WMH-5

Packaging and Integration Solutions at Terahertz Frequencies

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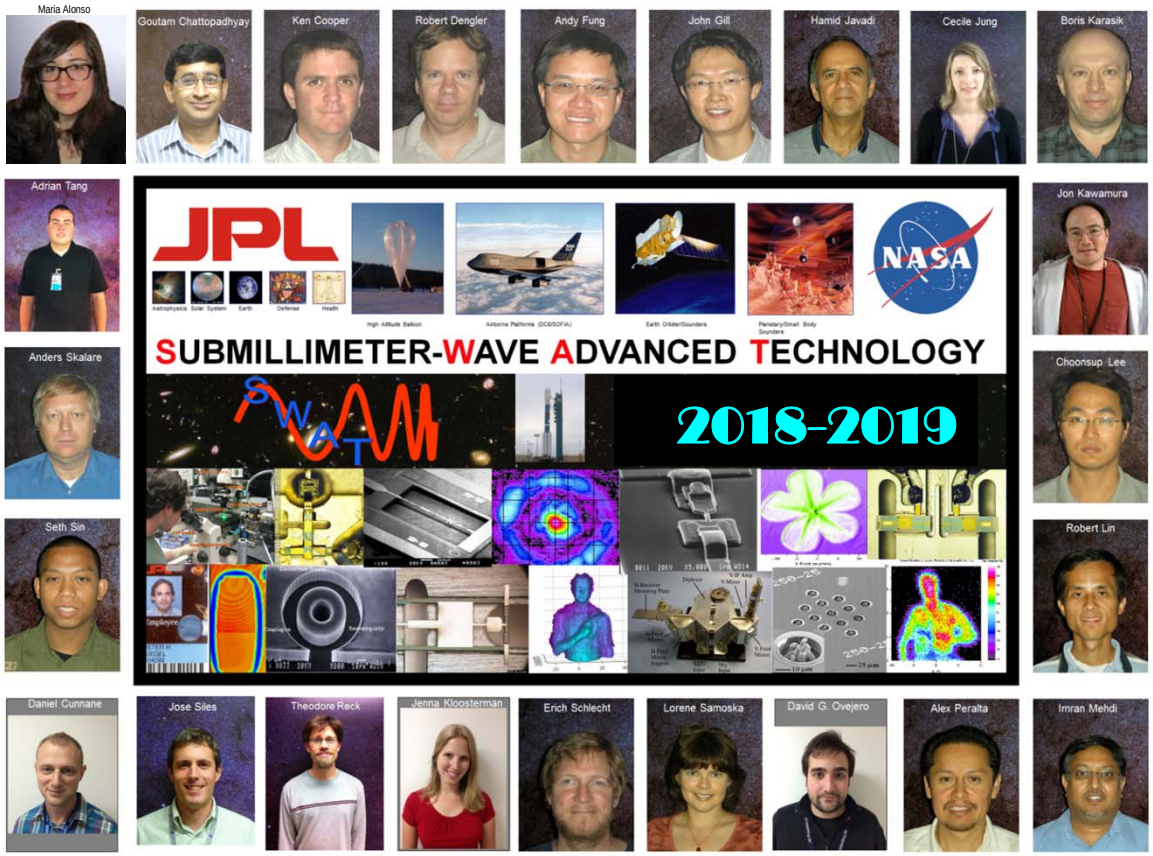
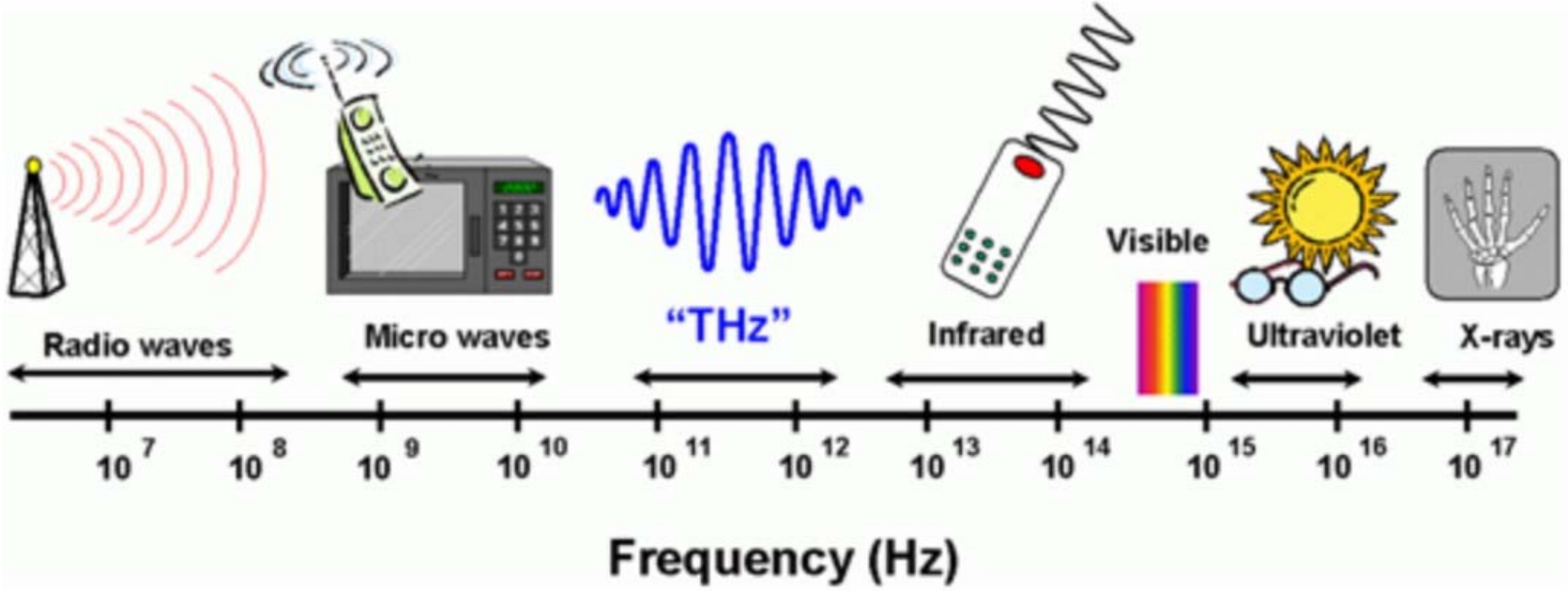
Acknowledgement



This work was carried out at the California Institute of Technology, Jet Propulsion Laboratory, under contract with the National Aeronautics and Space Administration.

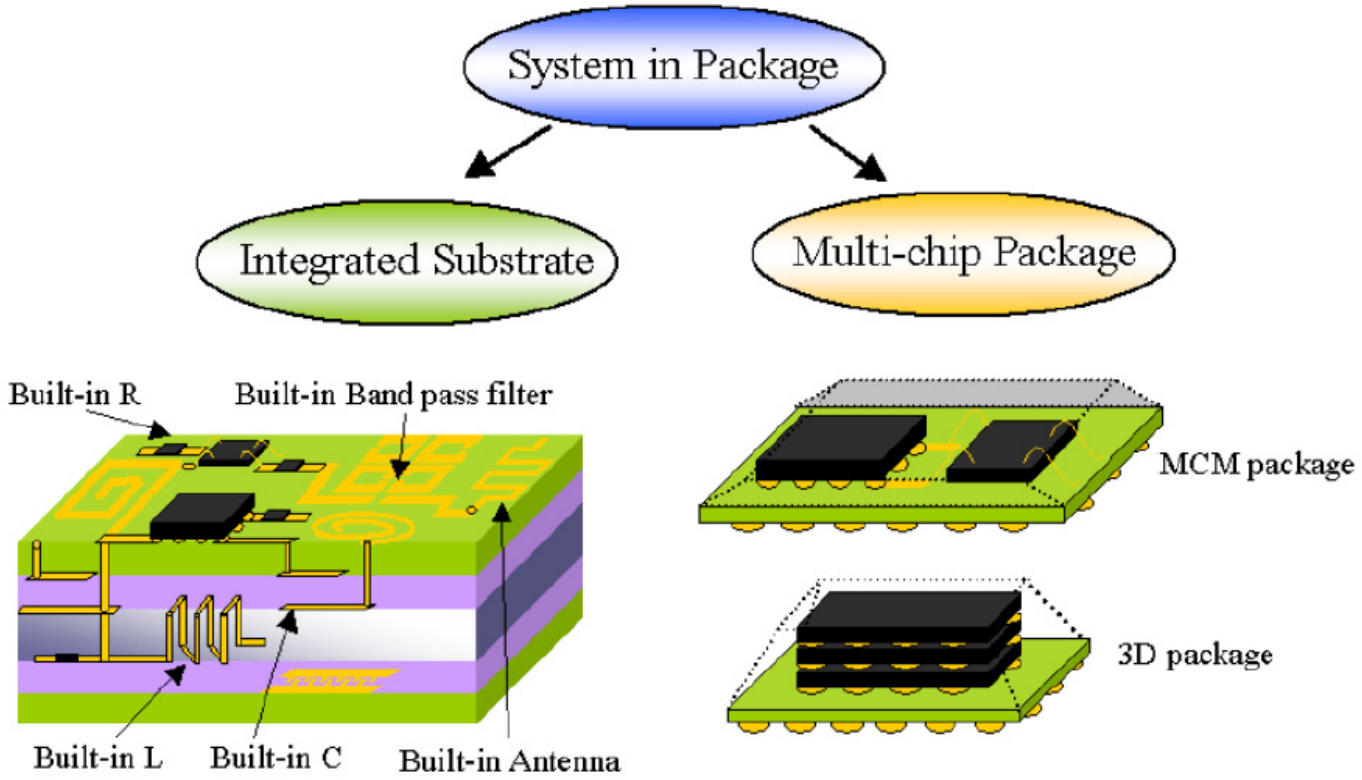
Terahertz (Submillimeter) Waves



Loosely defined: 1 mm > λ > 100 µm (300 GHz < ν < 3 THz)

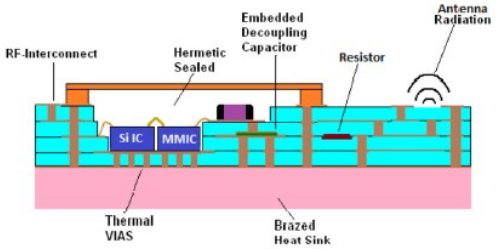
Most of the radiation in the Universe is emitted at submillimeter-wavelengths, peaking at 3 THz.

Packaging at Millimeter-Waves

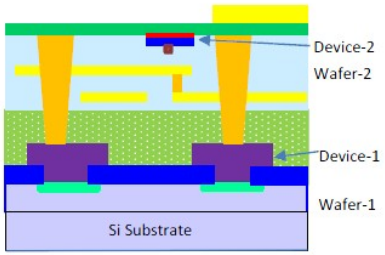


Different System-on-Package (SOP) Technologies

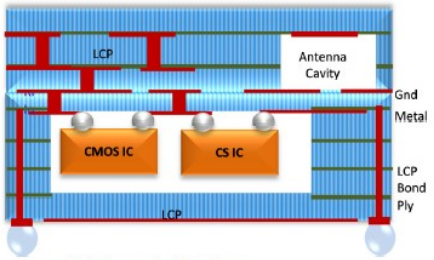
Packaging at Millimeter-Waves



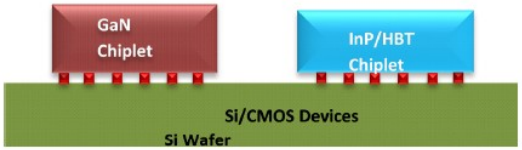
(a) Ceramic/LTCC



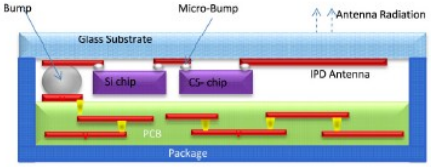
(d) Wafer-scale



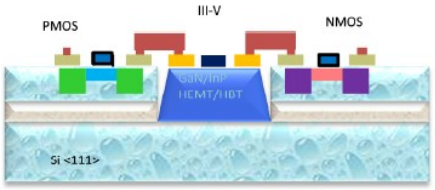
(b) Organic/Laminate



(e) Chiplets



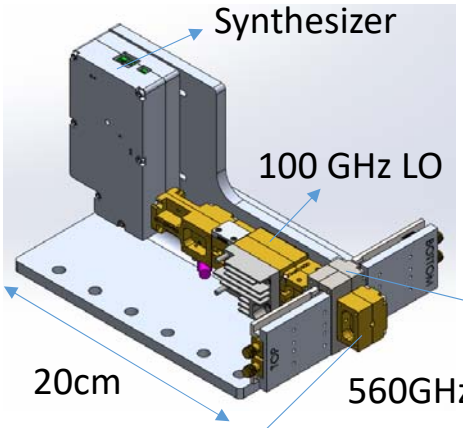
(c) IPD (Si/Glass)

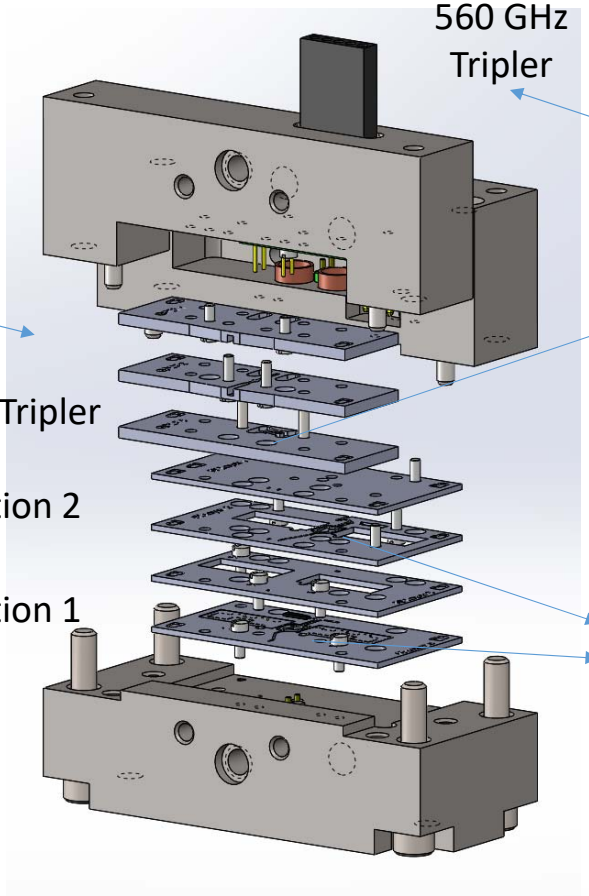


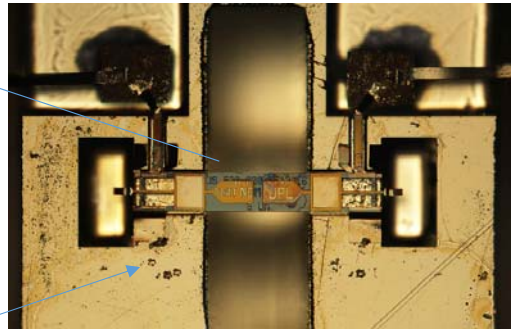
(f) Monolithic

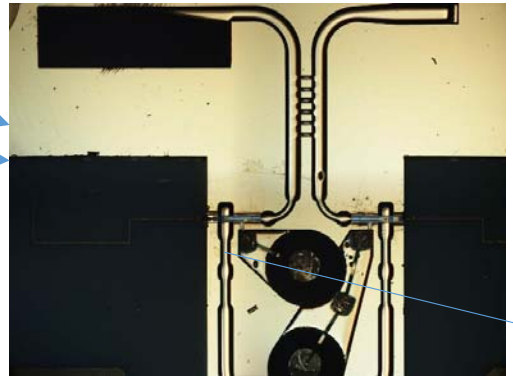
Multi-layer heterogeneous integration: Ceramic LTCC based, Organic Laminate based, Si/Glass based, Wafer-scale, Chiplets based. (Ref: K. Samanta)

Packaging at Submillimeter-Waves









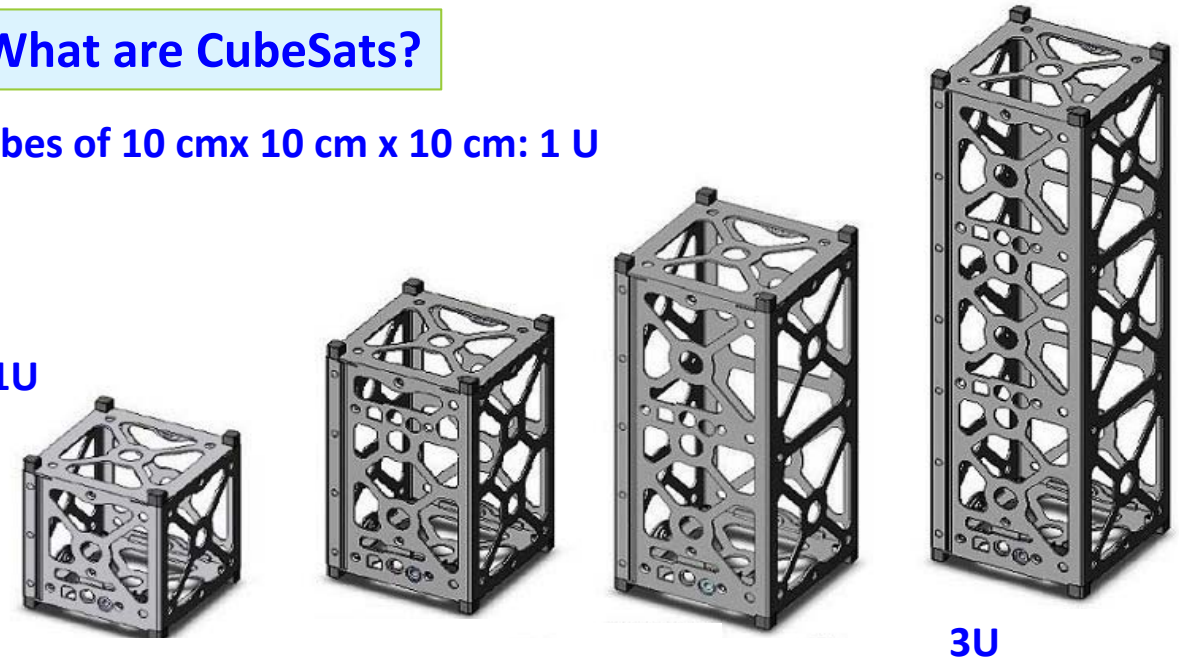
Mixers

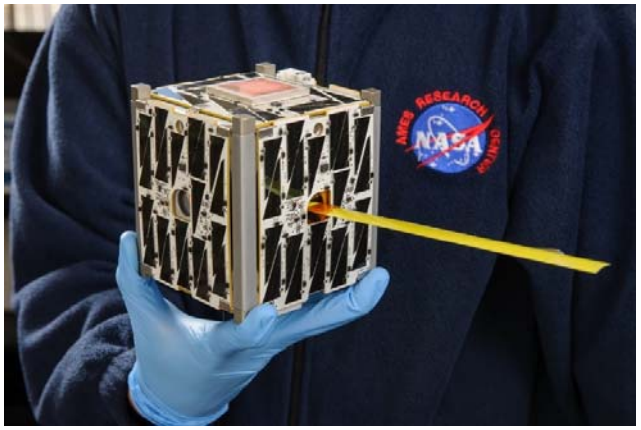
20x15x10 cm^3 package, 14 W DC Power

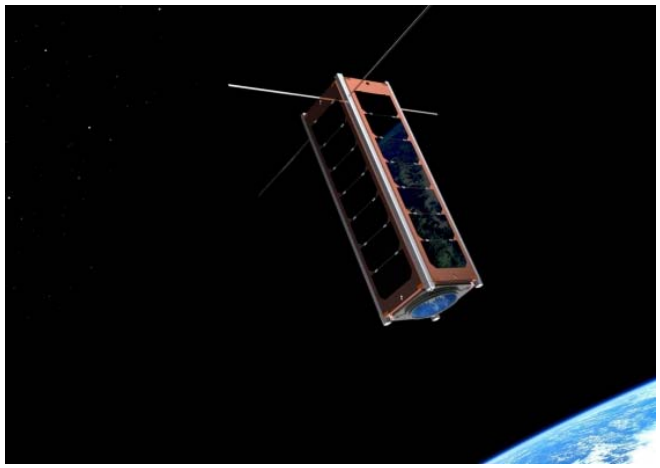
CubeSat and SmallSat Platforms

What are CubeSats?

Cubes of 10 cmx 10 cm x 10 cm: 1 U

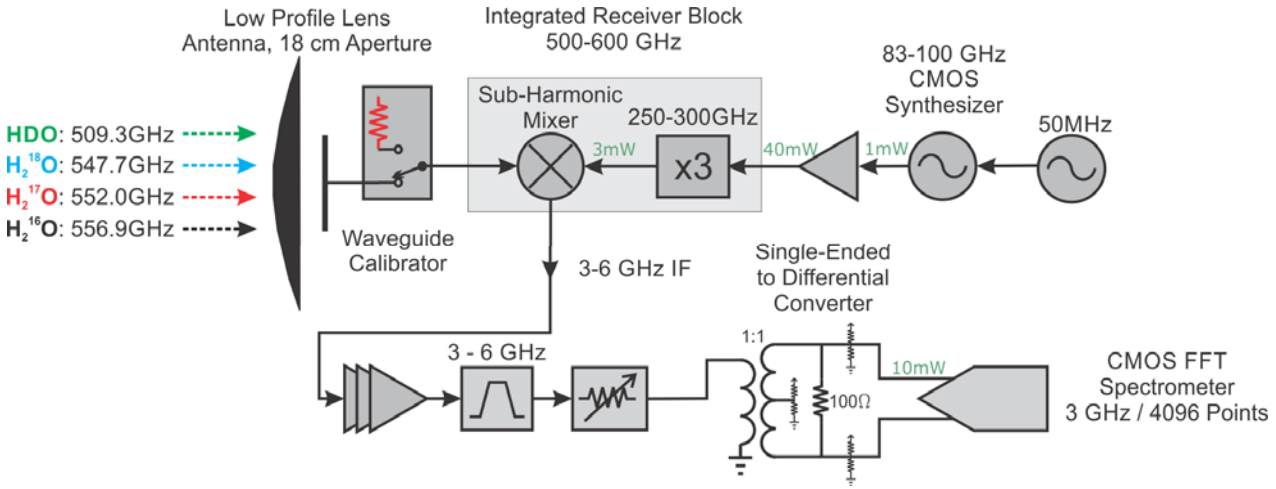






A shoe-box size satellite: includes navigation, communications, antennas, solar panels, and instruments, all on the CubeSat!

Typical Terahertz Systems



- **High-resolution room temperature heterodyne spectrometer 500-600 GHz band**
- **Low-profile ~18 cm diameter aperture antenna and feed**
- **Low-power CMOS based W-band synthesizer**
- **GaAs Schottky diode based subharmonic mixers and frequency multipliers**
- **CMOS based 3 GHz bandwidth, 4096 channels, low-power FFT spectrometer**
- **The target mass and power for the instrument is less than 2 kg and <5 W.**

Silicon Micromachining

Silicon Micromachining

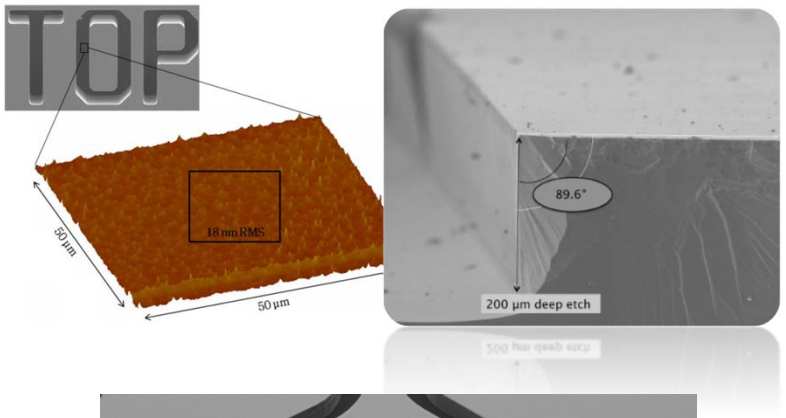
- Etch silicon wafer with plasma using a photolithographic pattern

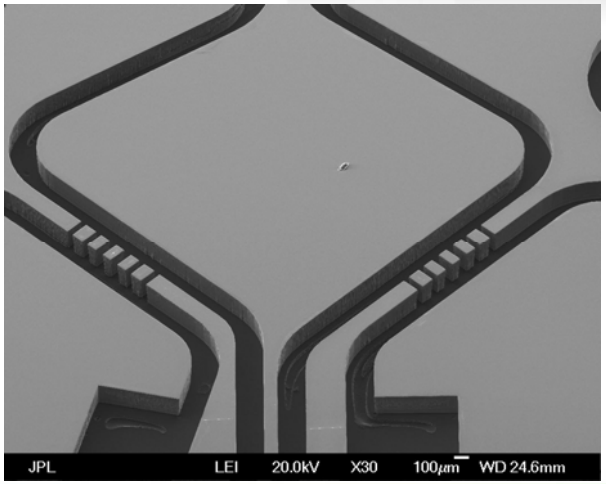
Advantages:

- Potential for lower cost because of batch-processed device fabrication, yielding better uniformity too.
- Lithographically precise feature definitions
- Integration of bias & IF lines on silicon itself. Future potential for integrated CMOS silicon devices.
- Potential for higher density 2D transceiver arrays.

Disadvantages:

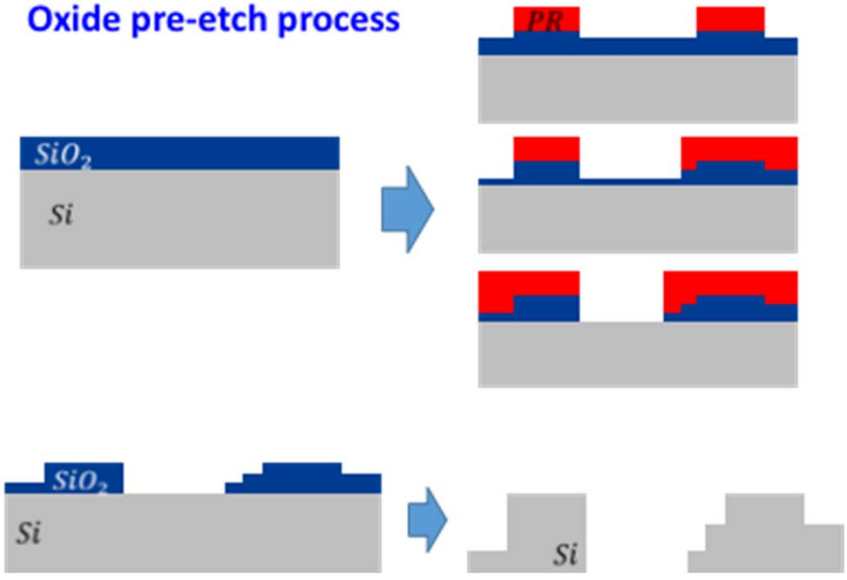
- Immature technology: need for process development: **Not anymore!**
- Challenge of wafer alignment.





Deep Reactive Ion Etching

- Use of an optimized **Bosch** process to etch the silicon: alternative exposures of SF_6 and C_4F_8 plasmas.

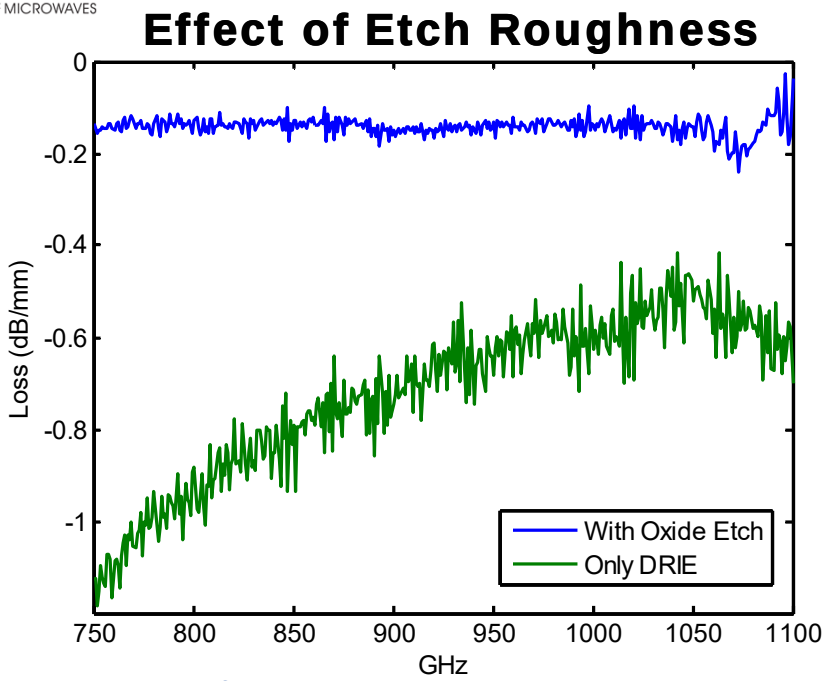


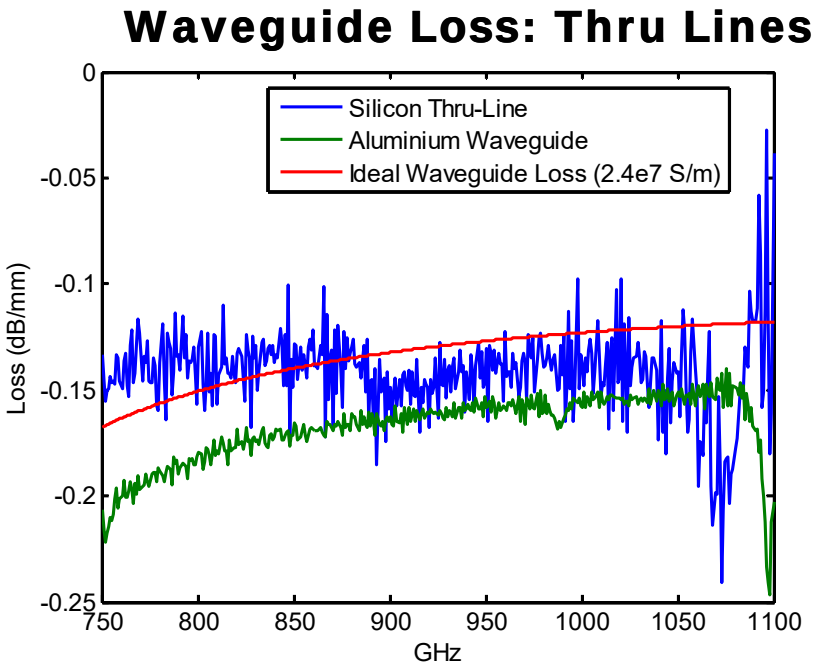
- Use of ***SiO_2* as hard mask** (selectivity 150:1) to etch *Si*
- Use of photoresist to do the SiO_2 patterning
- Etching of the differential pattern to ensure precise control
- Etching using Inductive Couple Plasma (ICP) process

- DRIE process to etch the silicon, with oxide as the sole mask
- No photoresist

DRIE process

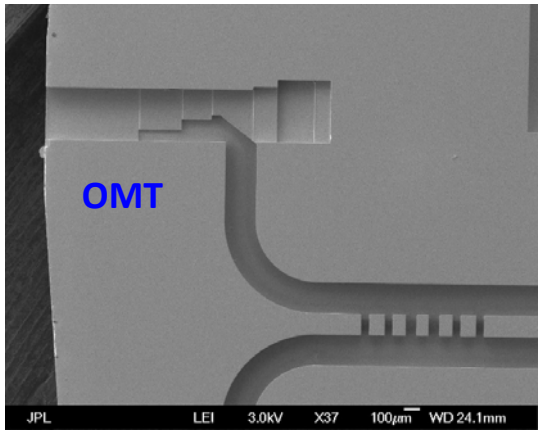
Deep Reactive Ion Etching

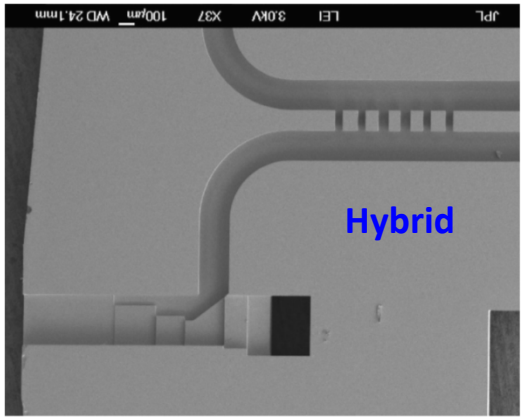


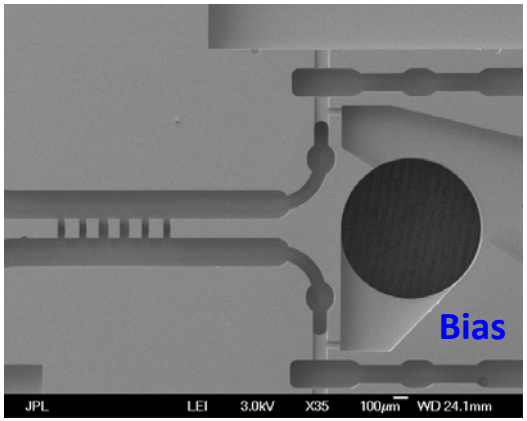


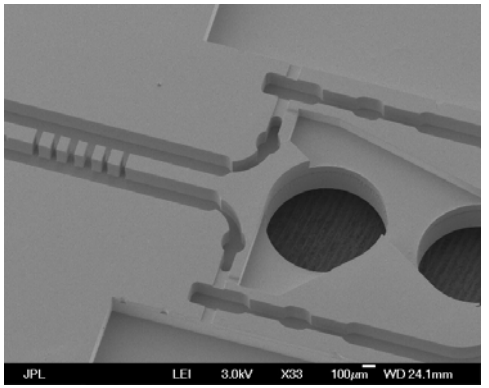
- Roughness from the DRIE process results in a roughness of 335nm—too high for these frequencies
- 2um of thermal oxide grown over wafer (1um into and 1um added to wafer)
- Oxide removed with wet etching
- **Process smooth rough features since oxide will penetrate peaks more than valleys**

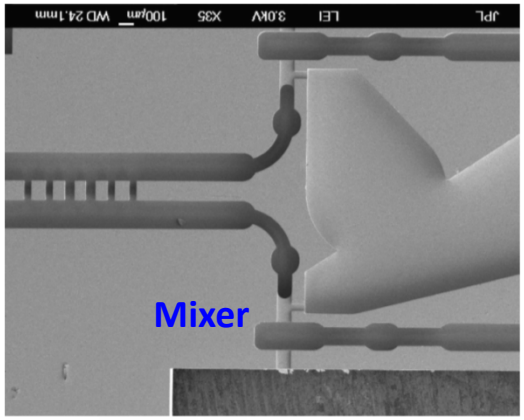
DRIE Components





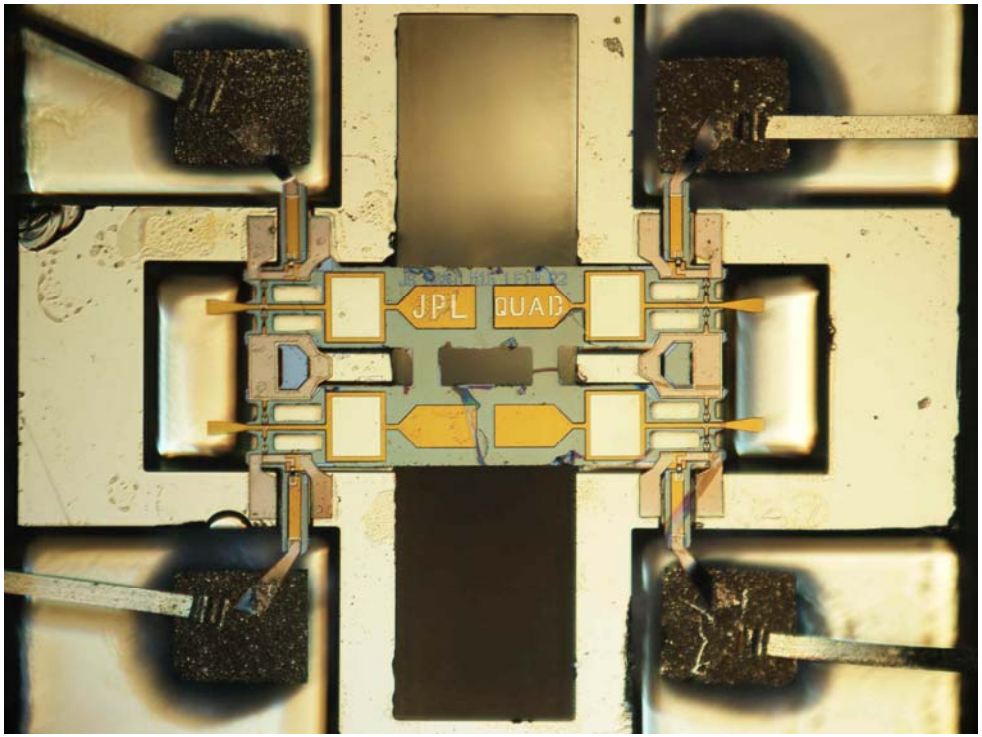


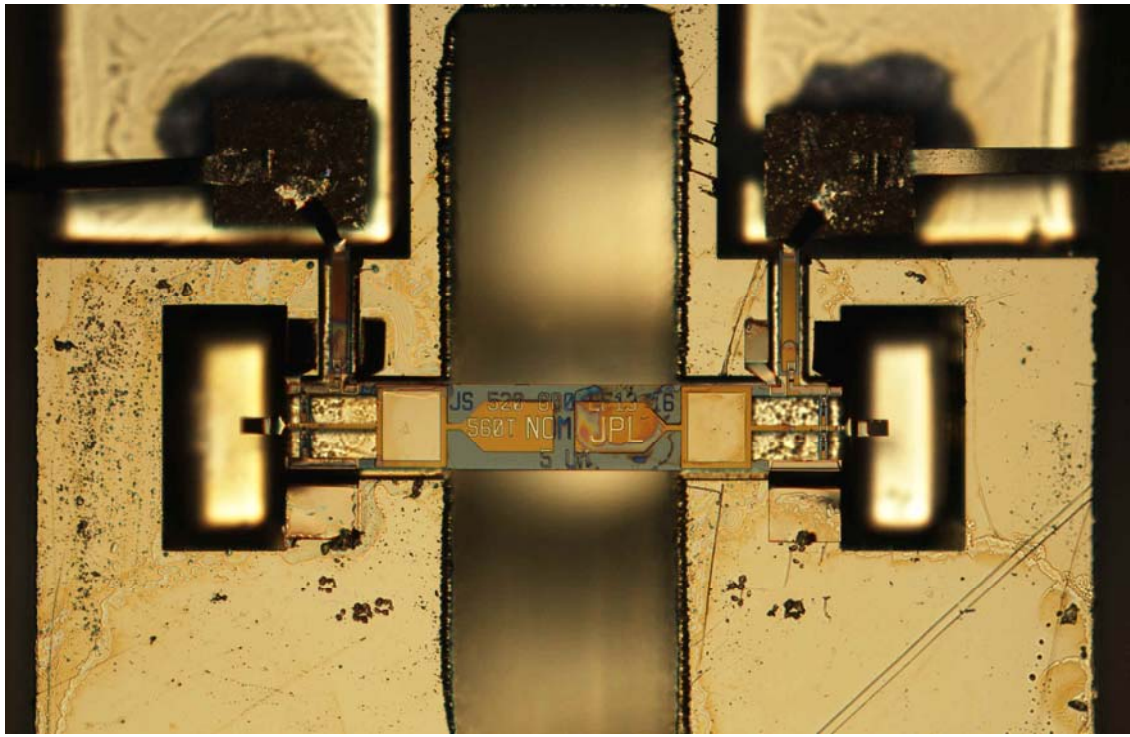




Different silicon micromachined layers before gold deposition.

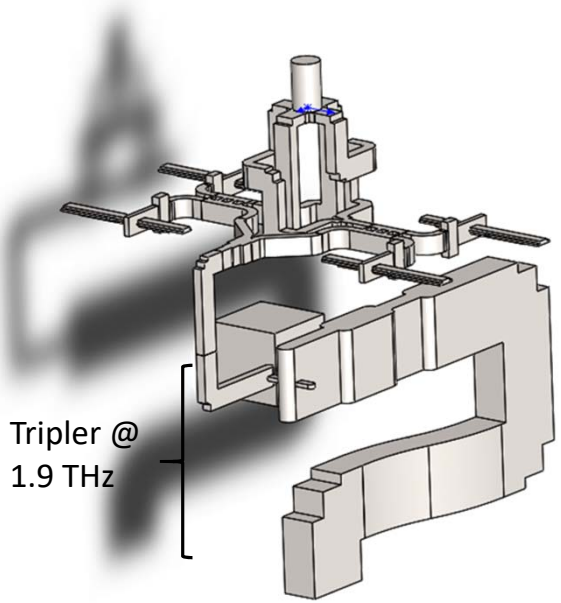
Integration of Active Devices

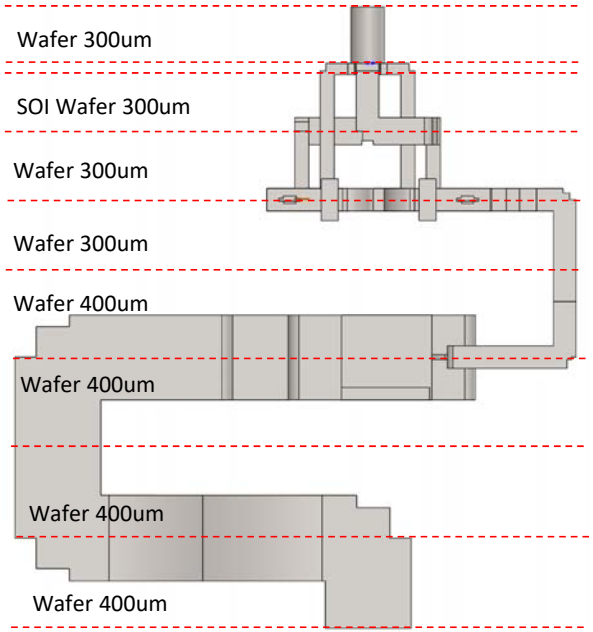


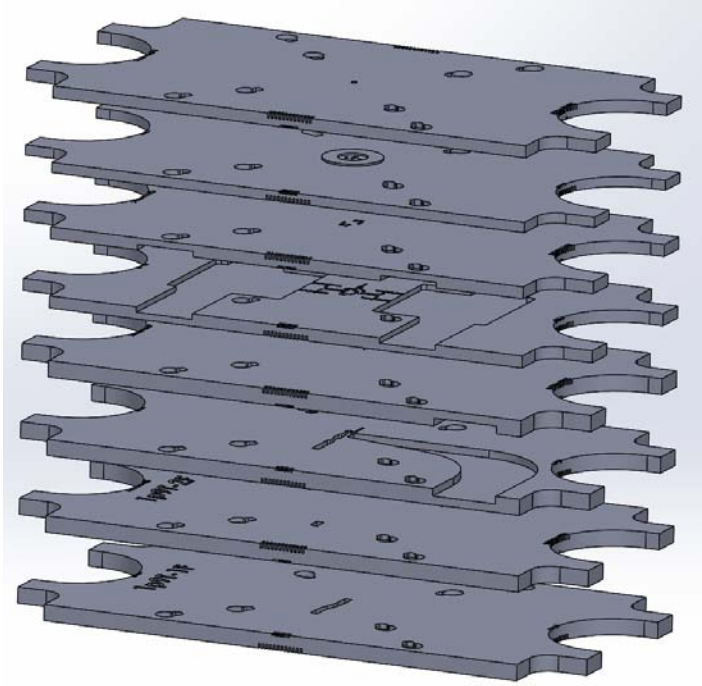


Vertical Integration

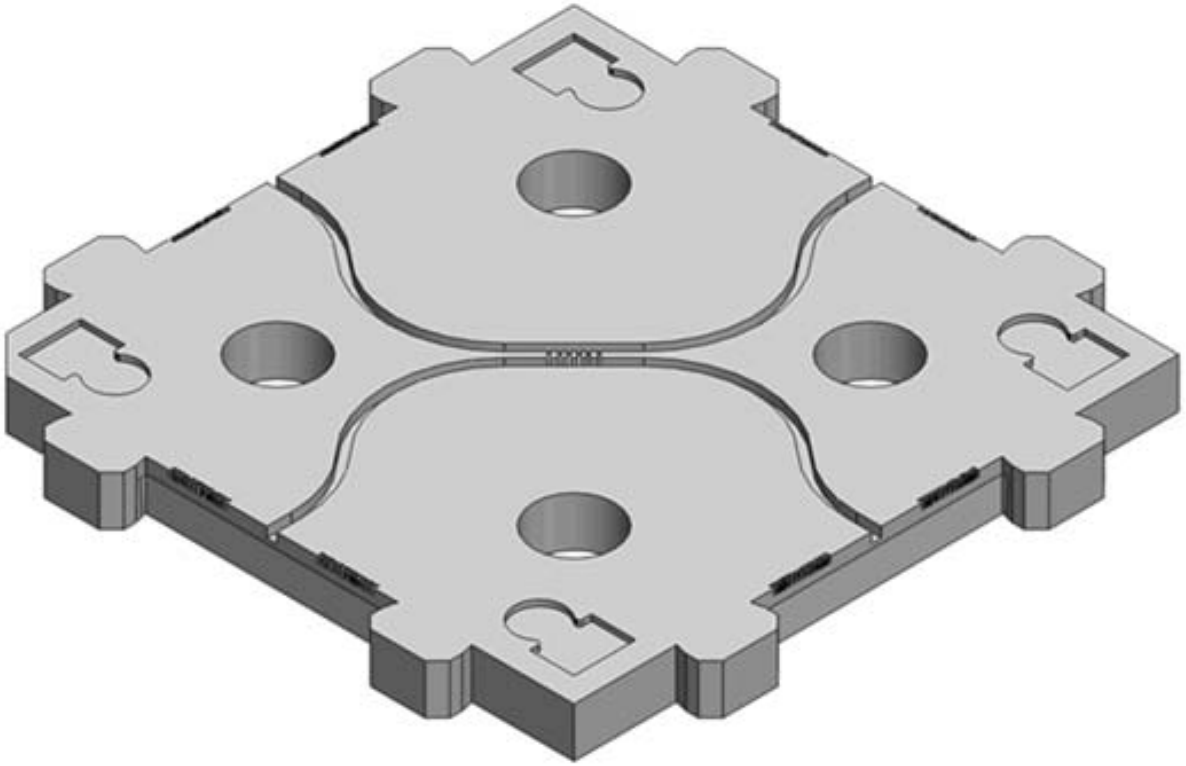
- Waveguide structures are fabricated on silicon wafers and **coated with gold,** stacked vertically

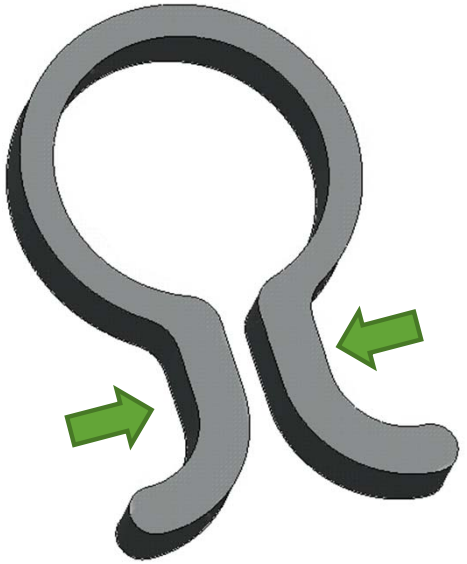




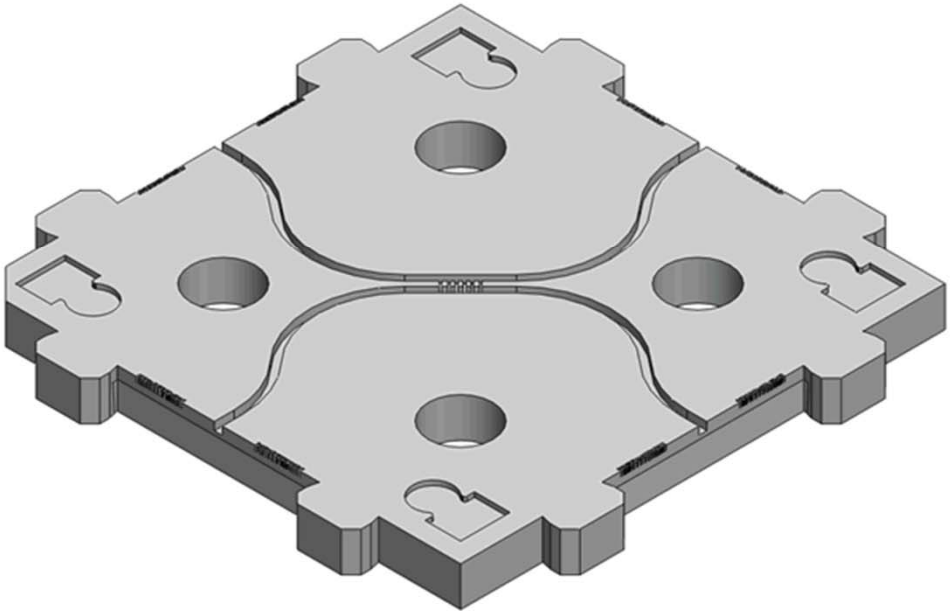


Alignment of Silicon Wafers

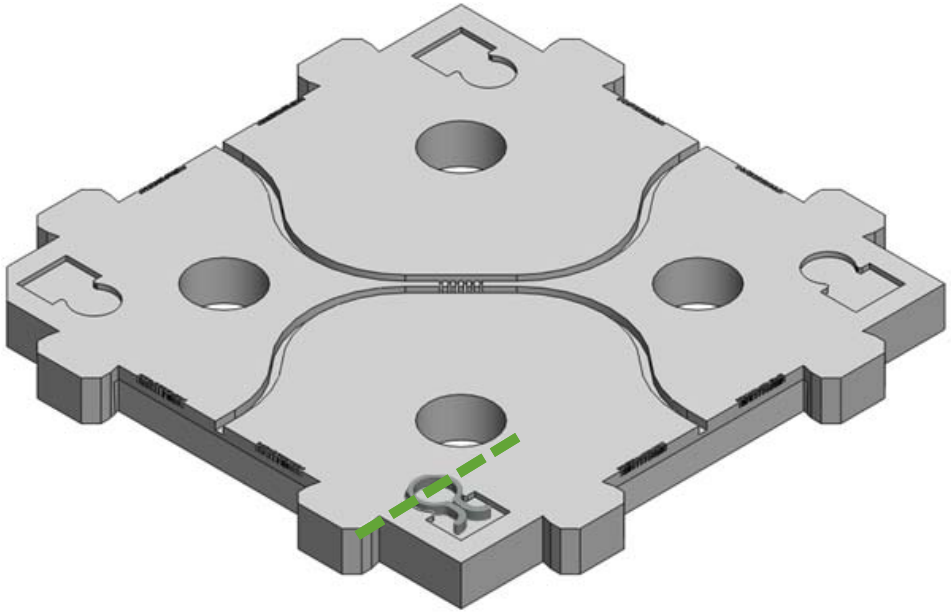




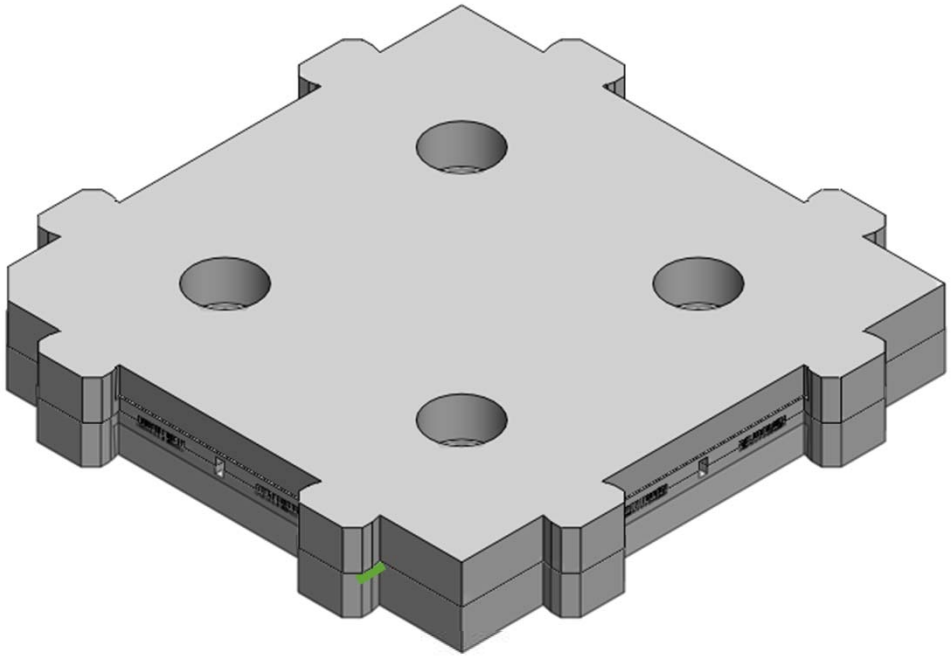
Alignment of Silicon Wafers



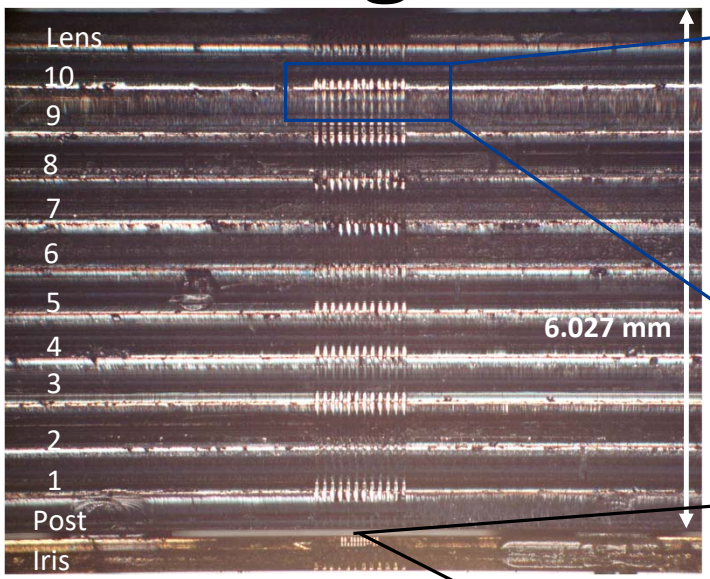
Alignment of Silicon Wafers

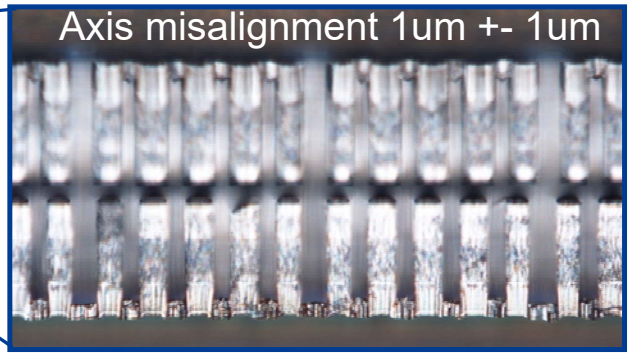


Alignment of Silicon Wafers

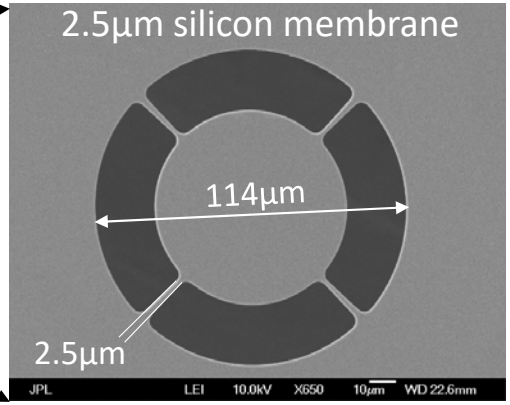


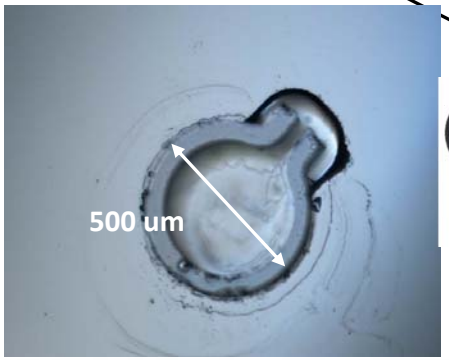
Alignment of Silicon Wafers





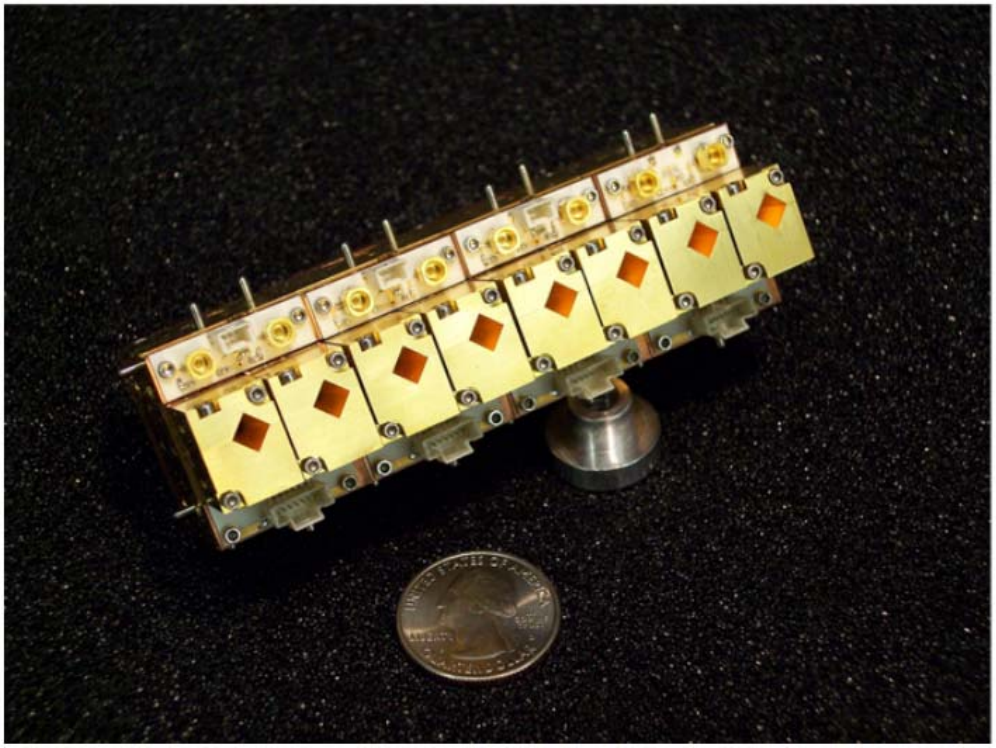
SEM of 1.9THz Iris





Alignment better than 1um!

Integrated System



8-Pixel Fully Functional 340 GHz Imaging Radar System.

Summary

- **Packaging is a challenge at millimeter-wavelengths**
- **It gets much harder at terahertz frequencies.**
- **Silicon micromachined waveguide based packaging seems to be a practical solution.**