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Wafer-Level Packaging of Aluminum Nitride RF MEMS Filters

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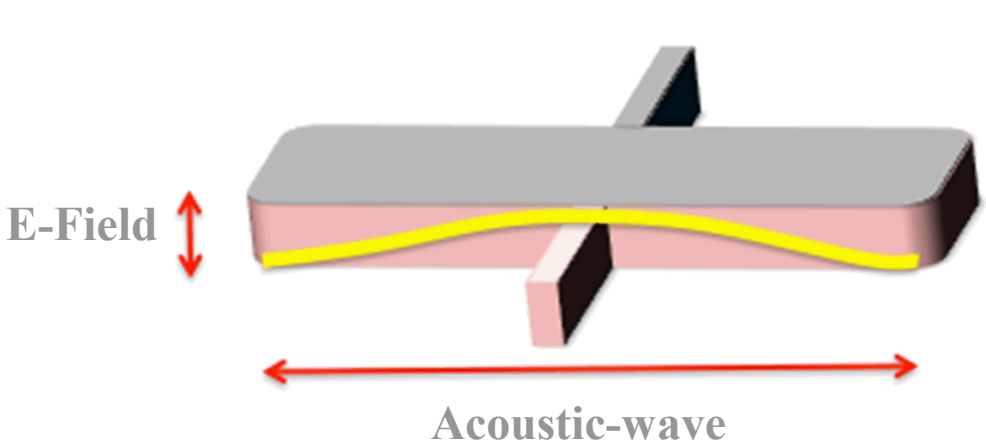
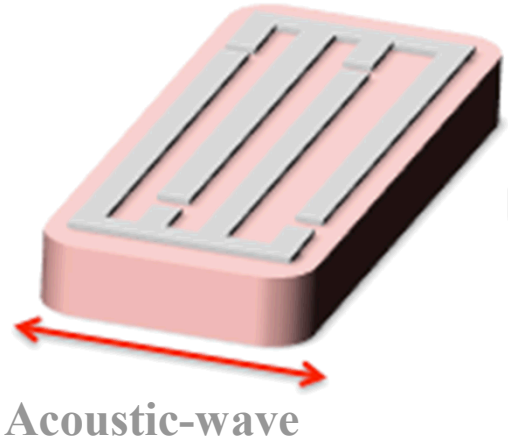
Agenda / Outline / Overview

- Lamb Wave AlN Resonators / Fabrication
- Wafer Level Packaging
- Post Fabrication Processes
- Fabrication Specifics

Lamb Wave AlN Resonators

electrical – acoustic conversion for frequency bandpass filters





$$f = \frac{\nu}{\lambda} = \frac{1}{2w} * \sqrt{\frac{\sum E * t}{\sum \rho * t}}$$

$$w = \frac{n\lambda}{2}$$

Width and length extensional thin film Lamb wave – metal on top and bottom of c-axis columnar aluminum nitride films create an electric field, electric field then creates a strain governed by boundary conditions, which allow only specific frequencies to exist inside the resonator

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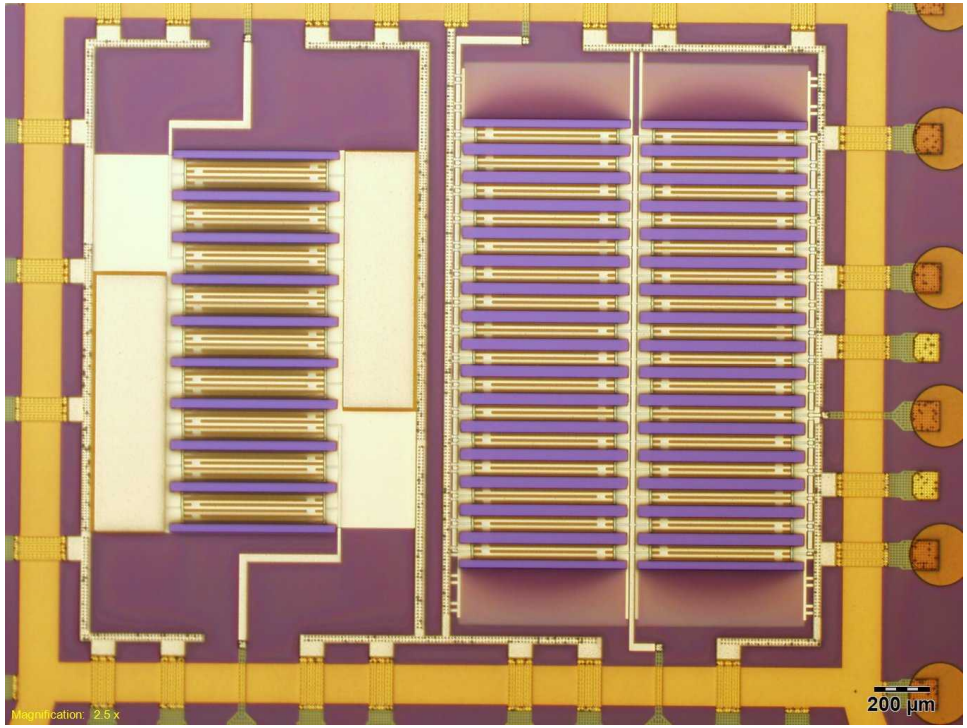
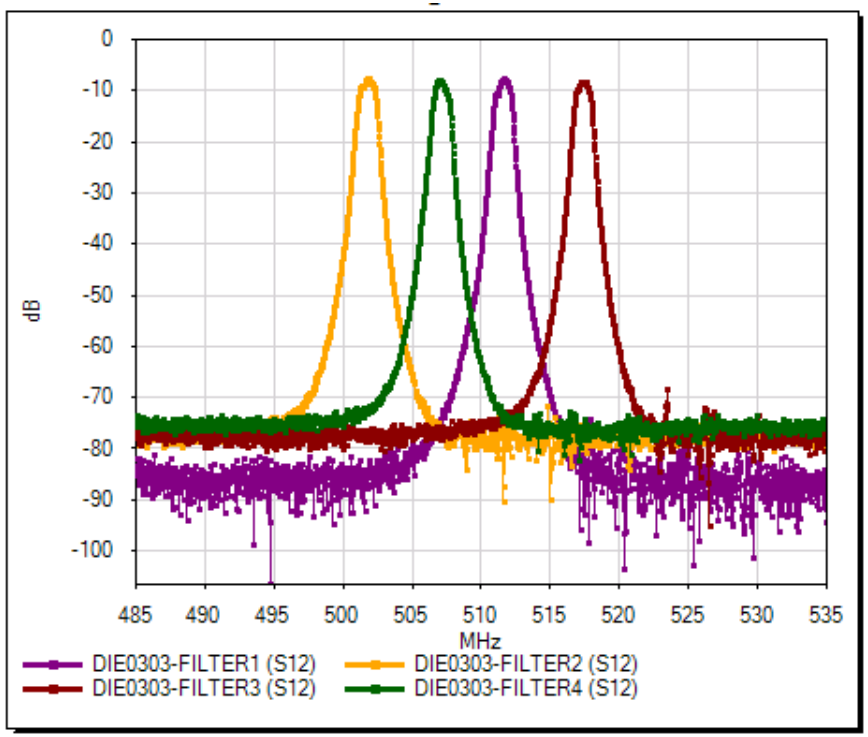
Lamb Wave AlN Resonators

applications: 2G, 3G, 4G wireless filters





Although other types exist, the Lamb wave acoustic resonator is interesting because the thickness is thin film (~750 nm) yet can accommodate different frequency devices all set by the lithography. Frequency range can be low (few 10's of MHz) or high (> 3 GHz).

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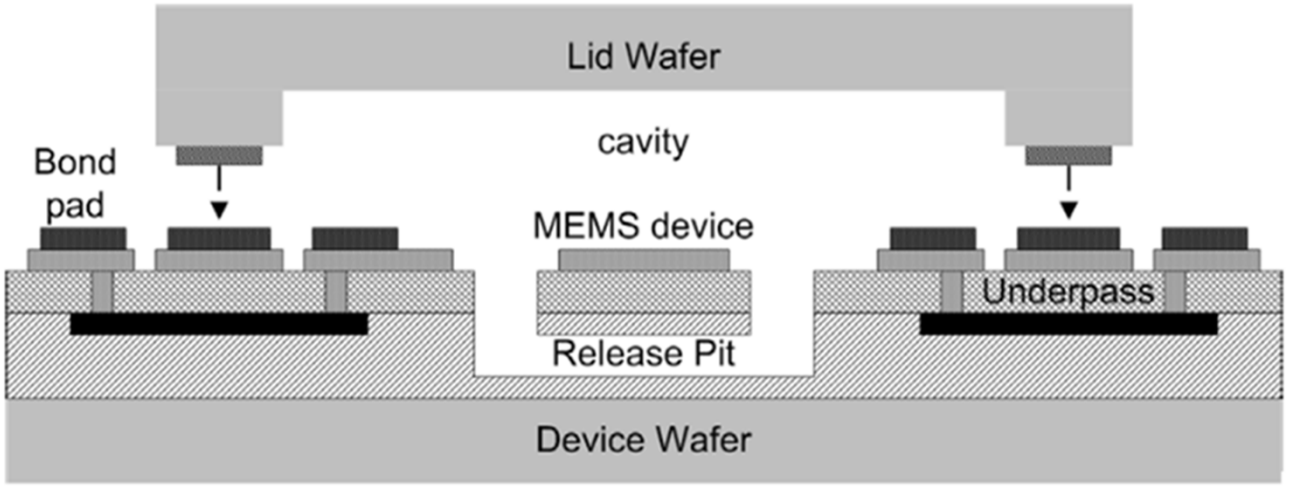
Wafer Level Packaging

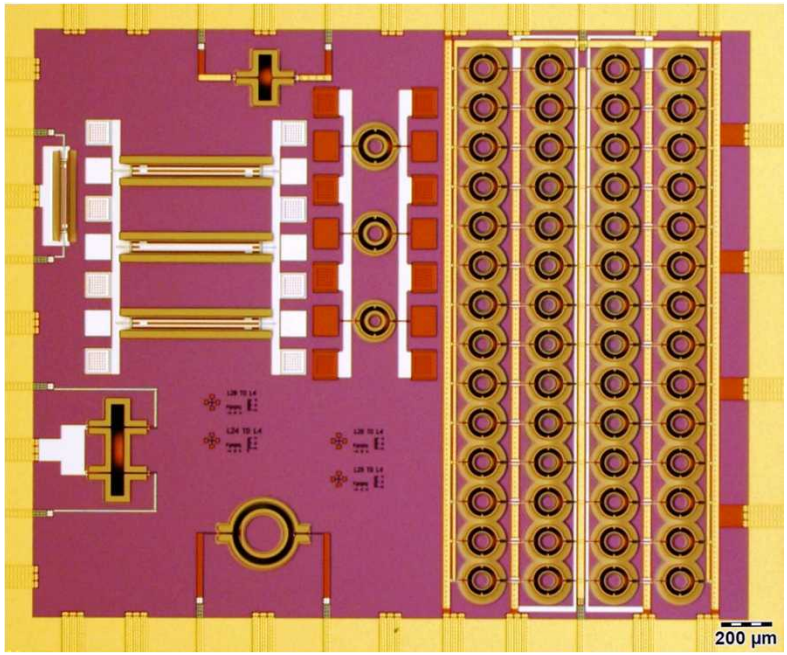
WLP of AlN Micro Resonators – The value proposition: if we fabricate a wafer full of devices, release at the devices at the wafer level, and then WLP them, the devices are protected for singulation and mounting.

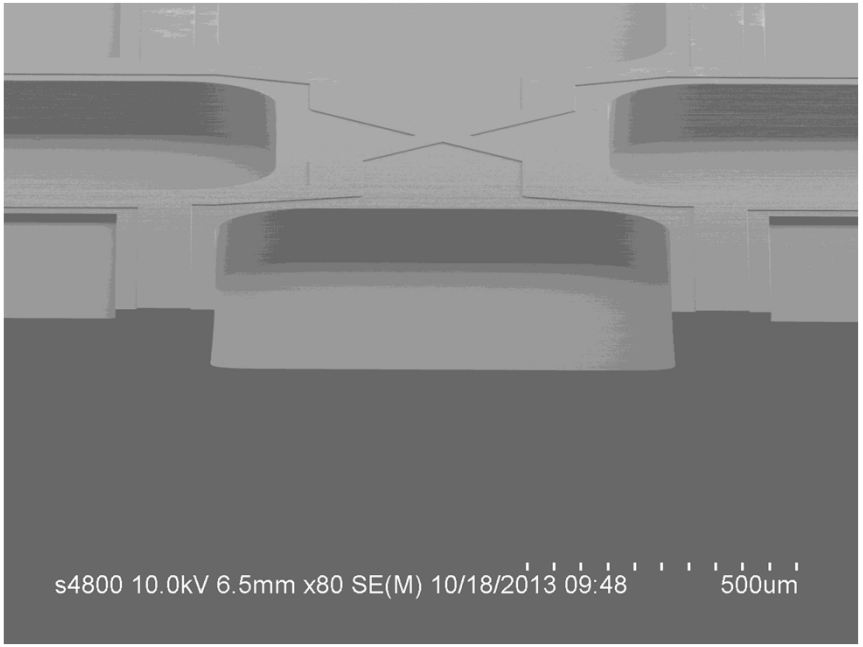


Fabrication sequence is, then, make a die and lid wafer in a CMOS factory, move to a μfab for post processing. This includes Au/NiV metal deposition and patterning, wafer level XeF_2 release, wafer bonding under vacuum, plasma back etch of the lid, auto-probing and RTA frequency trimming, and balling.

Wafer Level Packaging

Fabrication of Die & Lid Wafers – Die wafer consists of compensating oxide, tungsten underpass, bottom metal, AlN, and top metal on poly-Si release pit.

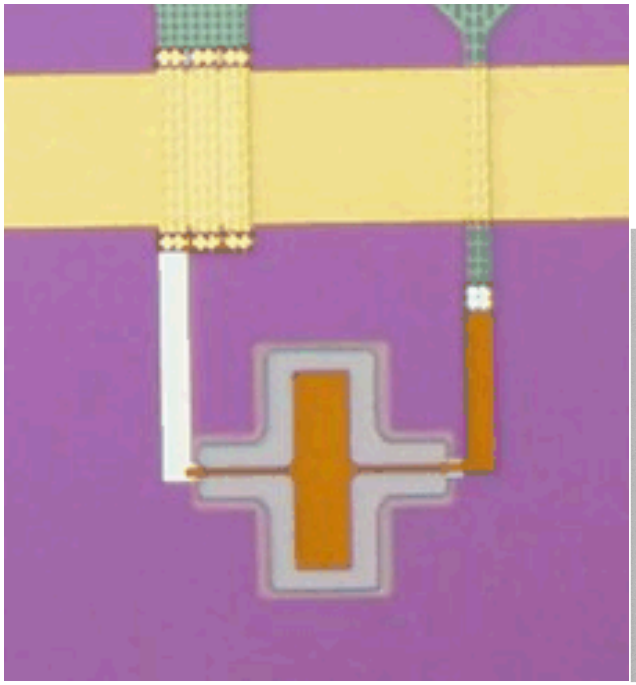




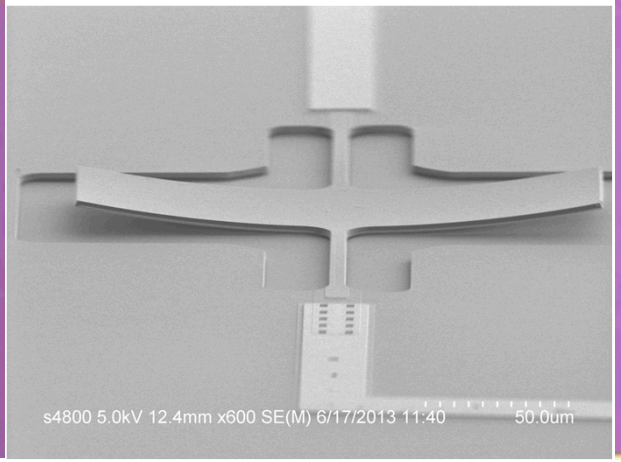
Lid wafer is made using 3 different silicon etches, thermal oxidation, and a-Si uniform deposition.

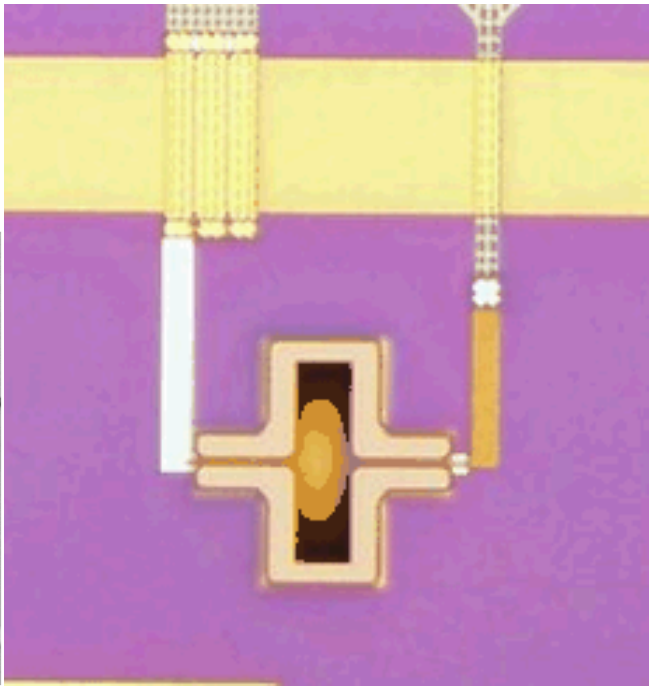
Wafer Level Packaging

XeF_2 Wafer Level Release – Since released devices are protected during dicing by the WLP, wafer level dry release becomes possible.



$$XeF_2 + Si \rightarrow Xe + SiF_4$$

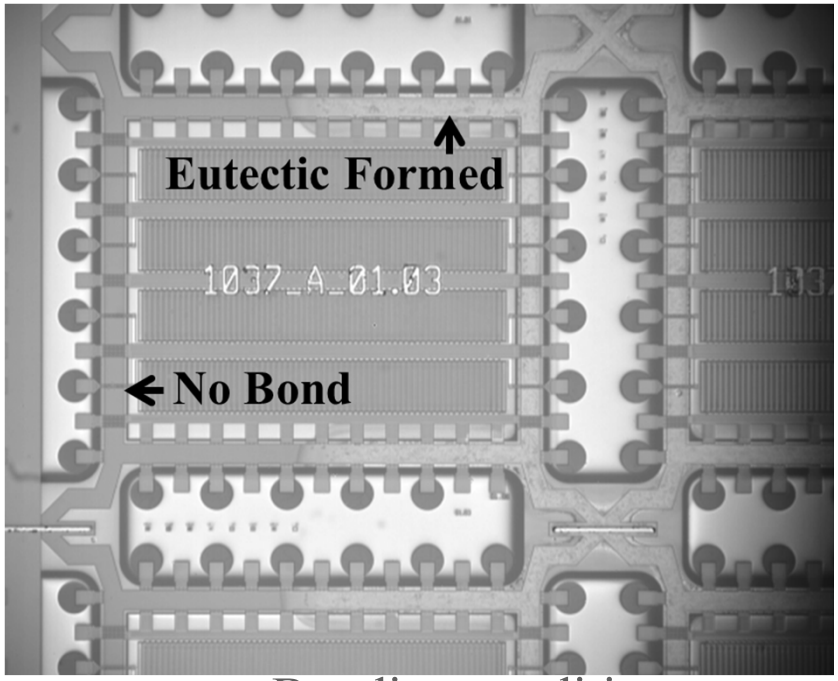


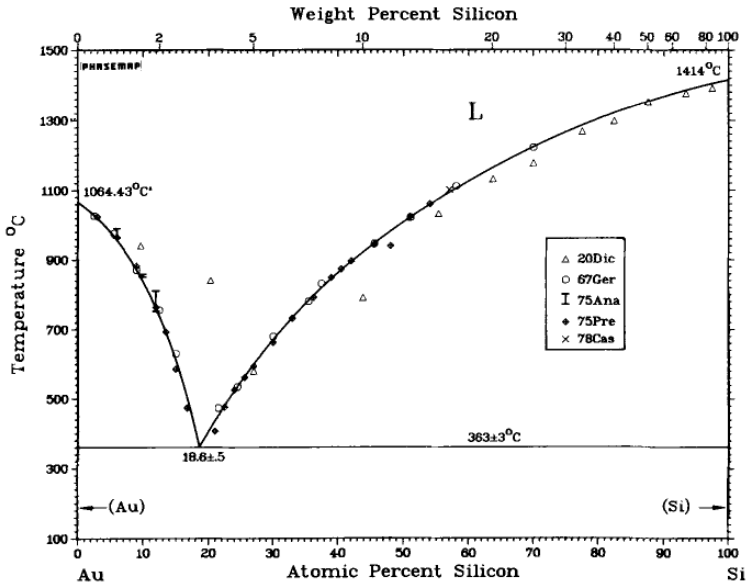


Devices' stress curl the device as the poly-Si is consumed during release.

Wafer Level Packaging

Bonding of Die wafer to Lid wafer in EVG 520 for a-Si/Au eutectic.





H. Okamoto and T. B. Massalski, 1983.

Bonding conditions – pumped to 10^{-6} Torr, 110 °C for 6-10 hours

Bond at 400 °C for 25 min at 3-5 kN force.

Cool down at 1 psi of N_2 purge to match chuck temperature cool down rate.

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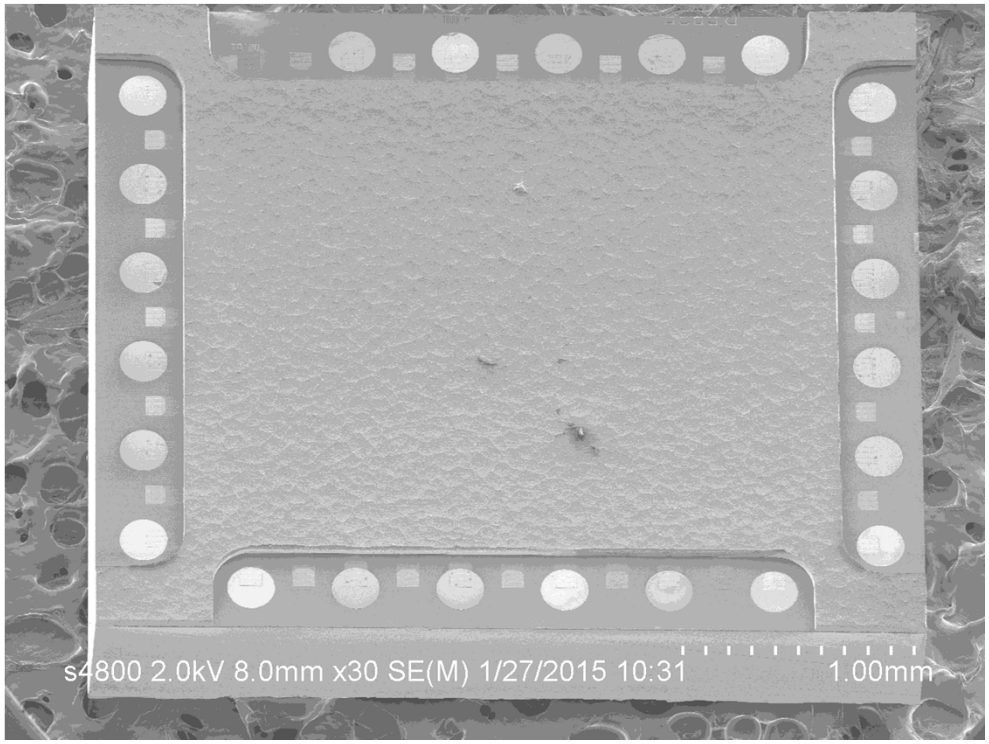
Wafer Level Packaging

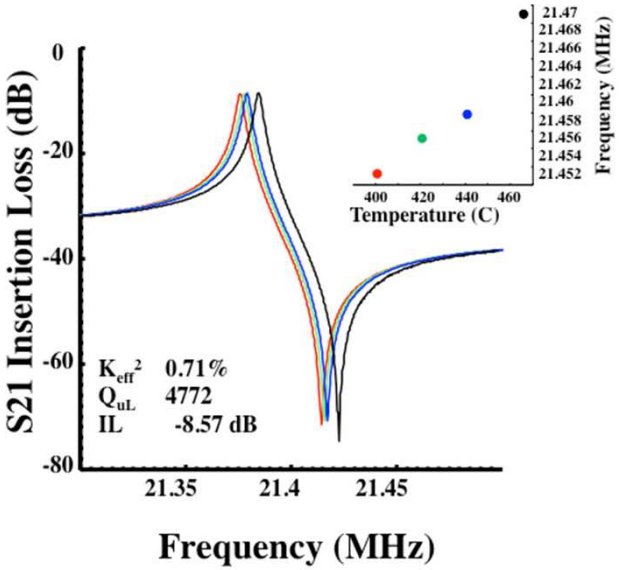
Plasma back-etch of lid wafer handle thins until the pads are exposed (SF_6 etch landing on Au and AlN with very high selectivity).

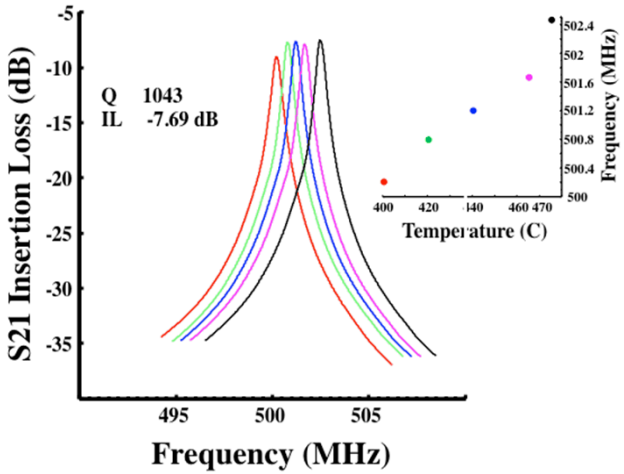


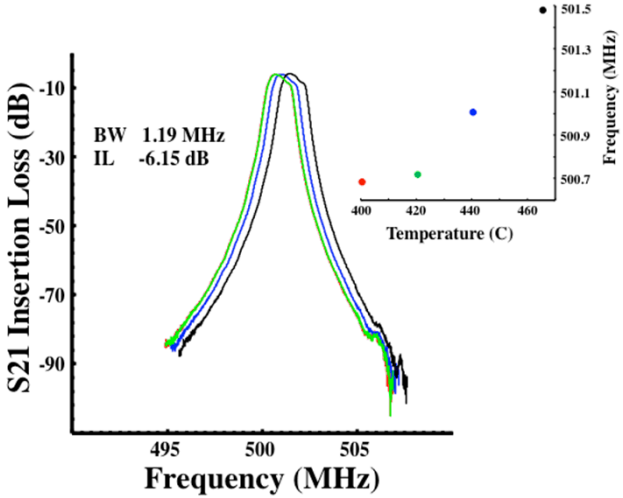
The dies are then singulated using a low water flow dicing saw.

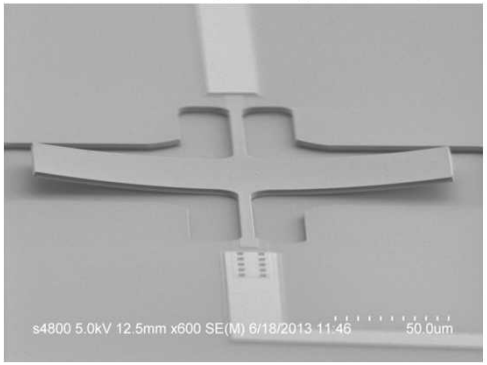
Post Fabrication Processes

Resonators are frequency trimmed using RTA.









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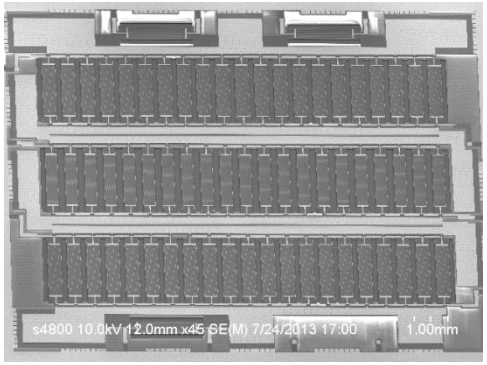

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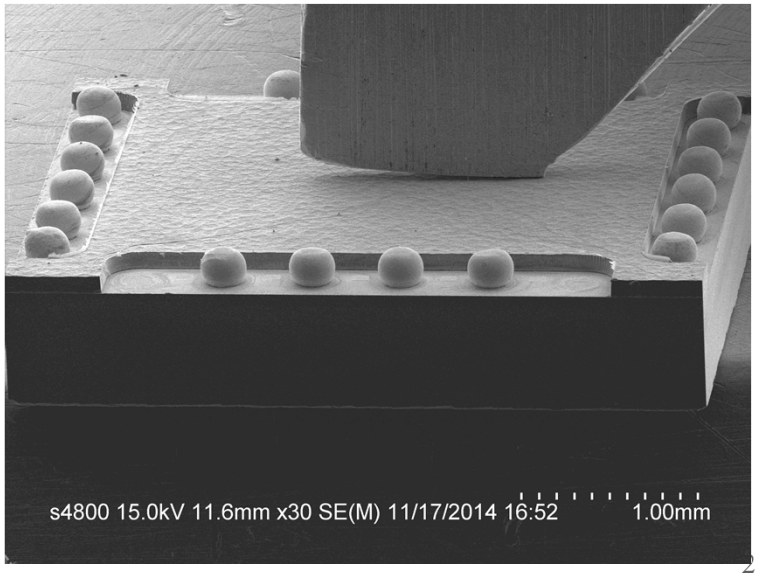
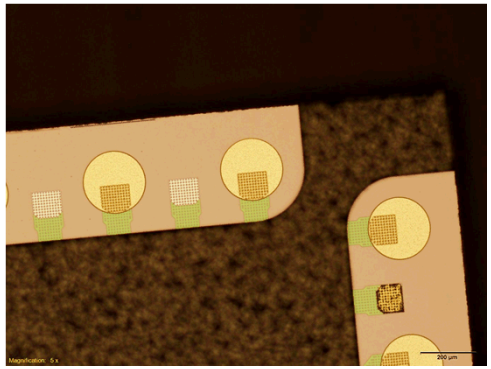
Post Fabrication Processes

Wafer Level Pb_{90}/Sn_{10} balling and Plasma Die Clean





ICP RIE plasma clean:

$_2$ plasma – 300 W bias, 60 seconds

SF_6 plasma – 300 W bias, 60 seconds

Balling is performed on Ti / NiV /Au (500/3000/1000 A) pads using a PacTech SB2-SM laser solder jetter. Balls are 250 µm diameter Pb_{90}/Sn… dispensed 280 µm above and melted using 5300 mA, 5 msec

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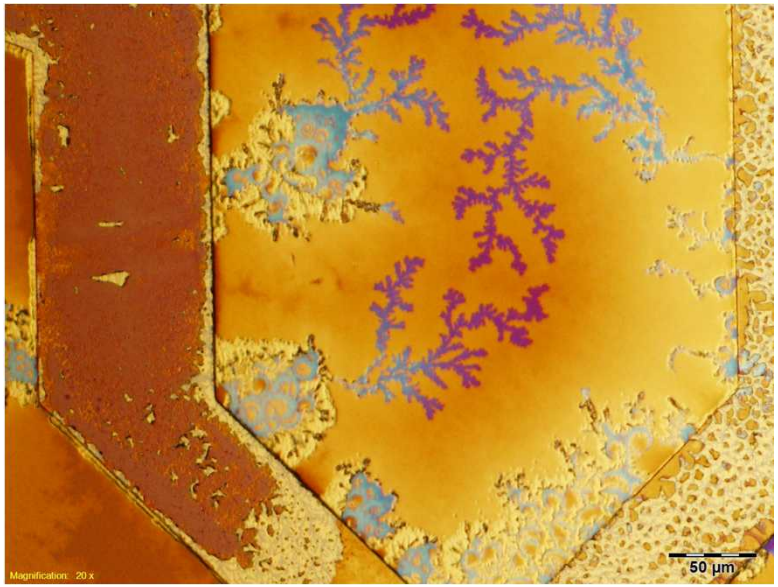
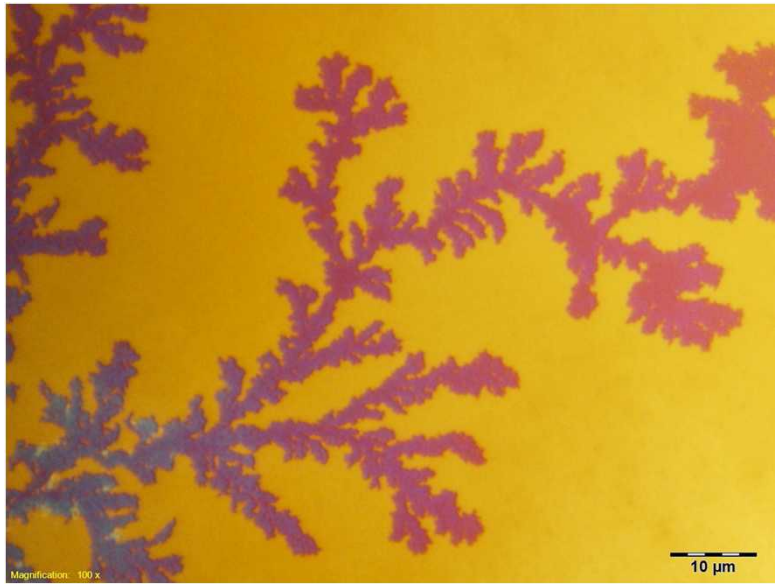
Fabrication Specifics

Metal Induced Lateral Crystallization – aSi/Au

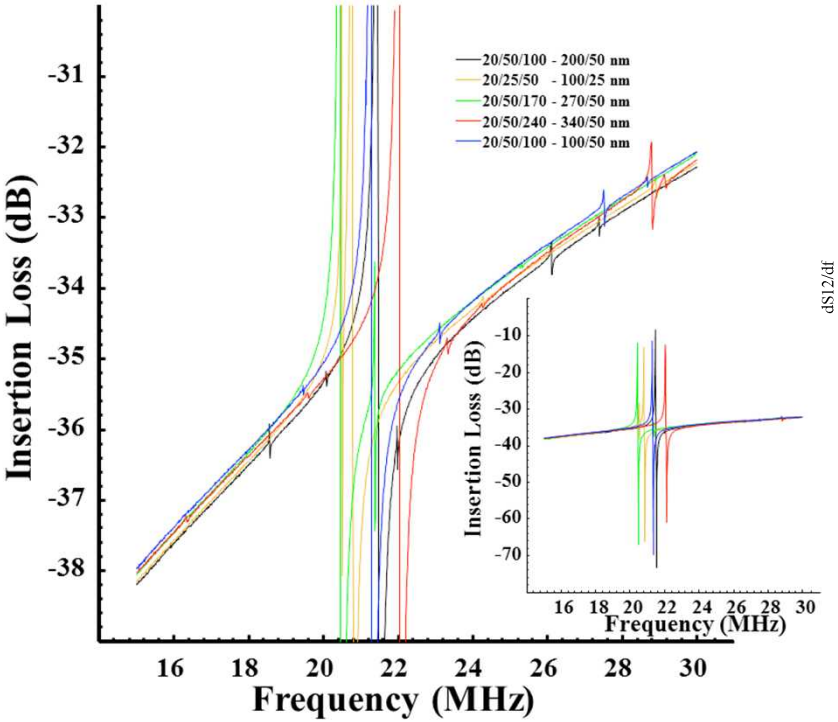




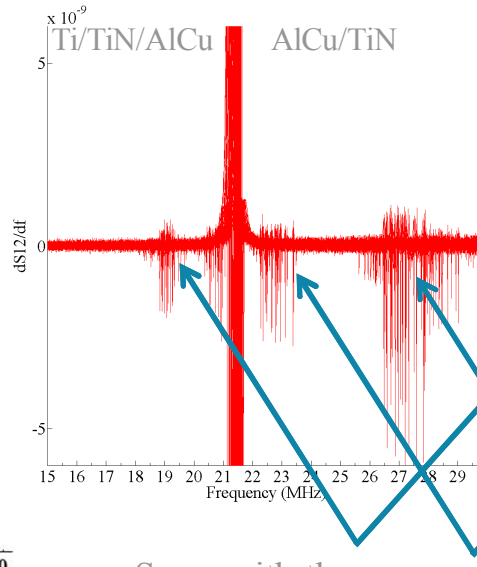
Bonding induced recrystallization of PECVD a-Si. Although the Au was restricted to the bonding seal ring, the aSi was coated over the full lid wafer.

Fabrication Specifics

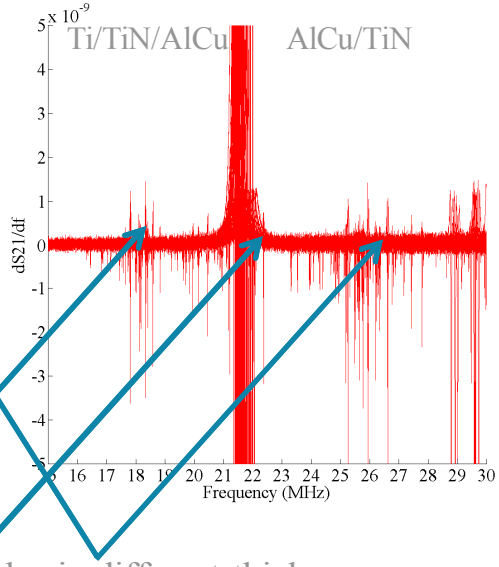
Metallization also affects resonator performance by introduction of and shifting of spurious modes (in this case, the tether is excited in an asymmetric mode).



20/50/100 – 100/50 nm



20/50/240– 340/50 nm



Spurs with the same modes in different thicknesses.

In this work, 5 different metal stacks were used (fab'd at the same time with same reticles) and 22 MHz resonators tested.

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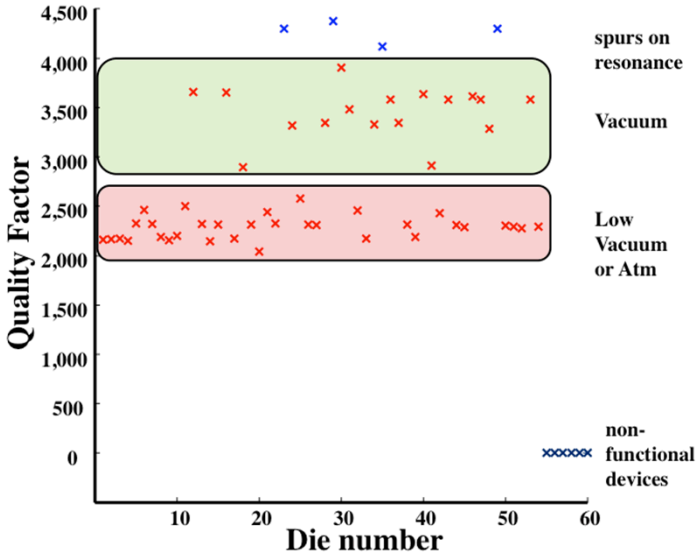
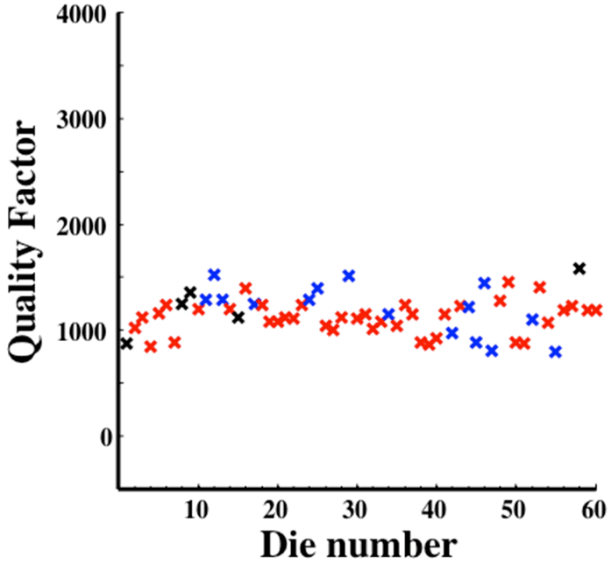
Fabrication Specifics

Resonator performance / yield: (15 die / reticle, 60 reticles / wafer)





22 MHz resonator – the low frequency makes this device very sensitive to package pressure. Of 60 die, 6 were non-functional, 4 had spurs on resonance, 17 had high Q's indicating vacuum, and 33 were low vacuum or atm.

500 MHz resonator – Of 60 die, 15 had spurs preventing 5 dB isolation outside resonance, 5 had unacceptable insertion loss (> -10dB), and 40 performed well.

Outlook & Summary

Multi-frequency, Lamb Wave AlN resonators and filter production demonstrated at the wafer level due to WLP sequencing.

Successful packaging demonstrated on hundreds of wafers with the following processes included:

- Wafer level MEMS release, hermetic bonding, balling, and frequency trimming
- Multiple frequencies demonstrated with good yield
- Fabrication specifics and 'gotchas' discussed

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Acknowledgements

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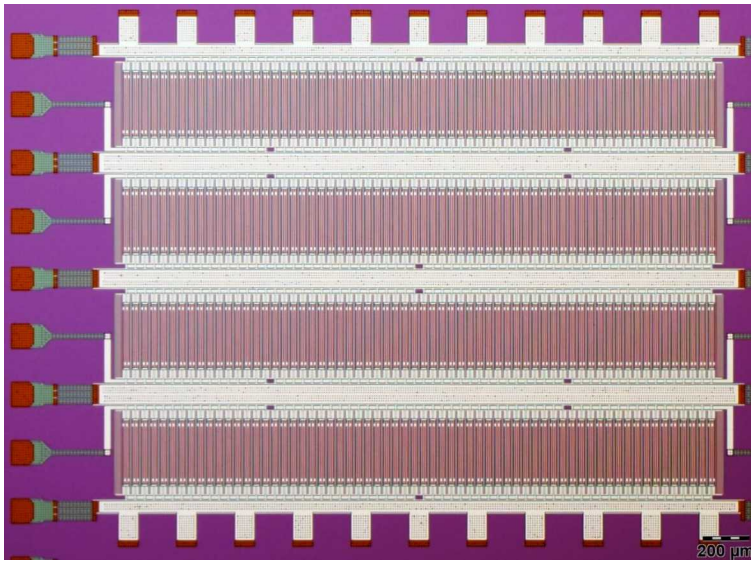
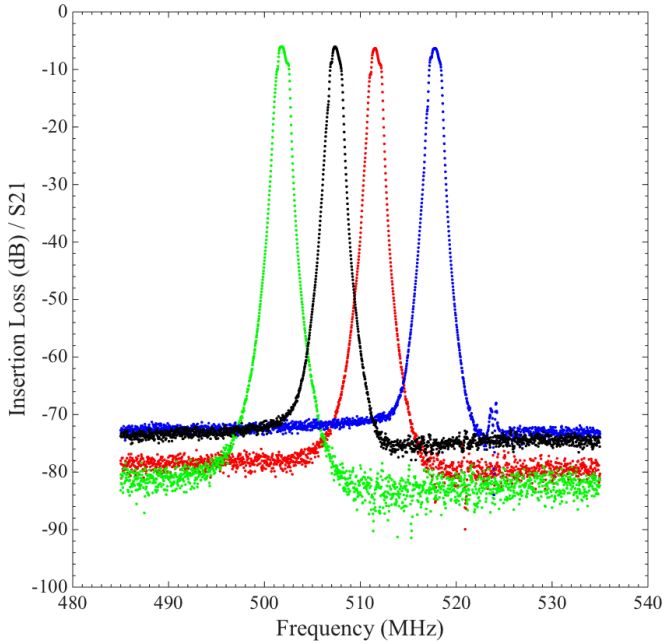
Todd Bauer
Jayne Bendure
Alan Mitchel
Dale Hetherington
Mike Daily
Dave Sandison





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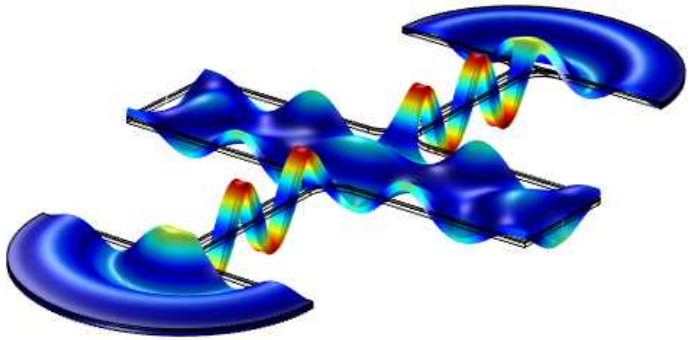
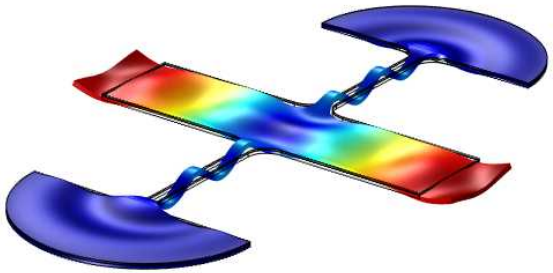
Fabrication Specifics

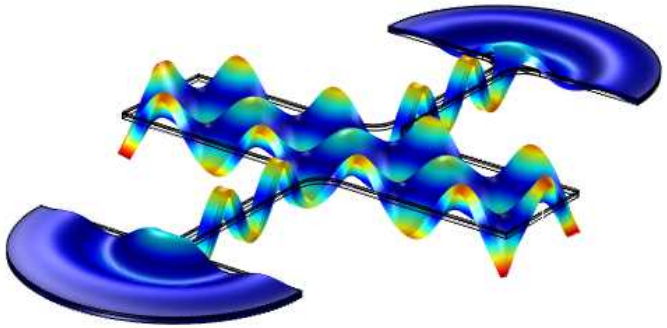
22MHz Wafer 11 – simulated 21.473 MHz

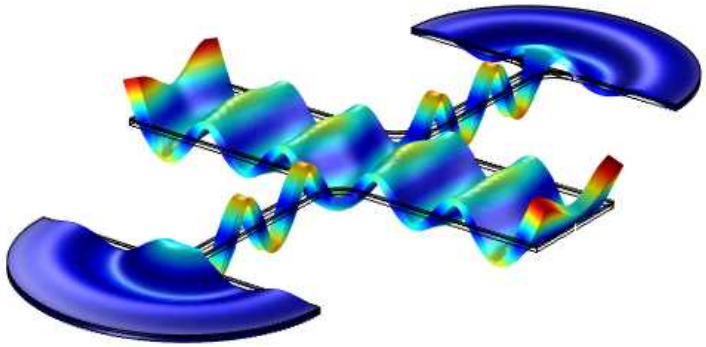




22MHz Wafer 11 – simulated 20.901 MHz

22MHz Wafer 11 – simulated 24.602 MHz





2MHz Wafer 11 – simulated 22.166 MHz

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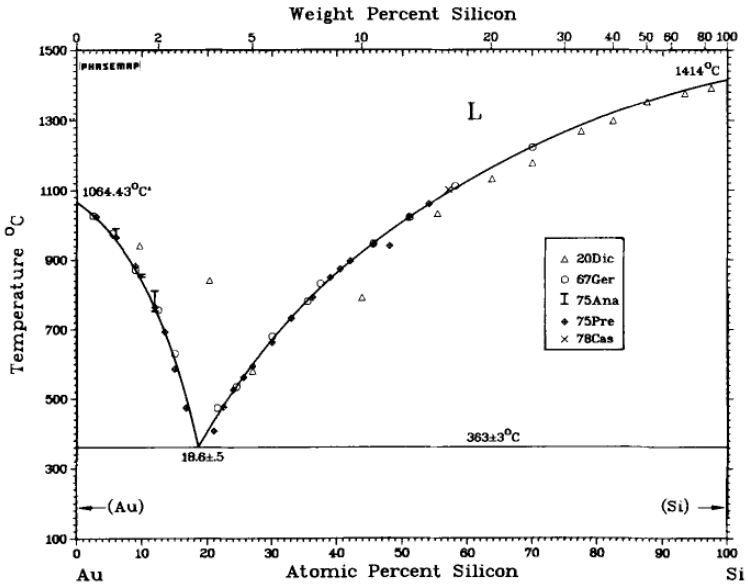
Wafer Level Packaging

The process described here utilized 136 nm of a-Si with 500 nm of Au to achieve the correct stoichiometry at ~19% at. Si. The bond is made at 400 C for 25 minutes, after 25 minutes at 125 C, to ensure complete reaction through the layers.



H. Okamoto and T. B. Massalski, 1983.