THz Heterodyne HEB receivers: options for large arrays and expected performance

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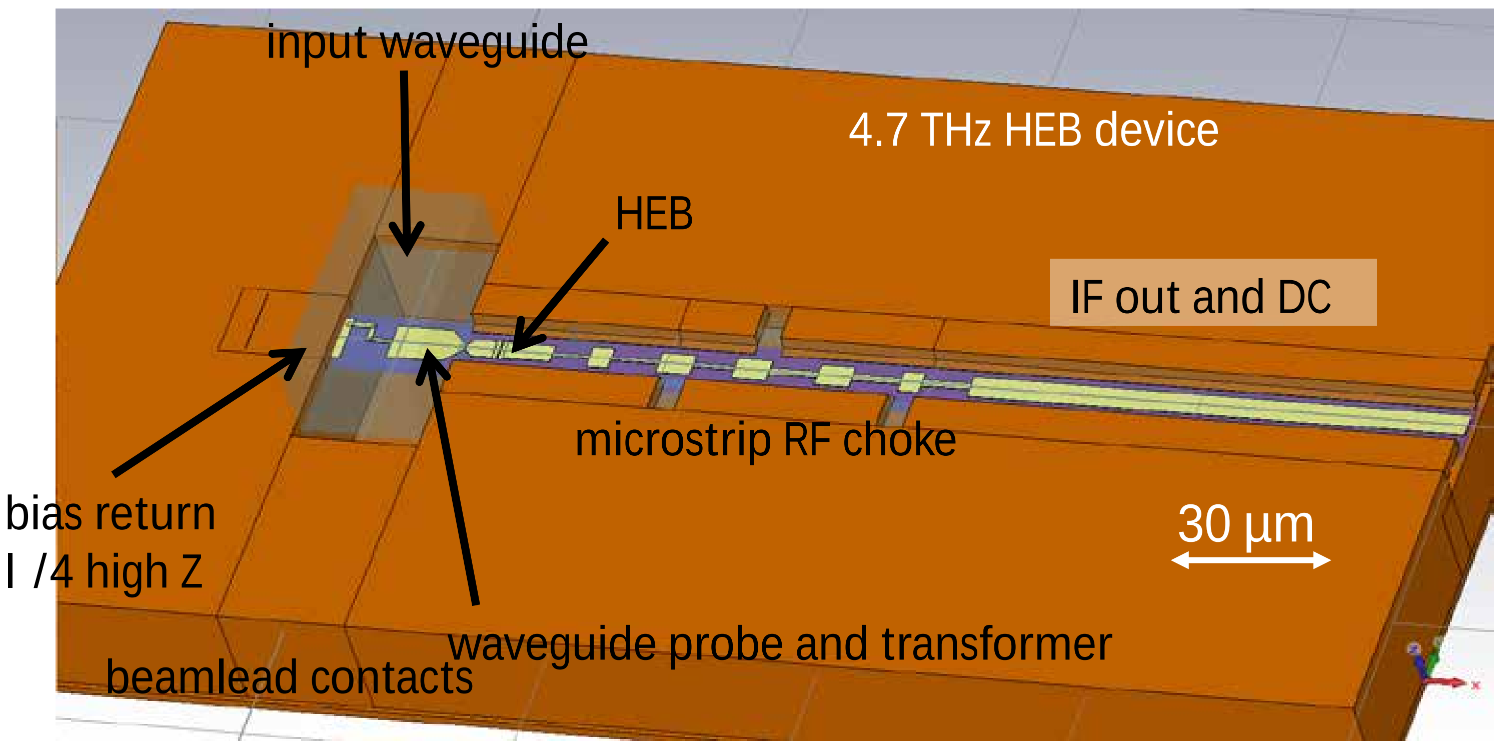
Outline

Waveguide/horn antenna mixers for THz arrays

- RF design for ultrathin substrates, beamleads
- HEB ultrathin NbN (NbTiN) film fabrication
- device processing for beamlead devices
- waveguides for THz mixers
- device/waveguide/horn integration
- Local oscillator power issues
- On-chip integration of RF circuits
- Lessons learned

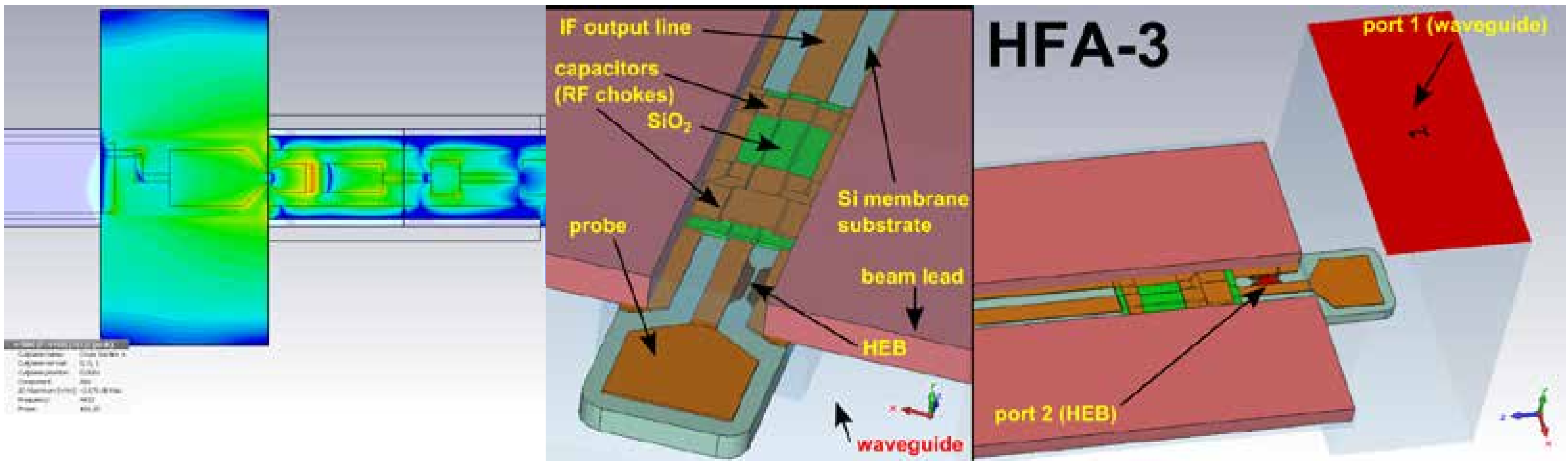
3D outline of device in waveguide

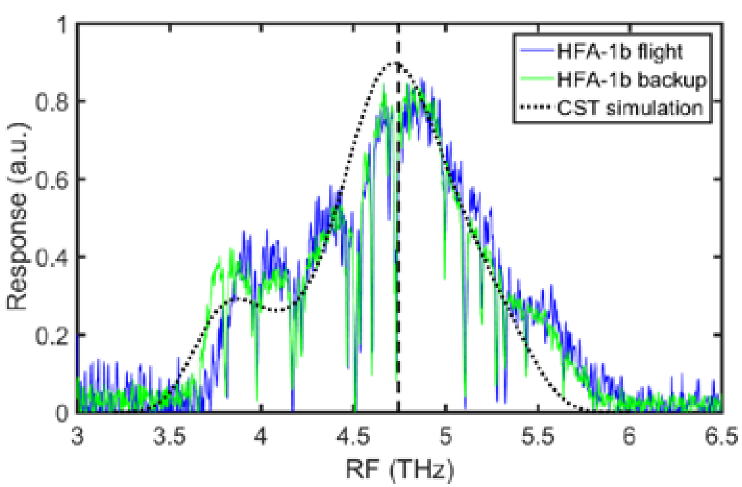
- Waveguide/horn: single mode, well defined beam
- Thorough 3D EM design needed for device
- THz characteristics of conductors and dielectrics
- Ultrathin substrate (suppress surface modes)

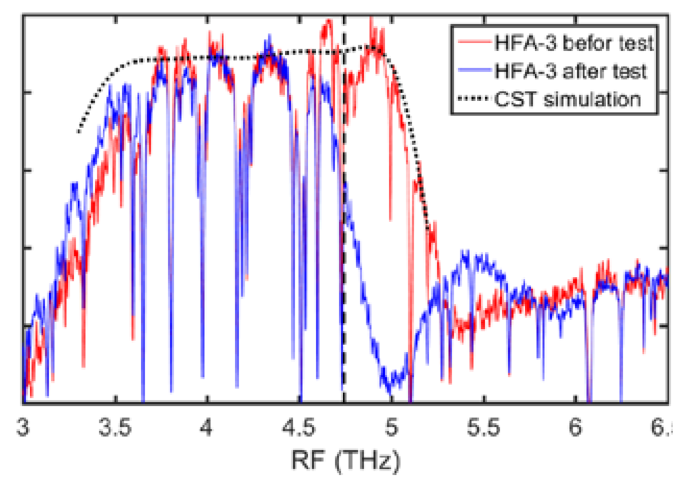


3D EM analysis

Modelling with CST, FTS verification (4.7 THz)

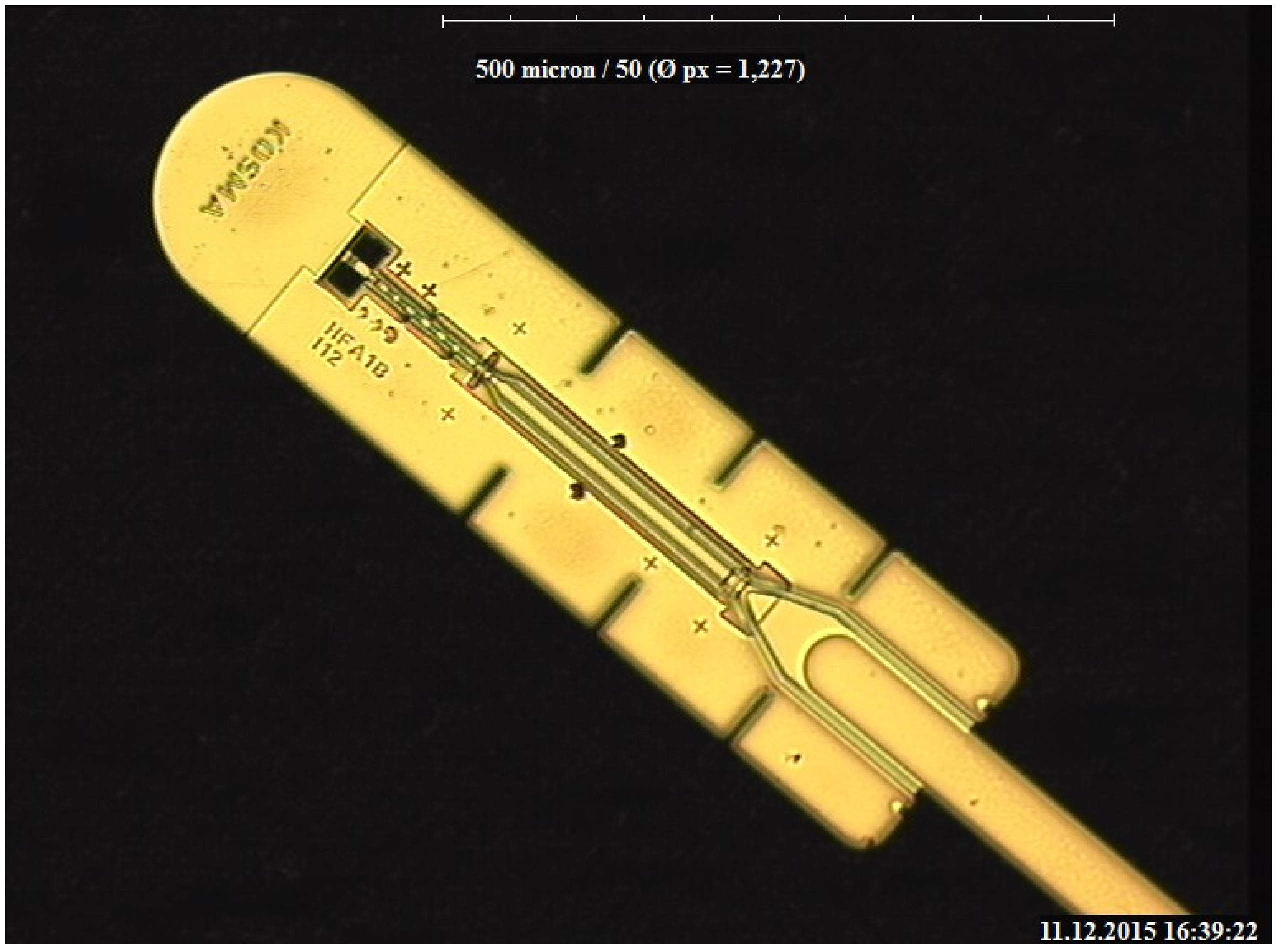




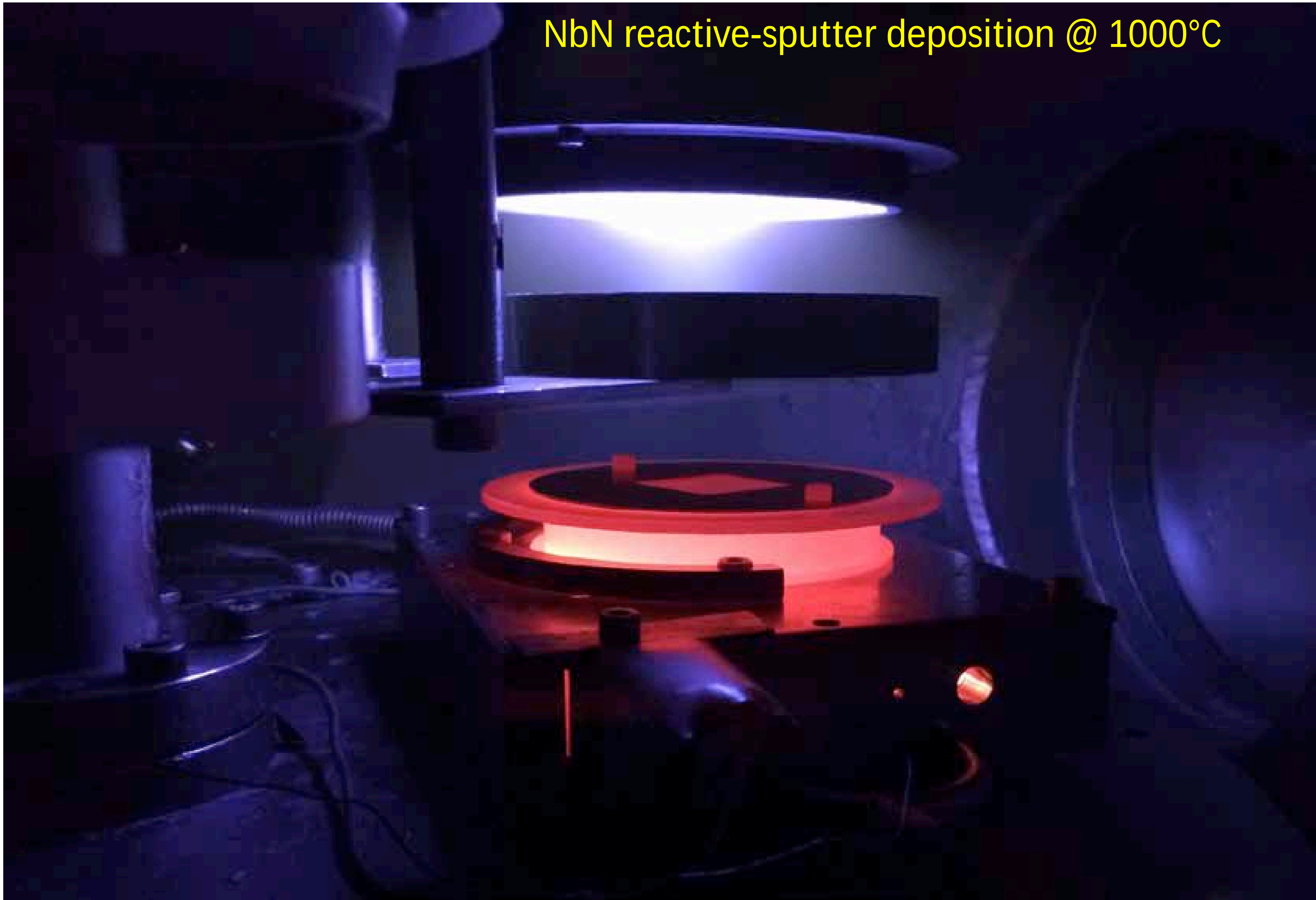


Key design feature: beam leads & shaped substrates

„RF gasket“ for horn waveguide, cooling path to block, RF & IF ground, mounting & contacting, registration



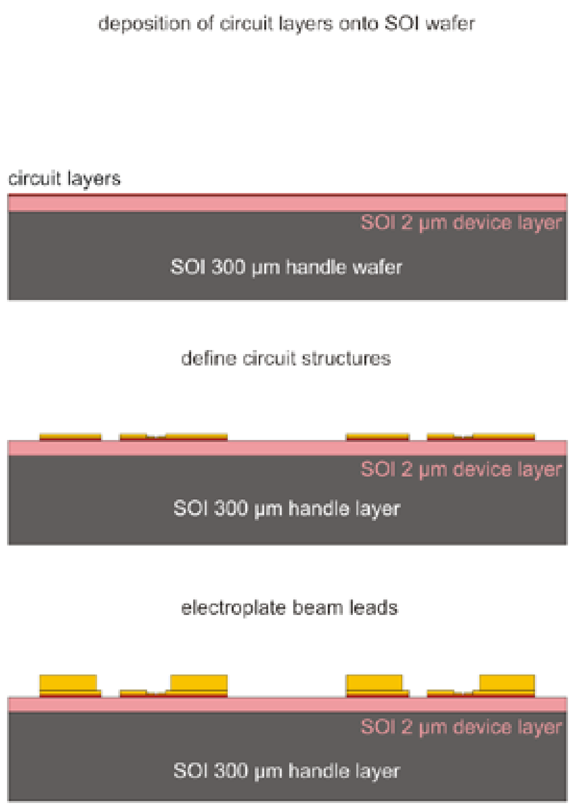
Key fabrication feature: NbN device layer



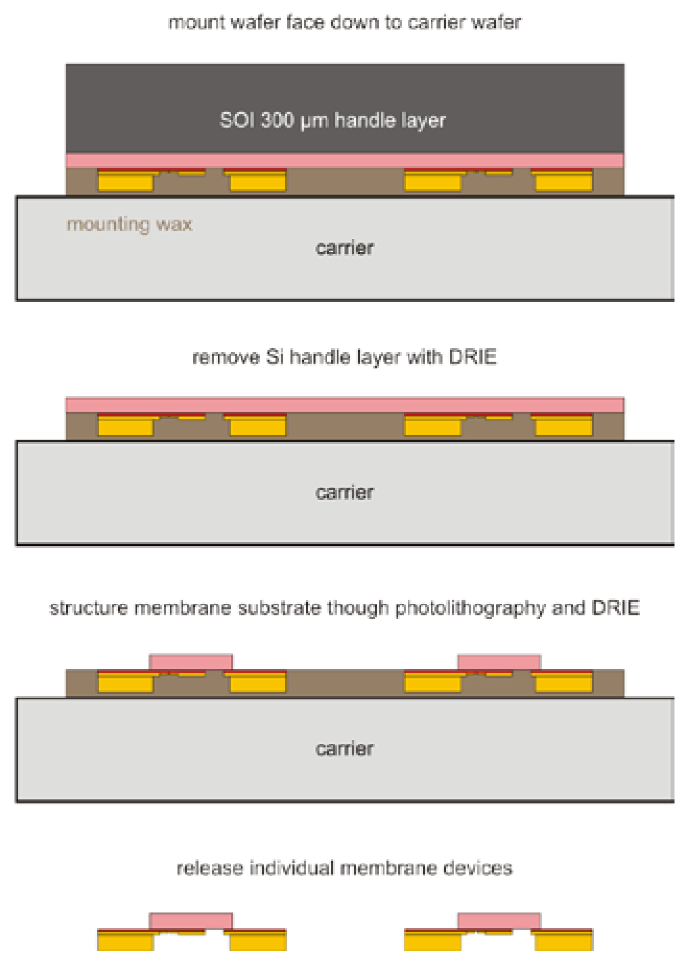
2 µm SOI membrane process

Hi-res Silicon-On-Insulator, 3µm electroformed beam leads

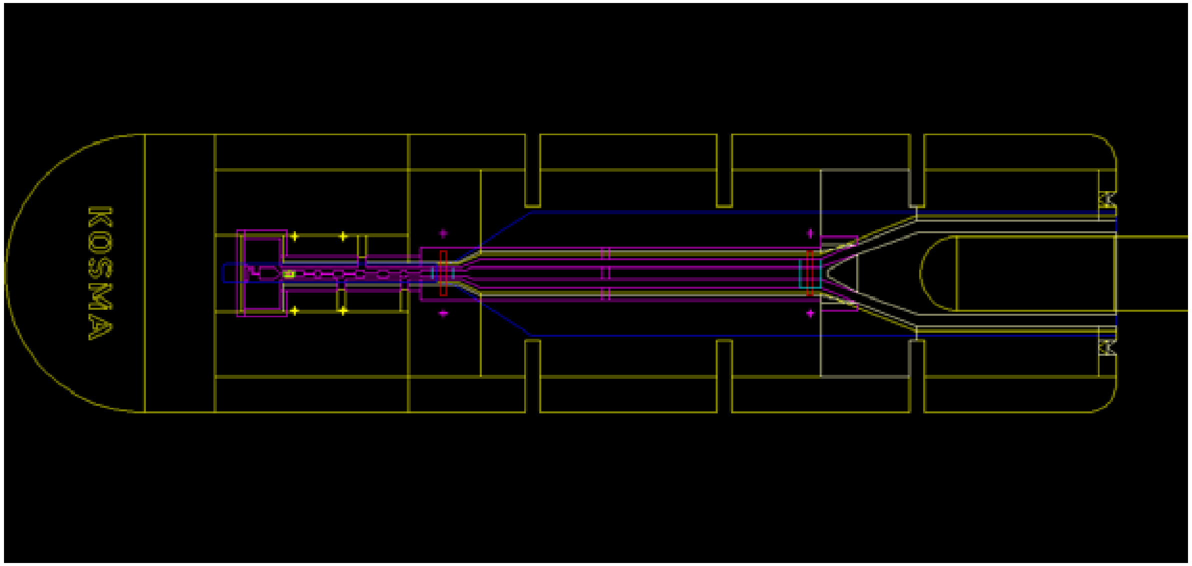
Front side processing



Back side processing



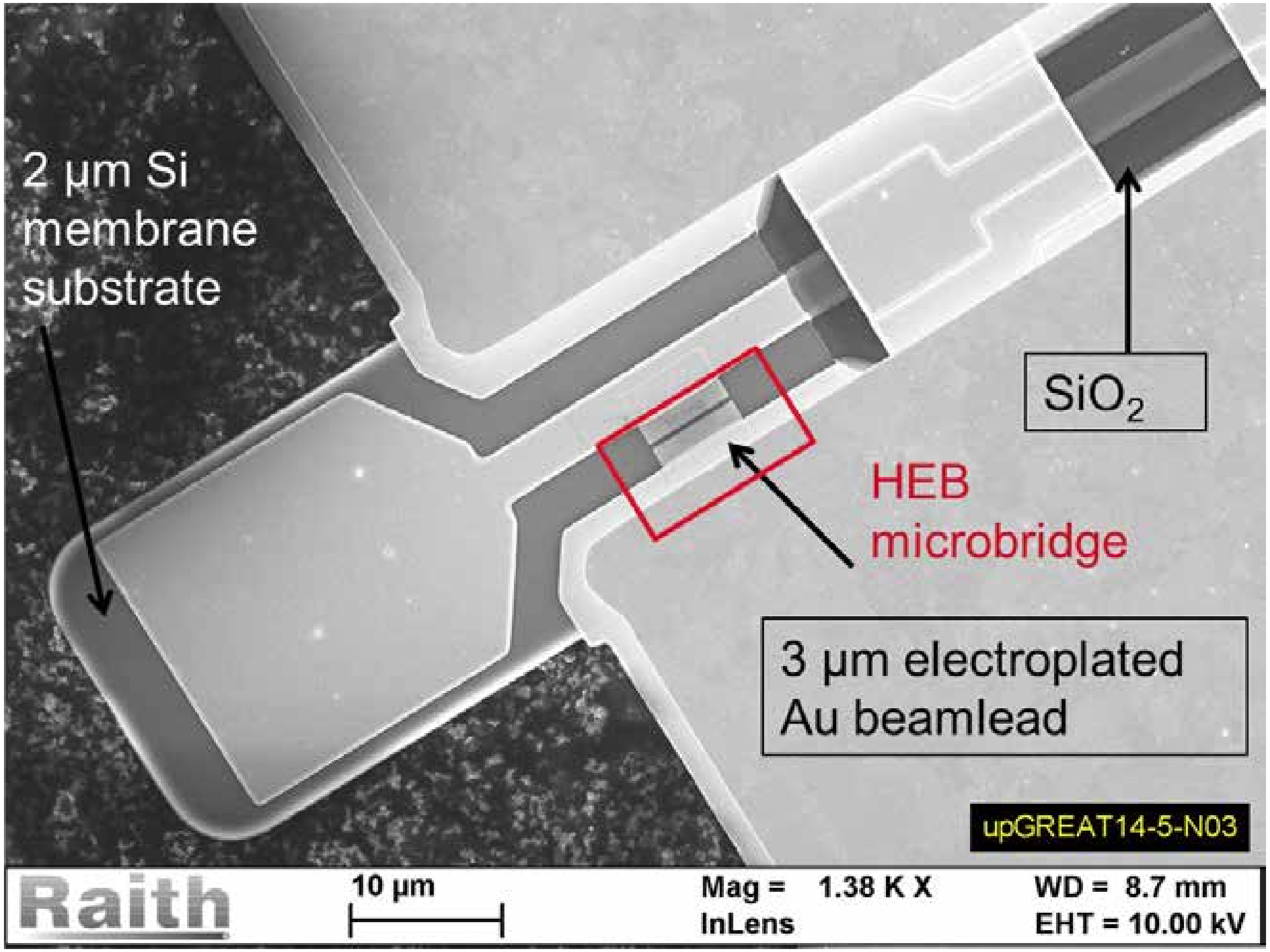
Mix-and-match Lithography



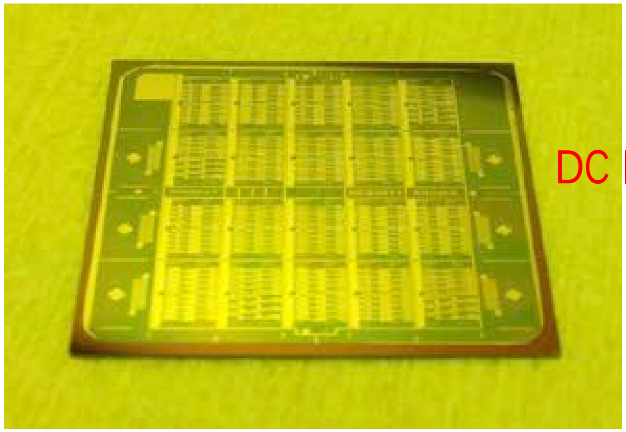
750 µm

- Raith PIONEER E-beam litho
- 5 E-beam levels
- Field stitching (3-4 fields)
- with overlap to UV 300nm optical lithography

E-beam lithography

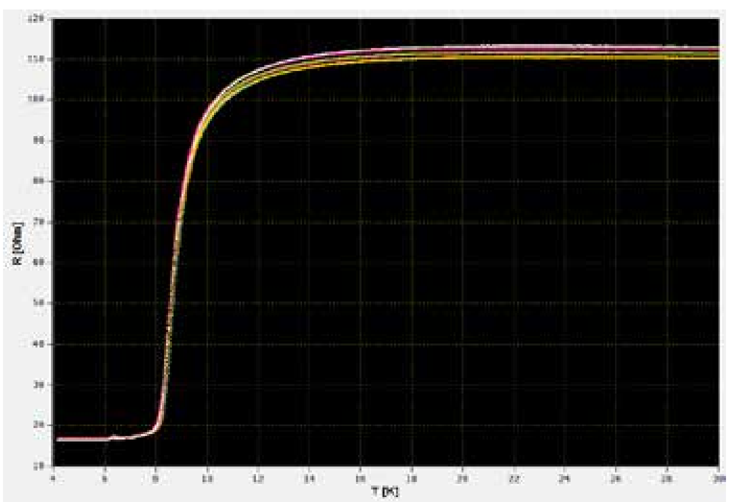


DC testing before backside process

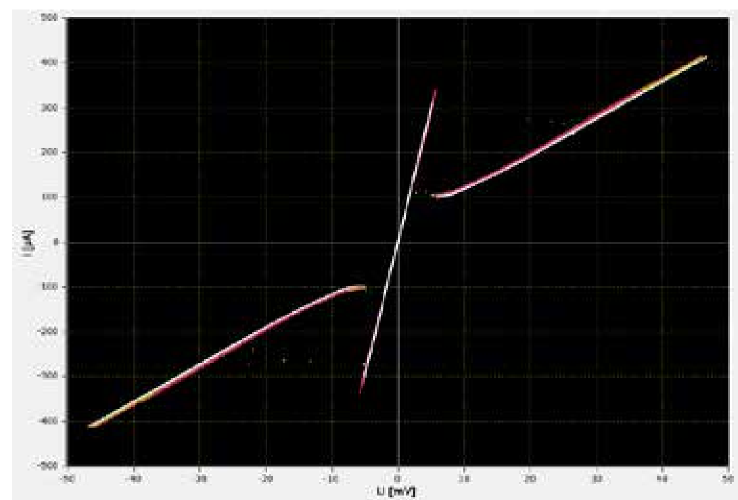


DC IV/RT

30 mm



R/T



I/V

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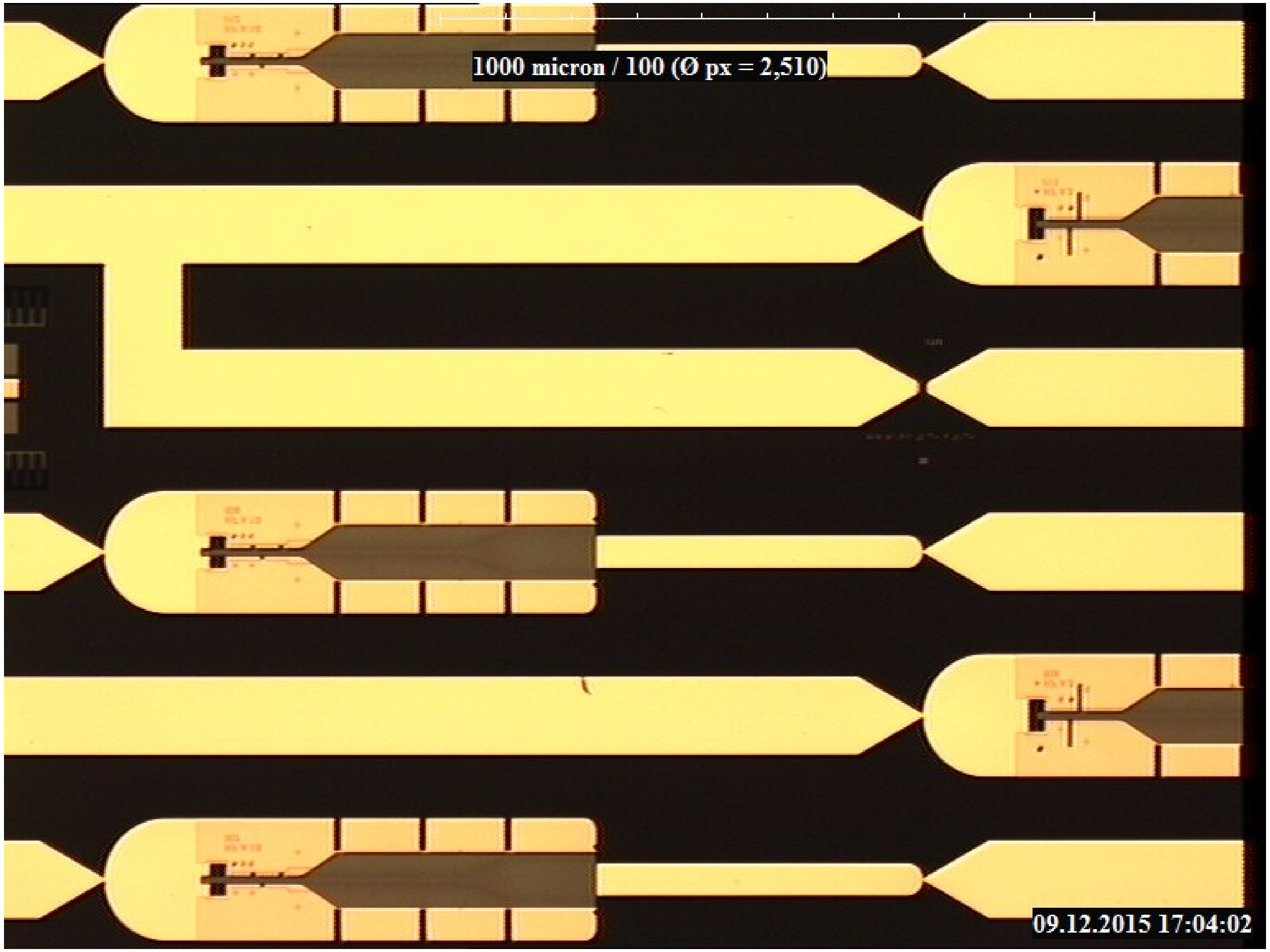
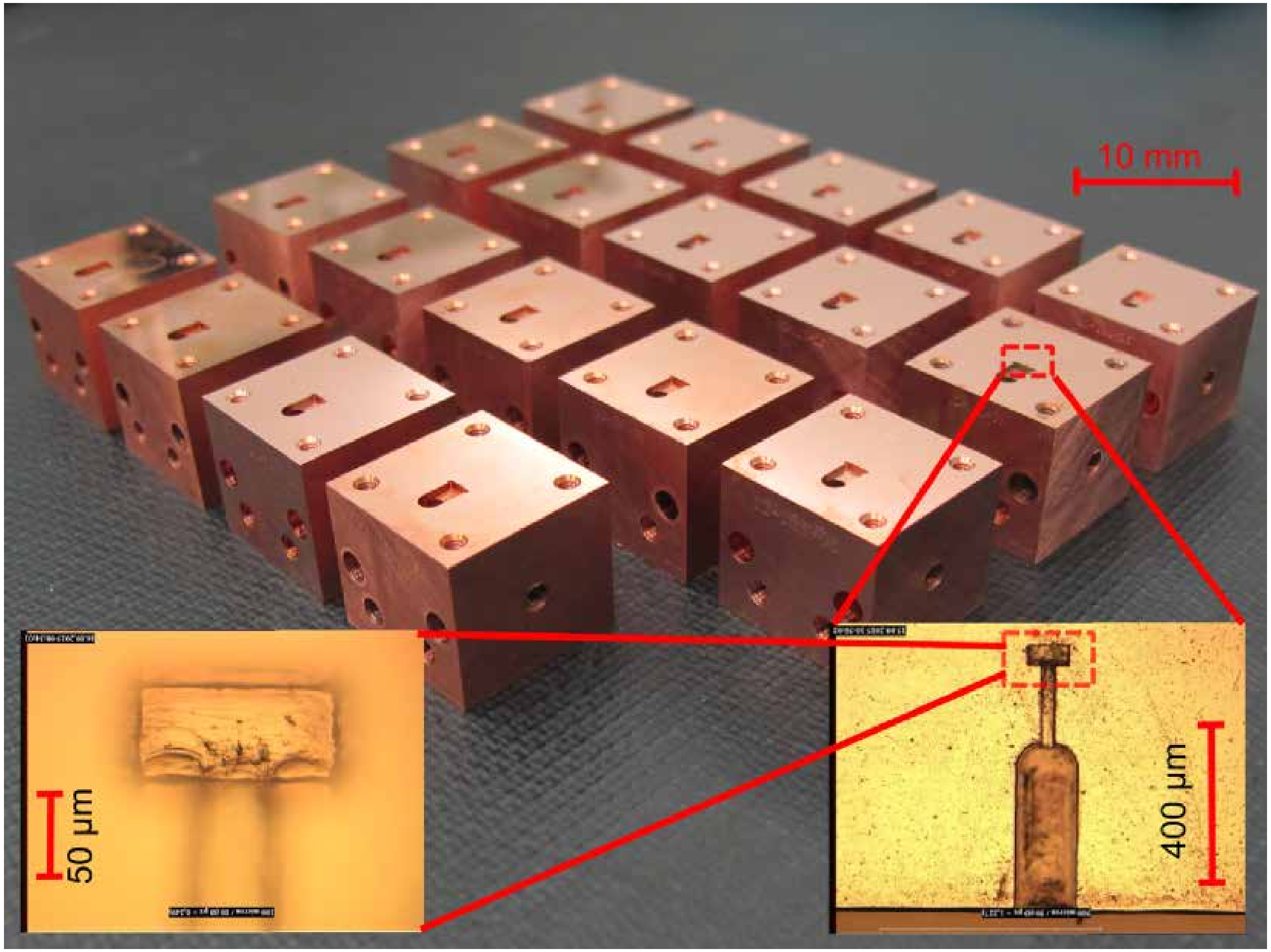
Backside processing

View of substrate side after DRIE etch of device Si
Shaped substrate + underside of beam leads



CuTe mixer blocks (1.9 THz)

Waveguide & substrate channel stamped w. steel tool



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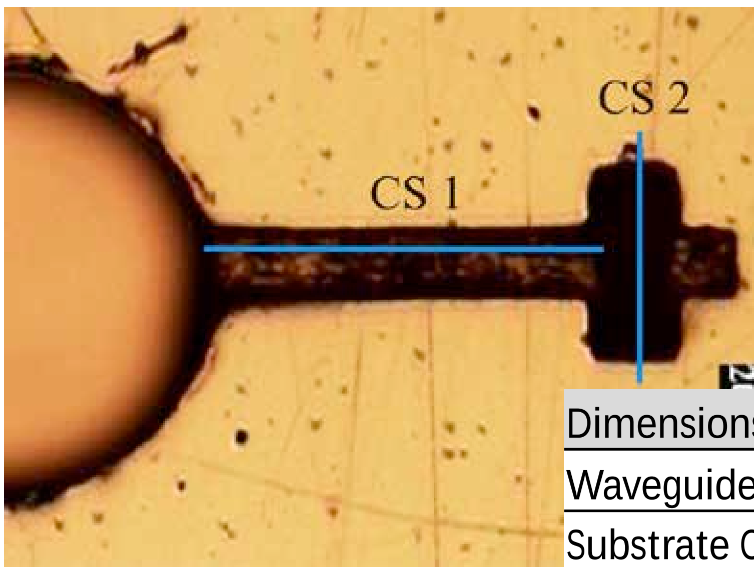
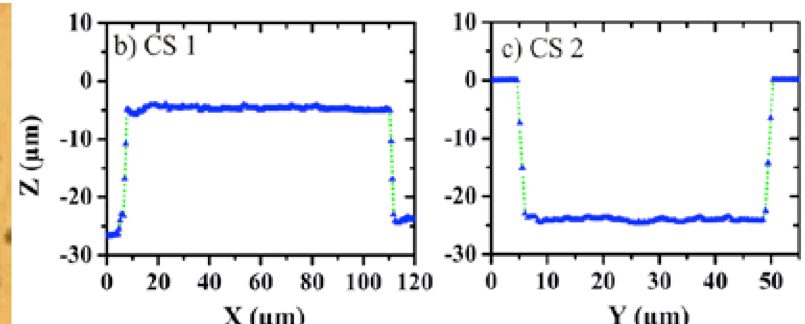
Surface quality (4.7 THz)

- Direct milled metal (CuTe alloy)
- achieved dimensional accuracy +/- 2 µm
- roughness Ra < 0.2 µm, RMS = 0.3 µm

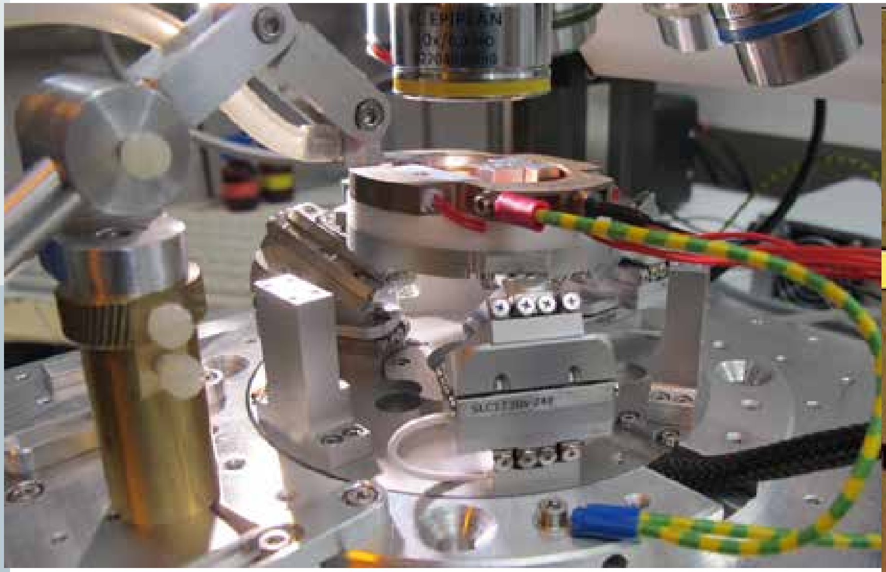


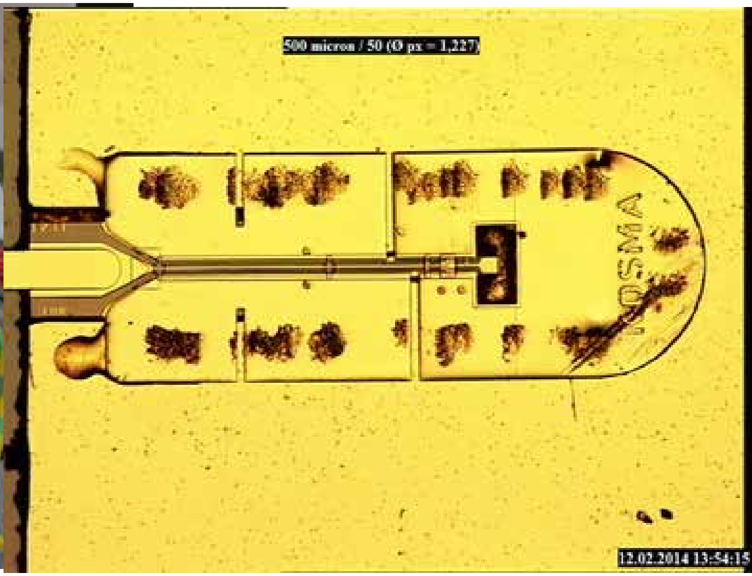


Dimensions & tolerances (µm)	Width	Length	Depth
Waveguide	24 (2)	48 (3)	22 (2)
Substrate Channel	14 (+2)	105 (-5)	4 (+2)

Assembly

- Device integration with SmarPod 6DOF nanomanipulator
- Custom vacuum tweezers for device handling
- U/S bonding to gold plated block





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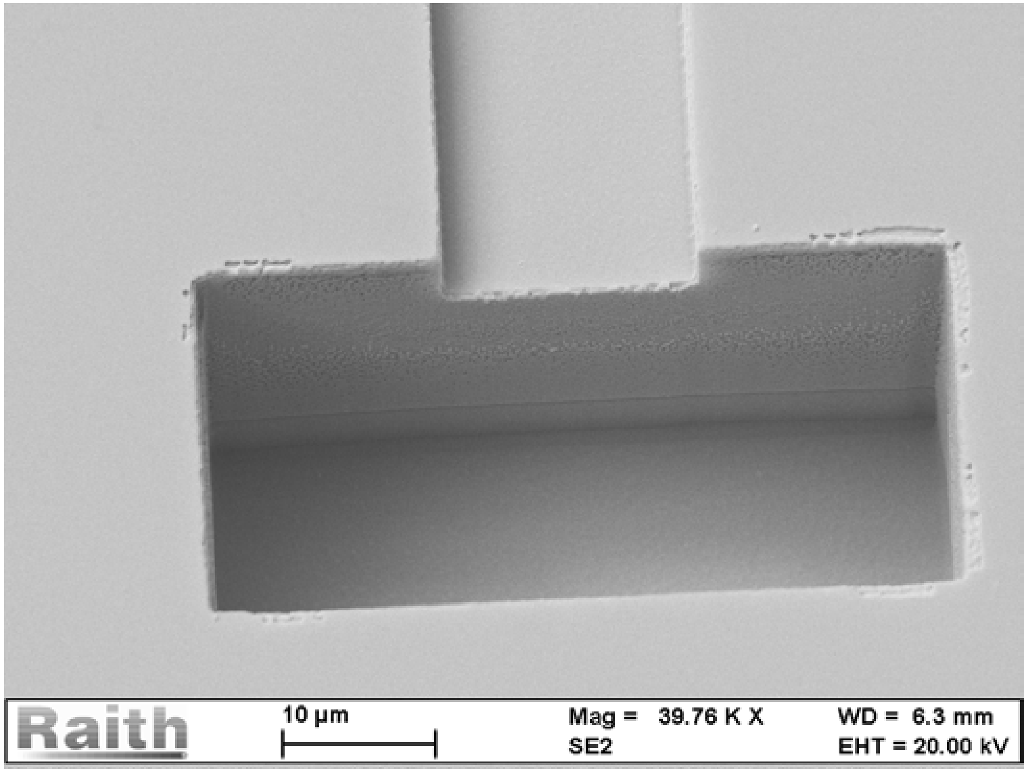
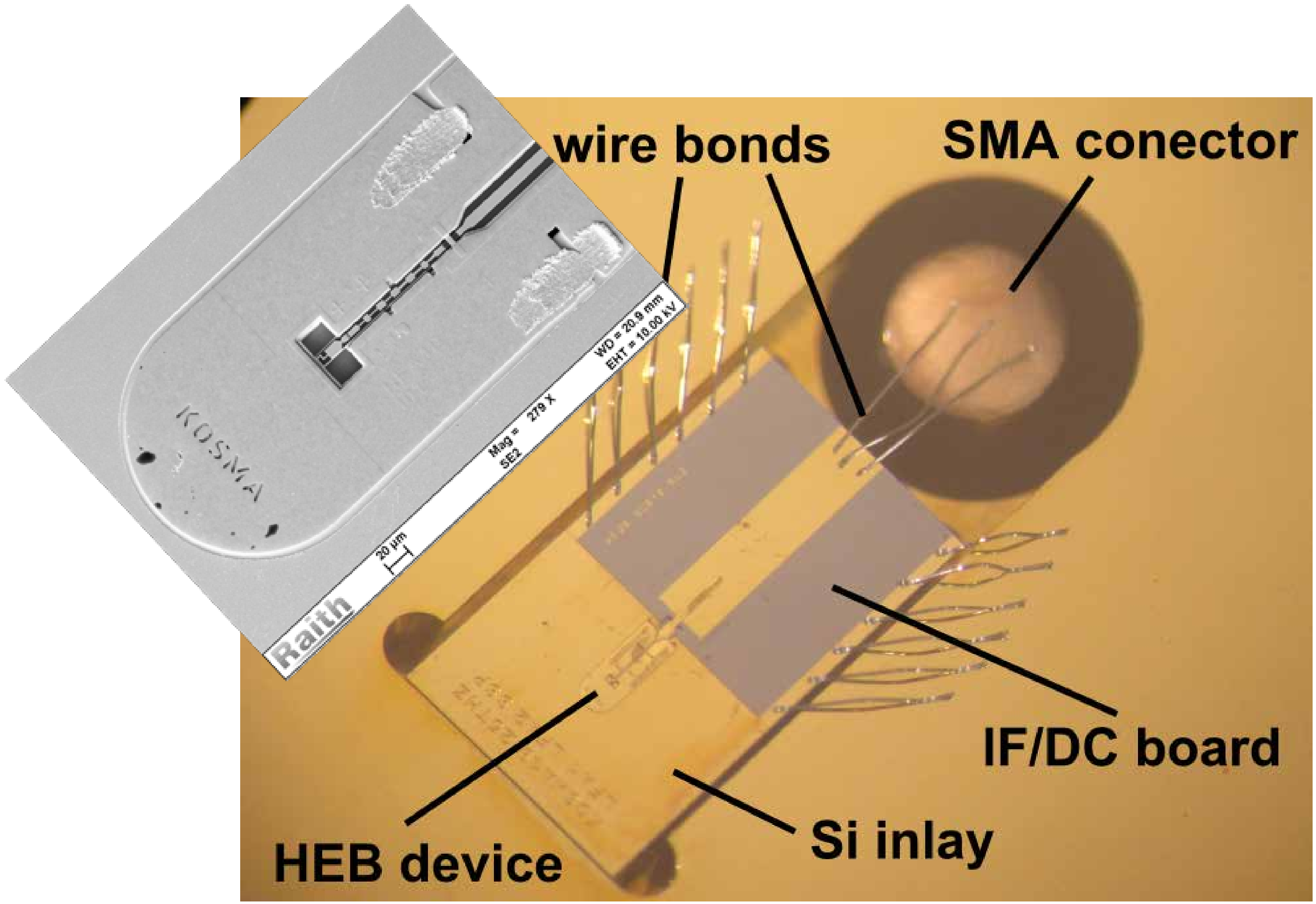
Road to 10THz? Si micromachining

- Multi-level deep reactive-ion etch (cryo)
- precise and reproducible lithographic definition
- Metal plating (Au) through sputter deposition



Si mixer block with device



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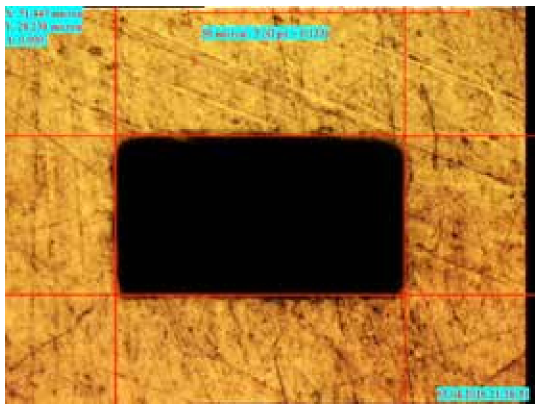
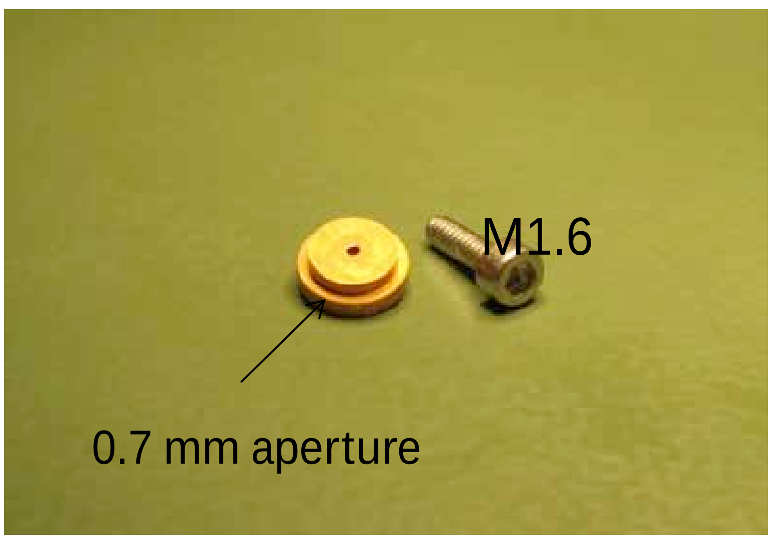
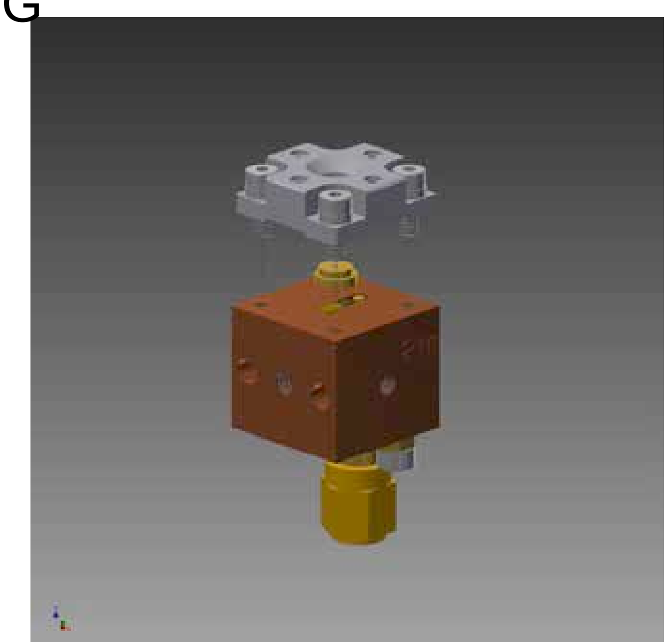
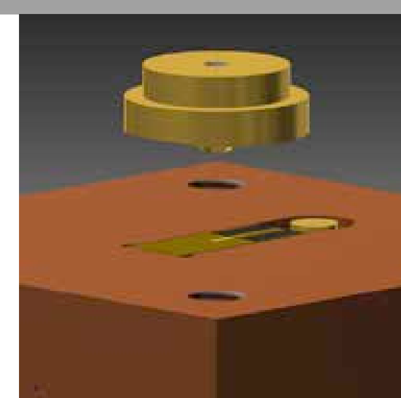
4.7 THz waveguide horn antenna

Smooth walled spline profile, circular to rectangular transition
Developed & electroformed by RPG



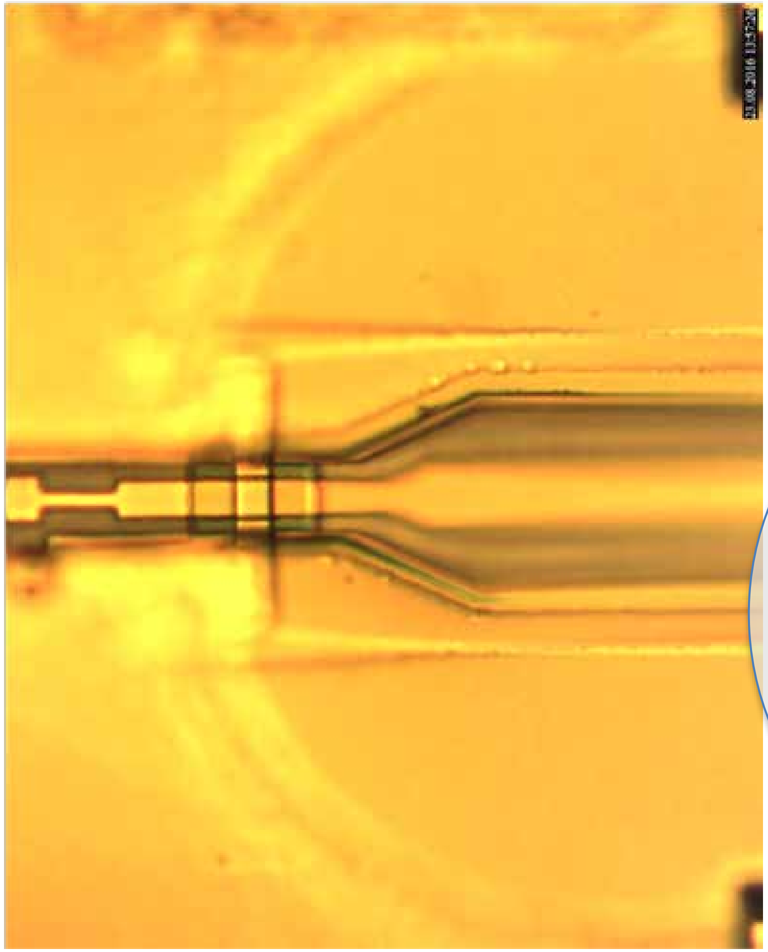


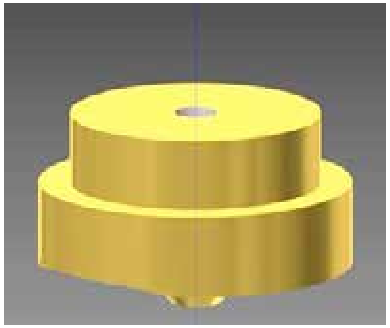




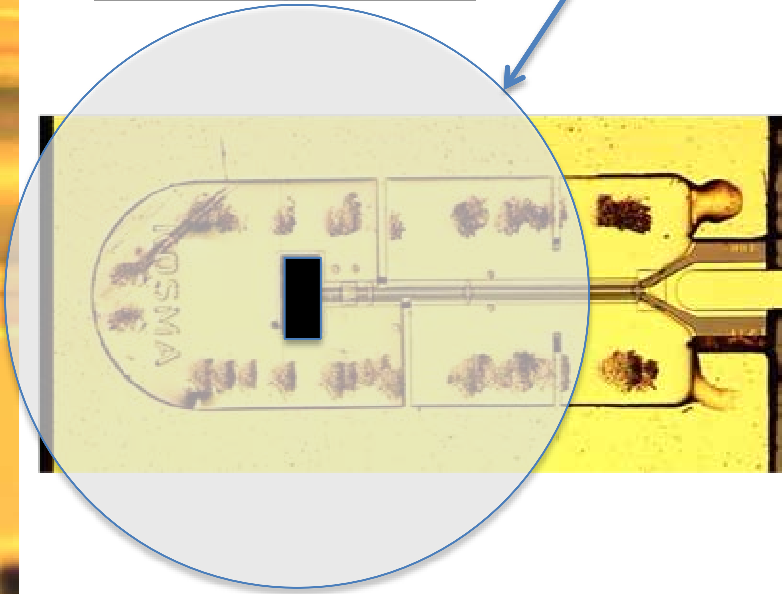
Mechanical stress on membrane

Waveguide ends in 0.8mm dia cone, presses on device beamlead, deforming CuTe block

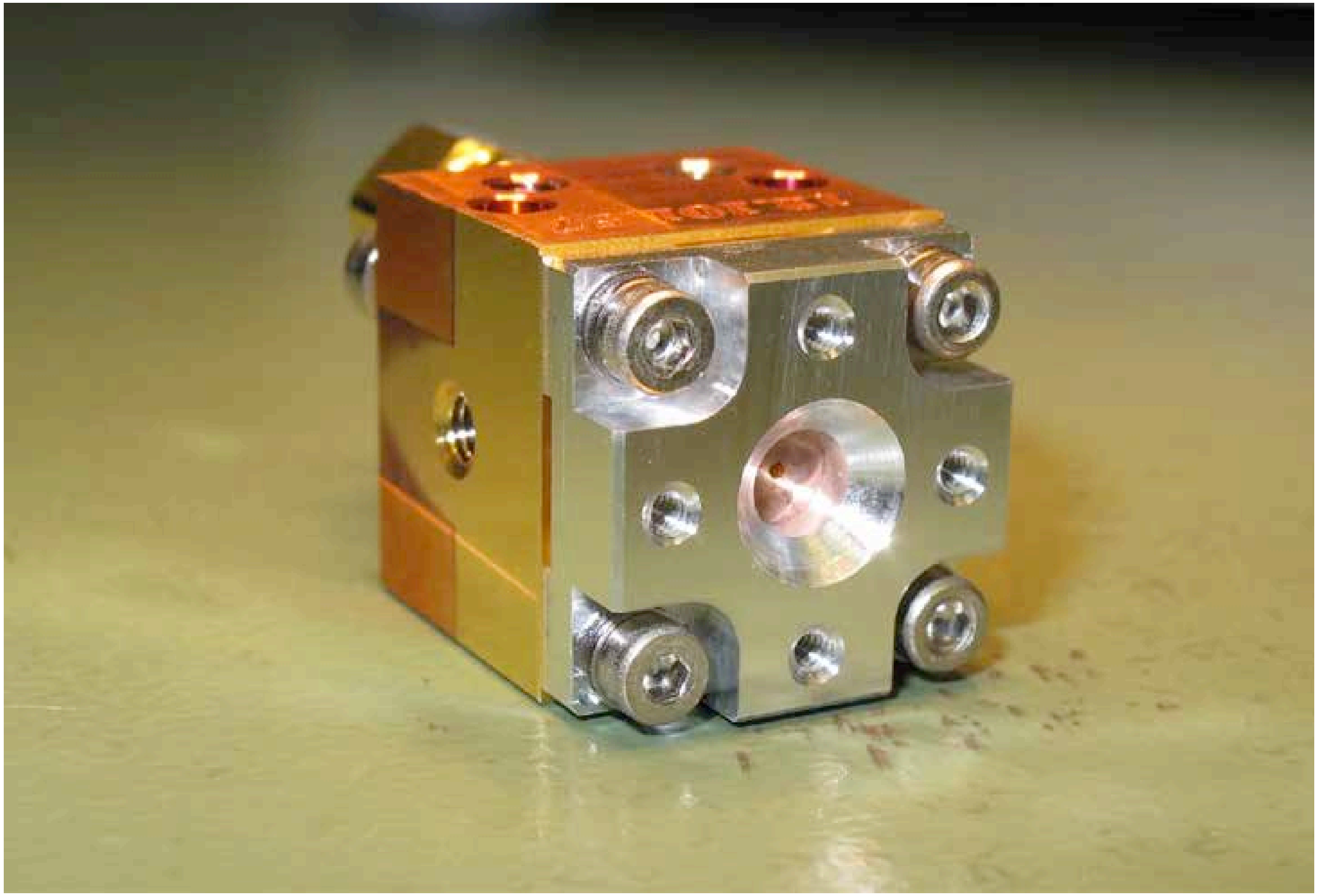




Dia. 0.8mm



4.7 THz flight mixer



Integration into facetted mirror assy.

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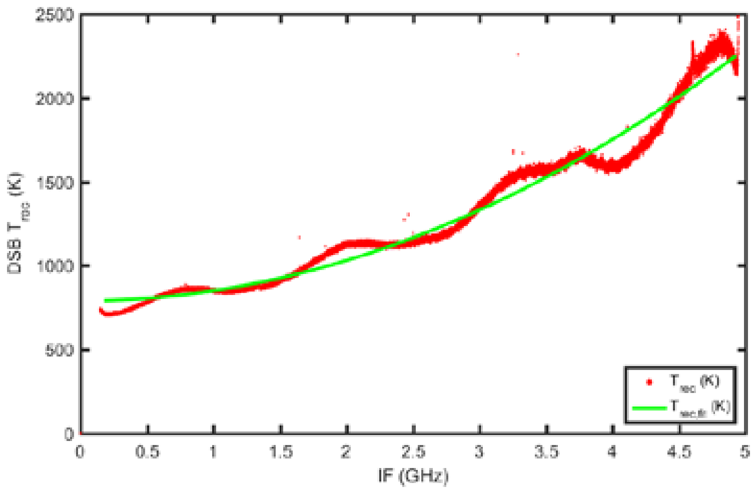
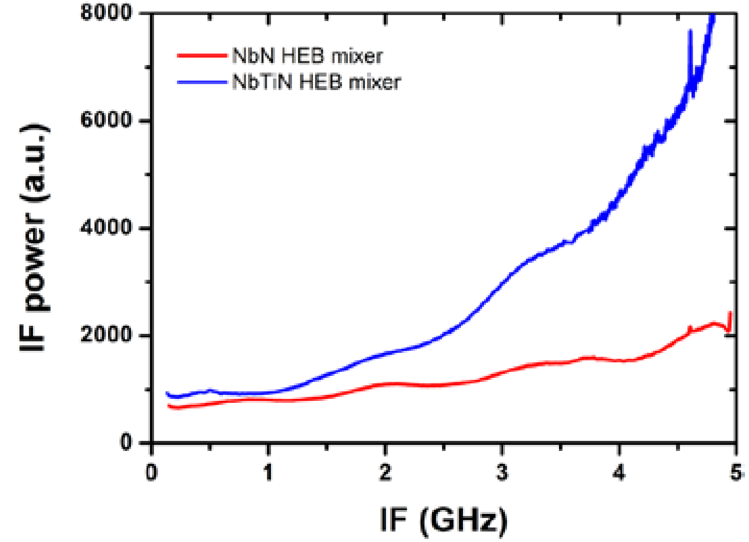
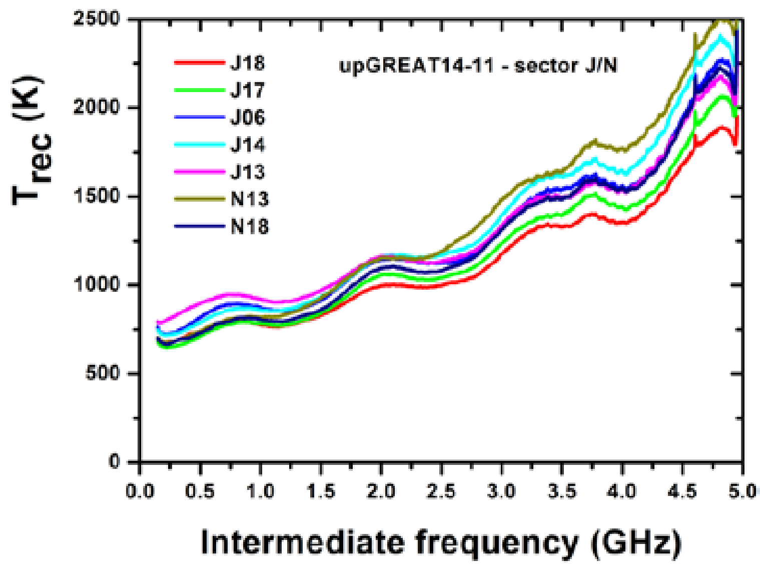
Performance (1.9 THz)







- IF bandwidth typical for NbN
- comparison to earlier NbTiN
- Much less LO power for NbTiN at same volume
- Trec uniformity good for optimally pumped devices

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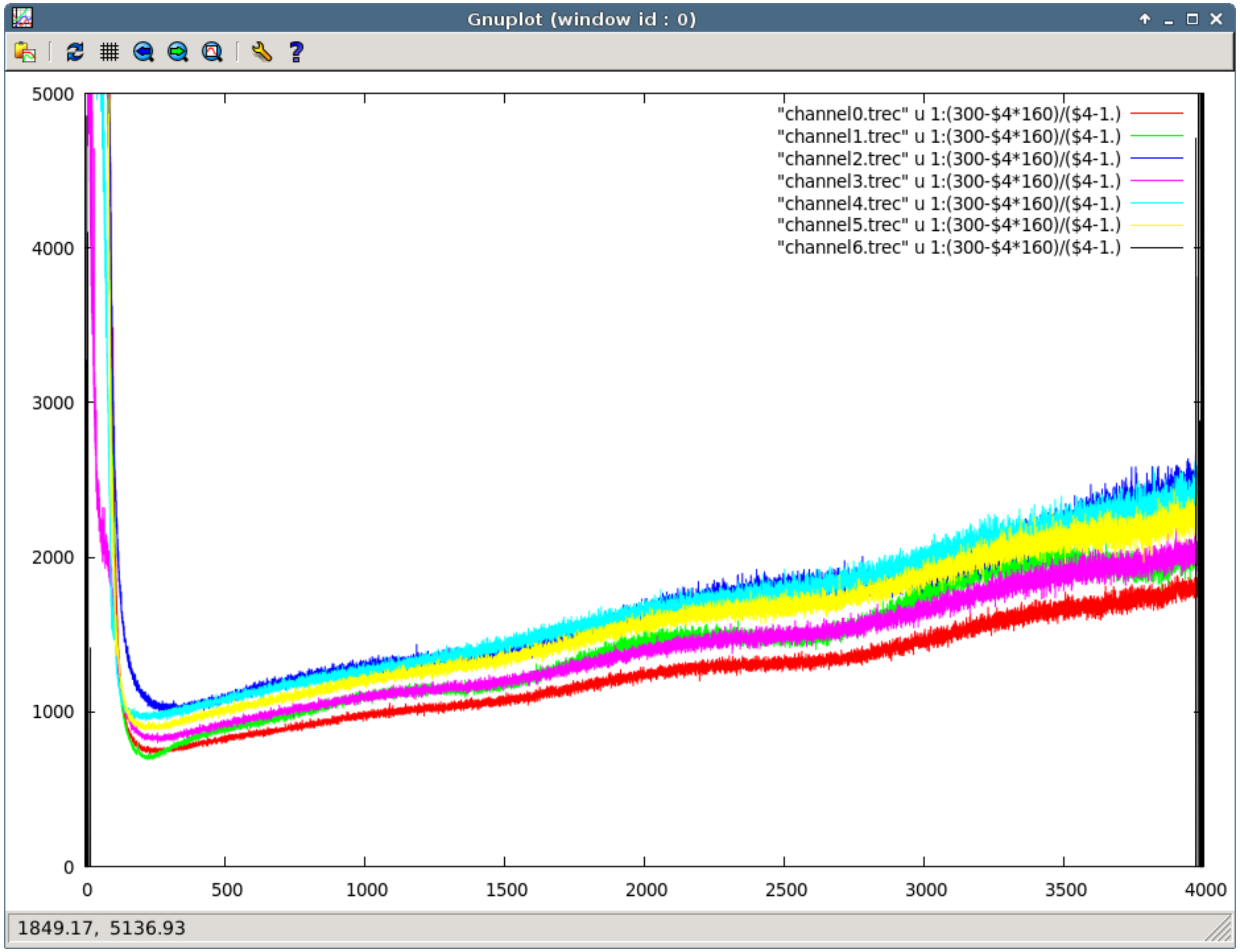
HFA results (4.7 THz)



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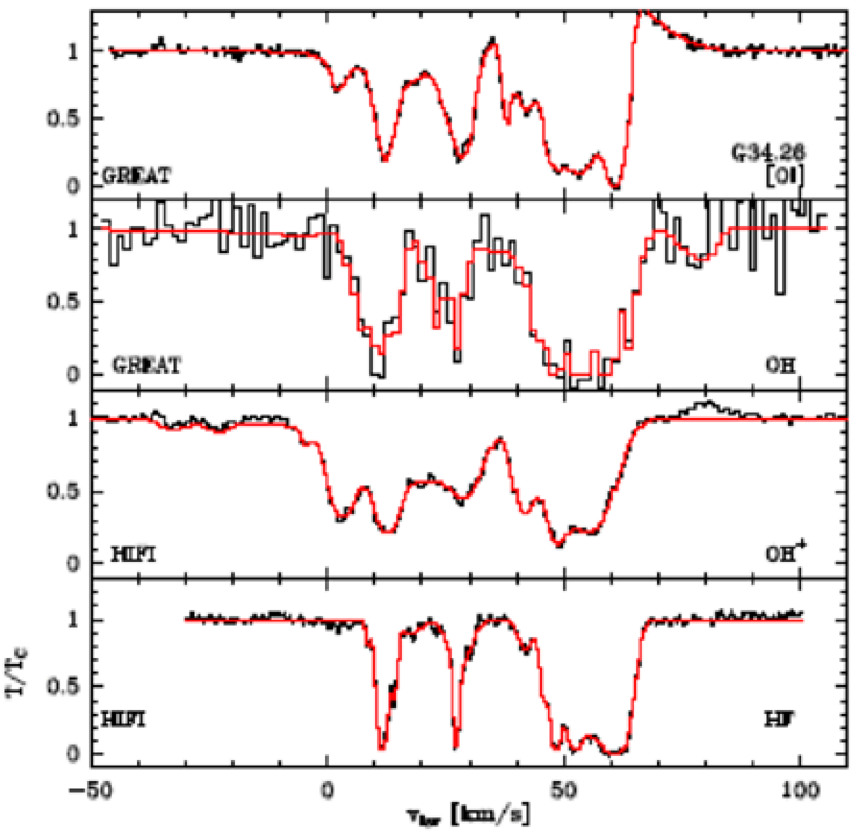
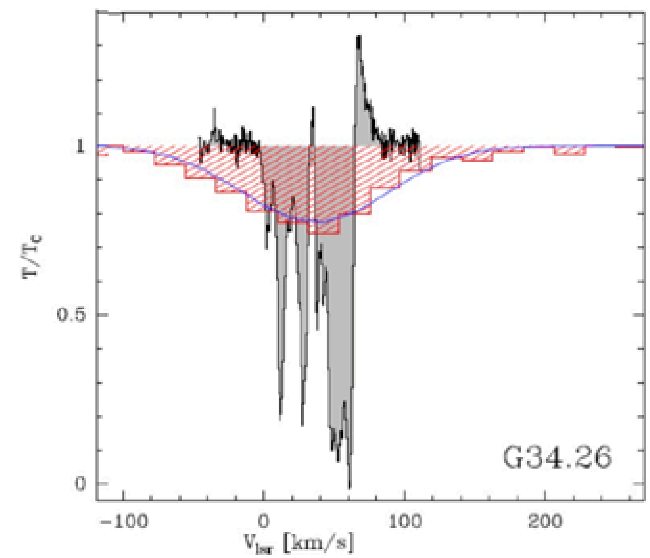
Oxygen chemistry in diffuse clouds

63µm 4.7 THz GREAT H channel result

[OI] absorption:



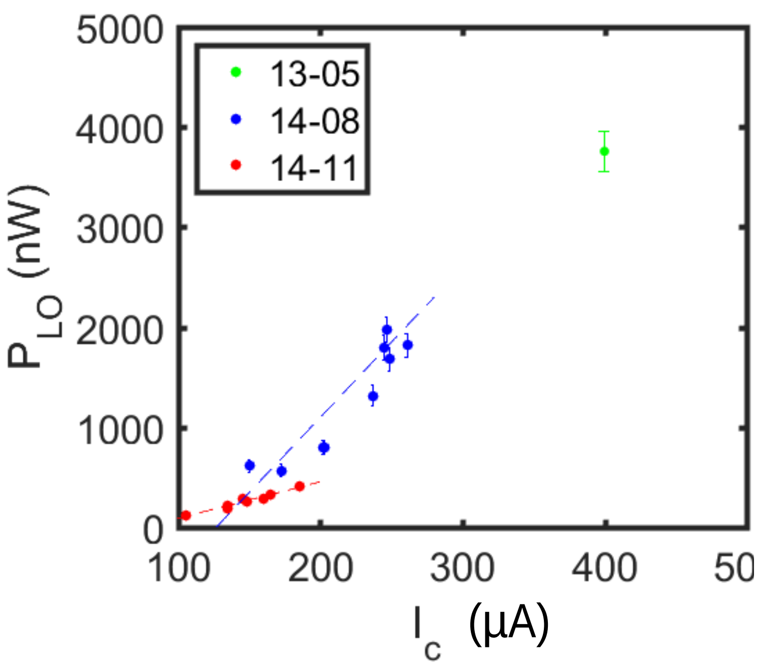
- Complex profiles in many sources

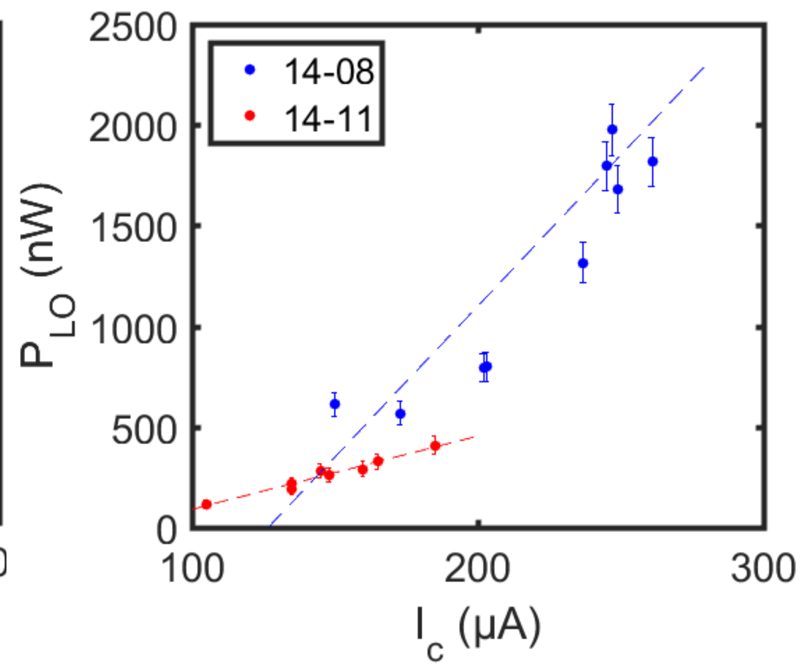


- PACS washes out all relevant information

V. Ossenkopf, Zakopane 2015
H. Wiesemeyer et al., A&A 585, A76 (2016)

LO power requirement dependence on Ic





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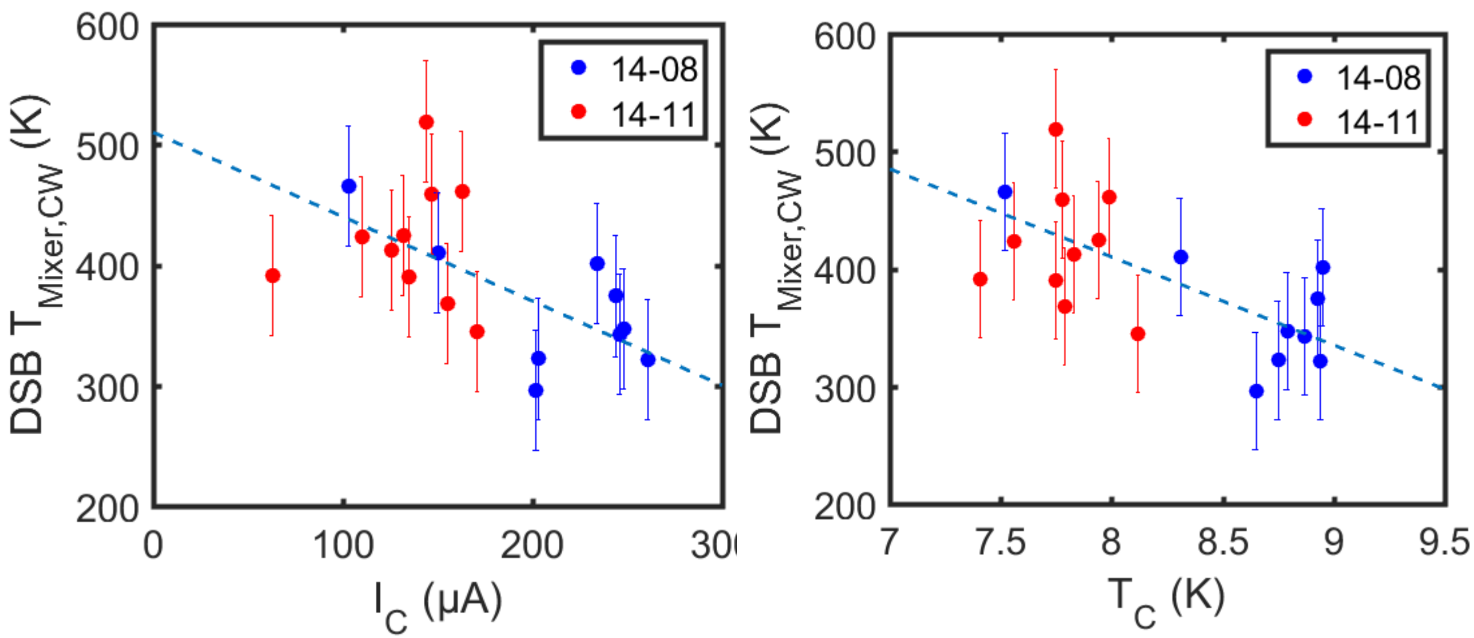
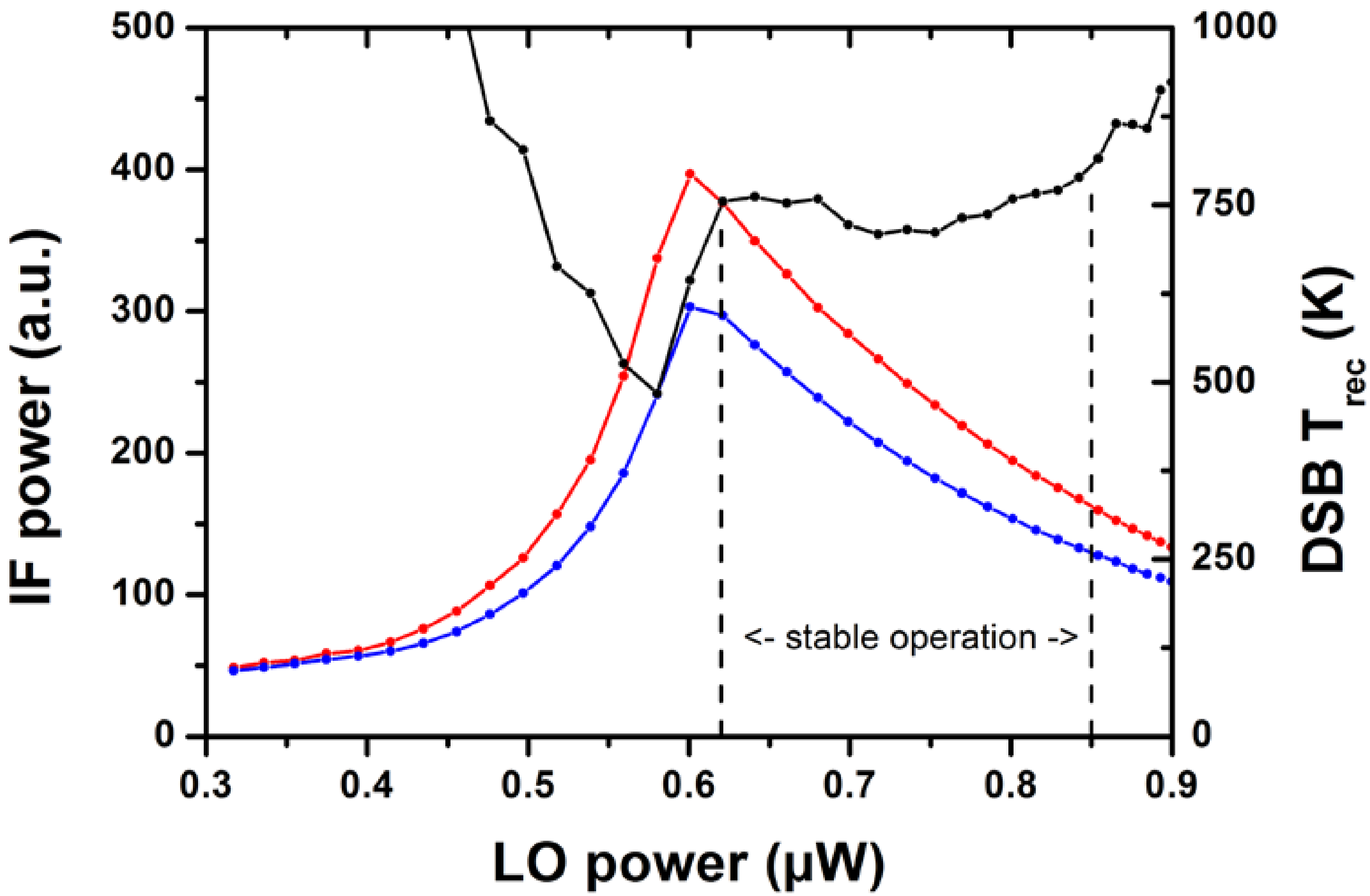
Trec vs. Ic, Tc

Perfomance penalty on thinner devices with less LO power requirement
(Batch 14-11 (red) thinner than 14-08 (blue)



LO power tolerance <= 30%



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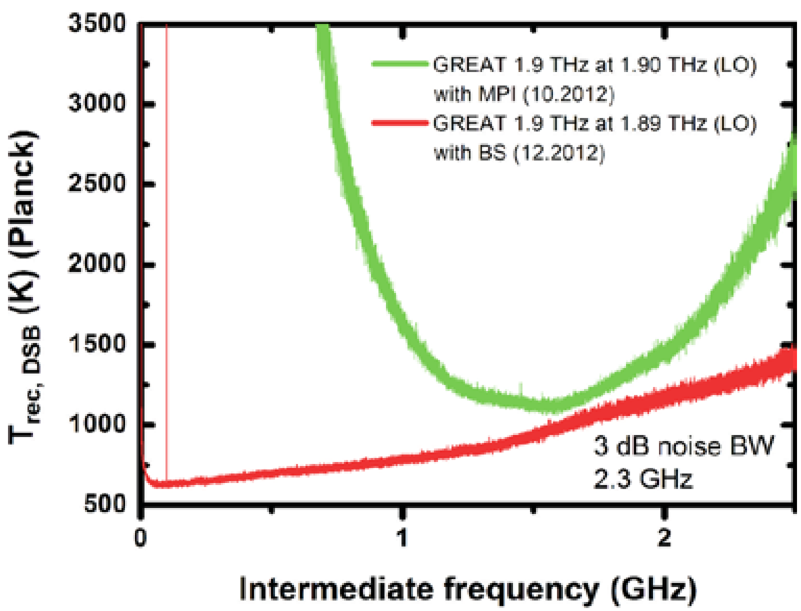
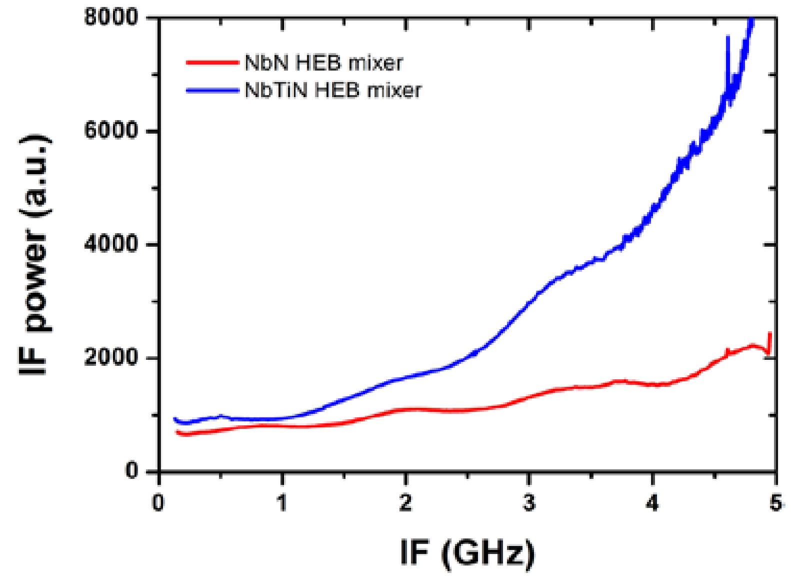
Martin Puplett Interferometer…

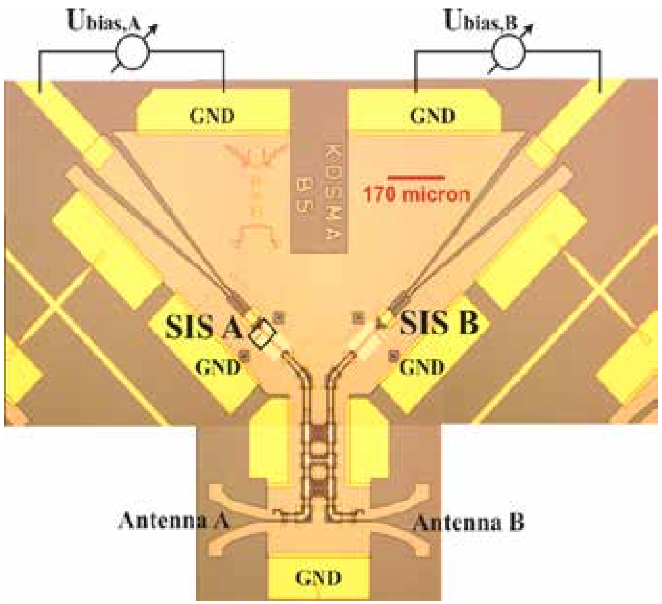
… to avoid LO power waste with beam splitter coupling?
Throws away most sensitive part of limited IF bandwidth





Balanced mixers

- Why do we throw away 90% of our LO power?
- Very sucessful 400-500 GHz balanced mixer design
- Key is 9µm shaped Si membrane



1 mm

Westig et al., Supercond. Sci. Technol. **24** (2011) 085012

3D EM design of balanced 1.9THz HEB mixer

- Follow-up on 400-500 GHz SIS design
- Realized in 2µm SOI technology
- On-chip integrated RF coupler

Lessons learned

- Waveguide mixers up to 5 THz show excellent performance
- + well defined horn beam,
  + single mode, RF bandwidth defined
  + on-chip circuit integration (balanced mixers)
  o demanding technology, but feasible for 7 + 14 pixels
- There is no such thing as enough LO power for THz arrays.
- NbN bandwidth is marginal for extragalactic work & interferometer diplexers
  - hope for MgB_2 (Sergey) or SIS to 1.5 THz?
- Uniformity needs improvement
- Very thorough prototyping needed for space applications
  - demonstrate >= 3 mixers
- Mixer developers need power-representative LO source
- As always: array mixer performance >= single mixer performance!