DESIGN OF ELECTRONIC MODULES & ASSEMBLIES
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Cost Optimizing vs. Reliability in EMS Assembling Activities

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OUTLINE

- Actual Trend & Constrains in EMS
- Correlation to PLC of SMT defects origin – macrostructural level
  - Case of PCB with Different Core Materials
- IMC issues at solder joint interfaces – microstructural level
  - Case of multiple reflow
- 4 P Soldering Model concept
- Cost reduction in DFM frame: Pin-In-Paste Applications
- Summary

Actual Trend & Constrains in EMS

2012 !

- Nivel crescut de integrare – Miniaturizare
- Frecventa înaltă: 30GHz
- Contactare fără plumb & noi materiale RoHS
- Condiții de lucru extinse – FIABILITATE
- Condiții de calitate totala – TQM / Six sigma
- Timp redus de lansare pe Piață
- Costuri reduse

SLC 309

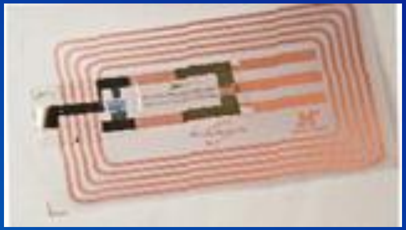
Infrared Preheating

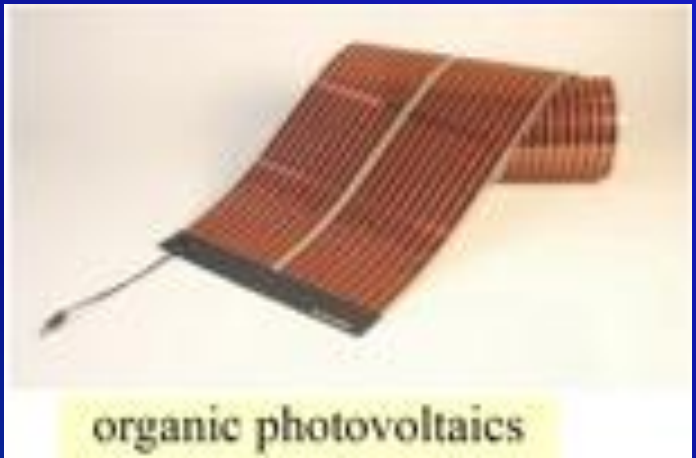
Adjustable heating time & performance

Soft vapour phase

Fast cooling system

Printed electronics





- **DIRECTIVE 2002/95/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment**

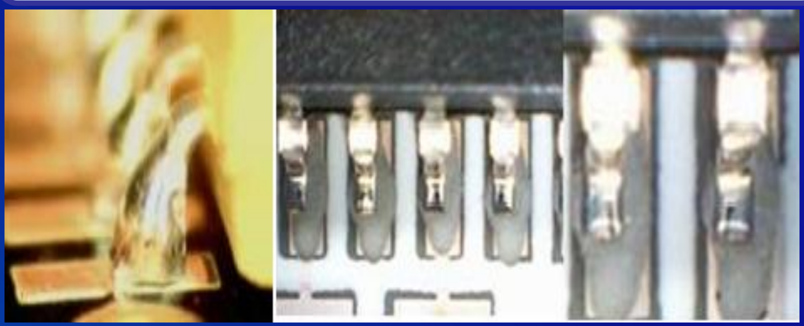
- **DIRECTIVE 2002/96/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 27 January 2003 on waste electrical and electronic equipment (WEEE)**

- **REGULATION (EC) No 1907/2006 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)**

Correlation to PLC of SMT defects origin

SMT specific defects vs. PLC

Components displacement - tombstoning



Solder alloy migrations - Wicking

Solder balls

Conception

↕

Design

↕

Logistics & Materials

↕

Manufacturing

Nr. Crt.	Defect / Origin	R & D				Materials			Process		
		PCB / Panel	Design Processing	Thermal Profile	Stencil	PIN	PAD	PASTE	Printing	Pick & place	Reflow
1	Solder balls, balling, spattering,	X	X	X	X	X	X	X	X	X	X
2	Poor wetting / de-wetting			X		X	X	X			X
3	Cosmetic Appearance					X	X	X			X
4	Case Movement, tombstoning, Draw brg.	X	X	X	X	X	X	X	X	X	X
5	Cold joint, dull joint			X		X	X	X			X
6	Voids			X		X	X	X	X		X
7	Pillow			X		X	X	X		X	X
8	Wicking			X		X	X	X			X
9	Whickers							X			
10	Cracking, delamination			X		X	X	X			X
11	Electromigration					X	X	X			
12	Electrochemical migration			X			X	X	X		X
13	Bridging	X	X	X	X	X	X	X	X	X	X
14	spike, excessive fillet			X	X			X	X		X
15	Nonmelting alloy			X	X		X	X	X		X
16	Graping			X	X		X	X	X		X
17	Orange skinning			X			X	X			X

PCB with Different Core Materials

Heat transfer in PCB structure

$$\alpha(T)[\mathrm{m}^2/\mathrm{s}] = \frac{\textit{căldura condusă}}{\textit{căldura stocată}} = \frac{\lambda}{\rho c}$$

$\alpha(T)$ = Difuzivitatea termică, $[m^2 \cdot s^{-1}]$;

λ = conductivitatea termică, $[W\ m^{-1} \cdot K^{-1}]$;

ρ = m/V, densitatea $[kg\ m^{-3}]$;

$\rho\ c$ = capacitatea volumetrică de căldură, $[J\ m^{-3} \cdot K^{-1}]$

T = temperatura, [K];

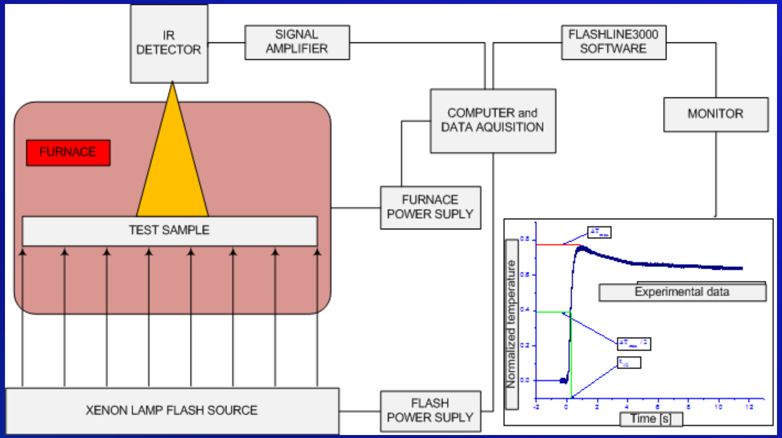
τ_{th} = constanta de timp pentru procesul de transfer al căldurii prin conducție în structura PCB;

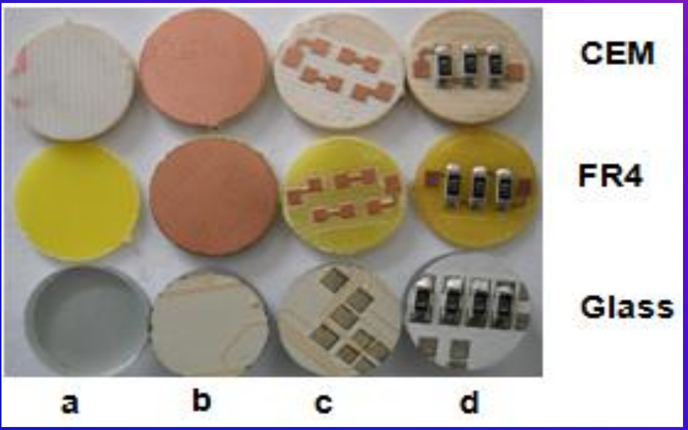
x = grosimea structurii PCBA, [m] = $V\ A_{th}^{-1}$.

$$\tau_{th} = x^2\ (\alpha)^{-1}$$

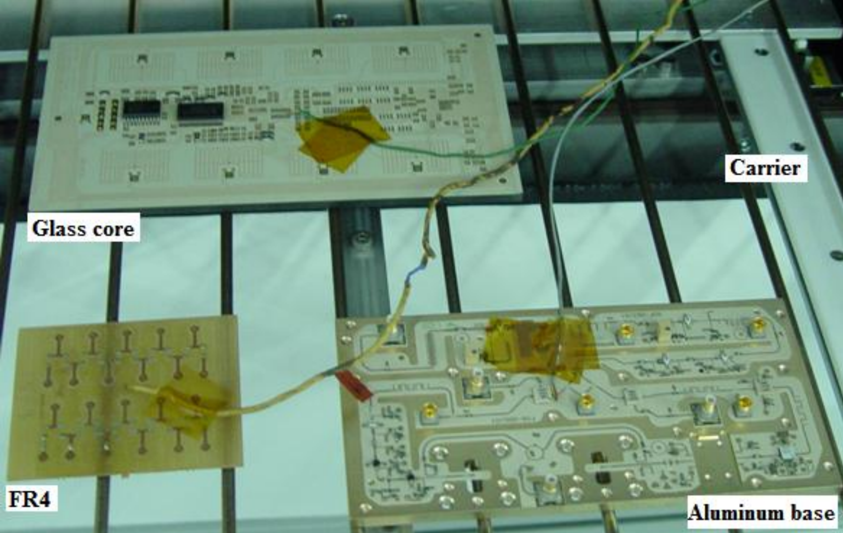
10:16:44

„Flash Diffusivity” method

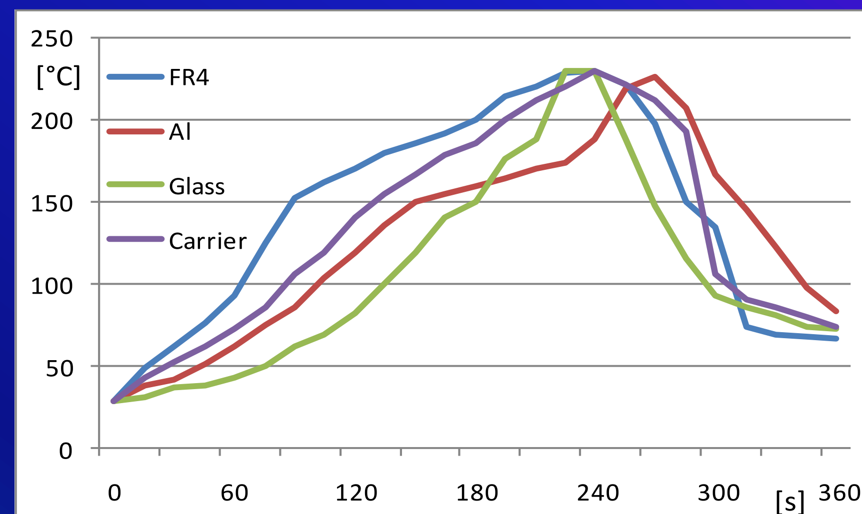




FR4	T [°C]	(α) Difuzivitate [cm^2/s]	(λ) Conductivitate [W/mK]	(c) Căldura specifică [J/Kg K]
FR4 Substrat	106	0.0027	0.47	916
Substrat & Trasee de cupru	110	0.003	0.42	746
Substrat, Trasee & Componente	105	0.0021	0.38	936



GCB, Al and FR4 PCBs core types on carrier in VPS machine

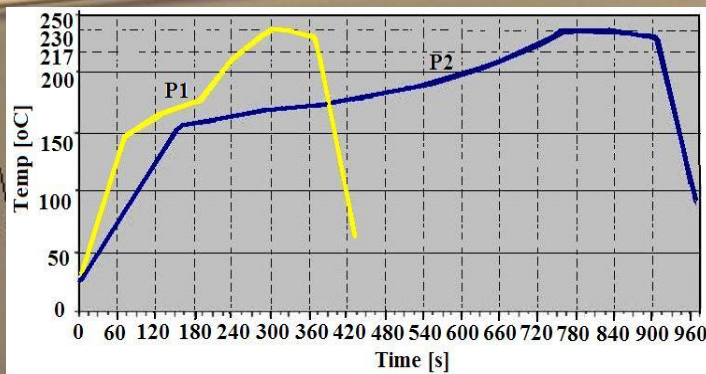


VPS thermal profile as function of substrate thermophisical properties

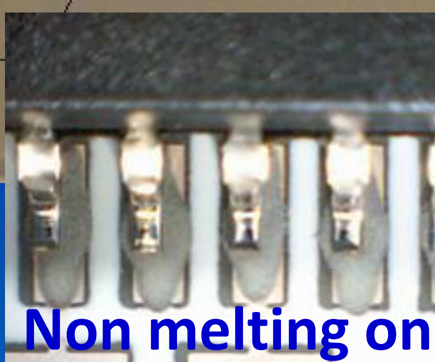
VPS applications: PCB with Different Core Materials

Longer thermal profile consequences over:

Pin
Pad
Paste



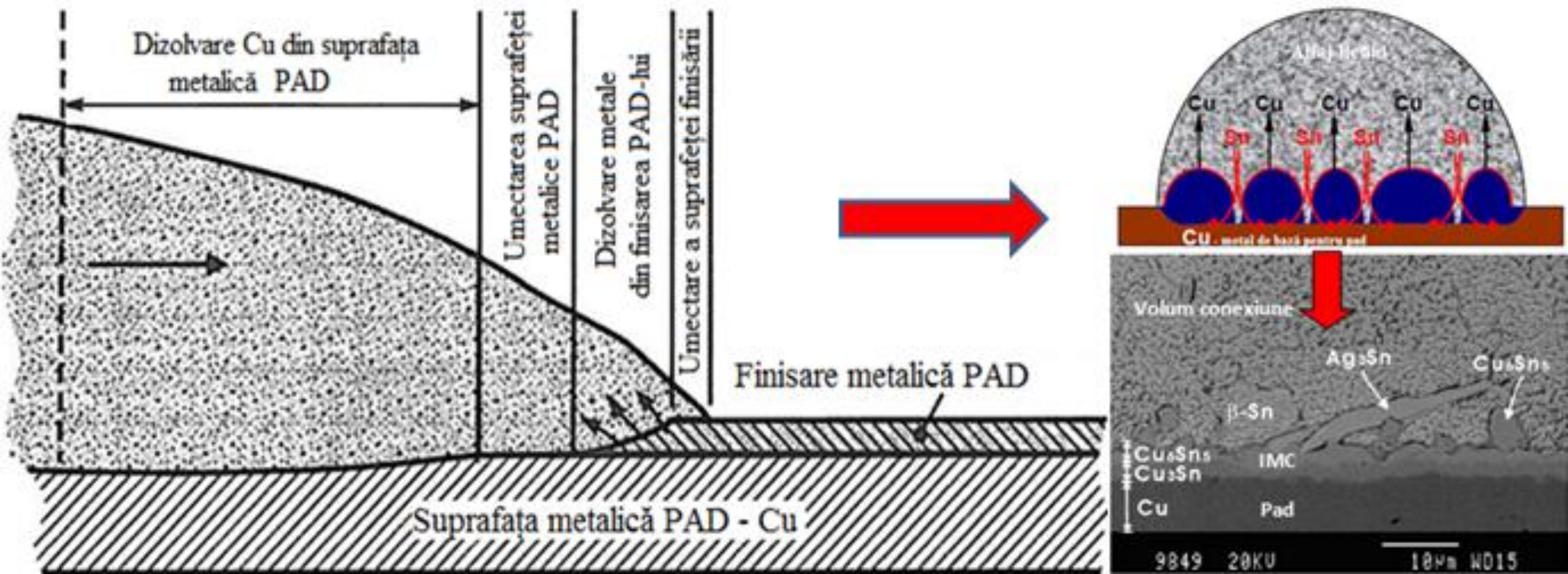
Parameter	P1	P2
Conveyor speed	0.8 m/min	0.4 m/min
Maximum temperature	245 °C	245 °C
Cycle duration	7 min	16 min
Zone 1 temperature	145 °C	145 °C
Zone 2 temperature	170 °C	170 °C
Zone 3 temperature	180 °C	180 °C
Zone 4 temperature	215 °C	215 °C
Peak 1 temperature	245 °C	245 °C
Peak 2 temperature	235 °C	235 °C
Cooling temperature	60 °C	100 °C



Non melting on pad - Wicking

Delamination

IMC issues at solder joint interfaces



Metals	Tin	Indium
Copper	Cu_4Sn, **Cu_6Sn_5**, **Cu_3Sn**, Cu_3Sn_8	Cu_3In, Cu_9In_4
Nickel	Ni_3Sn, Ni_3Sn_2, **Ni_3Sn_4** $NiSn_3$	Ni_3In, NiIn Ni_2In_3, Ni_3In_7
Indium	In_3Sn, $InSn_4$	-
Silver	Ag_6Sn, **Ag_3Sn**	Ag_3In, $AgIn_2$
Gold	**Au_5Sn**, **AuSn,** $AuSn_2$, **$AuSn_4$**	AuIn, $AuIn_2$
Palladium	Pd_3Sn, Pd_2Sn, Pd_3Sn_2, PdSn, $PdSn_2$, $PdSn_4$	Pd_3In, Pd_2In, PdIn Pd_2In_3
Platinum	Pt_3Sn, Pt_2Sn, PtSn, Pt_2Sn_3, $PtSn_2$, $PtSn_4$	Pt_2In_3, $PtIn_2$, Pt_3In_7

Proprietăţi	**Unităţi**	**Cu_6Sn_5**	**Cu_3Sn**	**Ag_3Sn**	**Ni_3Sn_4**
Densitate	g/cm^3	8,28 +/- 0,02	8,90+/-0,02	10,0	8,65 +/- 0,02
Duritate Vickers	GPa	6,5 +/- 0,3	6,2 +/- 0,4	2,9	?
Modul Young	GPa	85,6 +/- 0,65	108,3 +/- 4,4	78.9 ± 3,7	133,3 +/- 5,6
Coeficient Poisson		0,31+/- 0,02	0,30 +/- 0,02	0,34	0,33 +/- 0,02
Coeficient Dilatare	ppm/ºC	16,3 +/- 0,3	19,0 +/- 0,3		13,7 +/- 0,3
Rezistivitate	μΩcm	17,5 +/- 0,1	8,93 +/- 0,1		28,5 +/- 0,1
Capacitate Termică	J/gK	0,286 +/- 0,02	0,326 +/- 0,02		0,272 +/- 0,02
Conductivitate Termică	w/cmK	0.341 +/- 0,05	0,704 +/- 0,1		0,196 +/- 0,02
Difuzivitate termică	cm^2/s		0,24 +/- 0,03		0,083 +/- 0,01

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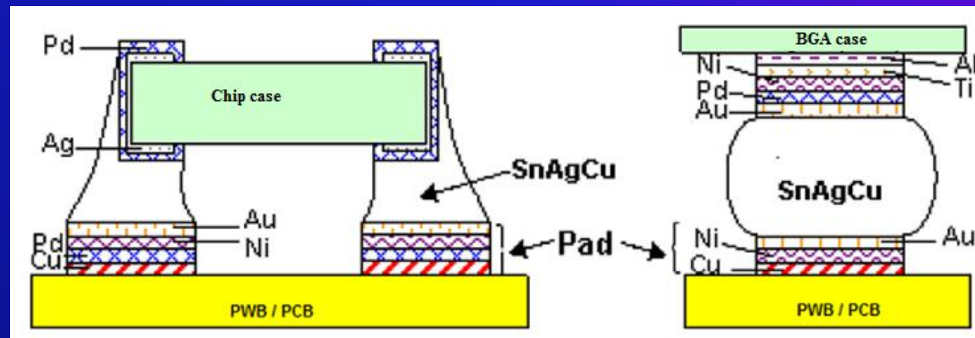
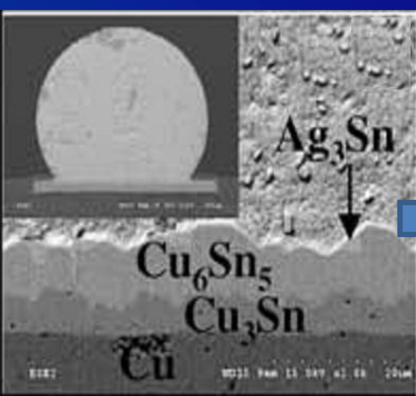
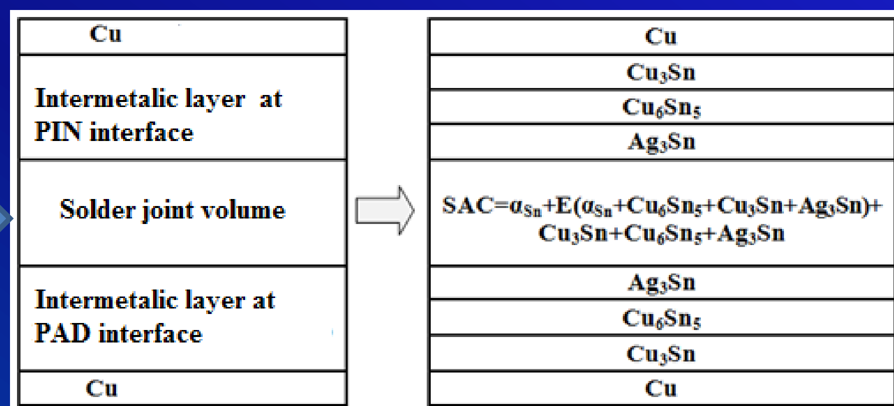


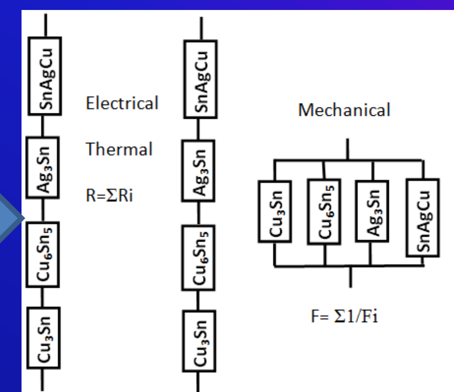
Pd
Chip case
Ag
SnAgCu
Au
Pd
Cu
Ni
Pad
PWB / PCB
BGA case
Ni
Al
Ti
Pd
Au
SnAgCu
Ni
Cu
Au
PWB / PCB



Ag_3Sn
Cu_6Sn_5
Cu_3Sn
Cu



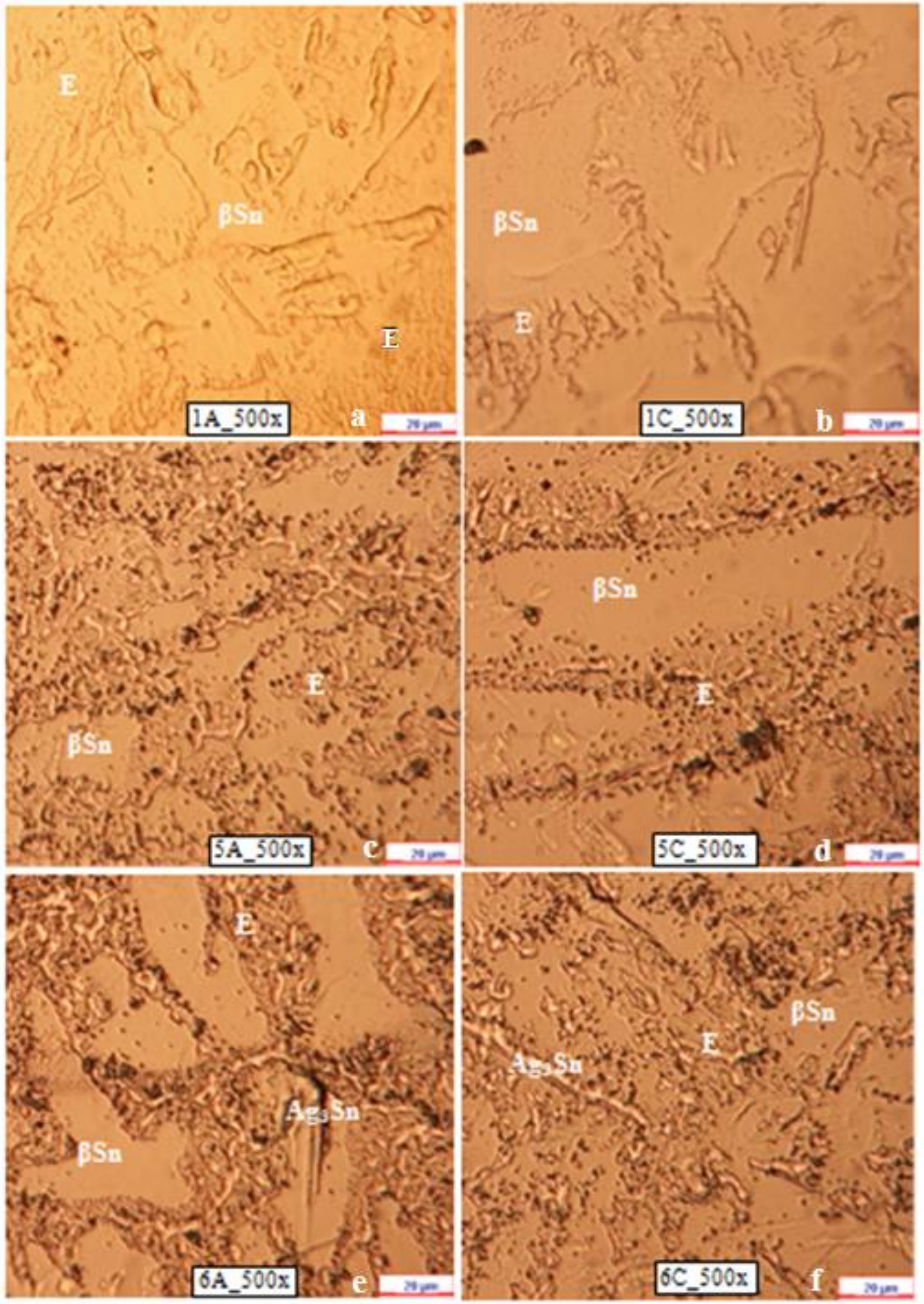
Cu
Intermetalic layer at PIN interface
Solder joint volume
Intermetalic layer at PAD interface
Cu
Cu
Cu_3Sn
Cu_6Sn_5
Ag_3Sn
$SAC=\alpha_{Sn}+E(\alpha_{Sn}+Cu_6Sn_5+Cu_3Sn+Ag_3Sn)+Cu_3Sn+Cu_6Sn_5+Ag_3Sn$
Ag_3Sn
Cu_6Sn_5
Cu_3Sn
Cu

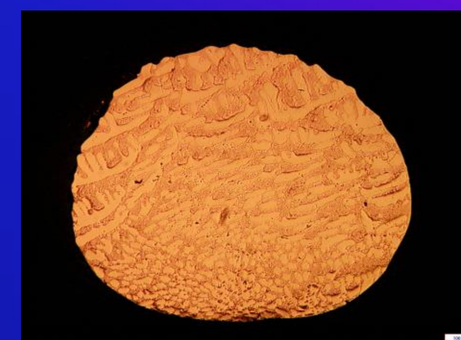


SnAgCu
Ag_3Sn
Cu_6Sn_5
Cu_3Sn
Electrical
Thermal
R=ΣRi
SnAgCu
Ag_3Sn
Cu_6Sn_5
Cu_3Sn
Mechanical
Cu_3Sn
Cu_6Sn_5
Ag_3Sn
SnAgCu
F= Σ1/Fi

1 = SN100C
2 = SN100C XF3
3 = SACX0807
4 = SACX0307
5 = SAC305
6 = SAC405

A = 4°C/s
B = 1.5°C/s
C = 0.5°C/s

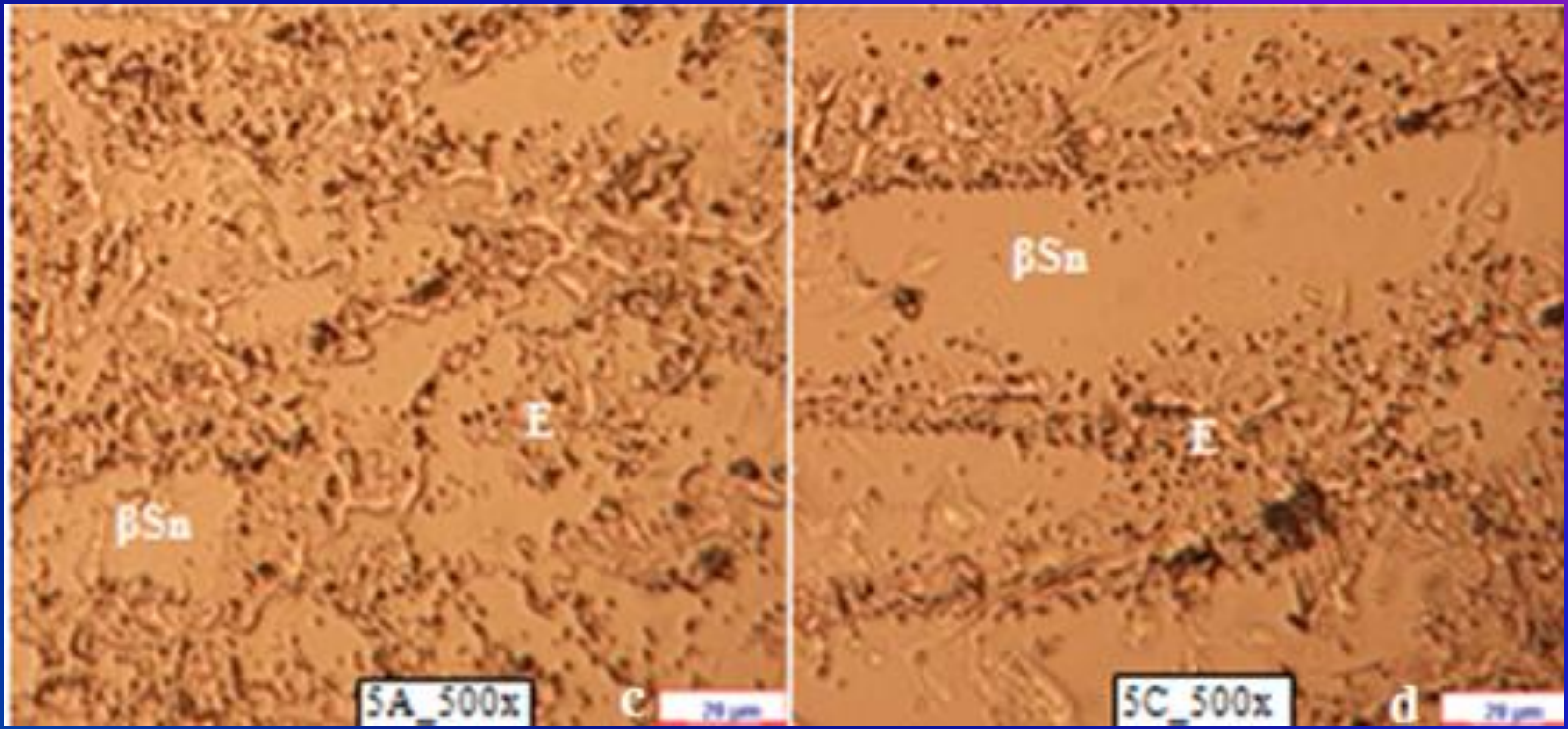




5C_100x

6C_100x

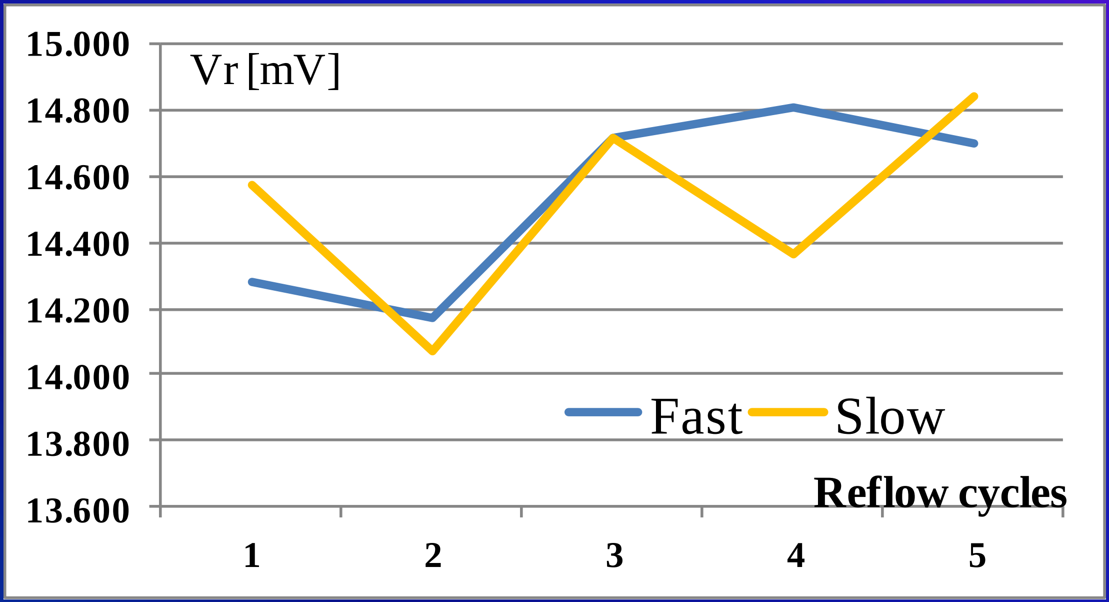
SAC 305



$$SXC = \beta_{Sn} + E\left(\beta_{Sn} + Cu_6Sn_5 + Cu_3Sn + Ag_3Sn + \sum_{1}^{n} X_pSn_q\right) + Cu_6Sn_5 + Cu_3Sn + Ag_3Sn + \sum_{1}^{n} X_pSn_q + V_{Incl}$$

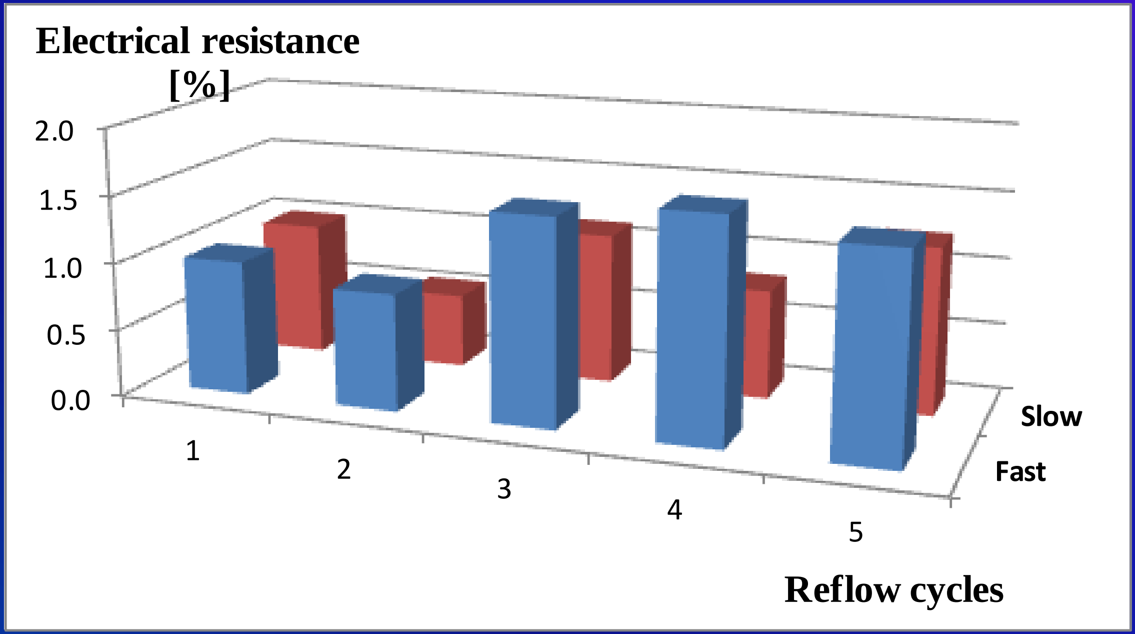
SXC = Aliaj tip Sn X Cu

Case of multiple reflow



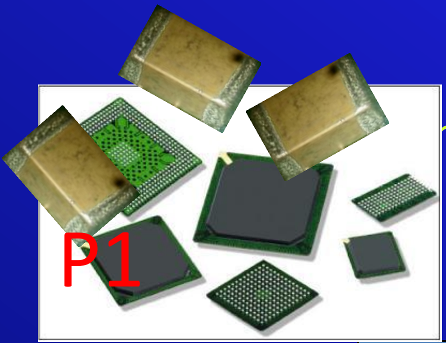
Voltage drop as function of reflow cycles

Electrical resistance variation compared to the resistance after the first reflow cycle



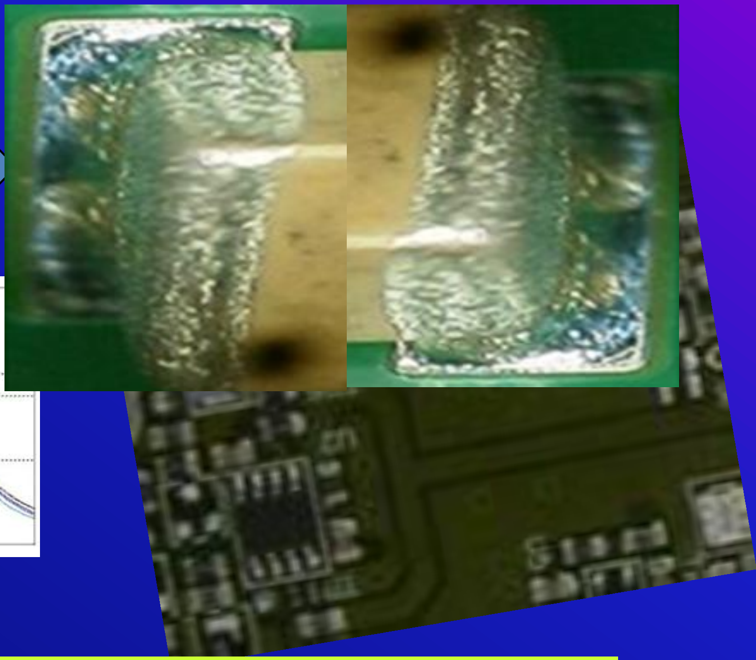
4 P Soldering Model concept

Electronic components



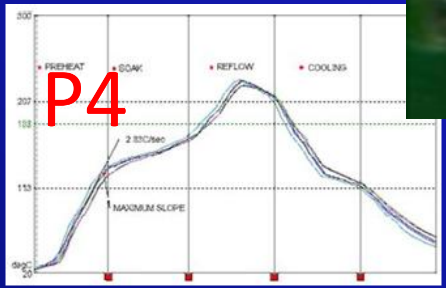
hermal profile

Solder joints



Solder Paste

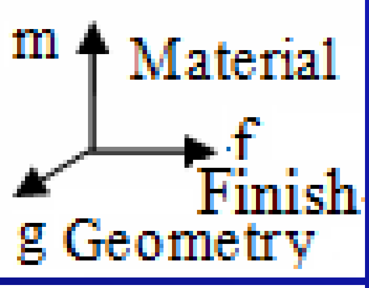
Soldering Process



Pad
NiAu, OSP, Ag-Im, HAL, Sn-Im

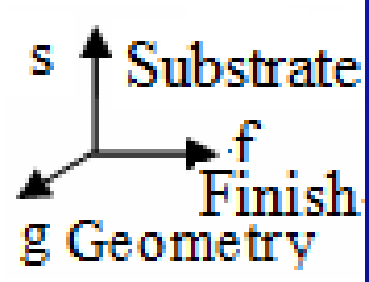
- **4P Soldering Model = 4 terms involve**

PIN-PAD-PASTE-PROCESS



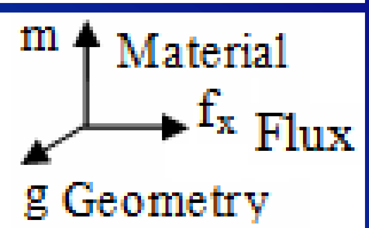
Define P_1 = Pin functions:

$P_1 = P_{1i}(g_i, f_i, m_i)$ [1]



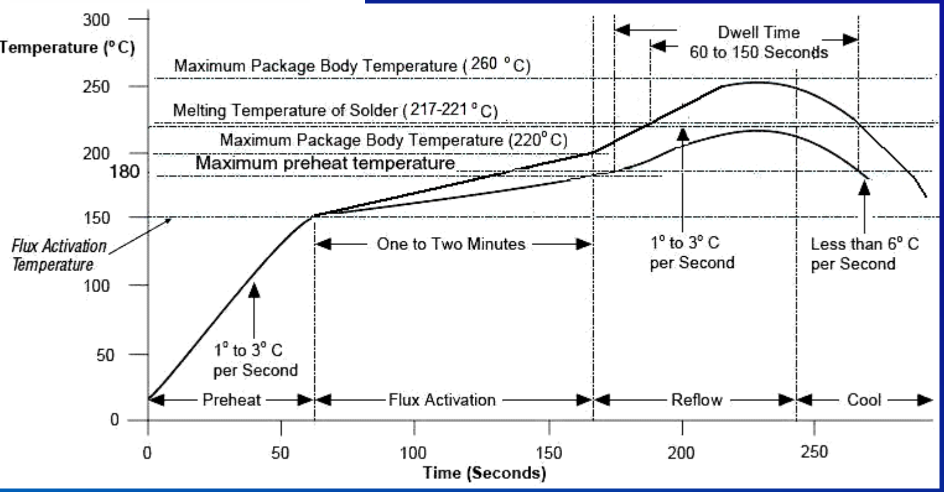
Define P_2 = Pad functions:

$P_2 = P_{2i}(g_i, f_i, s_i)$ [2]



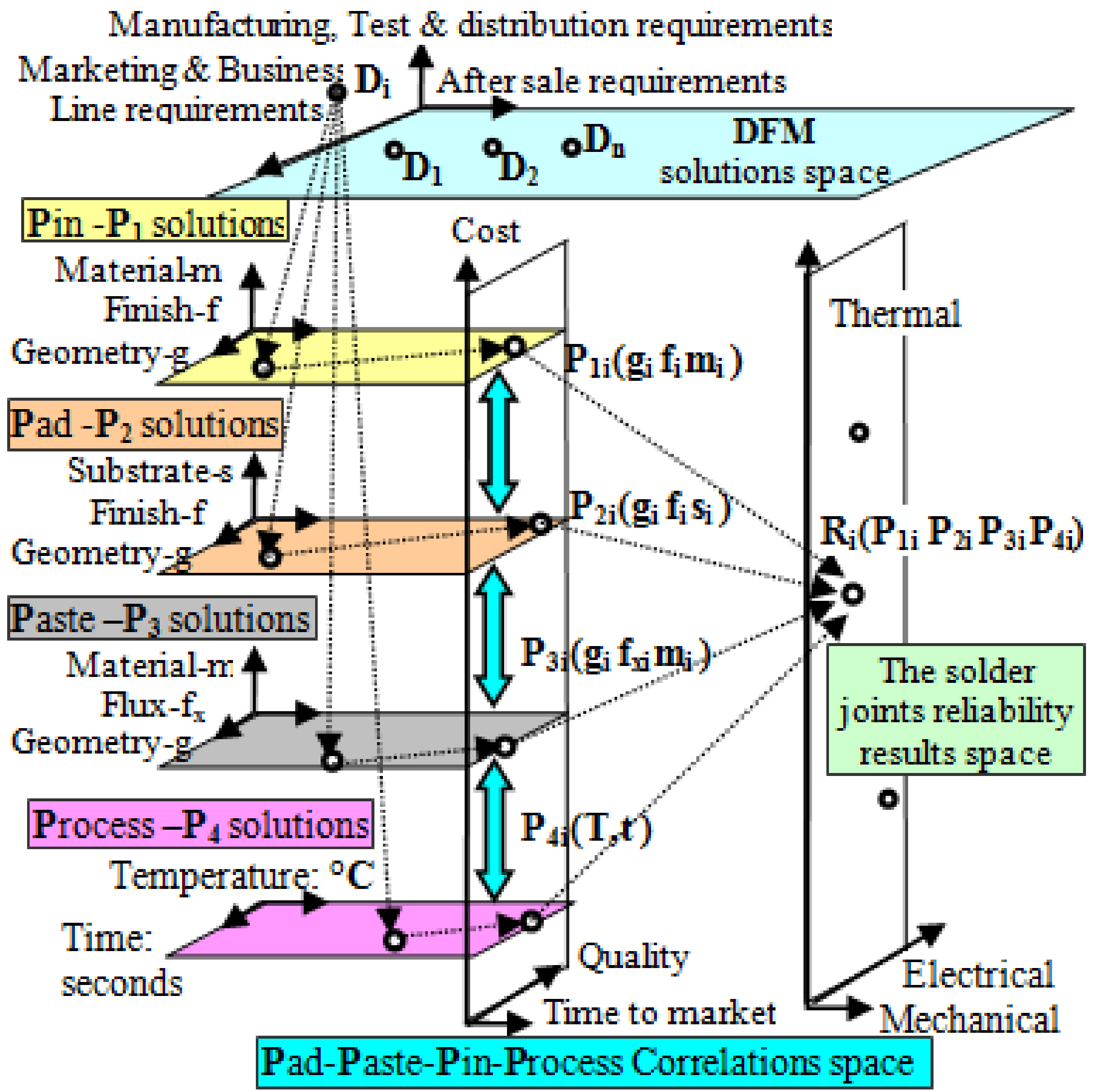
Define P_3 = Paste functions:

$P_3 = P_{3i}(g_i, fx_i, m_i)$ [3]



Define P_4 = Process functions:

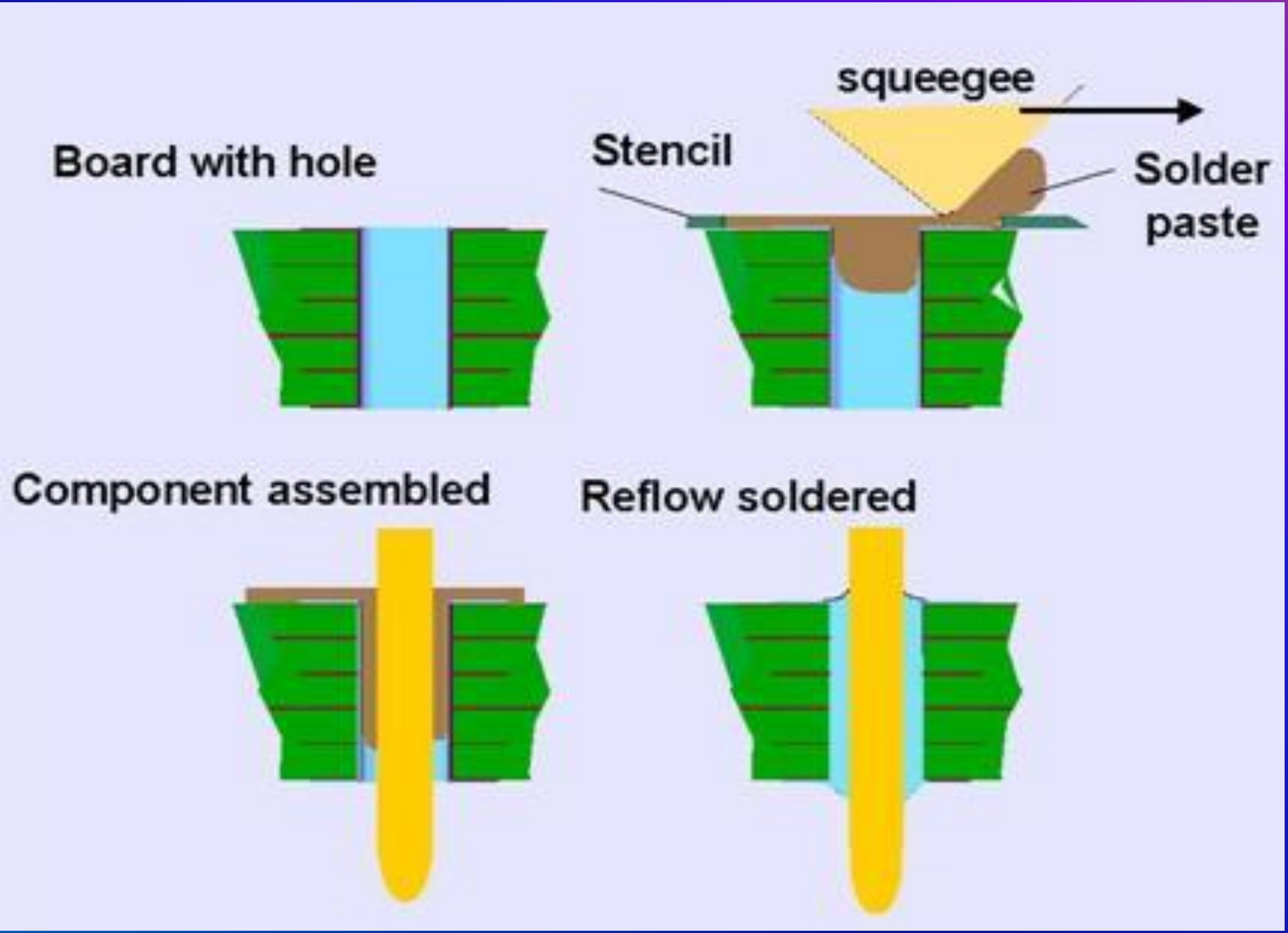
$P_4 = P_{4i}(T_i, t_i)$ [4]

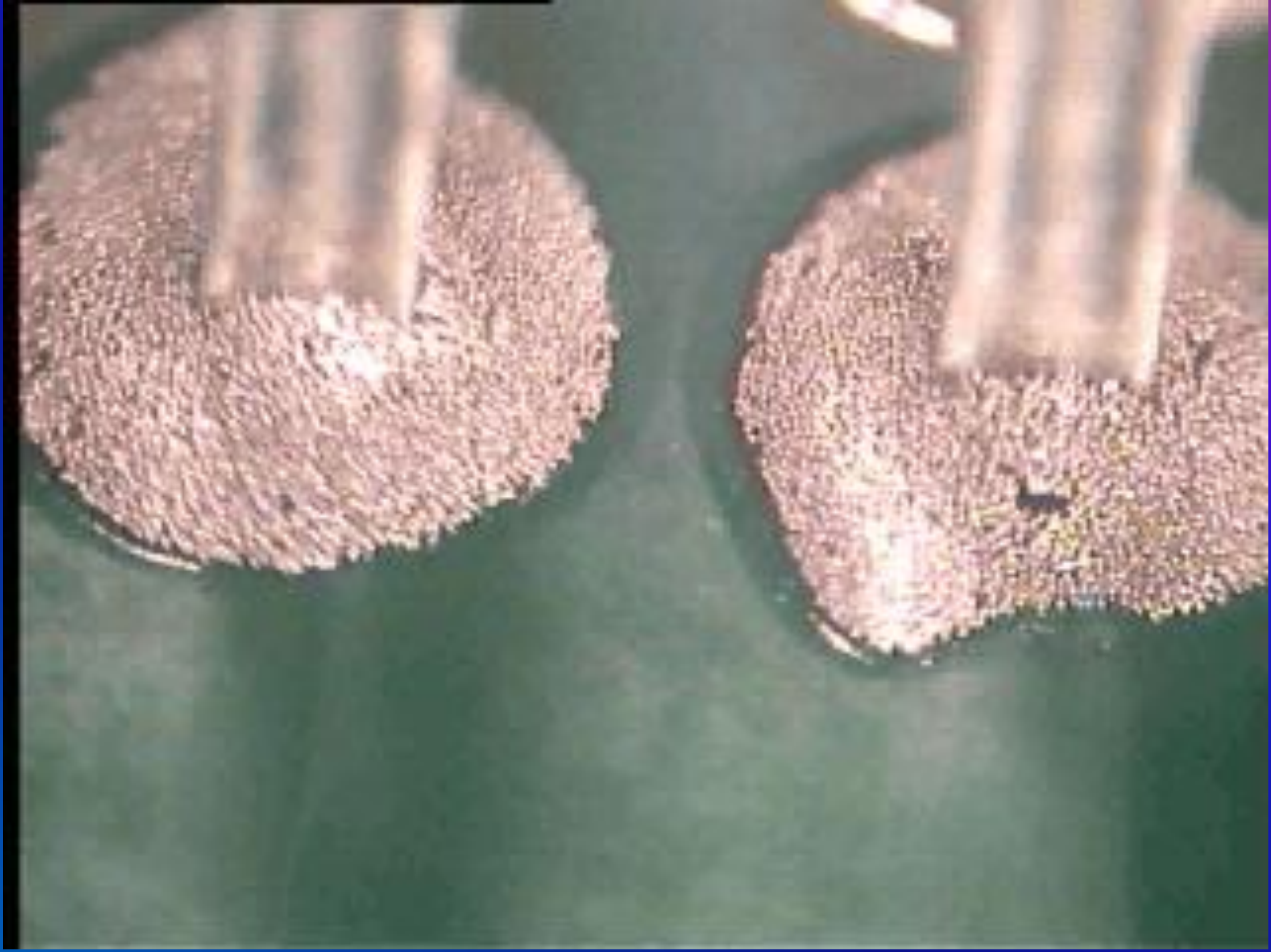


Manufacturing, Test & distribution requirements
Marketing & Business Line requirements
D_i
After sale requirements
D_1
D_2
D_n
DFM solutions space
Pin -P_1 solutions
Material-m
Finish-f
Geometry-g
Cost
P_1i(g_i f_i m_i)
Thermal
Pad -P_2 solutions
Substrate-s
Finish-f
Geometry-g
P_2i(g_i f_i s_i)
R_i(P_1i P_2i P_3i P_4i)
Paste –P_3 solutions
Material-m
Flux-f_x
Geometry-g
P_3i(g_i f_xi m_i)
The solder joints reliability results space
Process –P_4 solutions
P_4i(T,t)
Temperature: °C
Time: seconds
Quality
Time to market
Electrical
Mechanical
Pad-Paste-Pin-Process Correlations space

Cost reduction in DFM frame: Pin-In-Paste Applications

DFM !


squeegee
Board with hole
Stencil
Solder
paste
Component assembled
Reflow soldered



Summary

- **Electrical & thermal parameters depend by all P "actors" of the 4P soldering model was investigated;**
- **Pin-Pad-Paste-Process = 4P Soldering Model variables = Key Process Input Variables (KPIV);**
- **Pad-Paste-Pin-Process Correlations Space = KPIV proposed solutions synergistically interactions and correlations space;**
- **Solder Joints Reliability Results Space = reliability function space as univoque application of KPIV solutions.**

- **For each type of PCB it is necessary to adjust the thermal profile of the soldering process;**

- **The PCB structure influence significant the solder joints reliability;**
- $\tau_{th} = x^2 (\alpha)^{-1}$ **<u>important practical consequences</u>**

- **VPS soldering process contribute to the component thermal stress reduction (30°C maximum difference);**

- **VPS offer lower peak temperature & lowest ΔT;**

- **The solder joints can be considered result of a complex function of 4P Soldering Model whose dynamic elements, Pad-Paste-Pin-Process determine synergistically interactions and correlations.**

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Thank you for your attention

Do you have any Question ?

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FISA DE ANALIZĂ NOLOGICĂ						Total Nr. ORE/OM		Observații
Direcția:			Analiza tehnologică documentație pcb (pct. 1+2)					
Depart.:			Analiza și stabilire soluție tehnologică de asamblare (pct. 3)					
Intocmit:			Proiectare-reproiectare CAD-CAE-CAM, Stencil (4+5+6)					
Data:			Recepție IPC600 PCB tehnică și tehnologică (1.2.9)					
Nr. crt	**Denumire/ descriere produs**	**Cod produs**	**TITLU**				**CONȚINUT**	
1			1	Documentatie pcb - client	1.1.1	Desen de execuție PCB	Da/nu	
					1.1.2	Desen de execuție panel	Da/nu	
					1.1.3	CAE - schema	Da/nu	
					1.1.4	CAE - layout	Da/nu	
					1.1.5	CAM - gerber PCB	Da/nu	
					1.1.6	CAM - gerber panel	Da/nu	
					1.1.7	Model	Da/nu	
					1.1.8	Lista de materiale (include definirea capsulelor)	Da/nu	
					1.1.9	Observații IPC7351: documentația (modelul) - implicații tehnologice	Descriere	
			2	Caracterizare generala pcb	1.2.1	Dimensiuni PCB	mm	
					1.2.2	Dimensiuni panel	mm	
					1.2.3	Aperturi SMD top	Nr	
					1.2.4	Aperturi SMD bottom	Nr	
					1.2.5	Suprafața Cu SMD top	cmp	
					1.2.6	Suprafața Cu SMD bottom	cmp	
					1.2.7	Thermal relief - paduri top	Nr	
					1.2.8	Thermal relief - paduri bottom	Nr	
					1.2.9	Recepție PCB tehnică și tehnologică-observații IPC 600.	Descriere	
			3	Tehnologia de asamblare	1.3.1	Soluția tehnologica de asamblare	Descriere	
					1.3.2	Observații privind tehnologia de asamblare	Descriere	
			4	Proiectare / Reproiectare	1.4.1	CAD - desen de execuție PCB	ore	
					1.4.2	CAD - desen de execuție panel	ore	
					1.4.3	CAD - desen de execuție șablon	ore	
					1.4.4	CAE - schema	ore	
					1.4.5	CAE - layout	ore	
					1.4.6	CAM - gerber	ore	
					1.4.7	CAM - gerber panel	ore	
					1.4.8	CAM - gerber șablon	ore	
			5	Proiect panelare	1.5.1	Soluție panelare	Descriere	
					1.5.2	Timp necesar (1.4.2 + 1.4.7)	ore	
			6	Proiect șablon	1.6.1	Soluție șablon-grosime	Descriere	
					1.6.2	Număr total aperturi/ șablon	Nr	
					1.6.3	Timp necesar (1.4.3 + 1.4.8)	ore	
			7	Comanda șablon	1.7.1	Preț estimat /șablon	Moneda	
					1.7.2	Furnizor		
					1.7.3	Preț confirmat / data	Moneda	
					1.7.4	Expediere documentație șablon	Data	
			8	PCB	1.8.1	Cantitate / mod livrare	buc	
					1.8.2	Preț	Moneda	
					1.8.3	Furnizor		