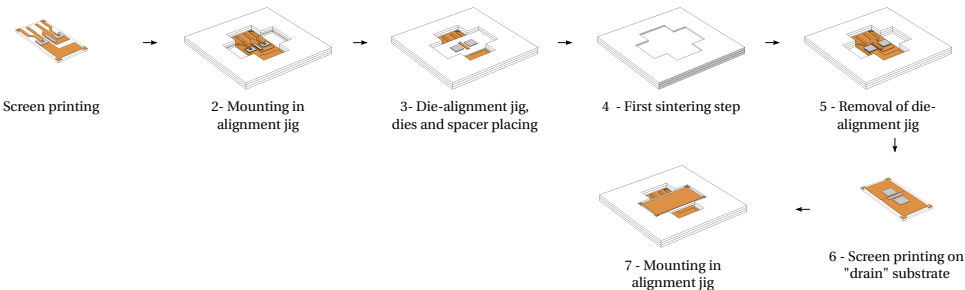
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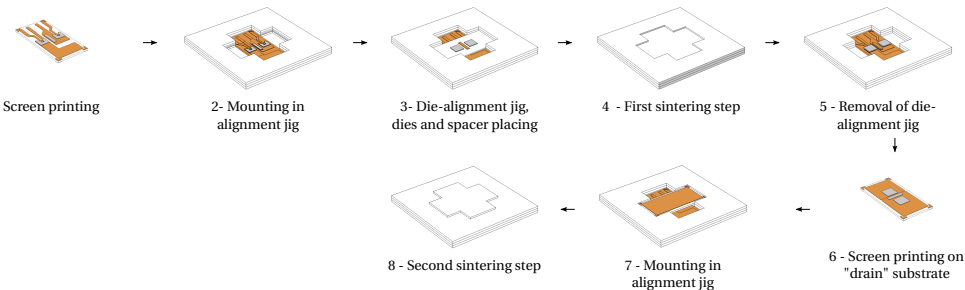
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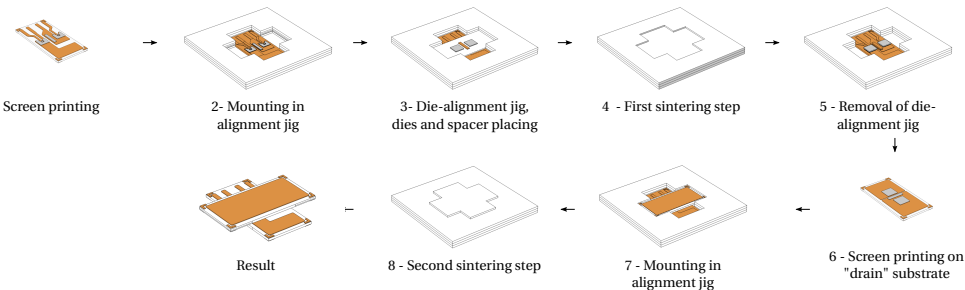
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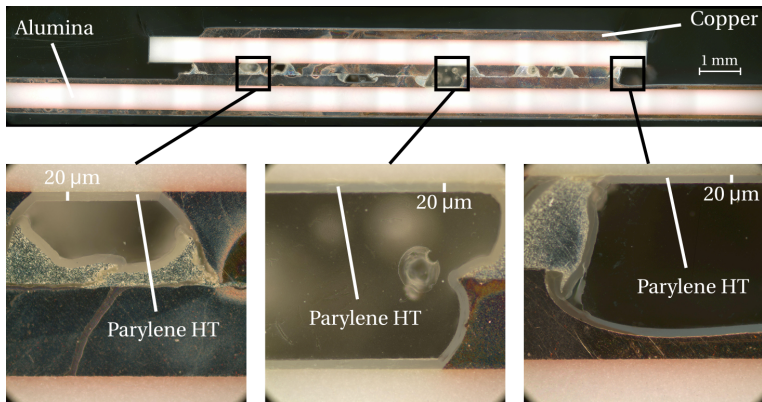


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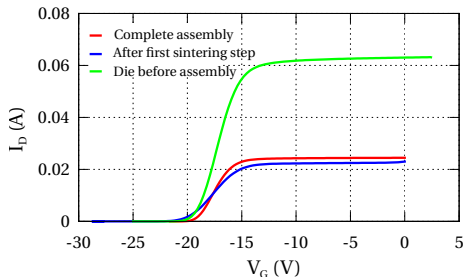


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# Encapsulation



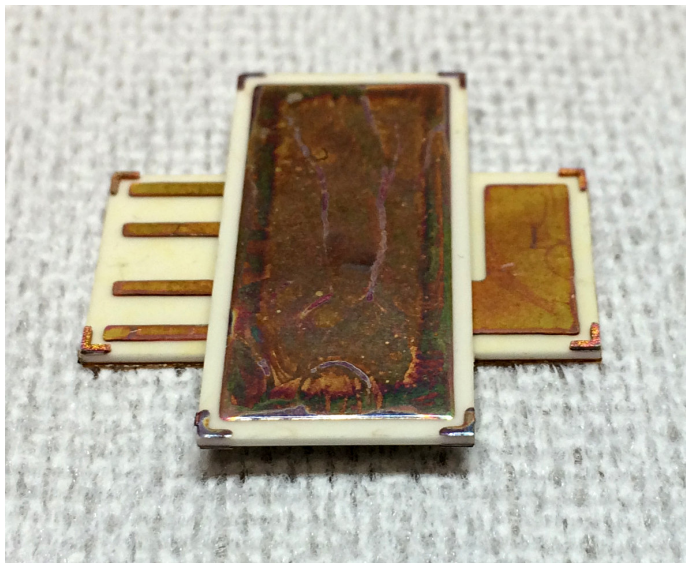
- ▶ Tests performed on a “sandwich” without dies
- ▶ Parylene thickness very uniform, including in intricate areas



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

Introduction

The 3-D structure

Silver migration

Module Manufacturing

**Conclusion**

# Conclusion

- ▶ 3D structure using only high-temperature-rated materials
  - ▶ Should be able to operate continuously at 300 °C, including passivation
- ▶ Silver migration is an issue
  - ▶ It can be slowed down using encapsulation
- ▶ Silver sintering is suited to rigid sandwich structures.
- ▶ Proposed etching technique offers satisfying resolution
- ▶ Package for demonstration of technology, no cooling attempted yet

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Thank you for your attention,

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