1EPN-02

Fabrication of a Silicon Backshort Assembly for Waveguide-Coupled Superconducting Detectors

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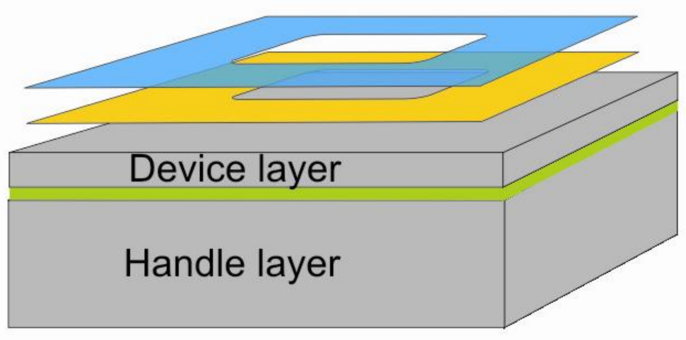
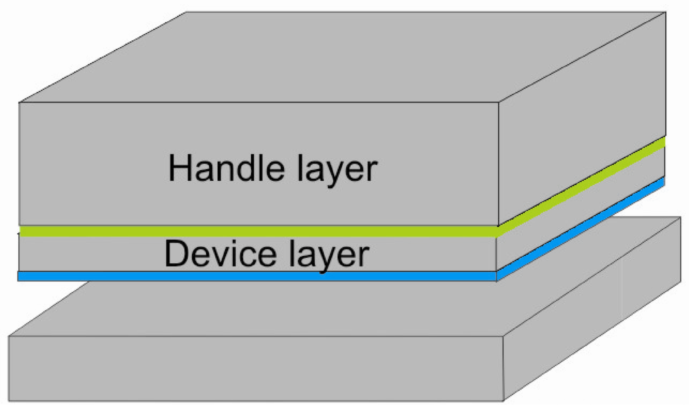
Overview:

The Cosmology Large Angular Scale Surveyor (CLASS) is a ground-based instrument that will measure the polarization of the cosmic microwave background to search for gravitational waves from a posited epoch of inflation early in the universe's history. We are currently developing detectors that address the challenges of this measurement by combining the excellent beam-forming attributes of feedhorns with the low-noise performance of Transition-Edge sensors. These detectors utilize a planar orthomode transducer that maps the horizontal and vertical linear polarized components in a dual-mode waveguide to separate microstrip lines. On-chip filters define the bandpass in each channel, and the signals are terminated in resistors that are thermally coupled to the transition-edge sensors operating at 150 mK [1,2].

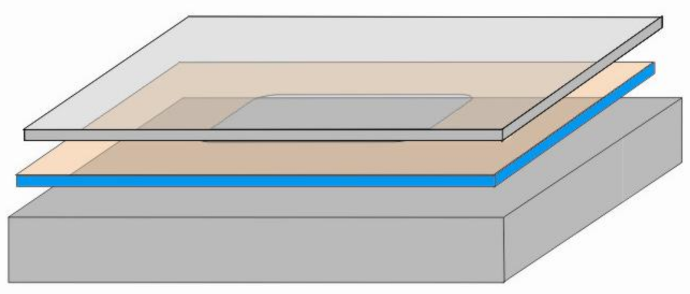
Detector Fabrication Process



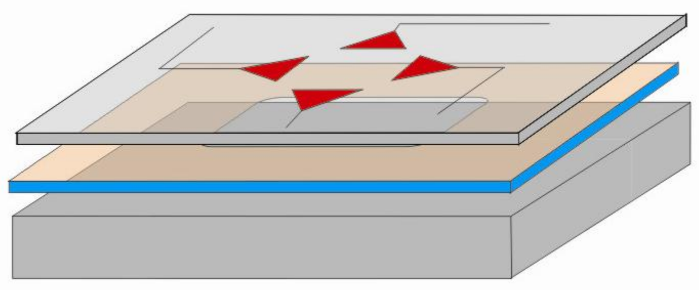
Silicon on Insulator (SOI) wafer: Deposit Nb ground plane and polymer layer for wafer bonding.



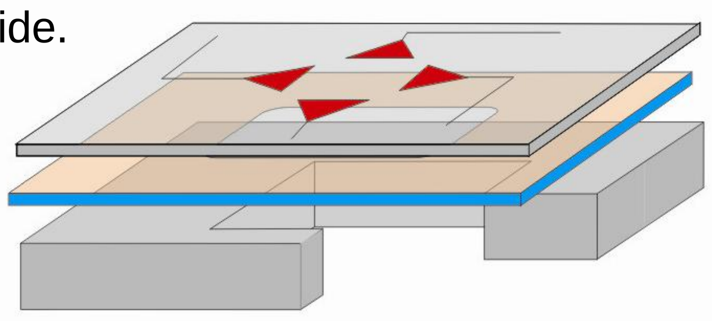
Bond to a low resistivity wafer which will function as an integrated silicon waveguide.



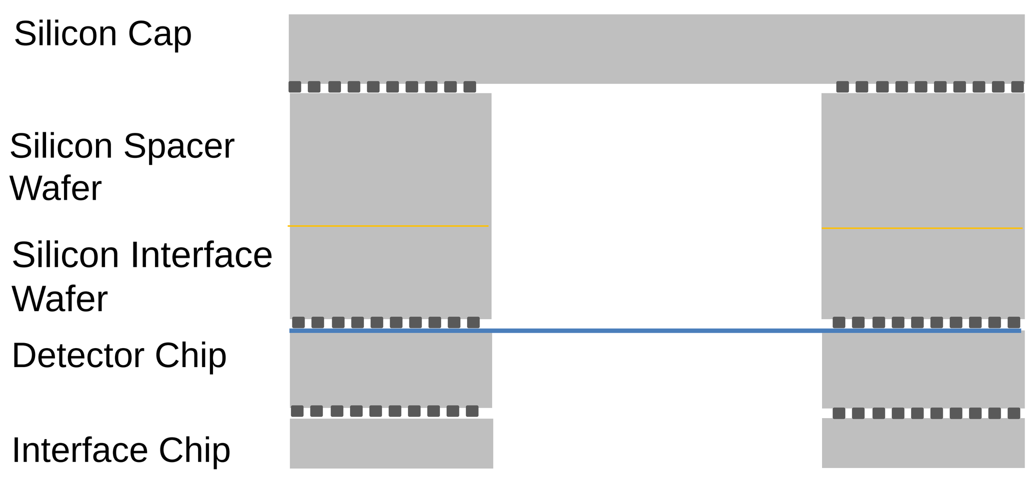
Remove the SOI handle layer and buried oxide. The 5 µm SOI device layer functions as the OMT membrane, TES thermal isolation membrane and microstrip dielectric.



Complete MoAu TES, niobium microstrip, and silicon thermal isolation processing on the device layer side.

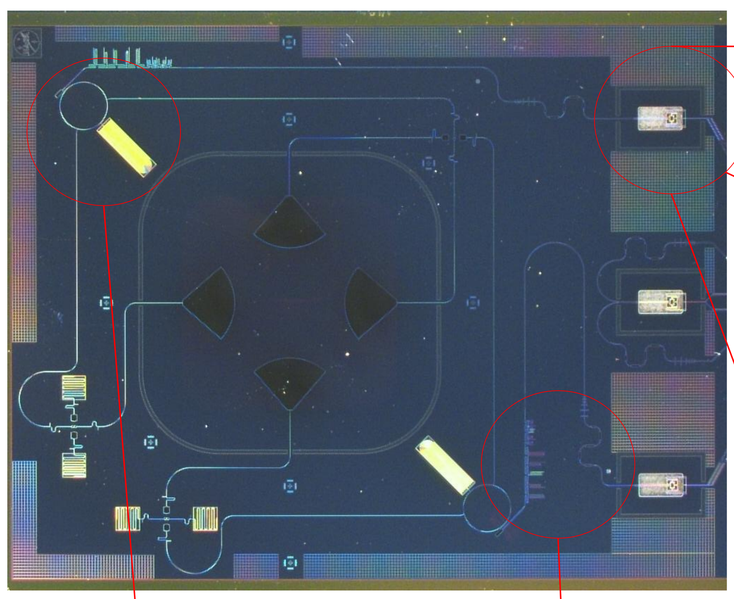


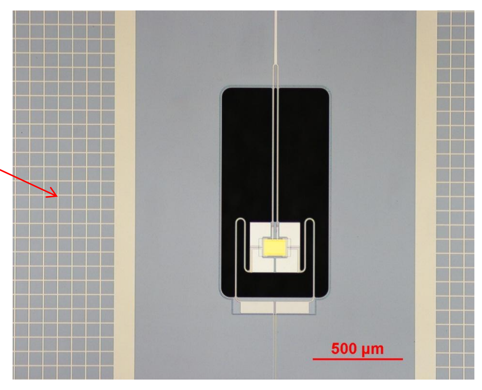
Temporary bond to pyrex wafer (not shown) and deep reactive ion etch (DRIE) to define OMT and release silicon thermal isolation membranes.



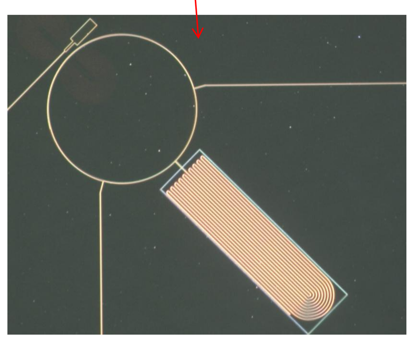
Au-Au thermo-compression bond separately fabricated silicon spacer, interface, and silicon cap wafers to create the backshort assembly. Epoxy bond backshort assembly and detector chip as well as interface chip.

40 GHz Detector

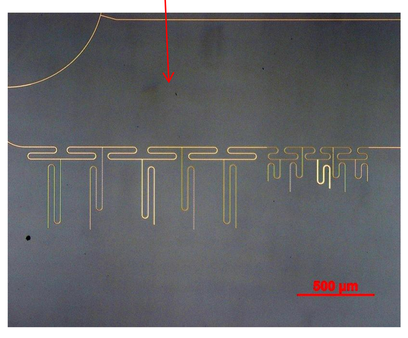




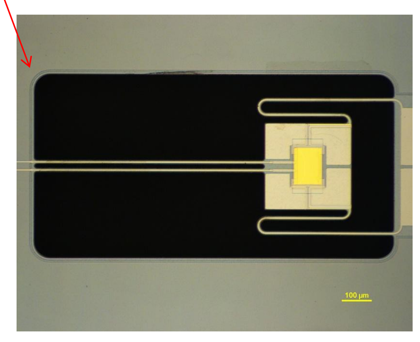
PdAu Grid Structure



Magic-T, a key component of the OMT, differences the signal from opposite antennas

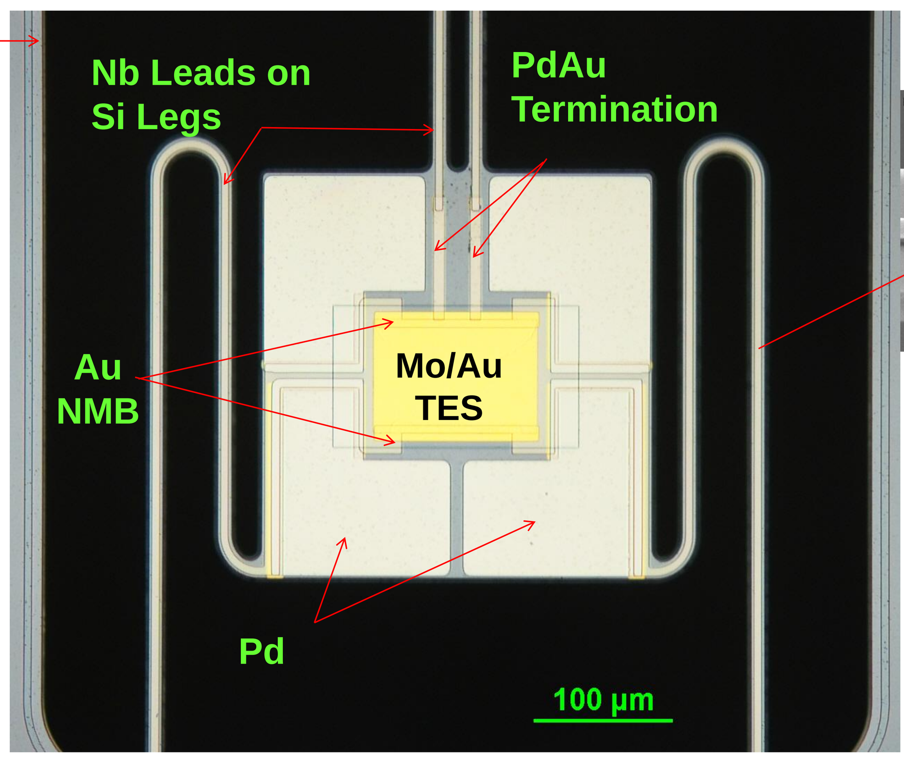


On-chip filtering

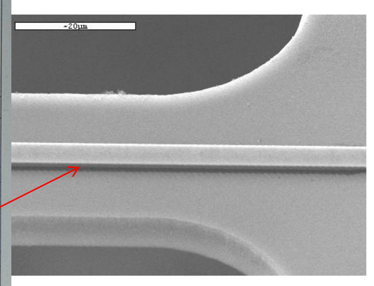


Si membrane for thermal conductance control

- Detector consists of a planar Orthomode Transducer (OMT) that separates the horizontal and vertical polarizations into individual microstrip lines.
- Once separated, each polarization is filtered for passband definition and terminated in a resistor that is thermally-coupled to a TES.
- Added PdAu grid structure to suppress stray out of band signal.
- Dark TES added for calibration.



Silicon membrane with TES

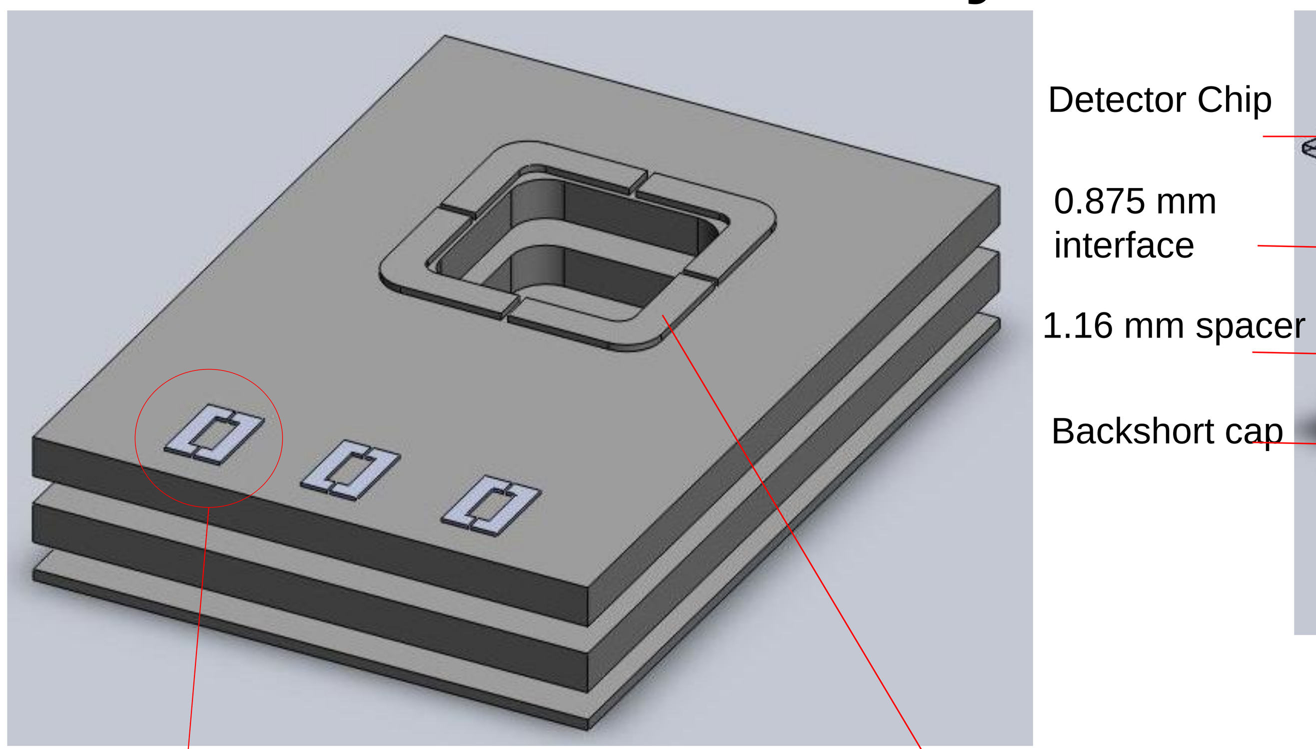


Silicon leg with Nb microstrip

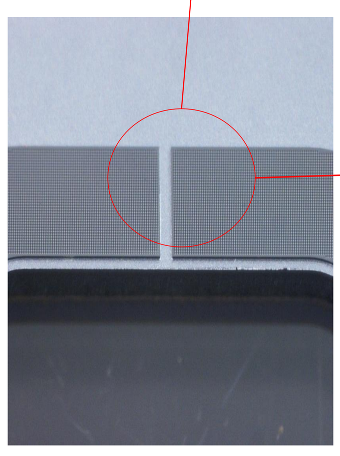
- Four silicon legs route Nb microstrip and bias lines to the TES and isolate TES from the thermal bath.
- PdAu resistors terminate the microwave signal in the TES.
- MoAu TES with targeted 150 mK transition temperature.
- Additional Pd provides added heat capacity in minimal area to maintain isothermal membrane temperature. Also functions as part of the via-less microwave termination.
- The length and width of each silicon leg have been designed to meet the required thermal response.
- Gold normal metal bar banks to suppress excess noise in the form of resistance fluctuations, vortex noise, etc.

Silicon Backshort

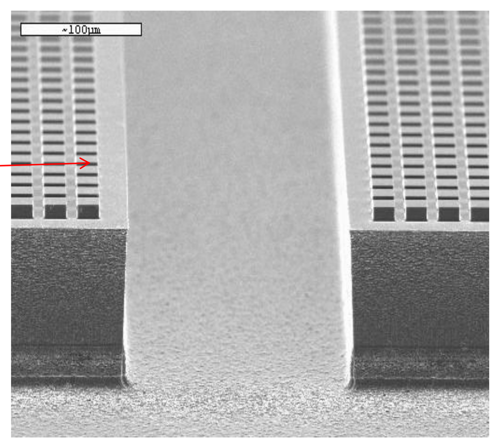
Fabrication and Assembly



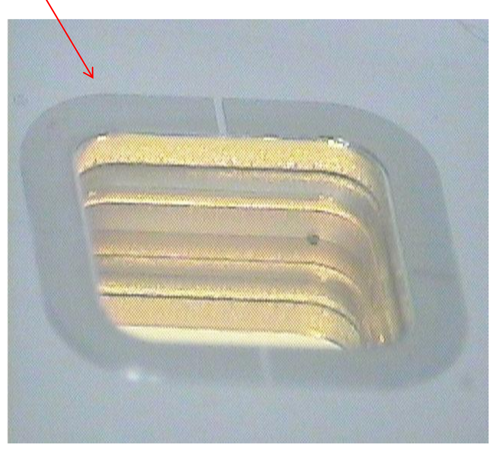
Backshort Assembly



Etched relief to prevent shorting detector microstrip



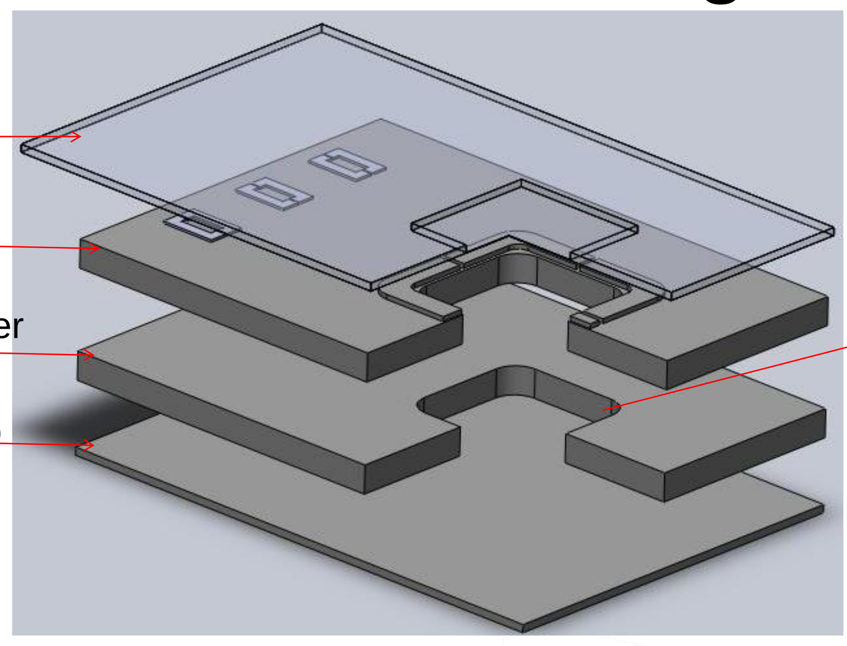
Etched relief with silicon pillars isolate the OMT and TES from out of band leakage



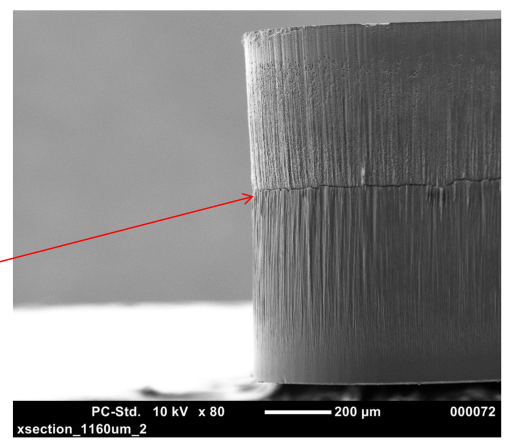
Waveguide cavity metalized after Au-Au thermo-compression bonding

- Silicon backshort assembly consists of 3 low resistance wafers:
  - 875 µm interface
  - 1160 µm spacer
  - 325 µm cap
- 875 µm interface and 1160 µm spacer wafer create the quarter-wave delay section.
- 325 µm cap wafer terminates the waveguide delay in a short.
- Wafers are micromachined using deep reactive ion etching.
- Interface wafer incorporates a 50 µm deep etched relief to prevent shorting of the detector microstrip.
- The 10 µm silicon pillars along the top of the relief contact the detector around the OMT and TES membranes.
- The three etched wafers are conformally coated with gold and bonded using Au-Au thermo-compression bonding [3], and individual backshorts are singulated by dicing.
- The backshort mating surface of the interface wafer is coated with niobium.

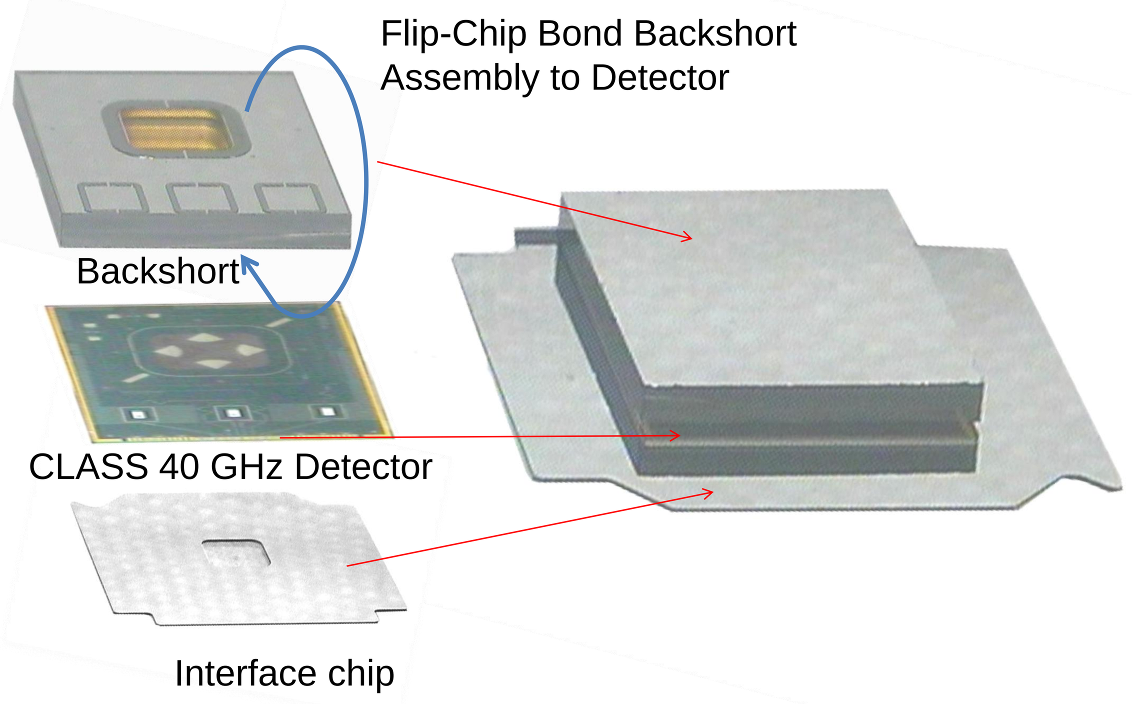
Detector Integration



Backshort integration to detector chip



Silicon sidewall profile etched by DRIE



Detector integrated with backshort and interface chip

- The detector and backshort chips are epoxy bonded at room temperature with a flip-chip bonder.
- A metalized silicon interface chip is integrated with the detector/backshort assembly by flip-chip bonding.
- The interface chip is formed by DRIE to provide registration structures for accurate alignment of the detector to the feed horns in the focal plane.

References

[1] D.T. Chuss, C.L.Bennett, N. Costen, E. Crowe, K. Denis et al "Electromagnetic Design of Feedhorn Coupled Transition Edge Sensors for Cosmic Microwave Background Polarimetry", Journal of Low Temprature Physics, 2012, Vol 167, No 5-6, 923-928.

[2] K. L. Denis, N. T. Cao, D. T. Chuss, J. Eimer, J. R. Hinderks, W.-T. Hsieh, S. H. Moseley, T. R. Stevenson, D. J. Talley, K. U.-yen, and E. J. Wollack, "Fabrication of an antenna-coupled bolometer for cosmic microwave background polarimetry," AIP Conference Proceedings 1185(1), pp. 371-374, 2009.

[3] C. H. Tsau, M. A. Schmidt, S.M. Spearing, "Characterization of low temperature, wafer level gold-gold thermocompression bonds", Proc. MaterialsScience of MicroElectroMechanical Systems (MEMS) Devices II, 1999, pp 171-176.