

Effect of Process Variables on Frit Bonding in MEMS Wafer Level Packaging

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ELECTRONIC MATERIAL SYSTEMS



Objective

Rapid market growth and miniaturization place stringent demands on device materials, including the quality of the seal made in frit bonding the cap wafer to the base wafer in MEMS. Seal quality depends on both glass material properties and processing conditions in the bonding equipment. This study evaluates the effects of frit bonding process variables and two types of sealing glass pastes on the quality of frit bonded seals in MEMS.

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A. DOE: Taguchi L18 screening design

• Seven factors

- one at 2 levels – *paste type Regular FX11-036 (qualitative)*
- six at 3 levels – *back fill, peak temp, peak time, ramp rate, bonding force, cooling rate*

Factor	A	B	C	D	E	F	G
	Paste	Back Fill	Peak Temp.	Peak Time	Ramp Rate	Bonding Force	Cool Down Rate
Row #	Type	Type	°C	Min	°C/min	N	°C/min
1	Regular	N2	400	15	5	3200	5
2	Regular	N2	430	30	18	4000	13
3	Regular	N2	460	45	30	4800	20
4	Regular	None	400	15	18	4000	20
5	Regular	None	430	30	30	4800	5
6	Regular	None	460	45	5	3200	13
7	Regular	Air	400	30	5	4800	13
8	Regular	Air	430	45	18	3200	20
9	Regular	Air	460	15	30	4000	5
10	Hot melt	N2	400	45	30	4000	13
11	Hot melt	N2	430	15	5	4800	20
12	Hot melt	N2	460	30	18	3200	5
13	Hot melt	None	400	30	30	3200	20
14	Hot melt	None	430	45	5	4000	5
15	Hot melt	None	460	15	18	4800	13
16	Hot melt	Air	400	45	18	4800	5
17	Hot melt	Air	430	15	30	3200	13
18	Hot melt	Air	460	30	5	4000	20

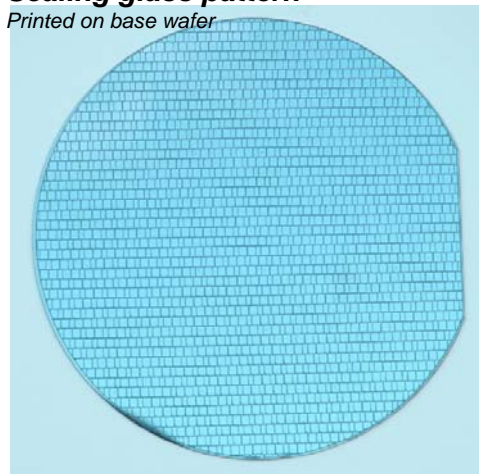
• Responses

- **Voids (score)**
 - Measure of severity of voids & do bonding
 - Average size of voids
 - Lower score is desired
- **Lead precipitates (score)**
 - None (0)
 - Small precipitates (0.5)
 - Normal precipitates (1.0)
 - Lower score is desired
- **Measure of defects in SEM microstructure**
 - Deloid at Si/glass interface (40)
 - Large voids (20)
 - Small voids (5)
 - Mud cracks (10)
 - Leafy precipitates (5)
 - Lower score is desired
- **Measure of defects in SAM scan**
 - % area looks hazy (not a good bond)
 - Lower score is desired
- **Optimize the values of input factors to attain the lowest overall score to realize good reliable frit bonded interface**

B. Experimental

Sealing glass pattern

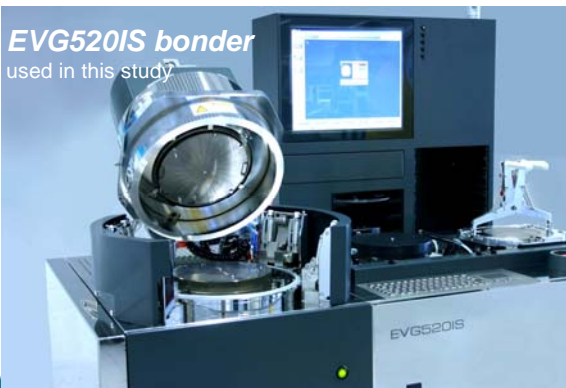
Printed on base wafer



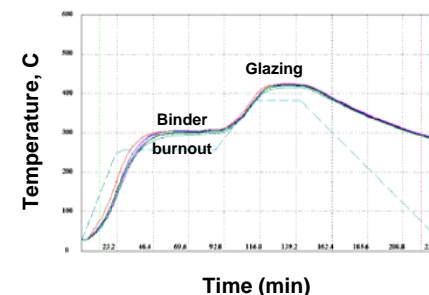
(Screen pattern - courtesy ST Microelectronics, Italy)

EVG520IS bonder

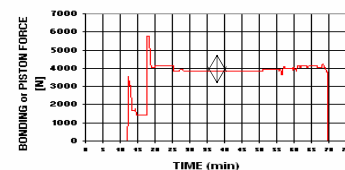
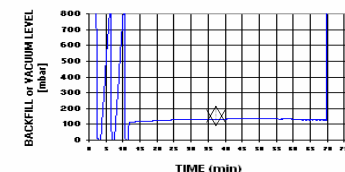
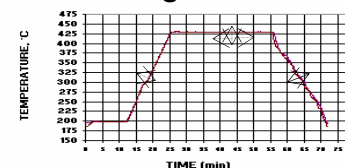
used in this study



Glazing



Frit Bonding



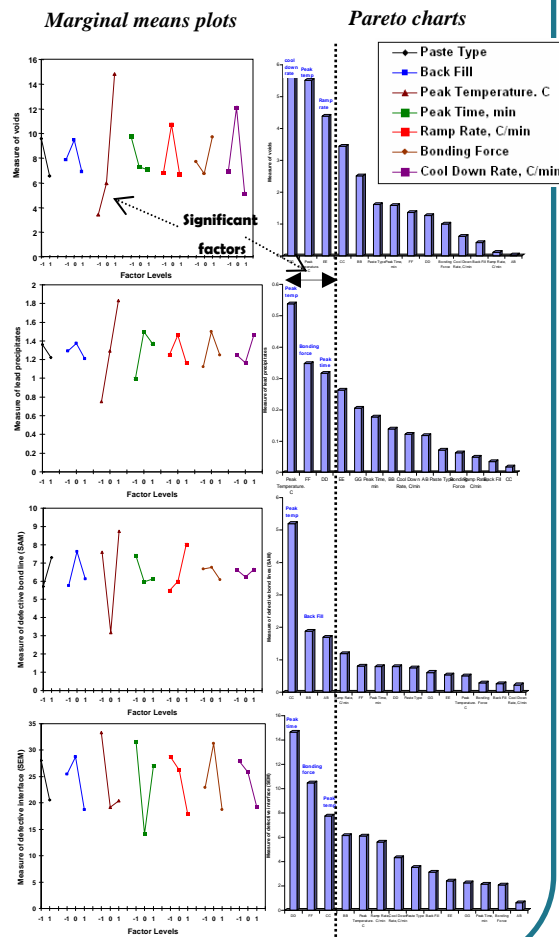
◊ Bonding variables studied

- Wafer used – 6” Si <100> boron doped with resistivity 0.01-0.02 Ω-cm

Print Thickness

dried: ~27 μm; glazed: ~17 μm; fired: ~9 μm

C. Plots to identify significant factors



Acknowledgements

We gratefully acknowledge the excellent SEM work by Mr. Dave Gnizak of Ferro, Independence, and the screen printing and firing work by Mr. Jeff Holthus of Ferro, CA

D. Results

Observed effects for different levels of factors considered for DOE

Factor	Paste	Back Fill	Peak Temp.	Peak Time	Ramp Rate	Bonding Force	Cool Down Rate	Random error	Void	Lead Precipitates	SEM Defects	SAM Defects
Row #	Type	Type	°C	Min	°C/min	N	°C/min	No	score	score	score	score
1	Regular	N2	400	15	5	3000	5	13, 18	5.25	0.25	62.5	8.99
2	Regular	N2	430	30	18	4000	13	37, 42	13.75	1.75	22.5	3.75
3	Regular	N2	450	45	30	4800	20	15, 39	17.50	2.00	17.5	9.92
4	Regular	None	400	15	18	4000	20	30	3.00	1.00	55.0	6.64
5	Regular	None	430	30	30	4800	5	17, 43	5.25	1.25	5.0	2.38
6	Regular	None	450	45	5	3000	13	22, 20	17.50	1.50	30.0	6.75
7	Regular	Air	400	30	5	4800	13	31, 25	7.50	1.00	27.5	2.84
8	Regular	Air	430	45	18	3200	29	14, 27	6.25	1.75	15.0	9.34
9	Regular	Air	450	15	30	4000	5	24, 15	15.00	1.75	27.5	10.26
10	Hot melt	N2	400	45	30	4000	13	35, 26	1.25	0.75	32.5	6.12
11	Hot melt	N2	430	15	5	4800	20	29, 36	3.00	1.00	12.5	1.21
12	Hot melt	N2	450	30	18	3000	5	12, 14	11.25	2.00	15.0	5.13
13	Hot melt	None	400	30	30	3200	20	38, 41	1.00	1.00	10.0	13.12
14	Hot melt	None	430	45	5	4000	5	28, 40	2.50	1.75	45.0	5.10
15	Hot melt	None	450	15	18	4800	13	23, 41	27.50	1.75	27.5	11.71
16	Hot melt	Air	400	45	18	4800	5	21, 19	2.50	0.50	22.5	8.45
17	Hot melt	Air	430	15	30	3200	13	45, 33	5.00	0.25	15.0	6.27
18	Hot melt	Air	450	30	5	4000	20	32	5.00	2.00	5.0	8.60

Blue coded conditions are optimums for each paste type from this study.

Inferences

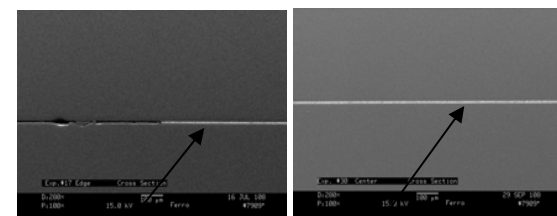
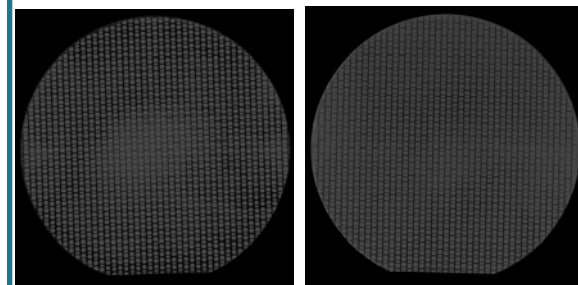
Factor	Paste	Back Fill to 100 mbar	Peak Temp. C	Peak Time Min	Ramp Rate C/min	Bonding Force N	Cool Down Rate, C/min	
Voids	To reduce void size	HM	yes	≤ 430 C	≥ 30 min	-----	-----	Faster
Lead ppts	To reduce lead ppts	HM	yes	≤ 430 C	15 min	-----	-----	Faster
Defects in SEM	To reduce debonds, voids & cracks	HM	yes	≥ 430 C	30 min OK	Faster	-----	Faster
Defects in SAM	To reduce poor bond lines	Reg	yes	430 C OK	≤ 30 min	Slower	-----	---

- Interaction plots show that as peak temperature decreases, peak time must increase to produce a good seal glass microstructure.

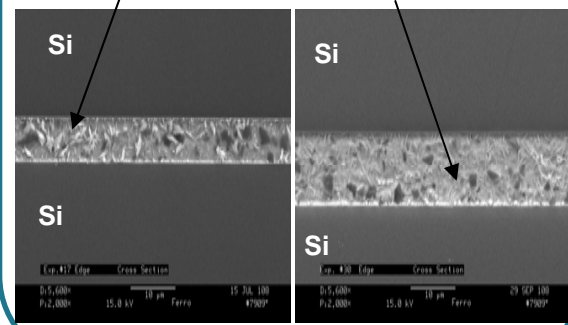
E. Main conclusions

- Peak temperature has the strongest influence on seal properties
- Defect score with HM ink is significantly lower over wider process conditions
- 400°C peak firing temperature is possible at certain combinations of factors for these sealing glass pastes

Regular vs Hot melt for optimum candidates SAM images of frit seal lines



Frit bonded interface (SEM)



Regular

Hot melt