Gold-Silicon Eutectic Wafer Bonding Technology for Vacuum Packaging

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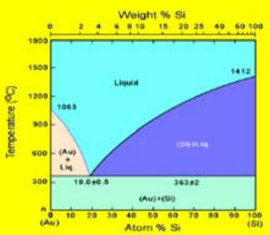
Project Description

Low-cost, simple, and reproducible hermetic/vacuum packaging technologies are required for many microsystems, including resonant devices and RF MEMS. Of the wafer bonding techniques available, eutectic bonding is one of the most attractive because it is easy to use, it forms a soft eutectic to allow bonding over non-planar surfaces, it can be done at slightly above the eutectic temperature (363°C for Au-Si), and it does not out-gas. Although Au-Si eutectic has long been used for die bonding and packaging, few have reported its successful use in vacuum packaging or even wafer to wafer bonding. There are several reasons for this, including non-uniform eutectic formation, insufficient eutectic material in between wafers causing non-uniform bonding, void formation, oxidation of bond surfaces, and poor surface contact/adhesion. This project aims at developing a uniform, high-yield, reproducible, silicon-gold eutectic wafer-level bonding technology used for vacuum encapsulation of MEMS.

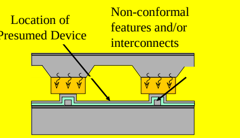
Au-Si Eutectic Bonding Technology

Why a Au-Si Eutectic?

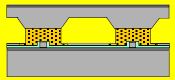
Above 363°C, the Au-Si eutectic liquefies allowing for the joining of non-uniform surfaces.



The Au-Si eutectic phase diagram.

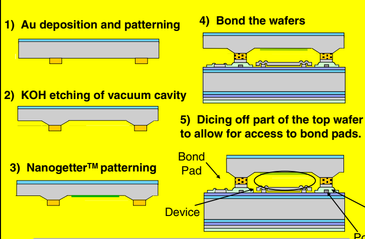


(a) Silicon is diffuses from both the cap wafer and the device wafer @ T>363 °C.

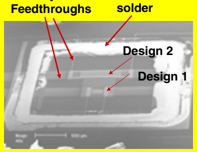


(b) Upon cooling, a strong diffusional and chemical bond is obtained.

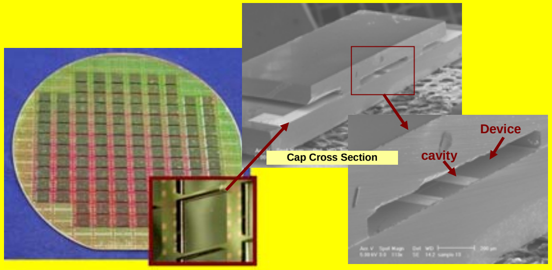
Fabrication



The process flow for device encapsulation.

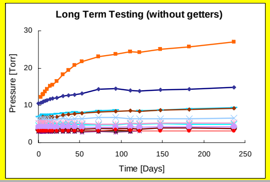


Two different Pirani gauge designs were used for pressure measurement in the 200 to 0.5 Torr and 5 Torr to 1 mTorr ranges.

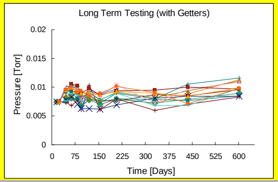


A wafer with 124 vacuum packaged devices fabricated using a Au-Si eutectic, a zoomed in view of a package and cross-section view of a package.

Results



In packages without getters, initial pressures of 1 to 12 Torr and changes of pressure of ~0 to 80 Torr/year were measured.



Packages with getters remains stable even after 600 days of testing.

Table 1: A summary of the reliability tests showing how many devices survived of the ones tested.

Test	Test Parameters	Bond Ring Width	
		150μm	300μm
Temperature/humidity (saline)	95ºC 200 h	1/5	4/5
Temperature	150 ºC, 100h	1/1	12/12
Thermal Cycles	50 cycles, -65 to 150ºC	-	6/6
Low freq. vibration	10 Hz, 2g, 12 hours	-	15/15
Low freq. vibration	30 Hz, 16.5 g, 12 hours	-	15/15
Shock	1m (>100g)	-	5/12
Shock	3m (>1000g)	-	1/12

RELIABILITY RESULTS/SUMMARY

- ***Temperature:*** Elevated temperatures do not appear to affect the pressure.
- ***Saline Soak:*** Bond ring width seems to make a difference in life time.
- ***Shock/vibration:*** Vibration and shock do not effect the pressure unless the cap is physically broken.

RESULTS SUMMARY/BENCHMARKING

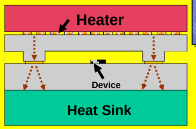
- **Development of a Au/Si eutectic bonding process.**
- **Pressures from 1 to 16 mTorr in a wafer level bonding process with useful reliability test data.**

Table 2: Good results are shown in the literature—but in general, they do not specify the details of their process (*N.I.= no information given).

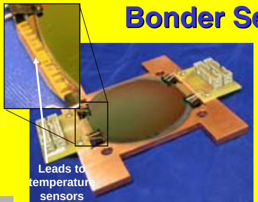
Institution	Bond Material	Bond Temp.	Bond Process	Pressure	Leak Data
Raytheon	Solder (unspecified)	N.I.*	N.I.*	4 mTorr	~950 Days
This Work	**Au-Si Eutectic**	**390**	Detailed	**1 to 16 mTorr**	**600 Days**
Flip Chip Dot Com	Solder (not specified)	N.I.*	N.I.*	7.5 mTorr	-
Samsung	Glass Frit	450	N.I.*	150 mTorr	-
LETI LIR, France	Au-Sn Solder	N.I.*	N.I.*	1 Torr	-
Delphi Automotive	Solder (unspecified)	N.I.*	N.I.*	1.5 Torr	42 days

Localized Heating

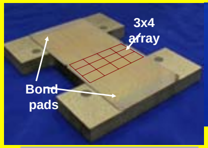
Bonder Setup



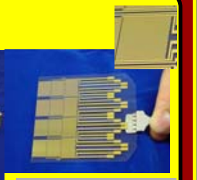
Using resistive backside heating, heat passes through the bond rings towards the heat sink so that the device stays cool.



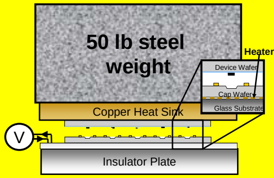
Wafers were aligned in a SUSS bonder and clamps were used to hold their alignment as they sat atop the copper heat sink. Also, part of the cap wafer was diced away (top left) to allow access to the temperature sensor leads and wire bonds were made to these leads.



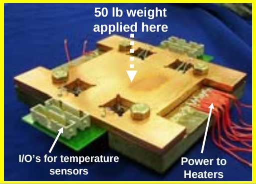
Heaters arrays sitting on the insulating plate.



A 3x4 heater array.



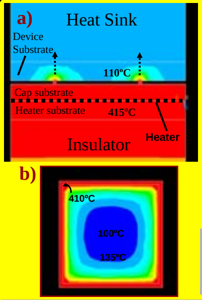
A schematic of the test setup.



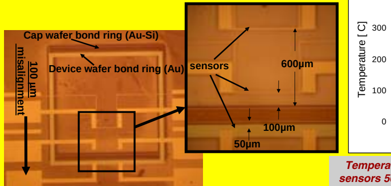
The total assembly where leads were soldered for connection to the heater.

The total assembly with the 50lb weight on top.

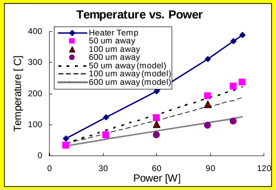
Results



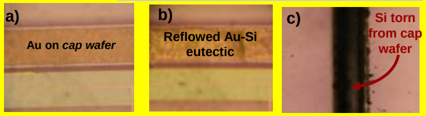
Modeling for the Si to glass bond, a) A cross section where the arrows indicate heat flowing to the heat sink. b) The bond ring which reached a temperature of 410°C while the center is only at ~100 °C. With this geometry, it should take about 750 W to heat 100 bond rings across an entire wafer.



A view through the backside of the glass device wafer which was clamped to the Si cap wafer showing the 100 μm misalignment and temperature sensors at different distances from the bond ring.



Temperature vs. time for the heater, and temperature sensors 50, 100 and 600 μm from the bond ring. (In this case a heater his used to heat 4 bond rings at a time).



a) Misaligned Au on the cap and device wafers before bonding and b) after bonding. c) Silicon torn from the cap wafer, adhering to the device wafer via a Au-Si eutectic bond, achieved through localized heating.

Acknowledgments

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