

Evaluation of printed-circuit boards materials for high temperature operation

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Introduction

Experimental Protocol

Definition of the test conditions

Test results

Conclusions

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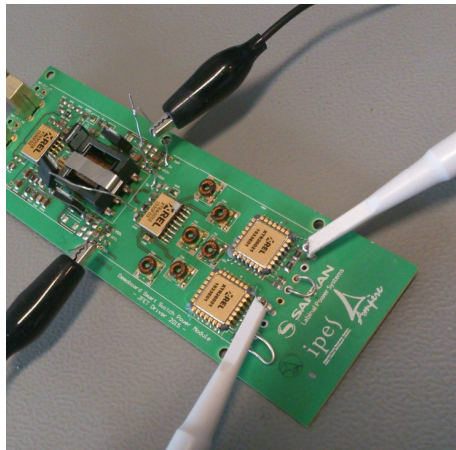
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Gate Driver for SiC MOSFET Power Module

- ▶ Relatively complex board
 - ▶ Several ICs
 - ▶ Large magnetic components
 - ▶ Not suited to power substrate (DBC)
- ▶ Need for prototyping solution
 - ▶ Easy procurement
 - ▶ Cheap
- ▶ Objective: eventually 200 °C
 - ▶ Current SiC MOSFETs limited to 175 °C



→ Use of Printed Circuit Boards

- ▶ Investigate behaviour of some PCBs at high temperature
 - ▶ First tests at Ampère on PCB ageing
 - ▶ Work on test protocol
- ▶ Propose a test configuration for gate driver circuits
 - ▶ Thermal cycling not investigated
 - ▶ Lab specific environment investigated (N₂ atmosphere)
- ▶ Also, investigation on solder
 - ▶ Not presented here
 - ▶ Same approach (cheap and easy solution for functional testing)

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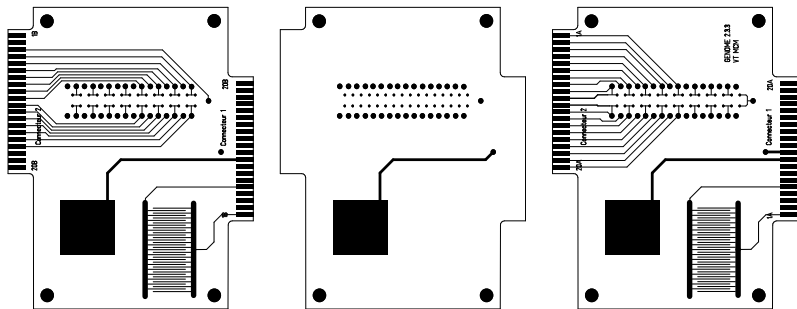
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Test Vehicles



- ▶ 6-layer PCBs, 70 μm Cu (2 oz), Ni/Au finish (6 μm /80 nm)
 - ▶ One set on FR-4 (Panasonic R-1755-V, $T_G > 170^\circ\text{C}$)
 - ▶ One set on polyimide (Arlon 85N, $T_G > 250^\circ\text{C}$)
- ▶ 3 test patterns:
 - ▶ Surface isolation resistance (500 μm spacing)
 - ▶ 20x20 mm² capacitance
 - ▶ Daisy-chained vias (450 μm hole diameter)

Ageing conditions



Source: MMM



- ▶ Isothermal ageing (“storage conditions”, constant temperature)
- ▶ Two atmosphere compositions:
 - ▶ Air (standard, forced convection oven)
 - ▶ Low-oxygen content (N_2 supply, O_2 content monitored to $<0.1\%$)

Electrical characterization

▶ **Surface Isolation Resistance:**

- ▶ Continuous bias: 25 V/mm, using HT interconnects (see paper for refs)
- ▶ Weekly characterization at room temperature (Keithley 2410 SMU, 200 M Ω max)

▶ **Plane capacitance patterns**

- ▶ Weekly characterization (Keysight E4990 impedance analyzer, 1–2 pF repeatability)
- ▶ Fixed test setup (BNC cables and edgeboard connector)

▶ **Resistance of the vias daisy chain**

- ▶ Weekly characterization (Keithley 2410 SMU, 10 $\mu\Omega$ resolution)



Source: Keithley

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Source: Keithley



Source: Keysight

Physical characterization



Source: Ohaus



Source: Leica



Source: Presi

- ▶ Weight measurement
 - ▶ Weekly characterization on a scale with 1 mg resolution
- ▶ Visual inspection
 - ▶ Weekly photographs with Leica M205C binocular
 - ▶ White balance and lighting conditions
- ▶ Cross sections
 - ▶ Preparation described in the paper

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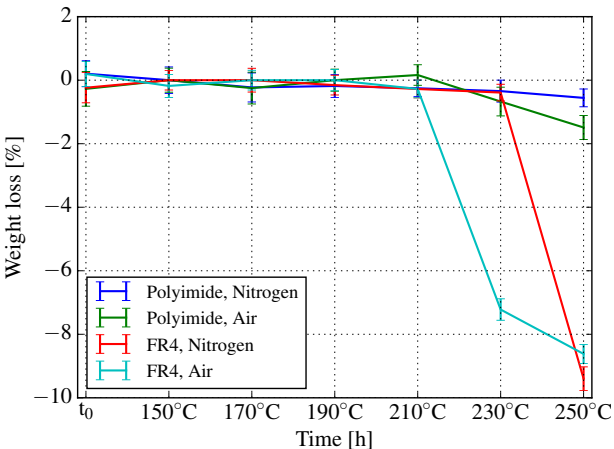
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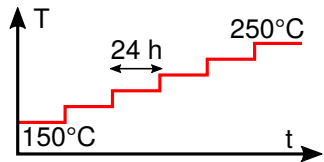
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Preliminary tests



Step stress

24 h temperature steps
20 °C increase
From 150 to 250 °C



- ▶ Weight loss measured on small coupons
- ▶ No change observed before 230 °C step
- ➔ 190 °C chosen for 1000 h storage tests

Summary of test conditions

- ▶ Atmosphere composition:
 - ▶ **Air**
 - ▶ **Oxygen-depleted** (<0.1 %)
- ▶ Boards dried for 6 h, 120 °C in air prior to ageing.
- ▶ Storage temperature: **190 °C**
- ▶ Test duration: **6 weeks** (1000 h)
 - ▶ Weekly characterization at room temperature

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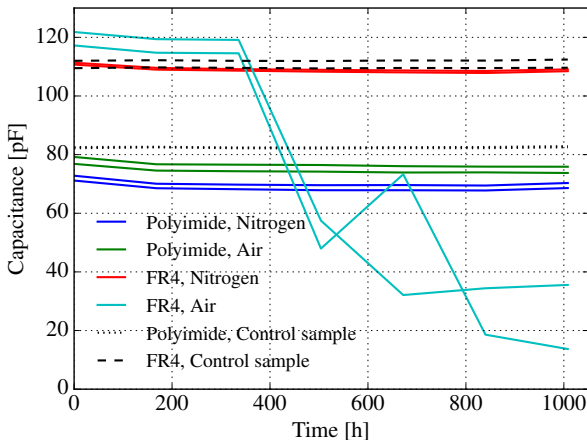
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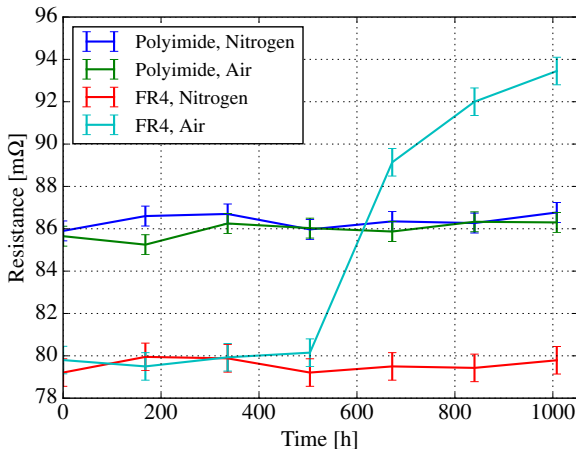
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Capacitance variation



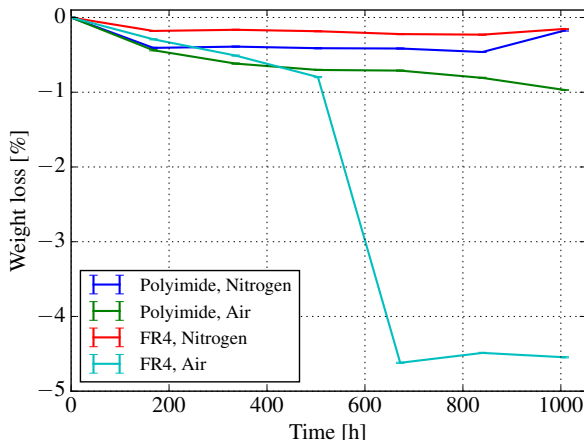
- ▶ No change on any board, except FR4, in air
- ▶ For FR4, in air, visible swelling around capacitor pattern (504 h)
- ▶ Blister may be caused by copper electrode, forming gas-tight area

Resistance of Vias



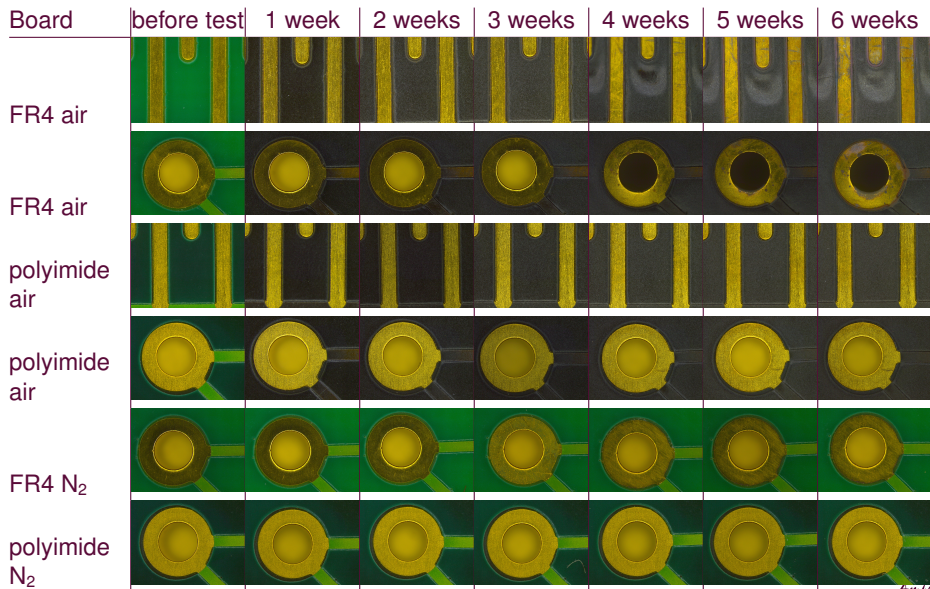
- ▶ As with capacitor patten, change only observed for FR4, in air
- ▶ Swelling of FR4 board causes increase in via resistance
- ▶ Occurs 1 week later than for capacitor (672 h)

Weight loss

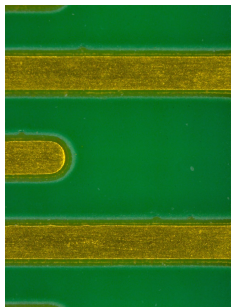


- ▶ Large weight loss for FR4, in air, after 672 h
- ▶ Noticeable weight loss (1 %) for polyimide, in air
- ▶ Negligible weight loss in N_2 , for polyimide and FR4

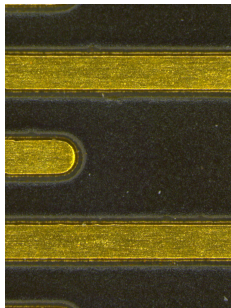
Visual inspection – 190 °C storage



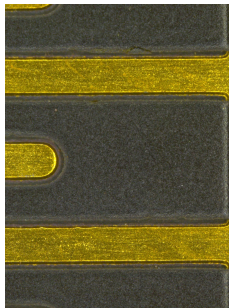
Visual inspection – FR4 board, 190 °C air storage



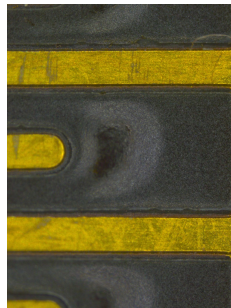
Initial



1 week (168 h)

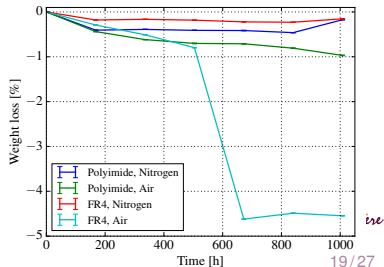


3 weeks (504 h)

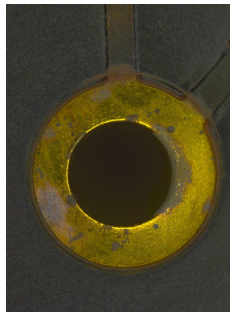
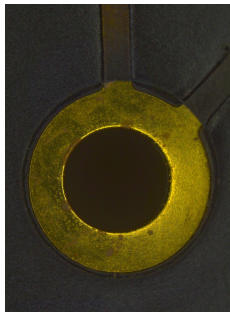
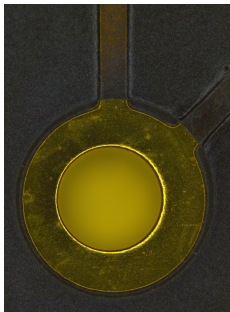
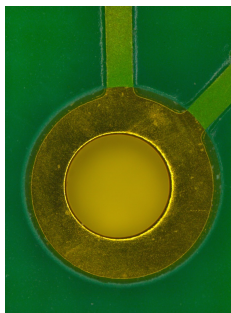


4 weeks (672 h)

- 1 week:** darkening of solder resist
- 3 weeks:** lighter hue
- 4 weeks:** inhomogeneous color, strong weight loss



Visual inspection – FR4 board, 190 °C air storage



Initial

3 weeks (504 h)

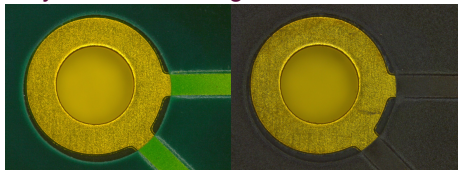
4 weeks(672 h)

6 weeks (1008 h)

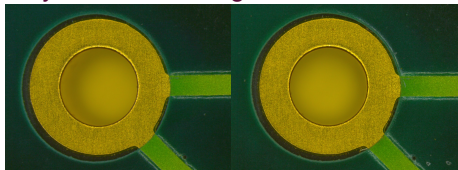
- ▶ Via metal (Ni/Au on Cu) remains unchanged up to 3 weeks
- ▶ Corrosion marks appear after 4 weeks
- ▶ Correlated with PCB weight loss

Visual inspection – others

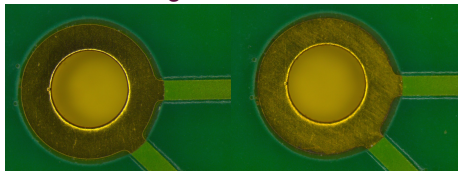
Polyimide, air storage, initial – 6 weeks



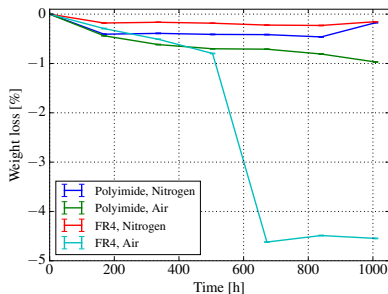
Polyimide, N₂ storage, initial – 6 weeks



FR4, N₂ storage, initial – 6 weeks

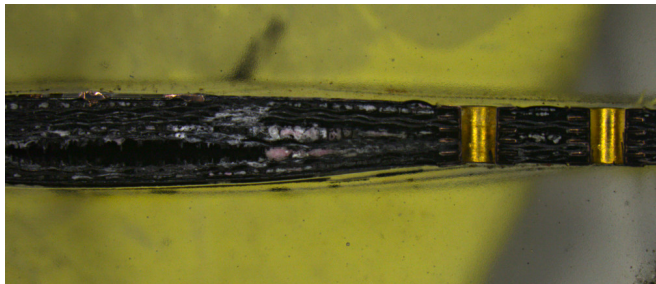


- ▶ For polyimide:
 - ▶ In air, darkening of solder resist
 - ▶ No other noticeable change
 - ▶ In nitrogen, no visual change
- ▶ for FR4:
 - ▶ No visual change
 - ▶ No corrosion of Au finish



Surface Isolation Resistance (SIR)

- ▶ Two SIR pattern biased and characterized per board:
 - ▶ One with Ni/Au finish
 - ▶ One with Ni/Au finish and screen-printed SAC
- ▶ All patterns exceed 200 M Ω (limit of test system) except FR4 in air
 - ▶ For FR4 in air, SIR drops to \approx 1M Ω after 4 weeks
 - ▶ Same behaviour for Au and SAC-finished patterns
 - ▶ Eventually, swelling so large that testing becomes impossible



Summary of the tests

- ▶ For samples stored in N_2 :
 - ▶ No noticeable change (polyimide and FR4)
- ▶ For samples stored in air:
 - ▶ Darkening occurs immediately (FR4 and polyimide):
 - ▶ No further degradation of polyimide (except continuous weight loss, 1 % over 1000 h)
 - ▶ Strong degradation of FR4 after 3 weeks:

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 - Degradation of solder resist
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 - ▶ Strong degradation of FR4 after 3 weeks:
 - 3 weeks: swelling, first where large copper patterns trap gases
 - 4 weeks: swelling propagates, large weight loss
 - 5-6 weeks: corrosion of Au finish

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- ▶ **Simple tests were found to be valuable:**
 - ▶ Weight loss (even off-line, with a standard scale)
 - ▶ Visual inspection (with reproducible image capture settings)
- ▶ **Electrical tests did not bring much information, but are required:**
 - ▶ SIR
 - ▶ Resistance of vias
- ▶ **Capacitance measurement caused early swelling**
 - ▶ Swelling was visible anyway
 - ▶ Copper pattern of test vehicles must be representative
 - ▶ Plain copper planes probably not recommended (meshed pattern better)
- ▶ No problem found with weekly tests at room temperature
- ▶ Edgeboard connector fine, except when board swelled too much
- ▶ No mechanical tests performed, no metal delamination observed.

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- ▶ As expected, FR4 ($T_g > 170$ °C) more sensitive to temperature than polyimide ($T_g > 250$ °C)
- ▶ Solder resist degrades rapidly at 190 °C
 - ▶ But this does not seem to cause much harm
- ▶ Atmosphere has a great influence
 - ▶ In air, even polyimide degrades, albeit slower than FR4
 - ▶ In nitrogen, no change observed
 - ▶ Interesting for functional testing purposes (cheaper PCBs)
 - ▶ Thermal cycling not considered here
- ▶ Solder to be investigated
 - ▶ SAC attach investigation at 190 °C failed (Pb contamination caused early failure)
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Thank you for your attention

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