Silicon Micro-Machined 2 THz Mixer for 3-D Winds

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Program: Spontaneous RT&D

Project Objective:

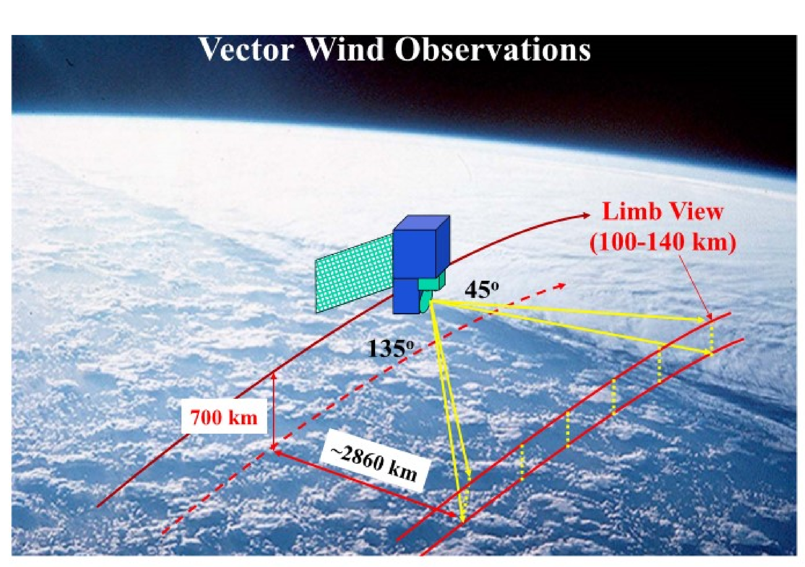
NASA's earth science directorate emphasizes understanding complex atmospheric dynamics in Earth's upper atmosphere. A heterodyne receiver front end is being developed to perform measurements in the lower earth atmosphere at 2.06 THz, where a neutral oxygen line exists. The silicon (Si) platform presented in this abstract is created to support a low-parasitic 2.06 THz Schottky diode mixer. The Si stack design is designed with considerations of having system uniformity, accuracy, and repeatability. By using Si micromachining, desired tolerances can be met with faster turnaround time, and losses at 2 THz operation can potentially be minimized relative to existing metal interfaces, thereby improving mixer performance. The capability to leverage Si fabrication and integrate the local oscillator (LO) and intermediate frequency (IF) signal onto a compact Si micro-machined package has the potential to introduce new features and design paradigms. Furthermore, a key challenge for this type of integrated architecture is to perform reliable testing given sub-millimeter constraints. With the features being etched onto two pieces of 350-μm Si wafer, the Si block is designed to be assembled with fine tolerance by incorporating both prior metal block assembly strategies and a novel optical alignment scheme.

Benefits to NASA and JPL (or significance of results):

NASA's earth science directorate includes as a focus understanding the atmospheric dynamics in Earth's upper atmosphere. It is scientifically important to measure the lower thermosphere for understanding the transition region between a well-mixed lower atmosphere to a diffusive separated thermosphere.

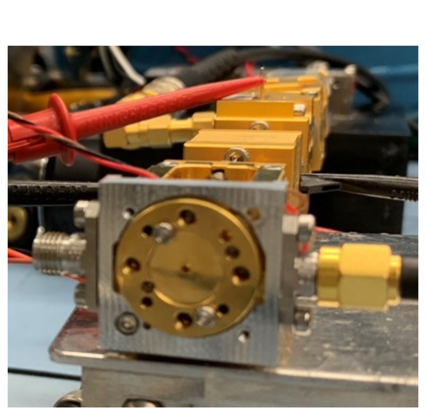
In order to complete thermospheric measurements, THz receivers with the following specifications is desired:
Room temperature operation
Development of local oscillator devices and circuits for THz regime
Schottky-diode technology for mixers in the one to five THz range

The wind velocity is measured in Lower Earth Orbit via Doppler shift and OI emission. This will be measured in conjunction with O2, which will be measured <100 km.

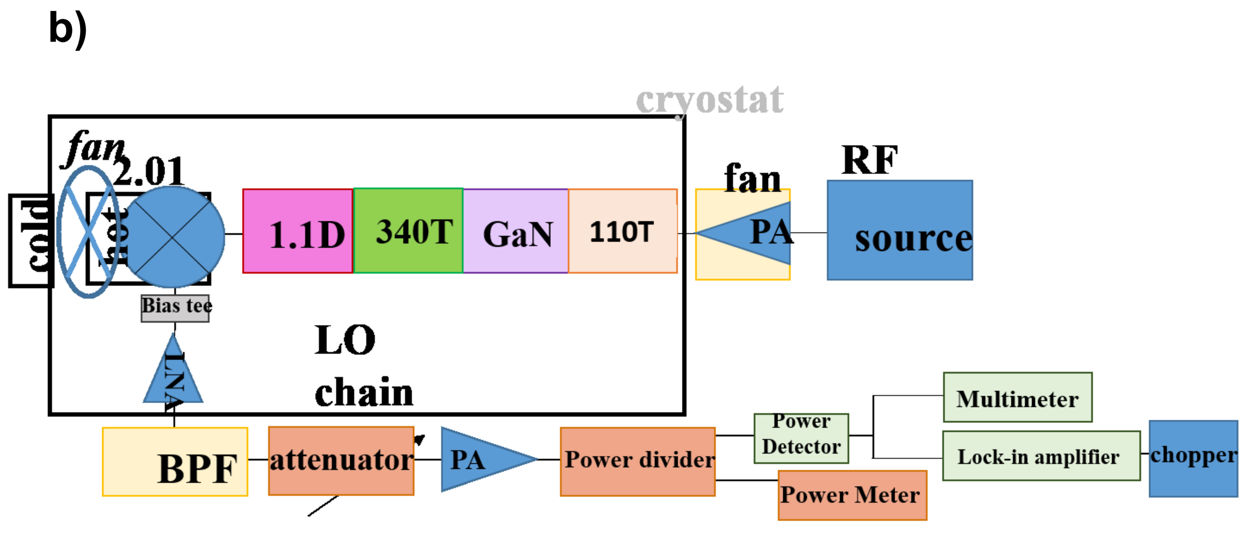


To make these measurements, we need receivers operating at 2.06 THz.

a)

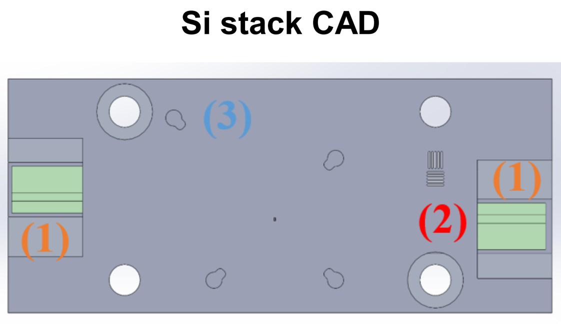


b)



[Figure 1: a) The image on the left is a front view of the 2.06 THz multiplier chain. The designed Si block is embedded into the front platform. This platform has dimensions of 20 mm x 20 mm x 5 mm, including the adapted 1 THz tripler block; The Si stack with electrical interface is 17.5 mm x 7.5 mm x .7 mm. b) The image on the right is a block diagram of the experimental setup.]

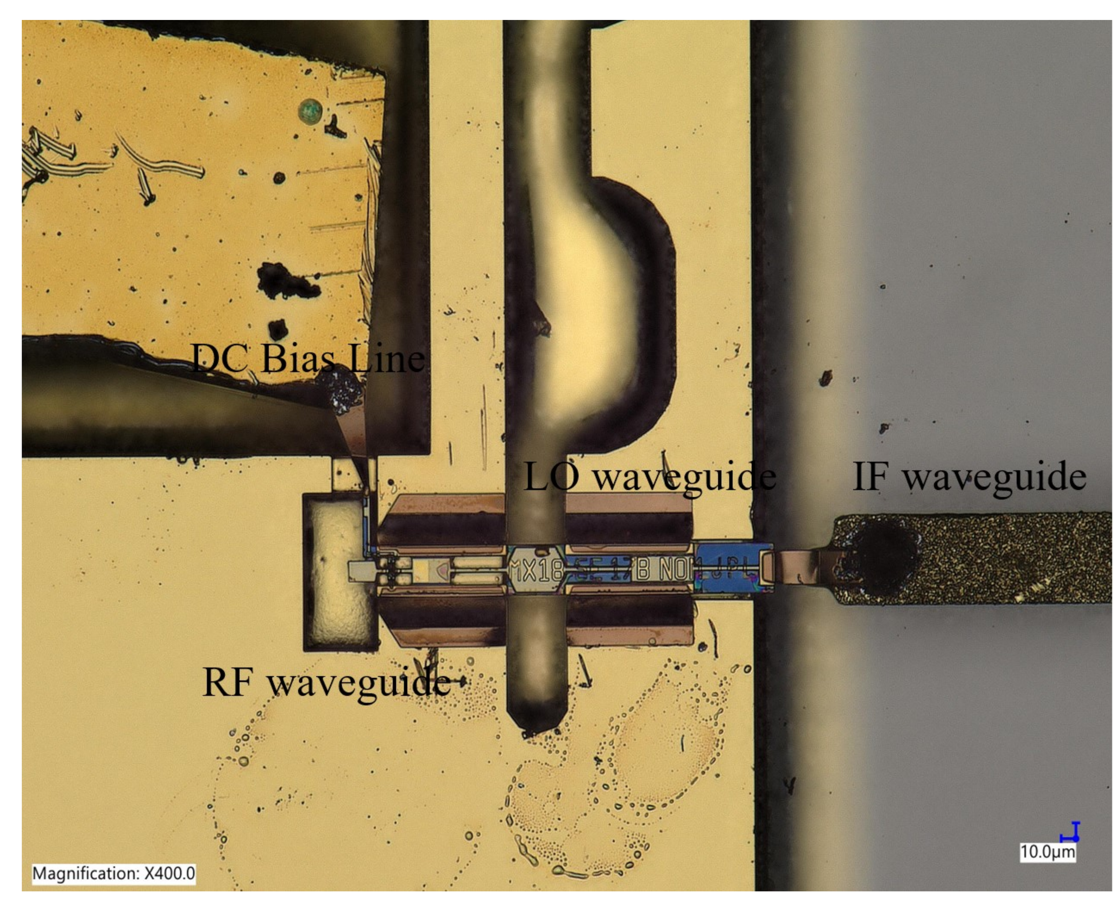
Si stack CAD



- Top and bottom Si pieces: 17.5 mm x 7.5 mm x .7 mm
- In order to have miniature dimensions, quartz-based IF boards (1) were designed, maintaining the low crosstalk levels with low-to-high impedance matching within architecture dimensions.
- Indirect monitor (2) of coupling through relative power shifts
  - Significant to design for testing verification
- Interfaces to 1 THz tripler block (not shown) and microlens via pins (3)
- Two options for coupling out signal via either horn antenna or microlens

FY18/19 Results:

•A fully solid-state receiver has been demonstrated at 2 THz with metal blocks. The Si micro-machined 2 THz mixer block was designed based on existing technology experience and was fabricated at the Microdevices Laboratory.
•Si micromachining allows us to achieve accuracy, repeatability, and uniformity for THz frequencies, enabling components in the 1 to 5 THz range.
•This technology will impact future flight missions by helping to enable larger scale array architecture with reliability at a much smaller area of around 400 mm^2 area than previously demonstrated.

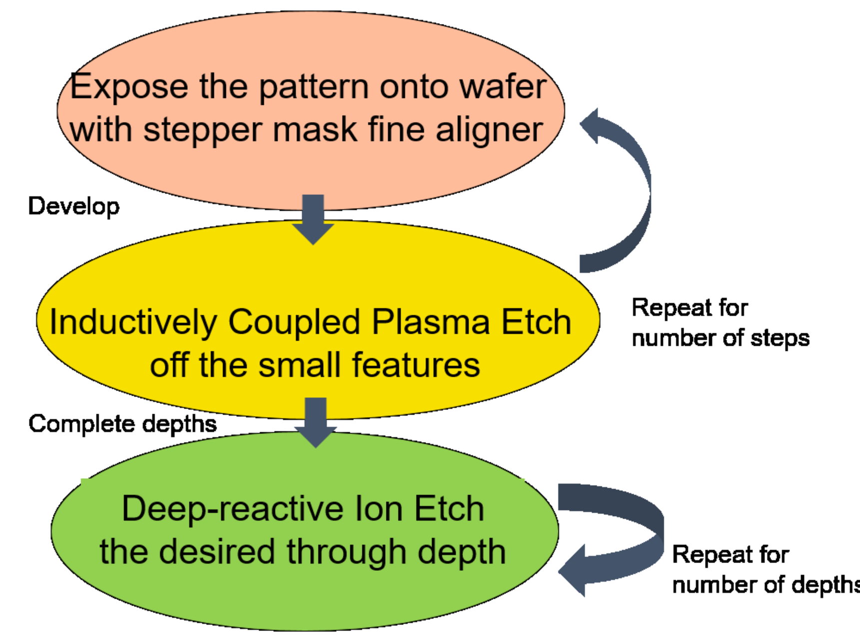


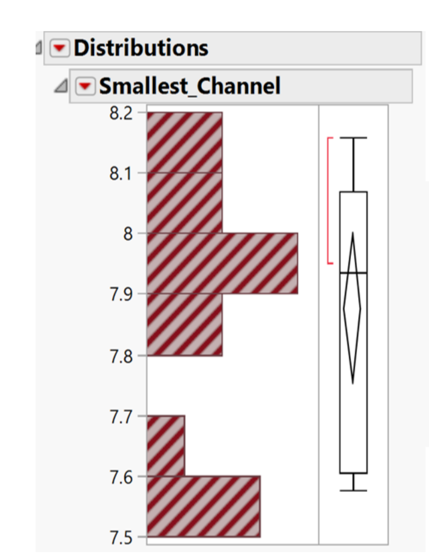
[Figure 2: Mounted Schottky-Diode Mixer in 2.06 THz Si-micromachined waveguide]

[Figure 3: Top-down microscope image of top and bottom stack on 4" Si wafer]

Si Micro-machining

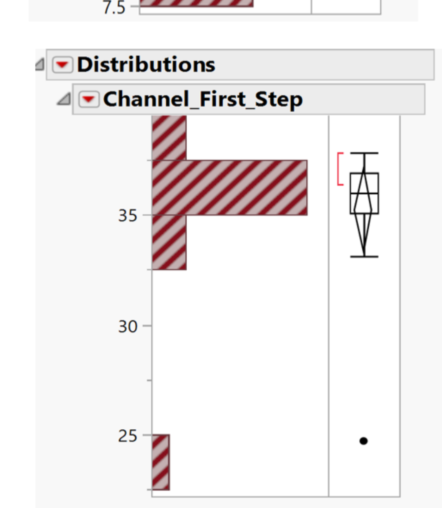
In order to have high-aspect ratio feature size in silicon, deep-reactive ion etching is used:
Consists of three-step cycle of etching (SF_6) and passivation (C_4F_8)





Summary Statistics	
Mean	7.8755714
Std Dev	0.2107772
Std Err Mean	0.0563326
Upper 95% Mean	7.9972706
Lower 95% Mean	7.7538723
N	14
Skewness	-0.383446
Kurtosis	-1.280691

5% average error

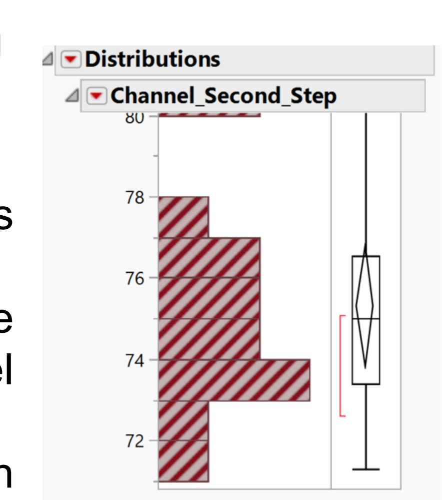


Summary Statistics	
Mean	35.202857
Std Dev	3.2665023
Std Err Mean	0.8730095
Upper 95% Mean	37.088879
Lower 95% Mean	33.316835
N	14
Skewness	-2.882735
Kurtosis	9.3715924

4% average error

Waveguide dimensions are critical to RF coupling and impedance matching at THz frequencies.

- Depths of unit samples are measured across wafer.
- The mean is measured to be the value of the desired depth, which indicates good wafer level accuracy in middle of process step.
- There is good device to device uniformity with small variance.



Summary Statistics	
Mean	75.314286
Std Dev	2.5946267
Std Err Mean	0.6934432
Upper 95% Mean	76.812379
Lower 95% Mean	73.816193
N	14
Skewness	0.6695052
Kurtosis	0.132935

4.6% average error

Publications:

C. P. Chen, D. Hayton, R. Lin, C Jung-Kubiak, J. Siles, M. Alonso, I. Mehdi, "Design and Fabrication of Silicon Stacked Architecture 2.06 THz Receiver Front End," International Symposium on Space Technology (ISST) (April 2019).
(Paper in preparation)

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