Low Temperature Hermetic Packaging for MEMS Devices

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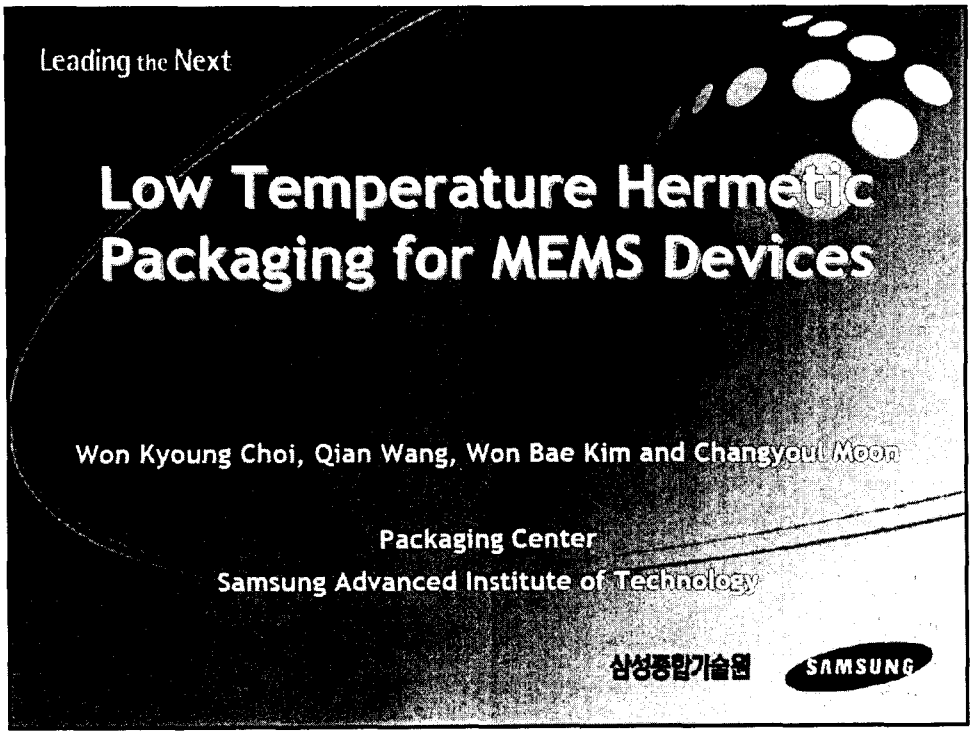

Outline

Leading the Next

- MEMS Packaging Issues & Hermetic Packaging
- Case Studies
  - 2D MEMS Scanner Hermetic Packaging using SnAgIn Solder for Laser Display
  - A Low Temperature, Hermetic Wafer Level Packaging using Au/Sn multilayer for RF MEMS Switch
  - CuSn Sealing for Low Temperature, Low Cost Hermetic Wafer Level MEMS Packaging
- Conclusions

MEMS Market (Major Players)

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MEMS Actuator/Sensor Applications

Communication — 269 M$
- Highly integrated Cell phone system
- RF Passive device, RFID
- Optical switching....
- EX: Agilent, Applied MEMS

Computing — 2,100 M$('04)
- Ink-jet printer
- Optical scanning
- On chip cooling system
- Mass storage
- EX: HP/ Lexmark, TI

Industry/Military — 646 M$
- Aircraft wing surfaces
- Gyroscope Navigation
- Missile control
- Cabin Pressure
- Probe testing
- EX: BAE System, Silicon Sen. Sys.

MEMS Sensors/Actuators fill the increasing need of electronic devices to interact with the physical world

Automotive — 1,292 M$('04)
- Airbag system
- Inertial navigation
- Pressure sensor
- Monitoring & control
- EX: ADI, Bosch, Delphi, Denso

Medical — 862 M$
- Lab-on-a-chip
- DNA analysis
- Chemical synthesis system
- EX: Affymetrix, Agilent...

Consumer — 215 M$
- Projection display (DLP)
- HDTV system, Optical scanning
- Pet Robot, Game pads, Headsets
- EX: TI, Philips

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출처: Broadview, '05.01 er

MEMS Structures

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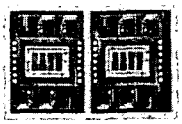
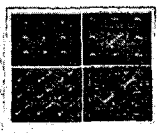
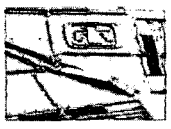
Class I	Class II	Class III	Class IV
No Moving Parts	Moving Parts, No Rubbing or Impacting Surfaces	Moving Parts, Impacting Surfaces	Moving Parts, Impacting and Rubbing Surfaces
			
Accelerometers Pressure Sensors Ink Jet Print Heads Strain Gauge	Gyros Comb Drives Resonators Filters	TI DMD ($1B) Relays Valves Pumps Optical Switches	

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Key Technology in MEMS Packaging

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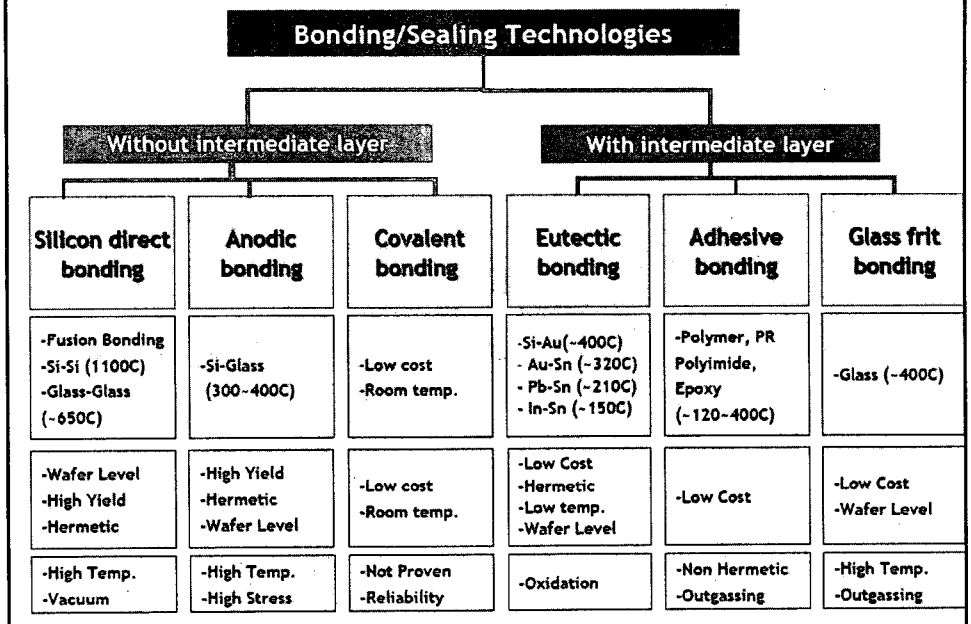

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Typical Issues in MEMS Packaging

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- Hermeticity
- Outgassing
- Warpaging during packaging/bonding (CTE mismatch)
- Stress induced during packaging or molding
- Low temperature bonding (<300°C)
- Thermal dissipation
- Low cost bonding & packaging
- High yield
- Low noise electrical interconnection (ex. Via hole)
- ETC..

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Hermetic Packaging

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- Definition :
  - Prevent diffusion of helium (He)
  - Leak rate should be lower than 5 x 10^{-8} atm·cc/sec in a small volume package (<0.40 cm^{-3})
- Hermeticity is the ability of a seal to maintain an acceptable level of stable and sometimes inert ambience for the packaged device.
- Maintain a high-vacuum environment in order to obtain a high Q-factor
  - MEMS accelerometers and gyroscopes
- Prevent ingress of moisture and contaminants
  - Thin-Film Bulk Acoustic Wave Resonators (FBARs)
- Increase the reliabilities regarding Stiction/ Mass change/Corrosion/Metal oxidation/Fatigue

Hermeticity Test_Gross Leak

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- Gross Leak (Bubble test)
  - Specimen is placed in FC-84 (boiling point 80°C) and subjected to a pressured environment for several hours
  - Specimen is dried and transferred into a chamber containing FC-40 (boiling point 139~189°C)
  - Specimen is dried and transferred into a bubble detection system containing FC-40 (Boiling point 139~189°C)
  - The system is heated to a temperature between the boiling points of the two fluorocarbon liquids.

Hermeticity Test_Fine Leak

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- Fine Leak Test
  - Specimen with cavity volume, V, is pressurized with high-pressure (P_b) helium in a bombing chamber for several hours (t_b)
  - Specimen is transferred into a He mass spectrometer
  - Spectrometer is switched on. The measured (apparent) leakage rate, R is proportional to the spectrometer output current.
  - The true leakage rate, L, is independent of the test conditions and is inferred from R.

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Hermeticity Criteria (MIL-STD-883)

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	Tracer	Condition Name	Remarks	Test Conditions				Normal Criteria for rejection		Principle & Apparatus
				Volumes (cc)	P_{bomb} (Pressurization)	T_{bomb} (Pressurization)	T_{test} (Evaluation)	Measured value (Rate in He^4 Gas in Air)	Equivalent (Rate in Air)	
Fine Leak detection	He	A1 "Fixed"	not be used if the max equivalent std leak rate limit is less than the limits specified herein for the fixed method.	< 0.05	75±3 psia	Min. 2 [hrs]	Max. 1 [hrs]	> 5 * 10-8 He	N.A.	Two chamber. -Pressurization -Evacuation "Apparatus"
				0.05 ≤ < 0.5	75 ±3 psia	Min. 4 [hrs]	Max. 1 [hrs]	> 5 * 10-8 He	N.A.	
				0.5 ≤ < 1.0	45 ±3 psia	Min. 2 [hrs]	Max. 1 [hrs]	> 1 * 10-7 He	N.A.	
				1.0 ≤ < 10.0	45 ±3 psia	Min. 5 [hrs]	Max. 1 [hrs]	> 5 * 10-8 He	N.A.	
				10.0 ≤ < 20.0	45 ±3 psia	Min. 10 [hrs]	Max. 1 [hrs]	> 5 * 10-8 He	N.A.	
		A2 "Flexible"	If the chosen dwell time is greater than 30 minutes, gratons shall be plotted to determine an R1 value which will assure overall with the selected gross leak limit compliance.	< 0.01	Var. [psia] (> min. 2 atm)	Var. [sec]	Var. [sec]	Measured R1	> 5 * 10-8	Two chamber. -Pressurization -Evacuation "Formula" "Apparatus"
				0.01 ≤ < 0.4				Measured R1	> 1 * 10-7	
				0.4 <				Measured R1	> 1 * 10-6	
		A4 "Unsealed"	gross leak testing is not required. However, not be used in lieu of the required leak testing of sealed packages.	The fixture and fittings shall be mounted to the evacuation port of the leak detector. Proof of housing integrity shall be verified by sealing a flat surfaced metal plate utilizing the gasket (and grease or fluid). Testing shall be performed by evacuation of the package cavity to 0.1 torr or less. Care shall be taken to prevent contact of grease with package (seal ring not included) to avoid masking leaks. The external portion of the package shall be flooded with helium gas either by the use of an envelope or a spray gun, at a pressure of 45 psia				> 1 * 10-8 He	N.A.	" Apparatus "
	Kr	B "Radio-isotope"	the possession and use of krypton-85 is permitted to all	< 0.01				> 1 * 10-8 Kr	N.A.	"Formula" " Apparatus "
				0.01 ≤ < 0.4				> 5 * 10-8 Kr	N.A.	
				0.4 <				> 5 * 10-7 Kr	N.A.	

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2 D MEMS Scanner Packaging for Laser Display

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Laser Display

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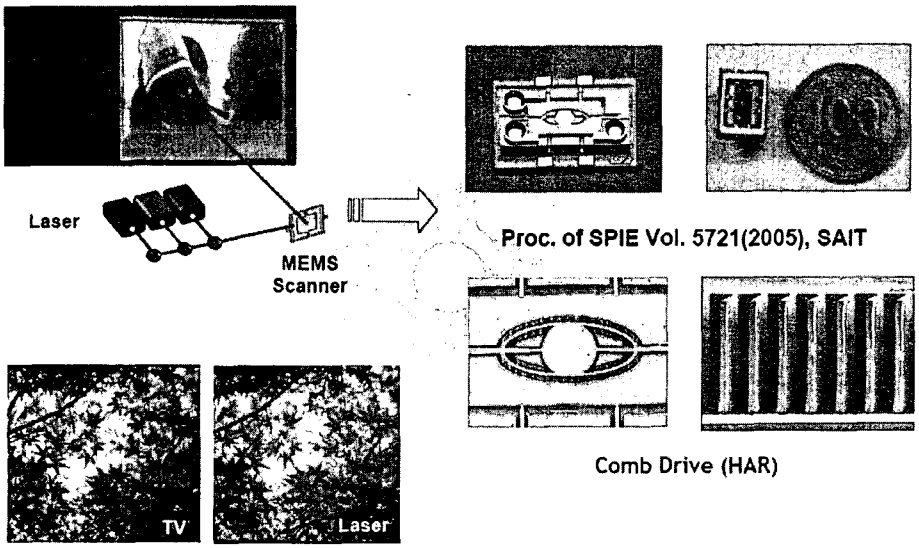

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Schematic Diagram of Micro Scanner

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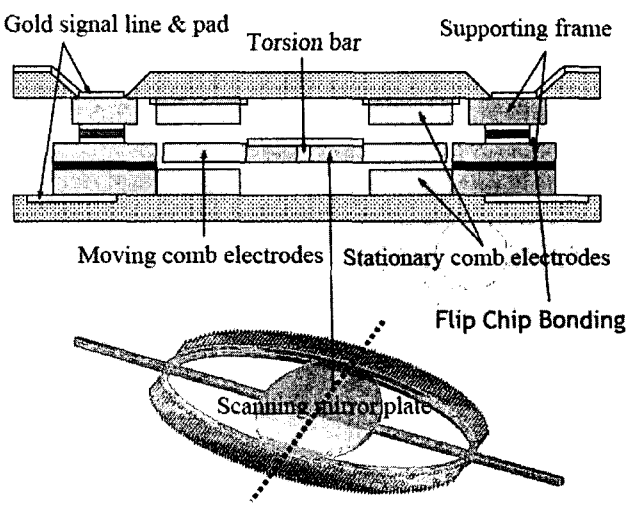

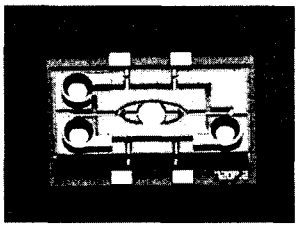

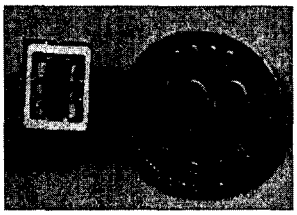

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Requirements for Micro Scanner Parts

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- Minimize the Optical Loss
  - Transparency of the window glass lid >99%
  - Absorb other scattered beams
- Hermeticity
  - To keep the scanner behavior uniform (Driving Frequency, Angle)
  - To protect the mirror reflectivity from being attacked by sulfuric gas
- High heat dissipation from the device to the outside
  - Thermal interface materials should be designed in the view of heat dissipation path.
- Process
  - The bonding temperature should be considered not to damage other components

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Package Design for Micro Scanner

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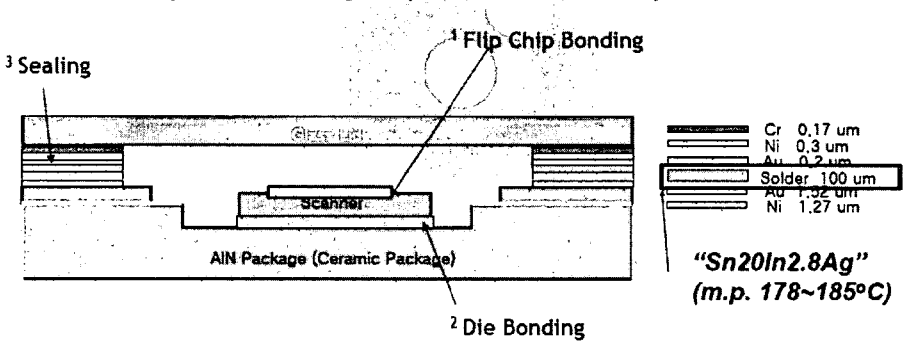
- Ceramic Package : AlN (~200W/mK)
- Glass lid : BK7
- Attachment Media ("Solder" was selected for "Hermeticity")
  : Flip Chip Bonding of Scanner ; AuSn (m.p. 280°C)
  : Die to PKG ; pure Sn (m.p.232°C)
  : Lid Sealing ; Sn20In2.8Ag (m.p.178~185°C,Indalloy) "Preform"



Hermetic Sealing Process

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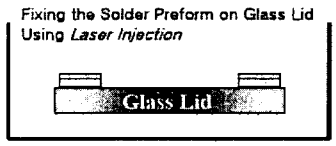
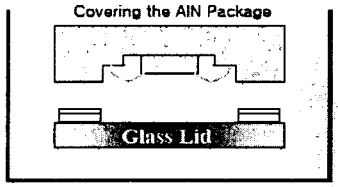
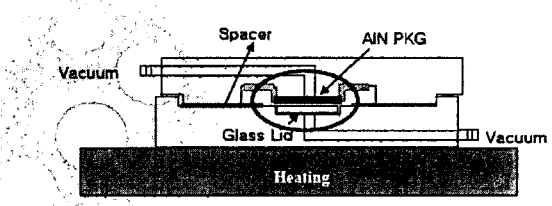
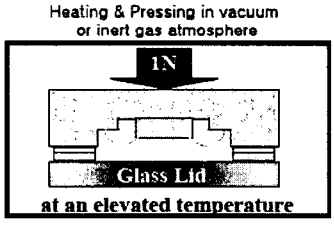


< Cross Sectional Diagram of Sealing Fixture >







DOE Results

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Vital Few X's

Reflow Temp	2 Level	220, 240 (°C)
Reflow Time	2 Level	1 , 2 (min.)
Spacer Thickness	2 Level	50, 70 (μm)
Cooling Rate	2 Level	Fast, Slow

Results

1. Hermeticity : < 1x10-8 atm.cc/sec in all conditions
2. Shear Strength : Some variations observed (3.77 ~ 17.41 kgf (23.86~110MPa))

xE-09 atm.cc/sec | kgf

StdOrder	RunOrder	CenterPt	Blocks	Temp	Time	acer Thickn	Cooling Rat	Hermeticity	hear Streng
1	1	1	1	220	1	50	0	2.00	17.41
2	2	1	1	240	1	50	1	1.60	13.68
3	3	1	1	220	2	50	1	1.20	14.25
4	4	1	1	240	2	50	0	1.50	14.75
5	5	1	1	220	1	70	1	7.50	11.12
6	6	1	1	240	1	70	0	5.00	8.14
7	7	1	1	220	2	70	0	2.00	3.77
8	8	1	1	240	2	70	1	4.00	7.10
9	9	0	1	230	1.5	60	0.5	1.70	10.47
10	10	0	1	230	1.5	60	0.5	2.00	15.25

C-mode SAM Images

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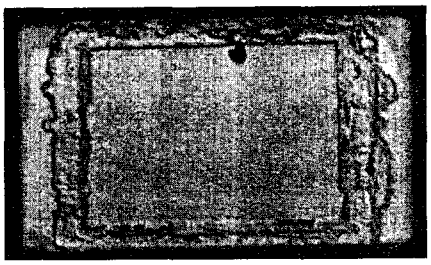
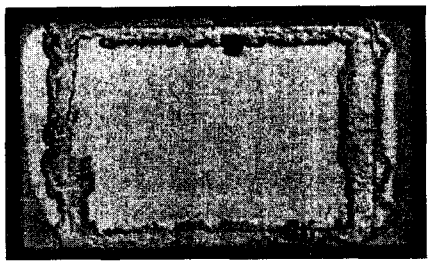
2. 240°C 1min 50μm fast cooling



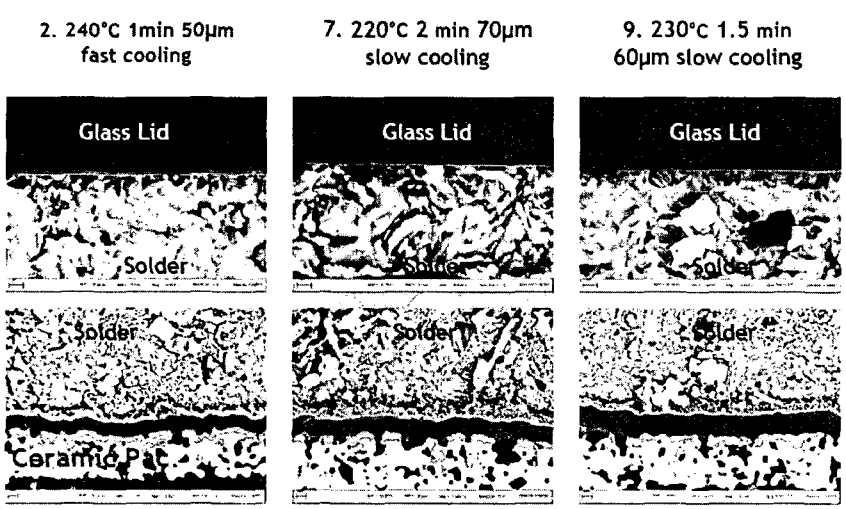
6. 240°C 1min 70μm slow cooling



- Continuous sealing with solder preform observed
- Any broken area not found
- Solder melted uniformly all around the sealing area
- Seems to be hermetically sealed

Cross-sectioned SEM Images at Interface

Leading the Next



- Confirm the strong chemical bonding between solder and metallization of glass lid & ceramic package

Hermeticity & Shear Strength

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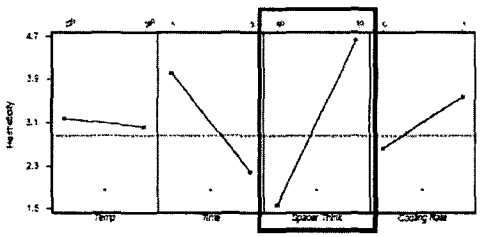
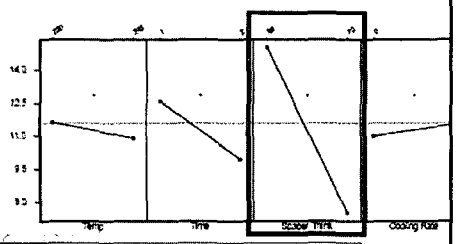
Main Effects Plot for Hermeticity

The lower is the better!



Main Effects Plot for Shear Strength

The higher is the better!



"Spacer Thickness" affects the most importantly.

- Reflow Temperature : Not much affect both characteristics
- Reflow Time : Opposite trend
- Spacer Thickness : Thinner is better.
- Cooling Rate : Slow cooling rate is better in a view of hermeticity.

Optimized Condition

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- Optimization was performed using a statistical program ("MINITAB").

Temp. : 230°C Time : 1min 40sec Spacer Thickness : 50 um Cooling Rate : 1.6°C/sec	Would be got ⇨	0.6x10-9 atm cc/sec 14.7187 kgf (~100MPa)

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Verification (Reproducibility Test)

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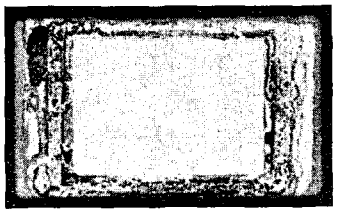
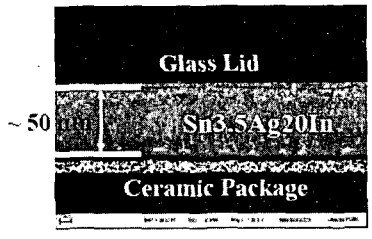
Opt. Process : 230 °C, 1.67min, 50 μm, Slow Cooling (1.6°C/sec)

❖ C-Mode SAM image



❖ Cross-sectioned view



	Hermeticity (10^{-8} atm cc/sec)	Shear Strength (MPa)
1	0.15	87.829
2	0.12	90.006
3	0.1	101.601
4	0.16	76.765
5	0.13	94.006
6	0.15	87.050
7	0.12	90.715
AVG	0.132($<1.0\times10^{-8}$) MIL-STD-883E	89.71

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Reliability_High Temperature Storage

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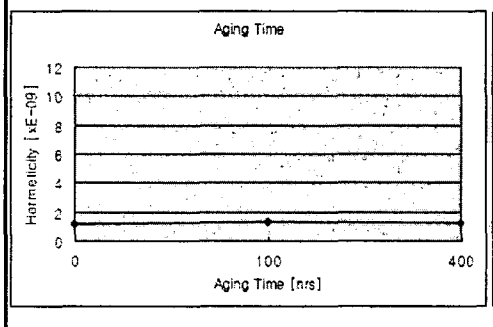
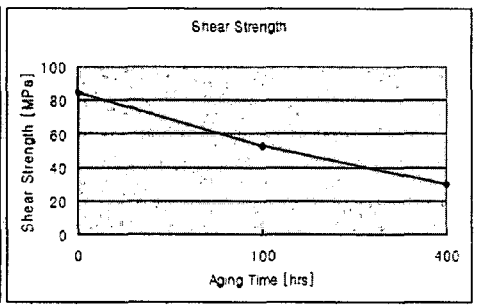
- Condition : 120°C, 100 hrs, 400 hrs in air
  (Bonding ; 230°C, 1.67min, 50μm, slow cooling (1.6°C/sec))

Heremticity



Shear Strength



-Hermeticity was kept less than $2x10^{-9}$ atm cc/sec

-Somewhat degradation of shear strength observed due to the softening of solder

Reliability_High Temperature/High Hu

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- 85%RH85C, 0, 500hrs, 1000hrs) : Reliability Spec. Passed
  : Applied Voltage : DC100V, AC70V

	MEMS Scanner Resonance Frequency	Hermeticity
0hr	22.68kHz	$1.32x10^{-9}$ atm·cc/sec
500hrs	22.665kHz	$2.8x10^{-9}$ atm·cc/sec
1000hrs	22.665kHz	$3.1x10^{-9}$ atm·cc/sec

Reliability_Thermal Cycling Test

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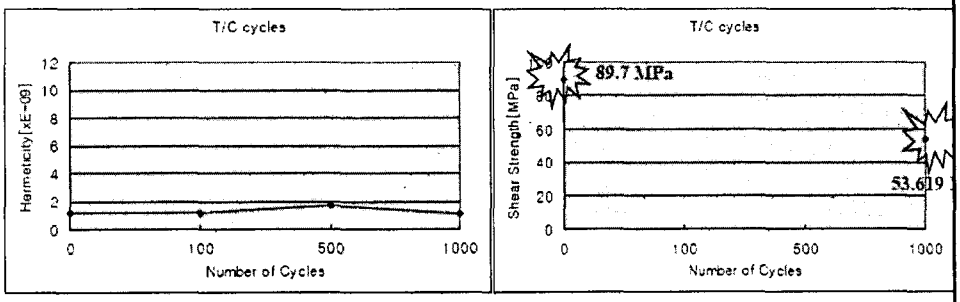
Conditions : -55~125C, 15min duration time, (5~10) min ramp time, x1000 cycles
(Bonding ; - 230°C, 1.67min, 50μm, slow cooling (1.6°C/sec))

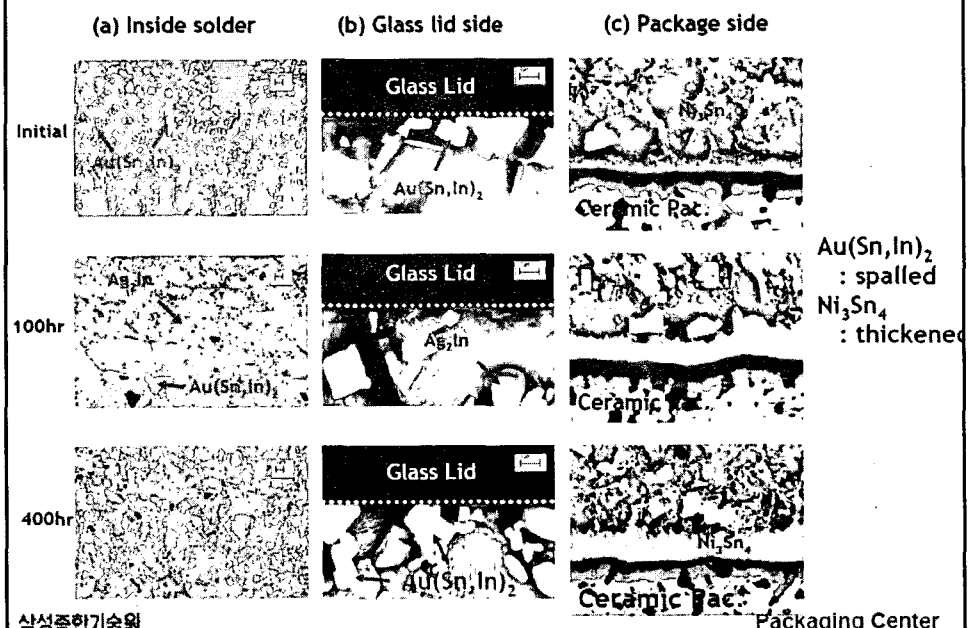


-Hermeticity was kept less than $2x10^{-9}$ atm cc/sec

-Somewhat degradation of shear strength observed but not much

Cross-sectioned SEM Images after [illegible]

Leading the Next



Summary

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- The hermetic package was successfully adopted to the micro scanner using Sn-2.8Ag-20In (Indalloy).
- Hermetic sealing process was optimized
  - 230°C, 1min40sec, 50μm spacer thickness, 1.6°C/min cooling rate
  - Hermeticity : <2x 10^{-9} atm cc/sec
  - Shear strength > 80 MPa
  - Complete sealing by seeing SAM Image
- Reliability tests (HTS & T/C) were performed
  - HTS (120°C, 400hrs) : Hermeticity < 2x 10^{-9} atm·cc/sec
    Shear Strength ~ 20 MPa
  - T/C (-55~125°C, 1000 cycles) : Hermeticity < 2x 10^{-9} atm·cc/sec
    Shear Strength ~ 50 MPa
  - Humidity (85%RH:85oC, 1000hrs) : Hermeticity < 3.1 x10^{-9} atm·cc/sec

Leading the Next

A Low Temperature, Hermetic Wafer Level Packaging for RF MEMS Switch

RF MEMS PKG Issues

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To provide mechanical & environmental protection to devices without degrading electrical performance

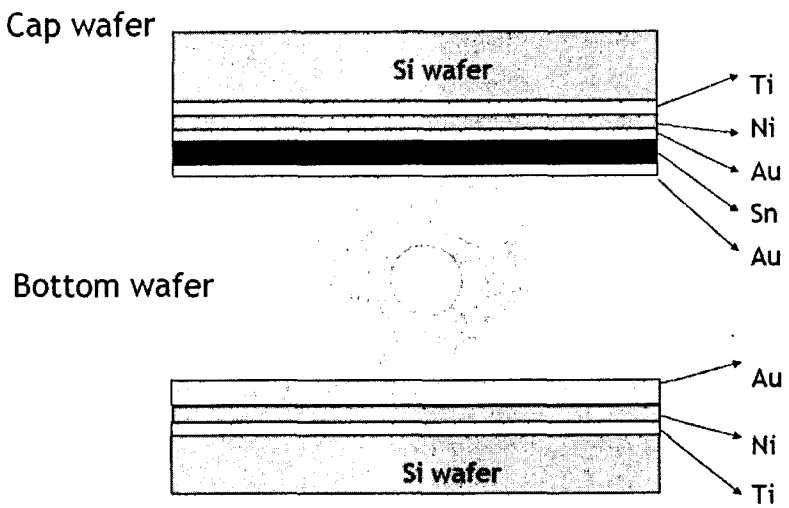
- Miniaturization
- Low temperature
- Hermetic sealing
- Reliability
- Low loss

Solution

WLP+ through wafer interconnection
(Protect device part during dicing)+(short length of interconnection)

Solder System Metallization

Leading the Next



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Bonding Profile

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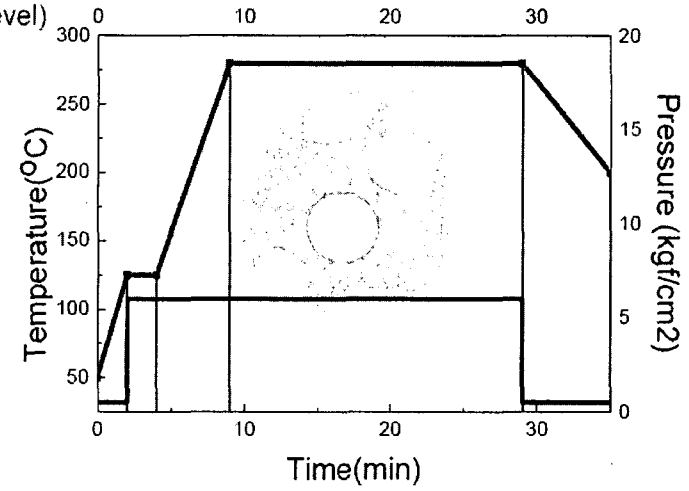
Ambience N2
(wafer level)



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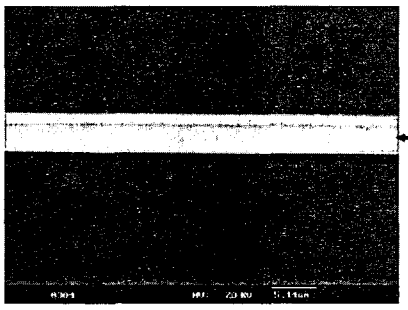
X-section SEM Image

Leading the Next



[Sealing area interface]

Void-free sealing interface is obtained (uniform)

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Evaluation Items

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Category	Item	Specification	Measurement	Result
Mechanical Characteristics	Shear Strength	>30MPa	Shear tester	Pass
	Microstructure of sealing area	Void free	SEM (or X-ray)	Pass
	Wafer Misalignment	±5um	Microscope	Pass
Hermetic Sealing	He Leak Rate		Helium Leak detector	Pass (1.6×10^{-8} mbar-l/sec)
	RGA (Residual Gas Analysis)	H_2O, N_2, O_2, Ar, CH_x Relative Quantity	RGA test instrument	Pass
RF Characteristics	Insertion Loss	Total loss <2.7dB (PKG loss <0.05dB)	CPW(Coplanar Wave Guide) + High Freq. Network Analyzer	Pass
Reliability	Thermal shock	No fail, no obvious properties degradation		Pass
	High temperature, high humidity storage			
	Pressure Cooker Test (PCT)			

Reference: MIL-STD-883F

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Summary

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1. A low temperature hermetic WLP scheme for RF-MEMS switch is presented, fabrication processes including through wafer interconnection are discussed.

2. A series of performance tests have been made for fabricated RF MEMS switch, and good results have been obtained which could satisfy the requirement.

3. Packaging structure presented in this paper has applied standard micromachining manufacturing technologies, therefore, the scheme is applicable not only for RF switches but also for a variety of RF MEMS devices such as duplexer, filter etc.

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CuSn Sealing for Low Temperature, Low Cost Hermetic Wafer Level MEMS Packaging

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Concept

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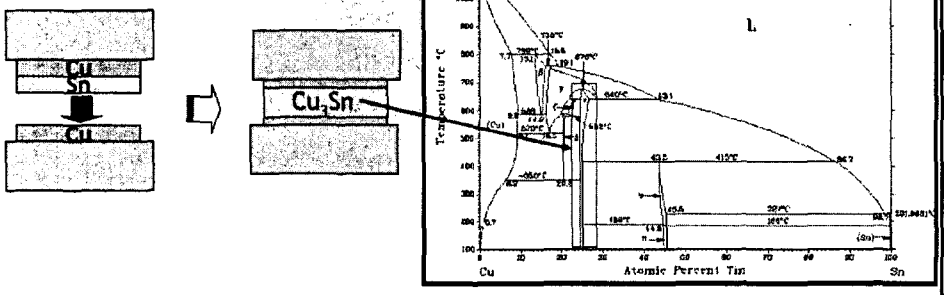
- Using Cu/Sn multilayer on Cu surface
- After reflow at an elevated temperature for long dwelling time, the joint would be changed to Cu_3Sn phase which has about 676°C decomposition temp.
- To get uniform ε (Cu_3Sn) layer



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Test sample for Bonding test of Cu/Sn

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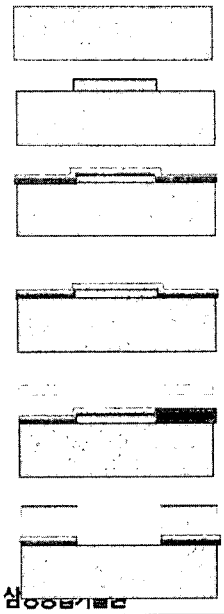
Cap wafer (Pyrex Glass wafers)



Wafer preparation

Photolithography
NRI-6000PY(Nega),
1.5um

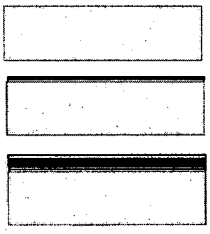
E-beam evaporation
Ti/Cu (500A,1000A)

PR mold
PR (THB-151N,Nega,
~70um)

Electroplating
Cu-Sn-Au

Remove PR

Bottom wafer (Si)

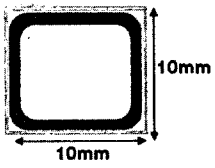


Wafer Preparation

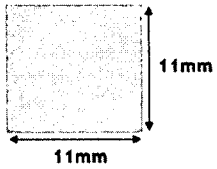
Seed layer deposition
E-beam evaporation
Ti/Cu (12 wafers)
400A/2000A

Metal electroplating
Cu/Au

<Cap Wafer>



<Bottom Wafer>



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Optimization Results

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- Seal Dimension : 10um Cu Thick, 300um Seal width
- Reflow Condition : 280°C, 10min, 6kgf/cm²

	Shear Strength	Hermeticity
1	8.28	1.3
2	7.41	2
3	8.5	3
4	9.24	2.6
5	7.76	4.1
6	7.3	1.1
7	6.35	3
8	9.22	2.2
AVG	8	2.4

Shear Strength : MPa
Hermeticity : 10^{-8} atm cc/sec

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X-sectional SEM Image

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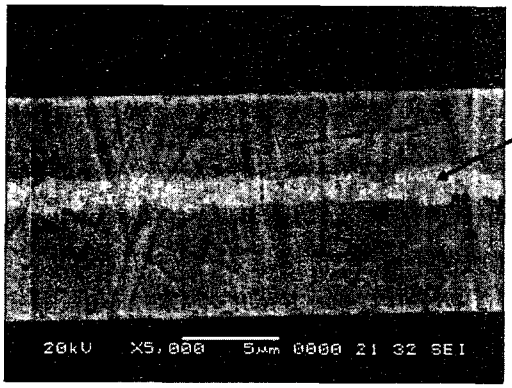

EPMA Analysis Result

Cu	Sn	Phases
90.5	9.5	FCC(Cu) + $\varepsilon(Cu_3Sn)$

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Fractured Surfaces

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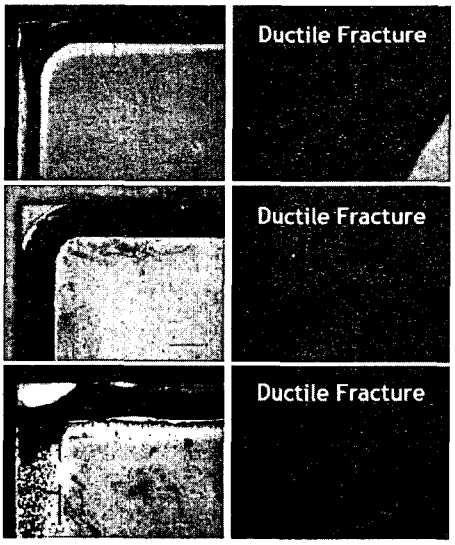

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Reliability Test

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- **High Temperature Test (125°C, 500hrs)**
- **Humidity Test (85°C:85%RH, 500hrs)**

	As-Sealed	HTS (500hrs)	Humidity Test (500hrs)
Hermeticity (atm·cc/sec)	2.4	2.9	3.5
Shear Strength (MPa)	8	10.12	8.25

Conclusion

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- Optimization Result
  - We've got average Hermetcity 2.4×10^{-8} atm cc/sec, average Shear Strength 8.00MPa.
- From the HTS, 85:85 reliability tests, the hermeticity and shear strength values were kept as a similar level to the value of the as-sealed PKG.
- Further tests are still going on, now.

CONCLUSIONS

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- Most of MEMS Packages require the hermeticity for their reliable moving behavior.
- Low temperature hermetic packaging was carried out at <300°C using various solder seals.
- SnAgIn sealed hermetic PKG could be obtained at 230°C reflow temperature, and AuSn and CuSn sealed hermetic wafer level PKGs were successfully shown through sealing process at 280°C.
- It was shown that these packages passed the standard reliability tests.