PASSIVE COMPONENT EMBEDDING IN PRINTED CIRCUIT BOARDS FOR SPACE APPLICATIONS

ELECTRONICS MATERIALS & PROCESSES FOR SPACE (EMPS) WORKSHOP
13-14/04/2016, PORTSMOUTH, UK

MAARTEN CAUWE[1], GERHARD SCHMID[2], STEVEN DE CUYPER[3], DENIS LACOMBE[4]

1. Center for Microsystems Technology, IMEC, Zwijnaarde, Belgium, Maarten.Cauwe@imec.be
2. AT&S, Leoben, Austria
3. QinetiQ Space, Kruibeke, Belgium
4. ESA (TEC-QTC), ESTEC, Noordwijk, The Netherlands

esa

QinetiQ Space

AT&S
www.ats.net

imec

CONTENTS

- PROJECT GOAL
- ECP TECHNOLOGY
- TEST BOARDS
- TEST PLAN
- TEST RESULTS
- SUMMARY
- OUTLOOK

esa
AT&S
QinetiQ Space
imec

© IMEC 2016

PROJECT GOAL

Investigate the suitability of embedding passive components in printed circuit boards for space applications

- Overview of available technologies for component embedding
- Assessment of the AT&S ECP® technology
- Evaluation of reliability of passive component embedding
- Realization of a functional demonstrator
- Procedures for procurement and qualification of PCBs with embedded components for space applications

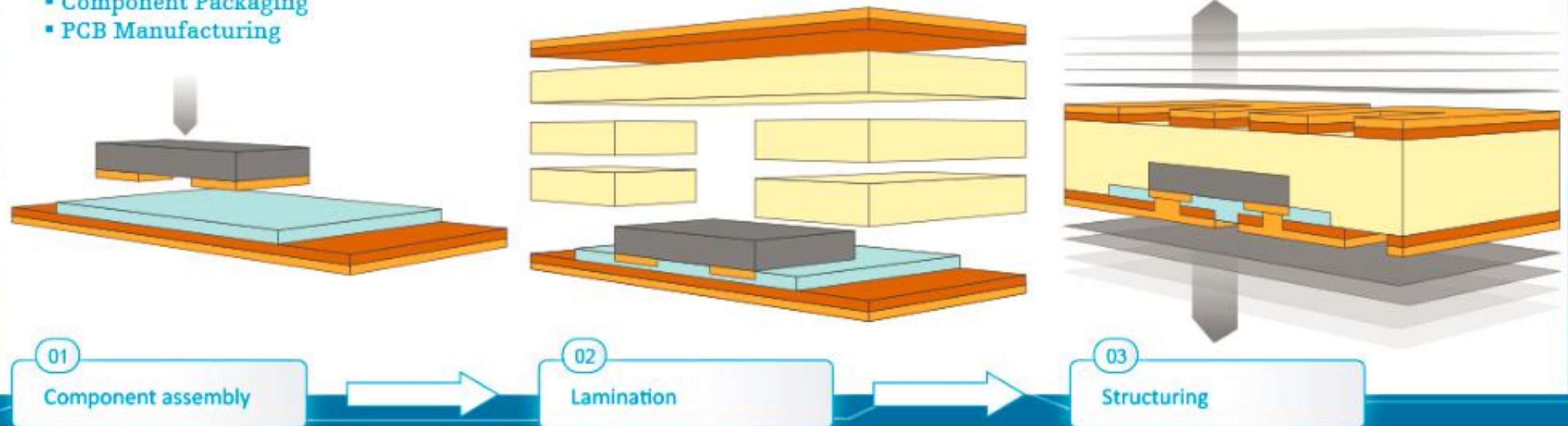
QinetiQ Space

AT&S

QinetiQ Space

imec

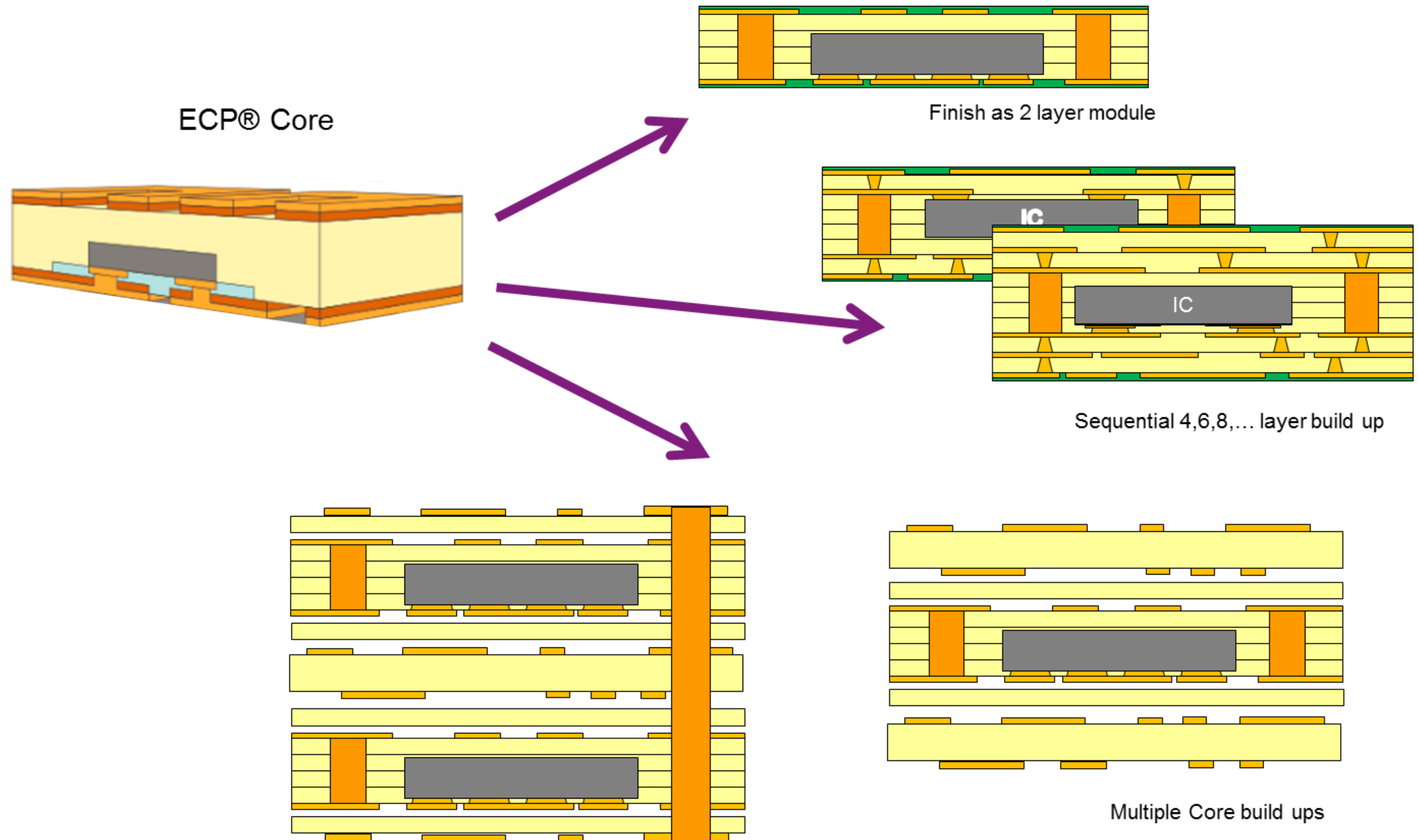
EMBEDDED COMPONENT PACKAGING TECHNOLOGY



- Embedding of both active and passive components
- Component thickness and pad metallization compatibility

esa
AT&S
QinetiQ Space
imec

EMBEDDED COMPONENT PACKAGING TECHNOLOGY



- Embedded core can be integrated in various PCB build-ups

esa
AT&S
QinetiQ Space
imec

EMBEDDED COMPONENT PACKAGING TECHNOLOGY

Available components for embedding

- Resistors

Size	Voltage (V)	Power (W)	Tolerance	Operating temperature	TCR
01005	*??*	*0.03*	*1 %, 5 %*	*-55 °C to 125 °C*	*200-300 ppm/°C*
0201	25	0.05	1 %, 5 %	-55 °C to 125 °C	200-300 ppm/°C
0402	50	0.06 – 0.1	1 %, 5 %	-55 °C to 125 °C	100-200 ppm/°C

- Capacitors

Type	Size	Range	Voltage (V)	Tolerance	Thickness (µm)	TCC
C0G	0201	1 – 100 pF	10 – 50	5 %	150 – 330	30 ppm/°C
X5R	*0201*	*0.1 – 100 nF*	*2.5 – 50*	*10 – 20 %*	*110 – 330*	*±15 %*
X5R	0402	1 – 4700 nF	2.5 – 50	10 – 20 %	110 – 330	±15 %
X7R	*0201*	*0.1 – 22 nF*	*2.5 – 50*	*10 %*	*150 – 330*	*±15 %*
X7R	0402	1 – 10 nF	6.3 – 25	10 %	150 – 330	±15 %

esa

AT&S

QinetiQ Space

imec

© IMEC 2016

TEST BOARDS

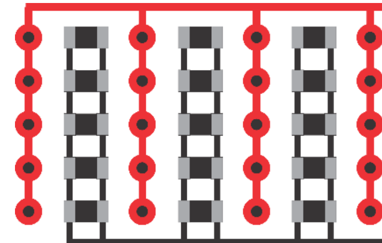
Board Type I

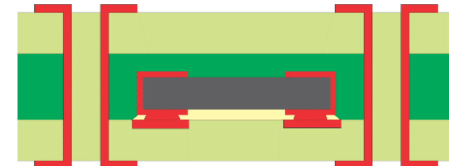
- Board level reliability and component characterization
- Components selection based on availability and BTII
  - 33 Ω, 0402 / 10 kΩ, 0402 / 10 kΩ, 0201 / 1 MΩ, 0201 from Panasonic
  - Murata 10 pF & 100 pF (0201, 150 µm), AVX 10 nF (0402, 300 µm, 16 V to 50 V and 150 µm, 6.3 V) and Murata 100 nF (150 µm, 6.3 V)
- Test structures
  - Probe pad test structure for electrical measurement of components
  - Disk, comb and tree test pattern for interlayer and intralayer insulation
  - Daisy chains (0-ohm resistors) for continuity and interconnect resistance
  - Interconnect stress test (IST) patterns on separate coupon

Layer	Material	Thickness	Spec
Soldermask			20
Copper		35 µm	35 +/-10
Pre-Preg	407678	111 µm	
Pre-Preg	407678		
Copper	408963	25 µm	25 +/-10
Pre-Preg	406871	422 µm	
Pre-Preg	406872		
Pre-Preg	406872		
Pre-Preg	406871		
Copper	408963	25 µm	25 +/-10
Pre-Preg	407678	111 µm	
Pre-Preg	407678		
Copper		35 µm	35 +/-10
Soldermask			20

Caps & Resistors 150µm
20µm
Caps & Resistors 300µm
20µm

Total thickness: 804 µm





AT&S

QinetiQ Space

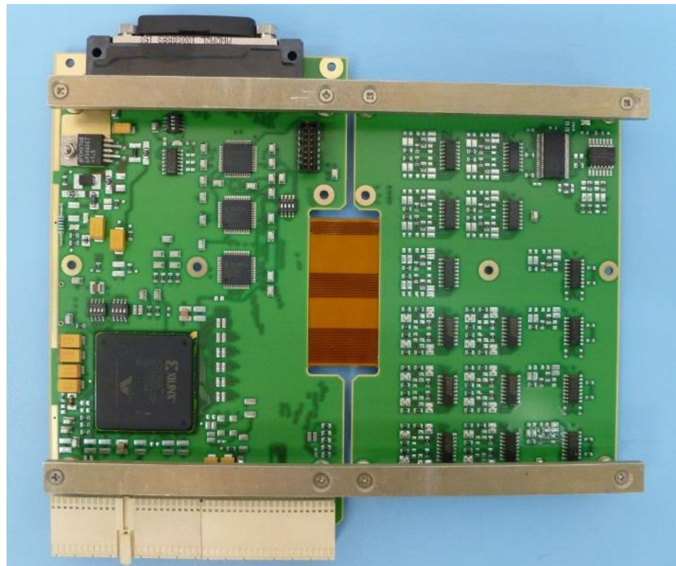
imec

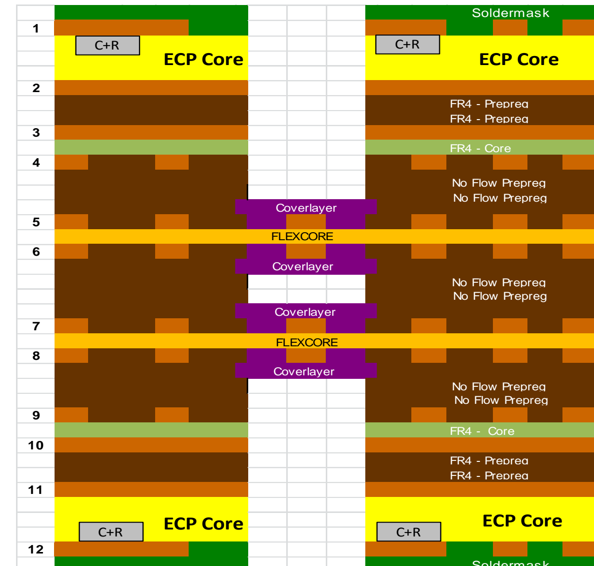
© IMEC 2016

TEST BOARDS

Board Type II

- Spacecraft Interface Module (SIM) board from QinetiQ Space
  - Redesigned for the use of embedded passives by AT&S
- Twelve layer rigid-flex construction with two embedded cores
- Initial electrical tests, FPGA tests and functional tests passed
- Performance is on par with the standard SIM-FUMO board



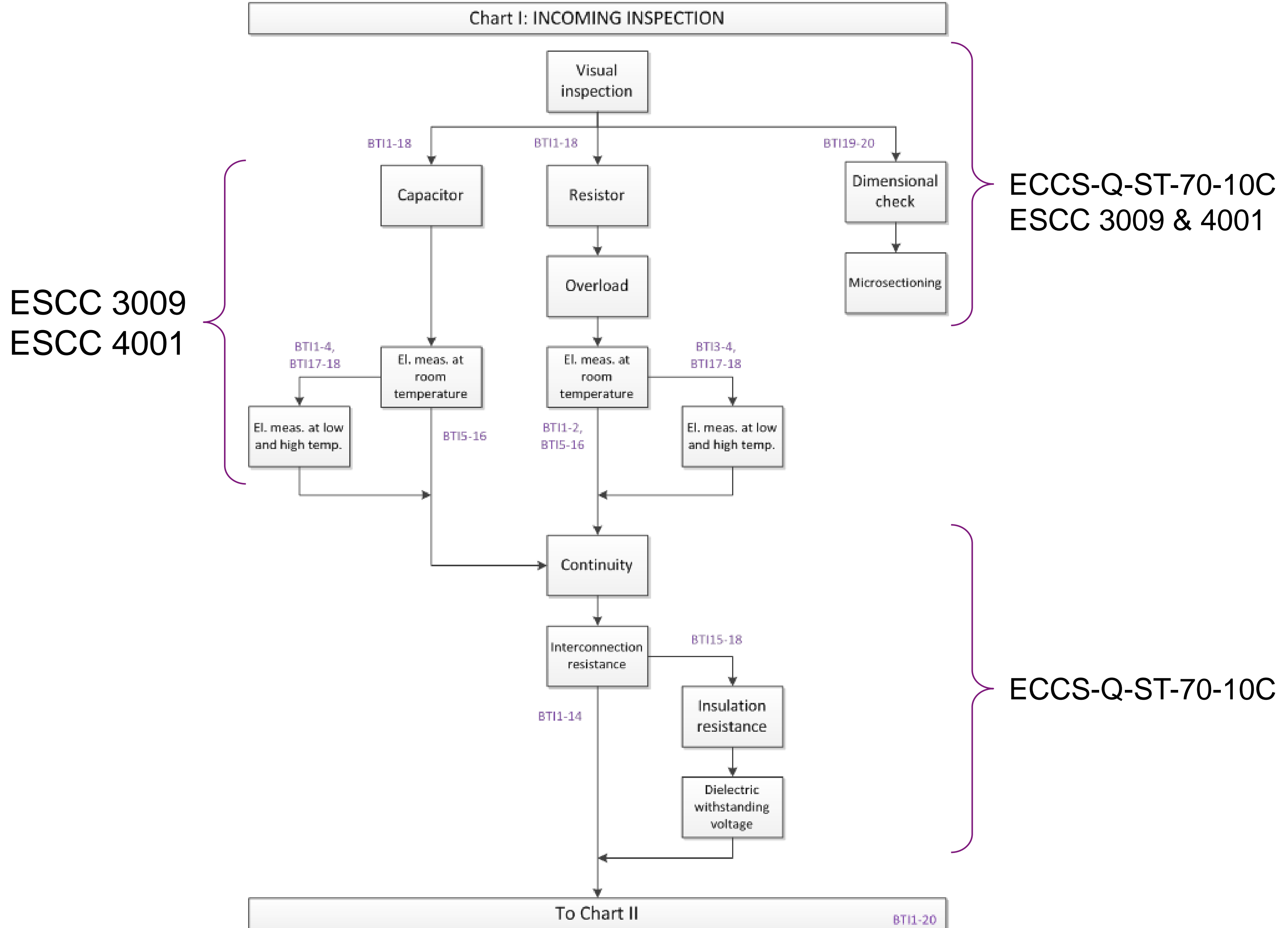


AT&S

QinetiQ Space

imec

EVALUATION TEST PLAN



esa
AT&S
QinetiQ Space
imec

EVALUATION TEST PLAN

Chart II: STRESS TESTING

INTERCONNECT LEVEL

- BTI1-2: Vibration → Continuity → Interconnection resistance → El. meas. at room temperature
- BTI3-4: Mechanical shock → Continuity → Interconnection resistance → El. meas. at room temperature
- BTI5-6: Bending → Continuity → Interconnection resistance → El. meas. at room temperature
- BTI7-8: Thermal cycling → Continuity → Interconnection resistance → El. meas. at room temperature

ECCS-Q-ST-70-38C
AEC-Q200-005

COMPONENT LEVEL

- BTI9-11: Resistor → To Chart III
- BTI12-14: Capacitor → To Chart III

ESCC 3009
ESCC 4001

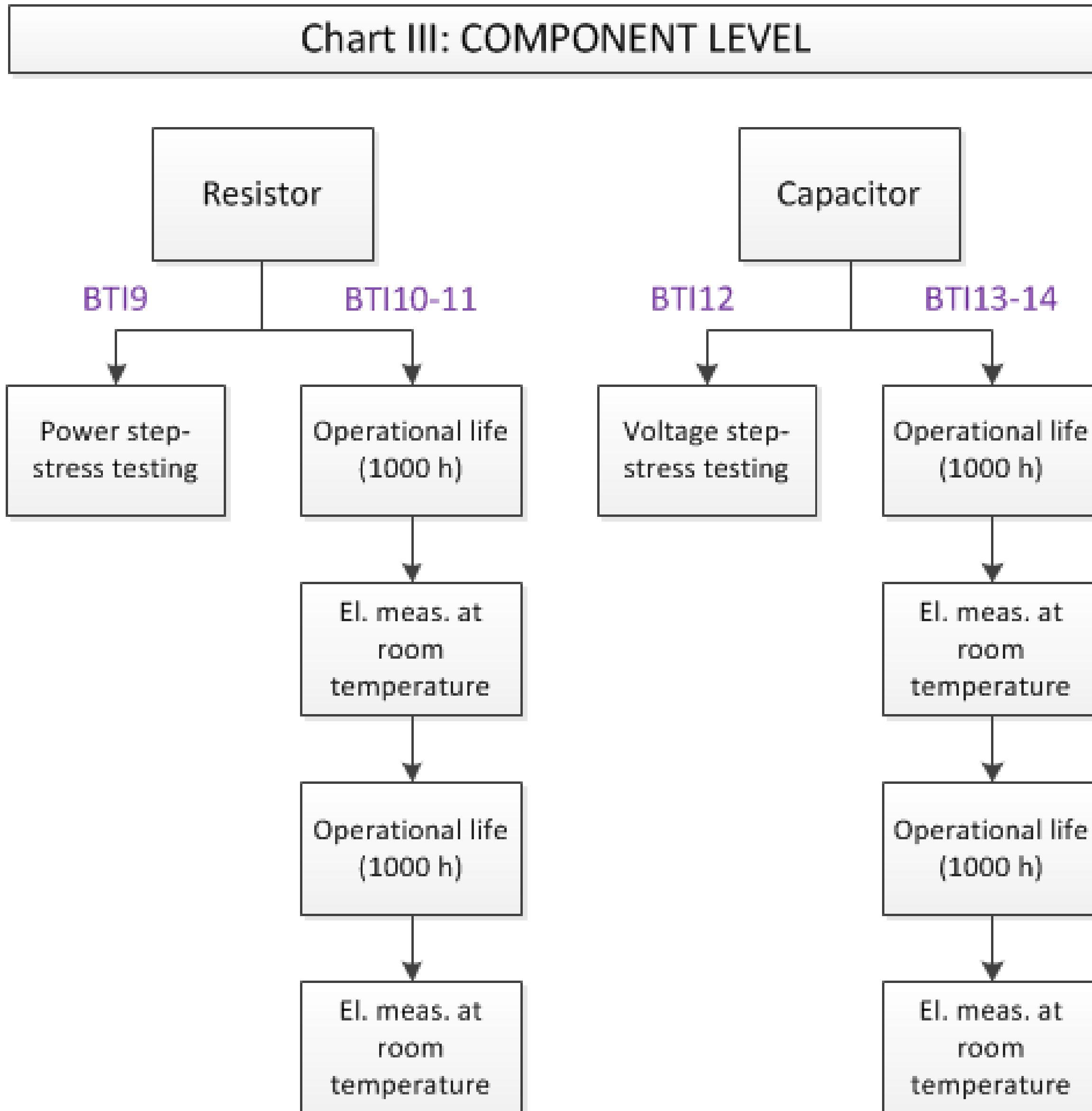
BOARD LEVEL

- BTI15-16: Thermal stress → Insulation resistance → Dielectric withstanding voltage → Continuity → Interconnection resistance
- BTI17-18: Damp heat → Insulation resistance → Dielectric withstanding voltage → Continuity → Interconnection resistance
- COUPON: IST → Continuity → Interconnection resistance

ECCS-Q-ST-70-10C

QinetiQ Space

EVALUATION TEST PLAN



esa
AT&S
QinetiQ Space
imec

TEST RESULTS

Test	Type	Resistor	Capacitor	0-ohm resistor	Board
Component values	Embedded				n.a.
	Surface-mount				n.a.
Overload	Embedded		n.a.	n.a.	n.a.
	Surface-mount		n.a.	n.a.	n.a.
Board insulation resistance	Embedded	n.a.	n.a.	n.a.	
Board dielectric withstanding voltage	Embedded	n.a.	n.a.	n.a.	
Vibration	Embedded				n.a.
	Surface-mount				n.a.
Mechanical shock	Embedded				n.a.
	Surface-mount				n.a.
Bending (AEC-Q200)	Embedded				n.a.
Thermal cycling	Embedded				n.a.
Thermal stress	Embedded			n.a.	
Damp heat	Embedded			n.a.	
IST	Embedded	n.a.	n.a.		n.a.
Operating life	Embedded			n.a.	n.a.
	Surface-mount			n.a.	n.a.

© IMEC 2016

TEST RESULTS

Component performance

- Resistors are within spec for 5 % tolerance, outside spec for 1 % tolerance
- Capacitors are within spec for capacitance, loss factor, insulation resistance and voltage proof testing
  - Multiple outliers below 1 GΩ on C0G capacitors
- Resistor operating life time
  - 0402 embedded resistors perform slightly worse than SMT resistors
  - 0201 embedded resistors started failing after 512 hours
- Capacitor operating life time
  - Decrease in capacitance is larger for the embedded components compared to their surface-mount equivalents
  - X5R capacitors out of spec after 1000 hours of testing

esa
AT&S
QinetiQ Space
imec

© IMEC 2016

TEST RESULTS

Board-level insulation

- Insulation resistance (3x < 1 GΩ) and dielectric withstanding voltage failure (4x < 1.5 kV/mm) between component and PTH
  - Two additional failures after thermal stress testing
- Micro sections show glass fibers extending to component

~200 µm

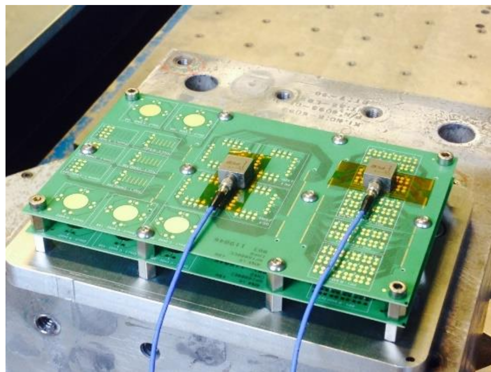
- Failure mechanism: carbonized epoxy at fiber cut results in conductive path between PTH and component

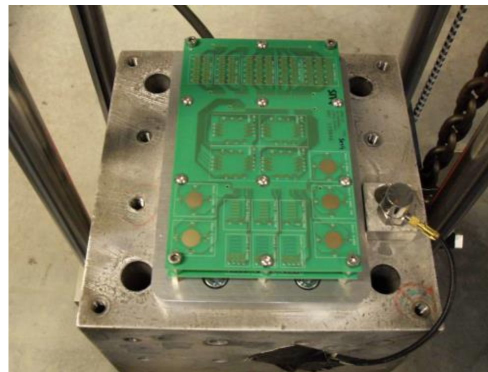
esa
AT&S
QinetiQ Space
imec

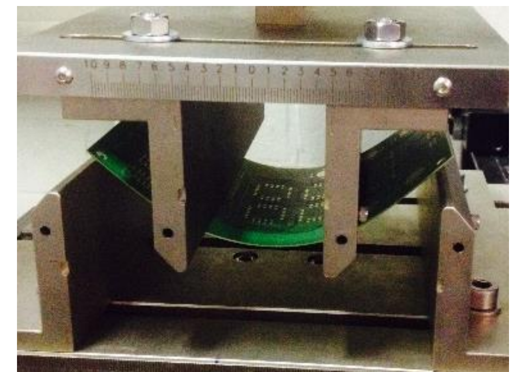
TEST RESULTS

Mechanical testing

- No failures in interconnection or components after vibration, mechanical shock and three-point bending
  - Capacitor insulation resistance in spec after testing
- No differences observed between embedded components and surface-mount components
- Four-point bending down to a bending radius of 56.2 mm revealed slight advantage of embedded components
  - 0402 and 0201 sized components small compared to bending radius





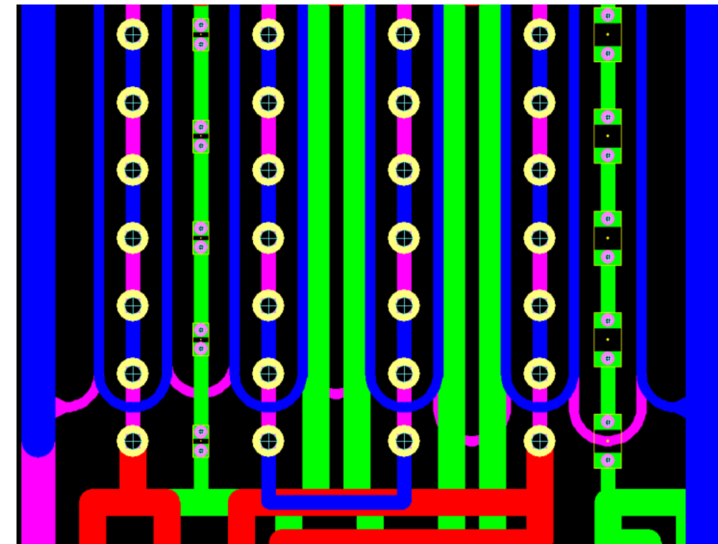


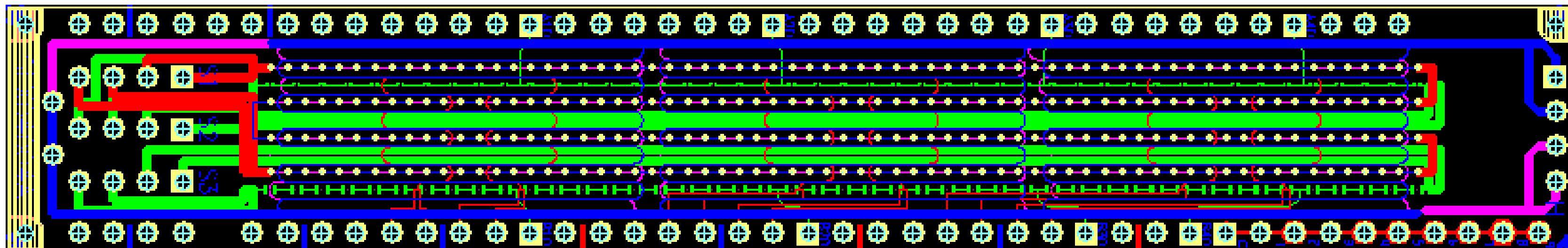
esa
AT&S
QinetiQ Space
imec

TEST RESULTS

Interconnection stress testing

- 10 coupons with SuperHeat only and three sense circuits including embedded 0-ohm resistors
  - PTH daisy chain (S1)
  - Daisy chain with 0201 resistors (S2)
  - Daisy chain with 0402 resistors (S3)
- 180 connections per coupon (PTH chain: 268 vias)
  - microvia is ±15 % of chain resistance
- Performed at PWB interconnect solution in Canada



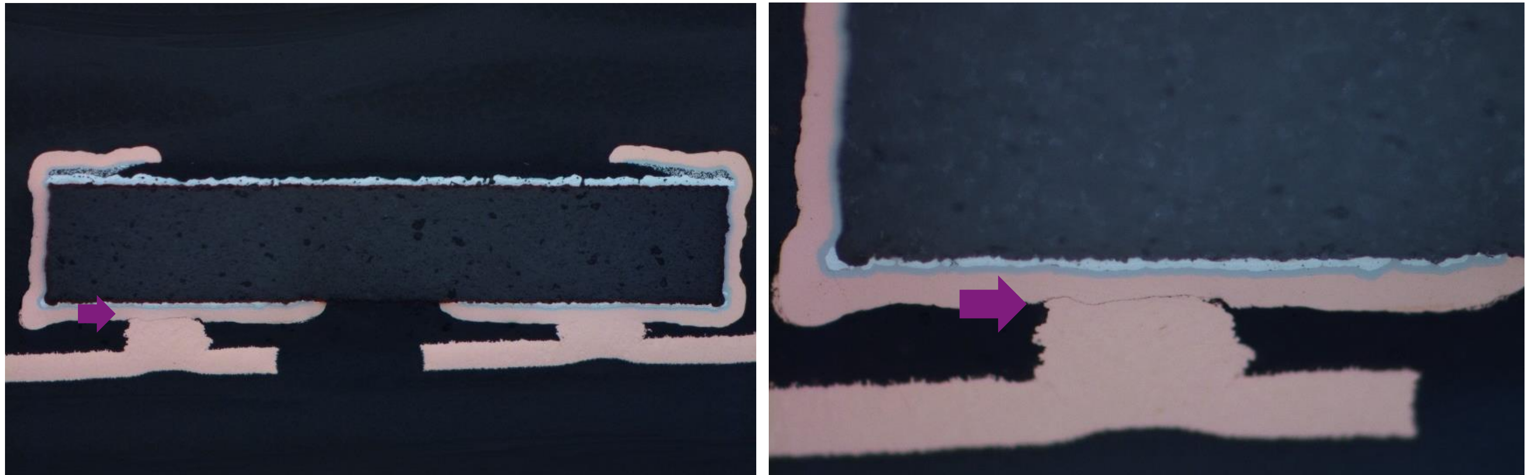


esa
AT&S
QinetiQ Space
imec

TEST RESULTS

Interconnection stress testing (IST)

- Test protocol (ESA IST draft test procedure QT/2014/030/SHv2)
  - 6 times preconditioning to 230 ºC
  - 1000 cycles at 150 ºC (sense PTH, 0402)
  - 100 cycles at 190 ºC (sense 0402, 0201)
- No failures after 1000 cycles at 150 ºC
- Two chains with 0201 resistors failed during cycling to 190 ºC
  - Failure mechanism: CTE_z of adhesive ($T_{max} >> T_g$) causes microvia to lift



esa

AT&S

QinetiQ Space

imec

SUMMARY

Status of passive component embedding

- Performance of embedding technology is at high level
  - Board Type II performed on par with its SMT counterpart
  - No failure observed in interconnection to component (except for IST)
- Embedding has minor impact on components
  - Component performance is adequate, except for 0201 resistors
  - Operating life time does not match space requirements
- Available components are limitation for space applications
  - Range of available values is limited, no European supply chain, voltage and temperature ratings not sufficient for derating
  - Qualification testing and lot screening need to be upgraded to ESCC requirements and better matched with embedded technology
- General considerations
  - Testing of PCBs with embedded component is challenging
  - No automated design flow for space PCBs with design rule checks
  - No repair possible

© IMEC 2016

WHAT'S NEXT?

Passive component embedding is in volume production for commercial applications

- Automotive qualification is ongoing

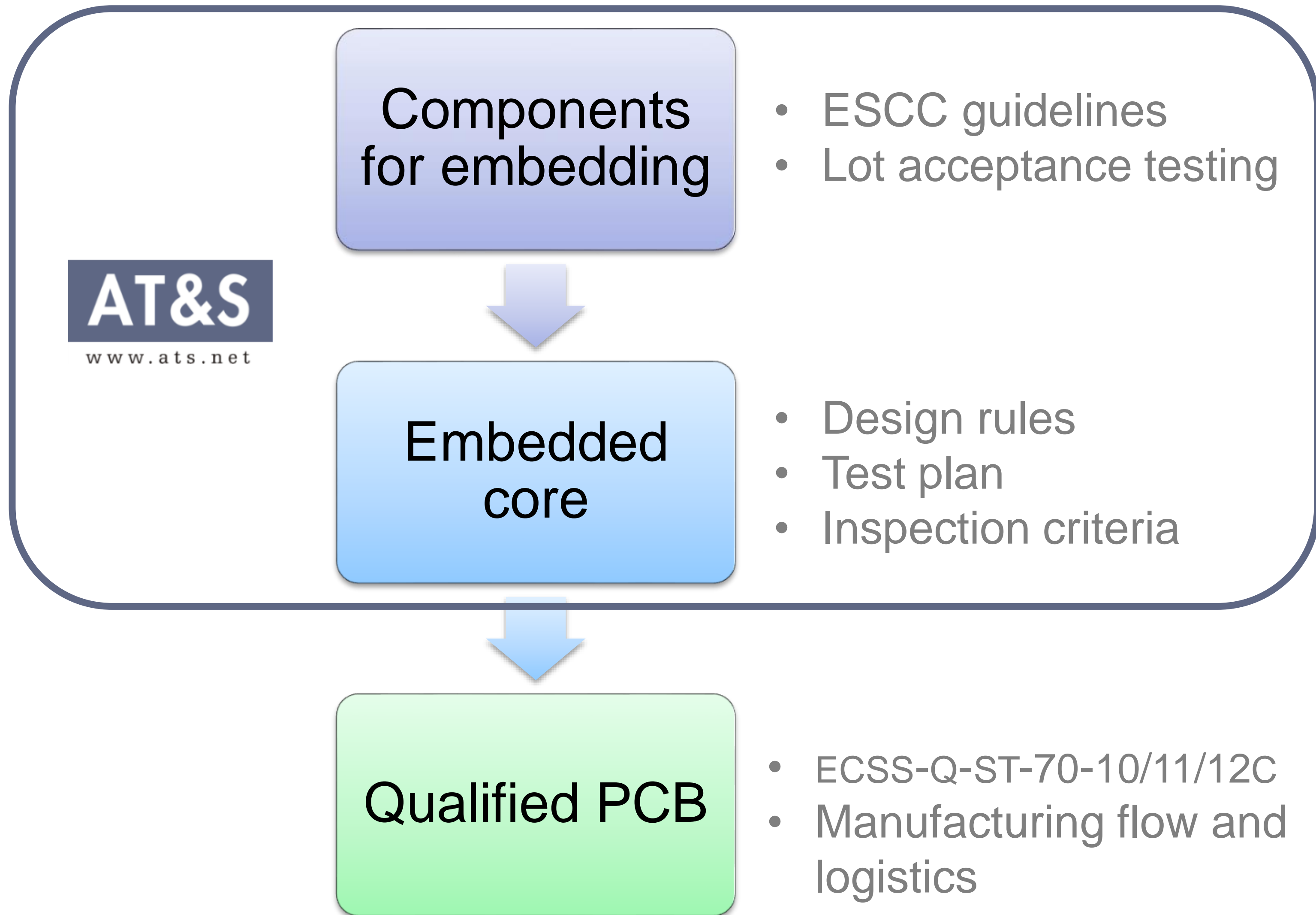
PCESA project demonstrated potential for space applications and identified remaining challenges

- Component availability
- Design rules for embedding
- Qualification and procurement

esa
AT&S
QinetiQ Space
imec

© IMEC 2016

PRODUCTION FLOW PROPOSAL



esa
AT&S
QinetiQ Space
imec

© IMEC 2016

OUTLOOK

Next steps

- Establish a European supply chain with an extension of the possible voltage, power and temperature ratings
- Implement qualification flow
  - Cooperation between AT&S and ESA qualified PCB supplier
  - Test methodology for PCBs with embedded components
- Define technology demonstrator with embedded passive components (GSTP IOD)
  - Verify design and procurement flow
  - Validate product reliability and performance
- Embedding active components
  - Diodes, MOSFETs
  - Small modules (PM, RF)
  - Power components (GAN)
  - More complex SIP modules

esa

AT&S

QinetiQ Space

imec

CONTACT

Maarten Cauwe

Imec-Cmst, Zwijnaarde, Belgium

Maarten.Cauwe@imec.be

Gerhard Schmid

AT&S, Leoben, Austria

G.Schmid@ats.net

Steven De Cuyper

QinetiQ Space, Kruibeke

Steven.DeCuyper@qinetiq.be

AT&S

QinetiQ Space

imec

ASPIRE
INVENT
ACHIEVE

imec