DUAL-POLARIZATION SENSITIVE KINETIC INDUCTANCE DETECTORS FOR BALLOON-BORNE FIR POLARIMETRY

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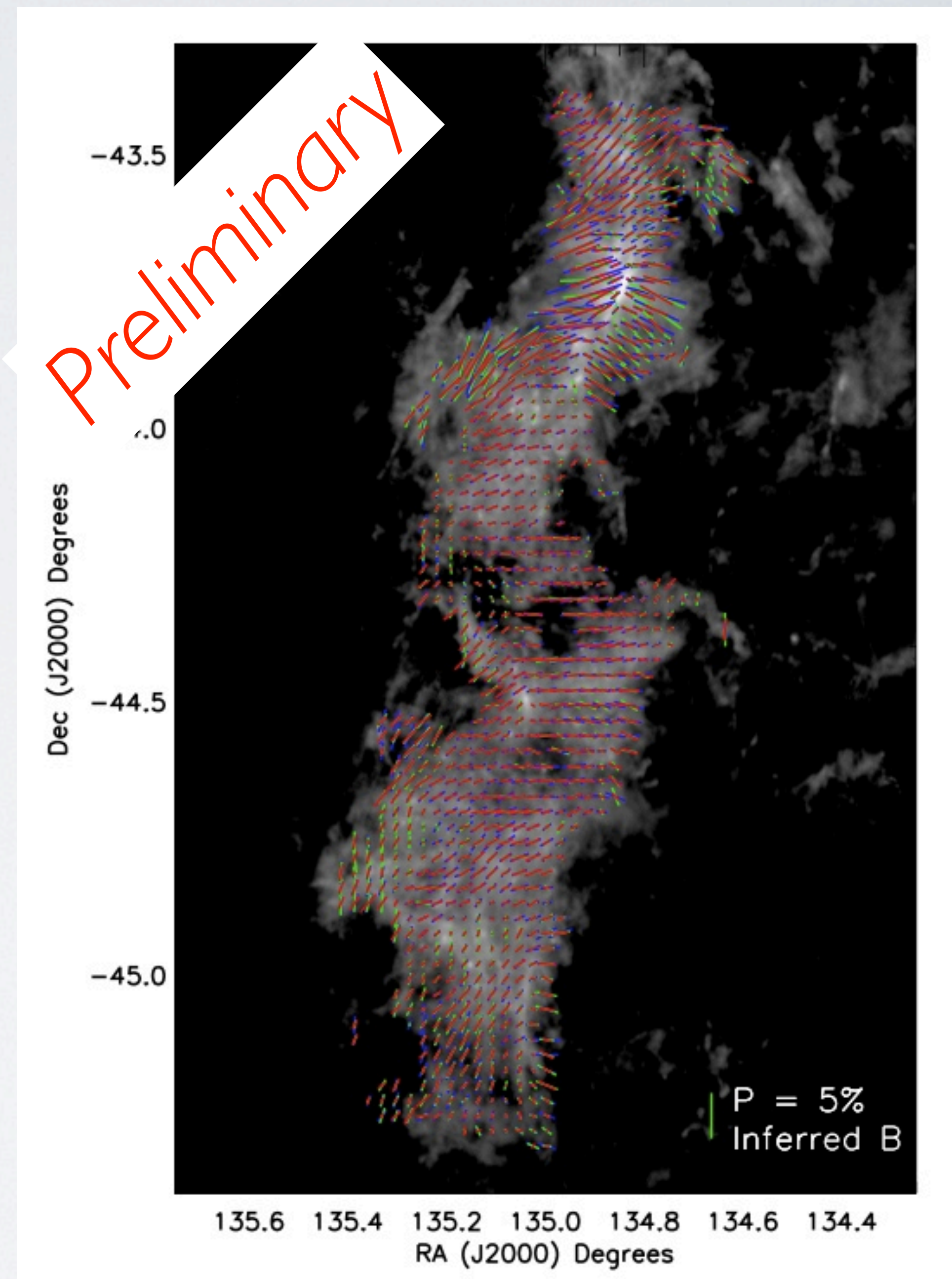
[2]Arizona State University
[3]University of Pennsylvania

BLAST: BALLOON-BORNE LARGE APERTURE SUBMILLIMETER TELESCOPE

- balloon-borne instrument flown 5 times **(E. Pascale et al 2008)**
- observes at 250, 350 and 500 μm
- what regulates star formation? **(Crutcher 2004)**
- polarimetry with stepped half wave plate and wire grid analyzer
- horn-coupled spider-web NTD bolometers
- there's a movie! www.blastthemovie.com/homepage

Vela C molecular cloud



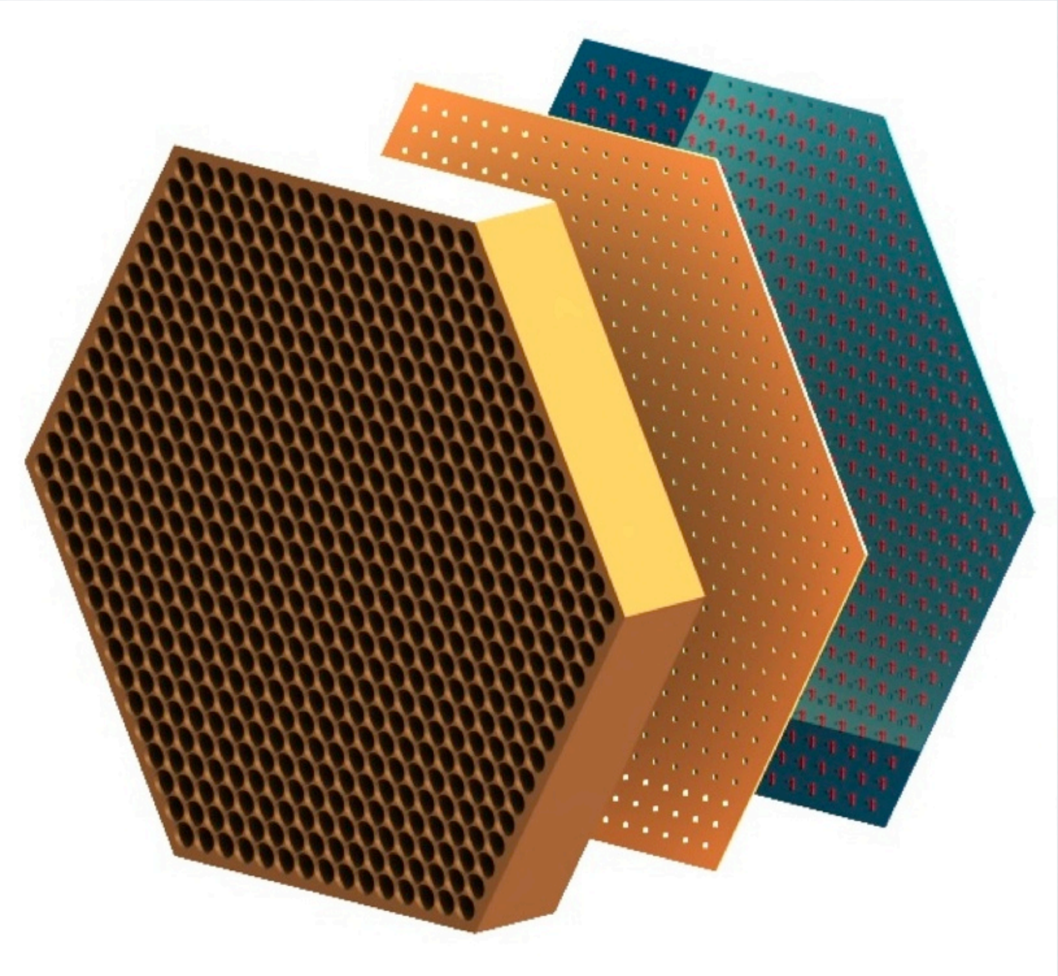
Hershel measurement from Hill et al. 2012

ÜBER-BLAST

- funded by NASA
- increased spatial resolution (22 arcmin at 250 μm)
- four times the field of view of BLAST (340 arcmin^2)
- 32 times the mapping speed of BLAST
- arrays of feedhorn-coupled MKIDs operated at 300mK
  - exploring 4.5K and 1.5K TiN
  - excellent 1.5K Tc uniformity with TiN/Ti/TiN trilayer

"Proximity-Coupled Ti/TiN Multilayers for use in Kinetic Inductance Detectors", M.R. Vissers
Monday June 24, Session A, Poster 403

- planned flight at end of 2016

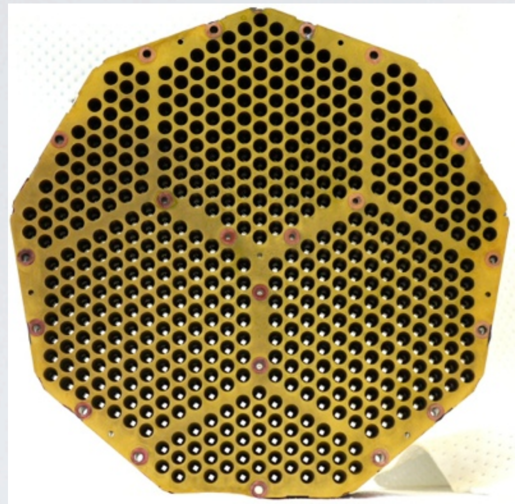


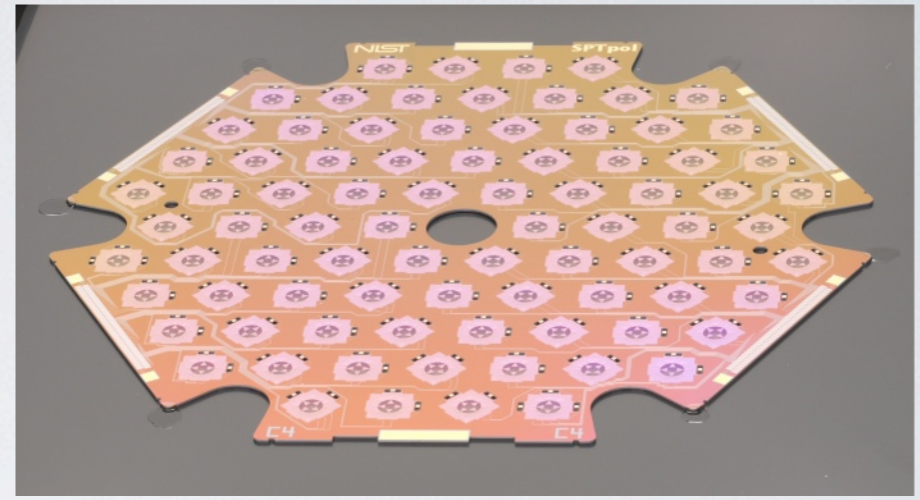
Central Wavelengths	**250**	**350**	**500**	μm
Number of pixels	590	245	165	
Background power	17	12	9	pW
Background NEP	17	12	8.7	$\times 10^{-17}$ W/$\sqrt{\text{Hz}}$

~1000 pixels = 2000 KIDs

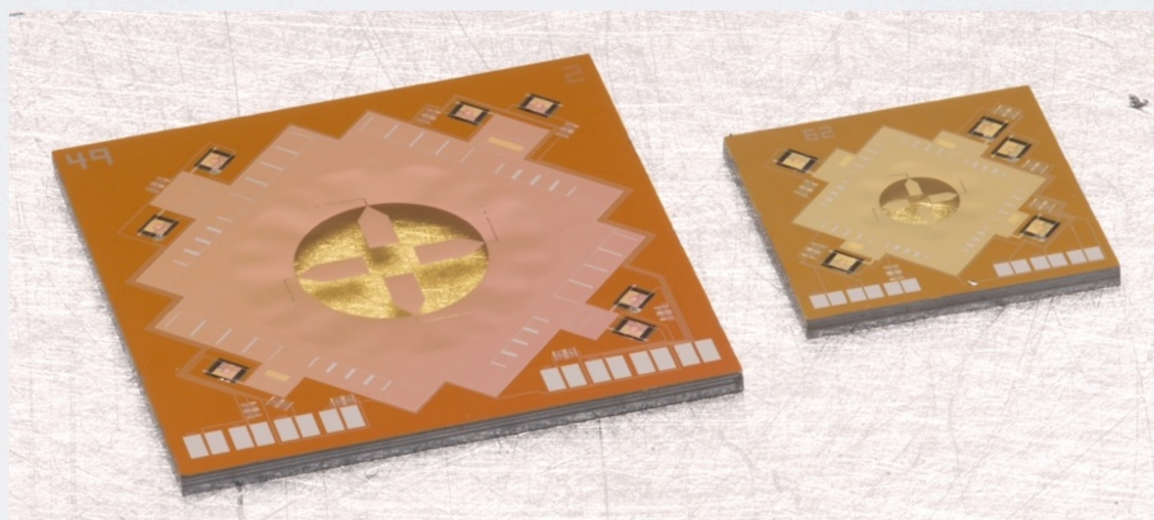
NIST FEEDHORN COUPLED POLARIMETERS

30% fractional bandwidth





octave single-mode bandwidth



6:1 bandwidth

NIST FEEDHORN COUPLED POLARIMETERS

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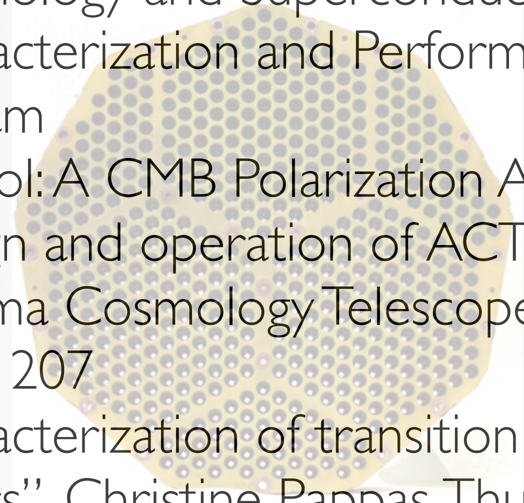
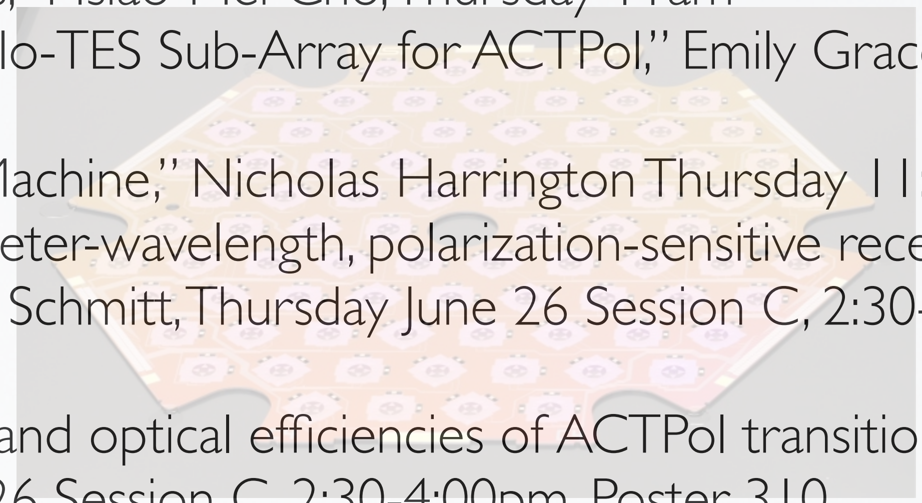
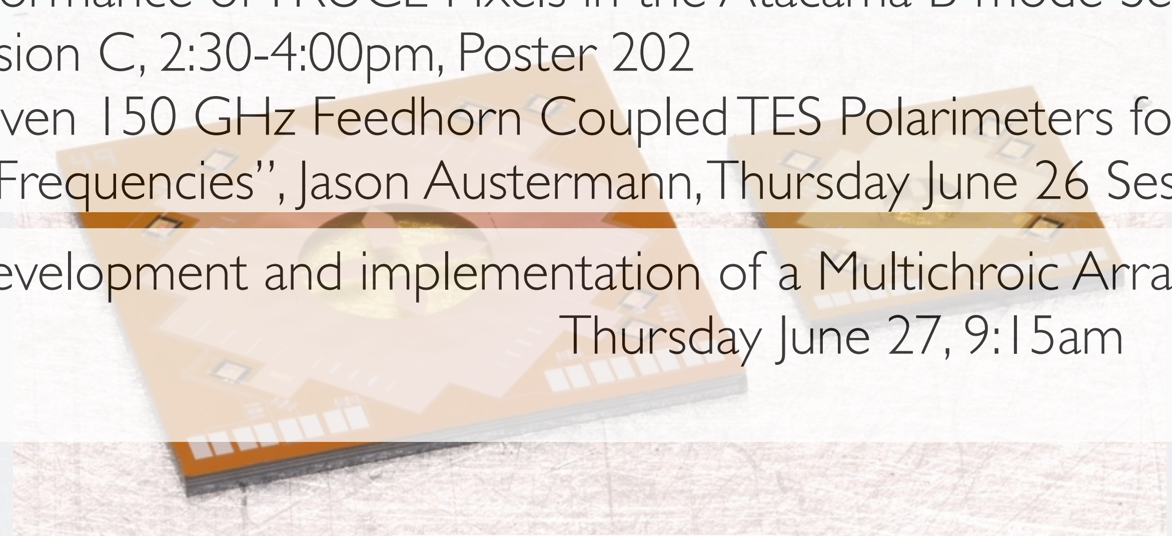




- "Cosmology and Superconducting Devices," Hsiao-Mei Cho, Thursday 11am
- "Characterization and Performance of a Kilo-TES Sub-Array for ACTPol," Emily Grace Thursday 11:30am
- "SPTpol: A CMB Polarization Anisotropy Machine," Nicholas Harrington Thursday 11:45am
- "Design and operation of ACTPol, a millimeter-wavelength, polarization-sensitive receiver for the Atacama Cosmology Telescope," Benjamin Schmitt, Thursday June 26 Session C, 2:30-4:00pm, Poster 207
- "Characterization of transition properties and optical efficiencies of ACTPol transition-edge sensors", Christine Pappas, Thursday June 26 Session C, 2:30-4:00pm, Poster 310
- "In Situ Performance of TRUCE Pixels in the Atacama B-mode Search", Sara Simon, Thursday June 26 Session C, 2:30-4:00pm, Poster 202
- "Scaling Proven 150 GHz Feedhorn Coupled TES Polarimeters for Operation at Other Microwave Frequencies", Jason Austermann, Thursday June 26 Session C, 2:30-4pm, Poster 200

octave single-mode bandwidth

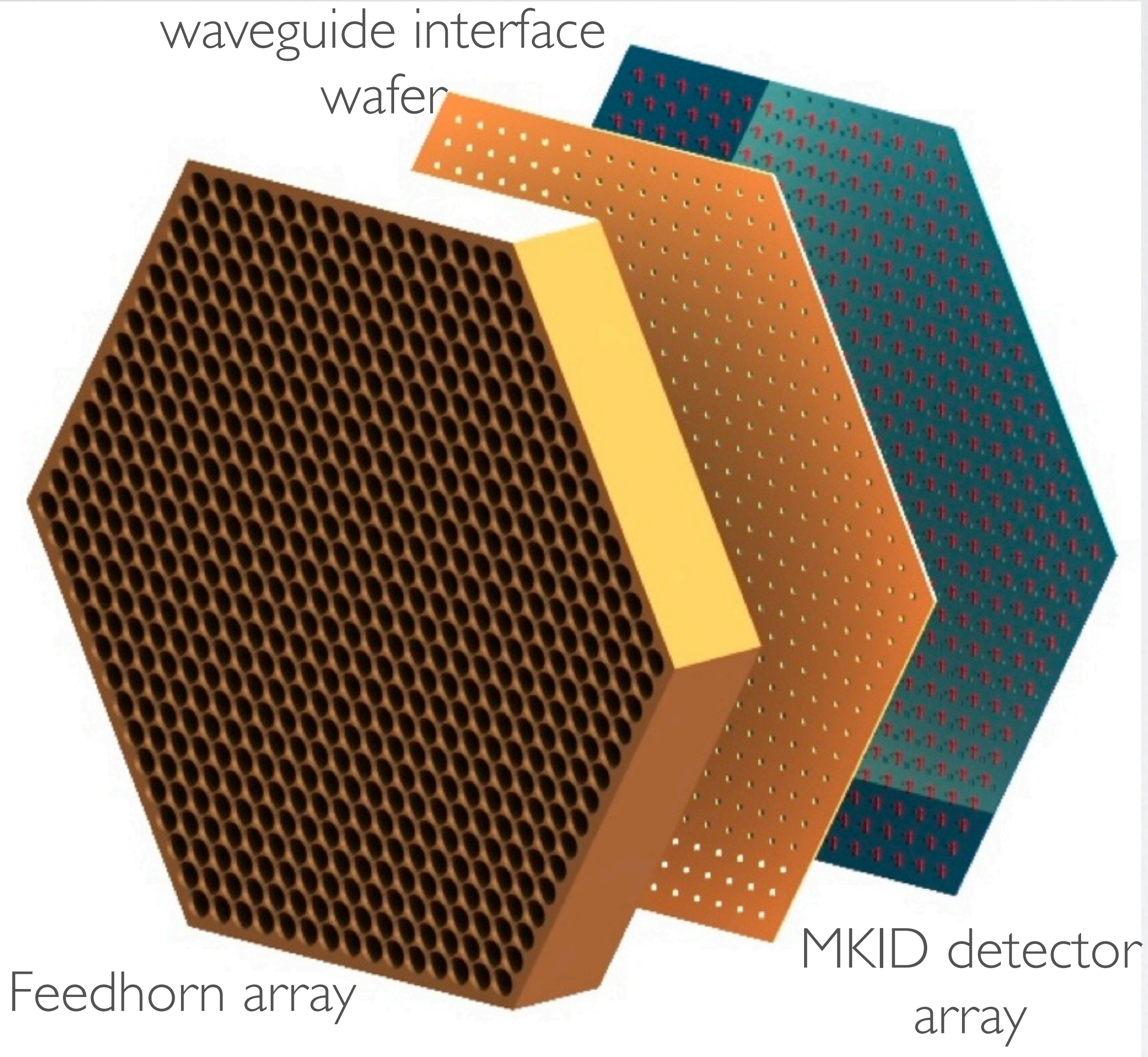


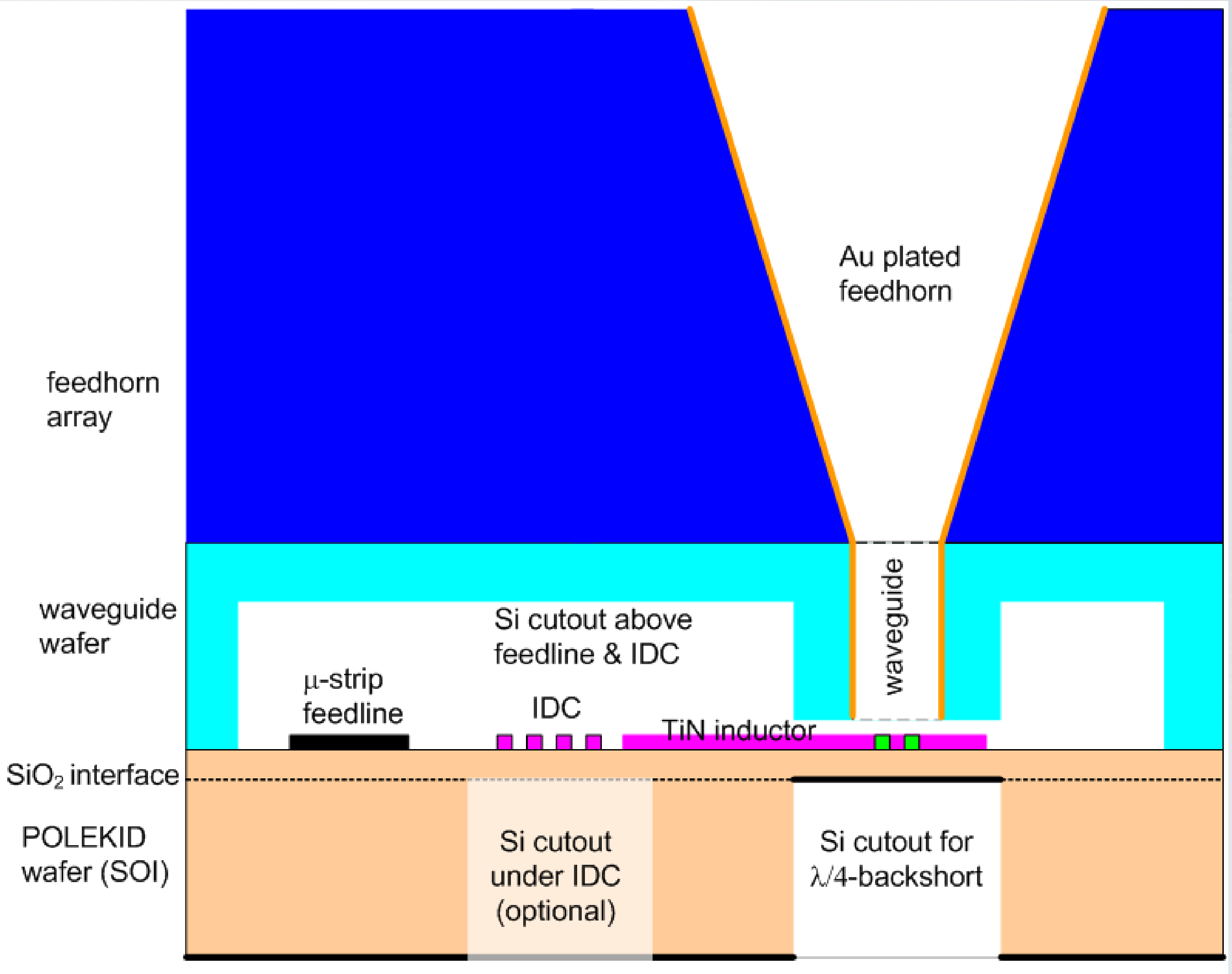
"Development and implementation of a Multichroic Array for ACTPol", Rahul Datta Thursday June 27, 9:15am

6:1 bandwidth

"Horn Coupled Multichroic Polarimeters for Measurements of the CMB", Jeff McMahon, Thursday June 26, 2:30-4:00pm, Poster 101

OPTICAL COUPLING

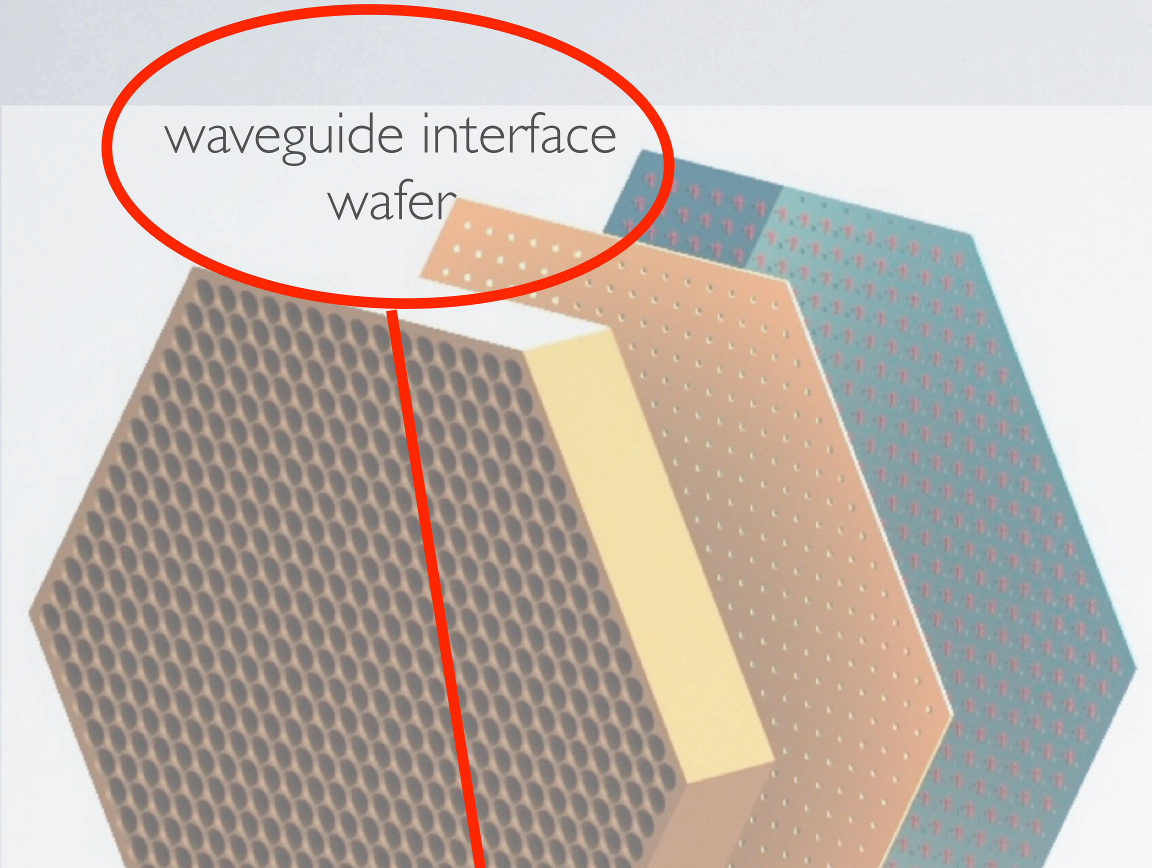


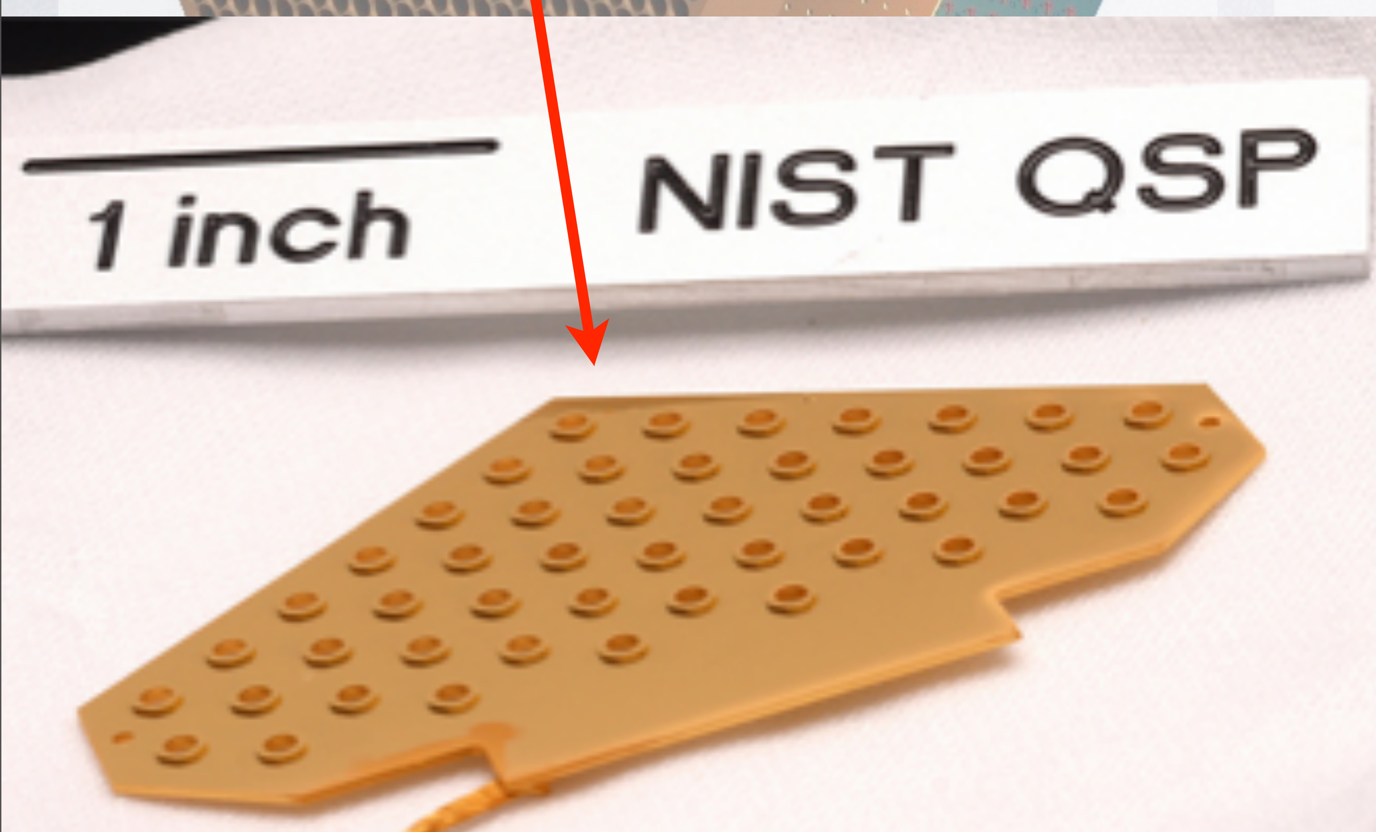


- 30% fractional bandwidth
- contoured feed transitions to square waveguide
- couple detector to TE_{10} mode

- front-side illuminated TiN LEKID-pair sits at quarter wavelength from backshort
- backshort created with silicon micro-machining using SOI wafer

OPTICAL COUPLING





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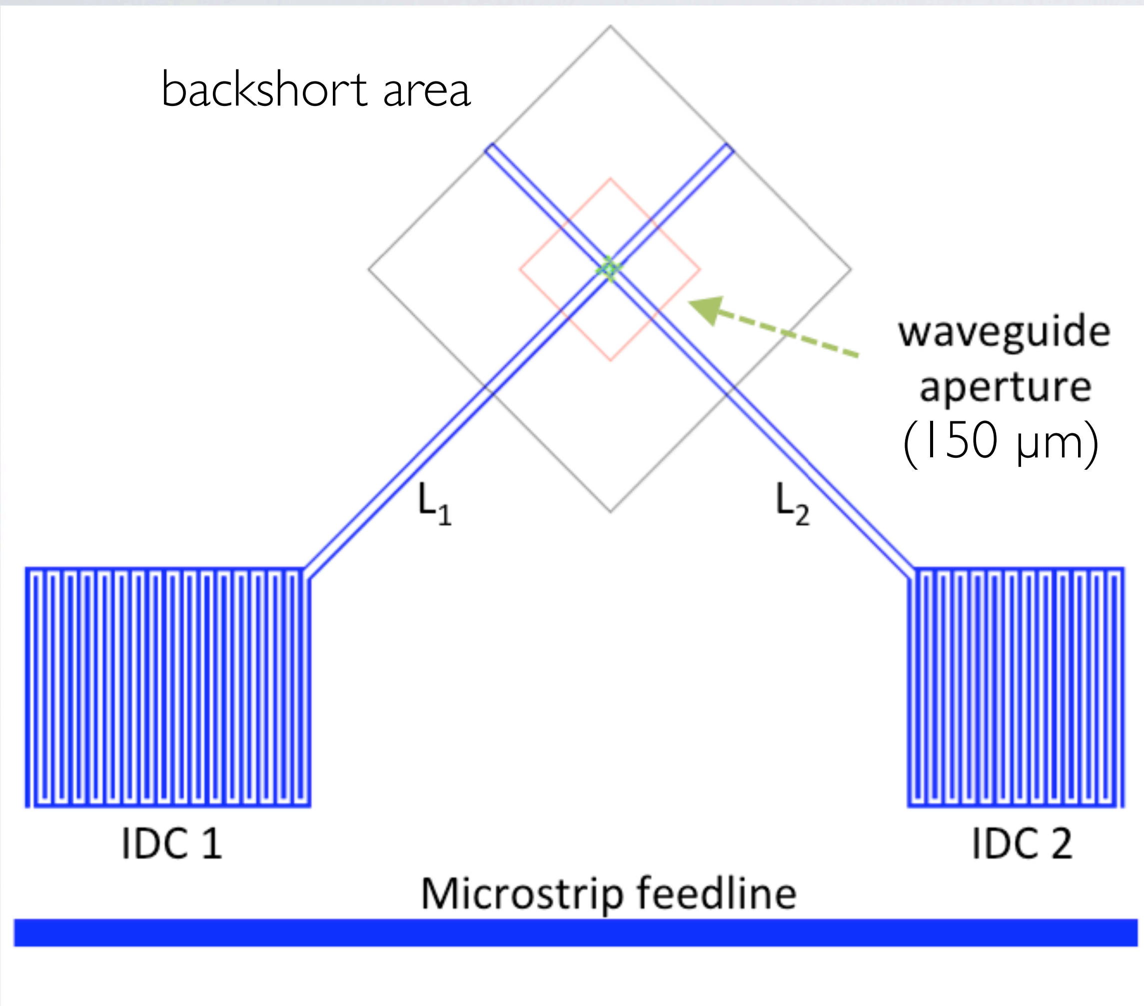
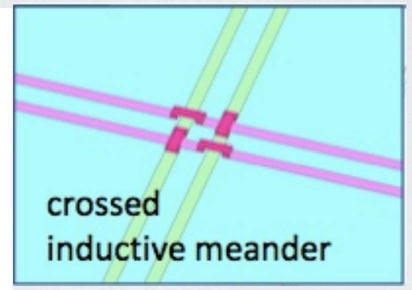
DUAL-POLARIZATION MKID IDEA

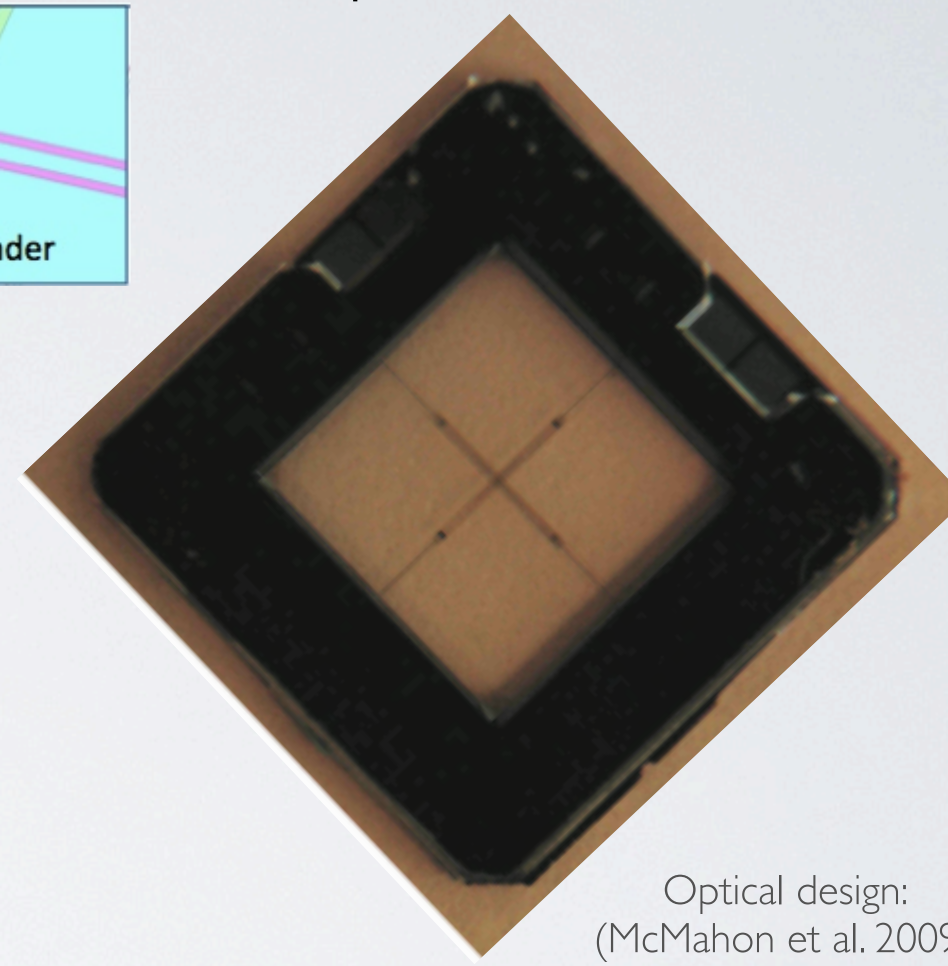
250 μm band pixel design





- design realizes separate sensitivity to X/Y linear polarizations within single spatial pixel above 1 THz
- two lumped element KIDs (Doyle 2008) made of TiN
- $f_o \sim 3$ GHz
- \`single-turn' inductor is absorber of FIR photons
- $V = 75\ \mu m^3$
- loaded $Q_i = 60{,}000$

SPTpol 90 GHz

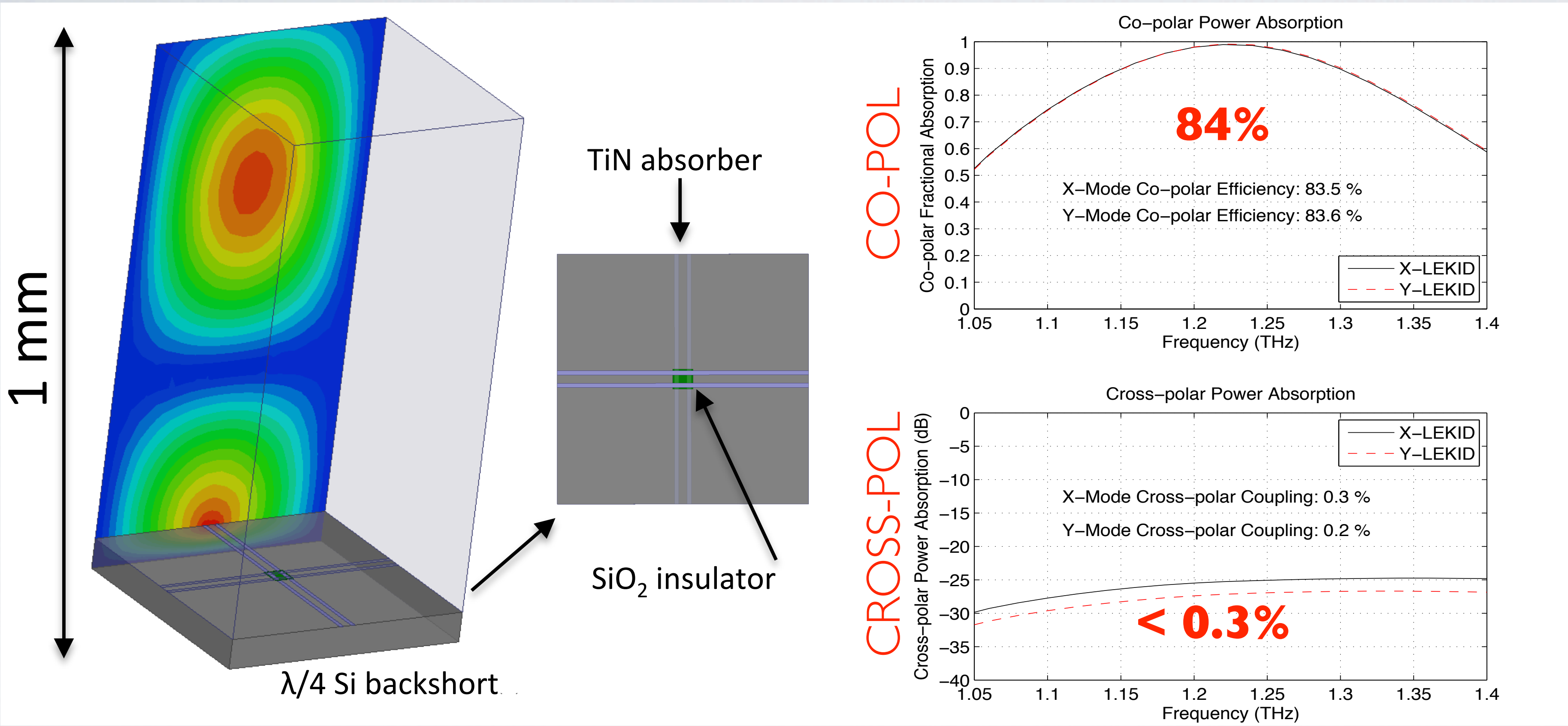


Optical design: (McMahon et al. 2009)

- large interdigitated capacitors (IDCs, $\sim 1\,mm^2$) achievable due to feedhorn coupling (2.5mm pixel spacing)
- cross-wafer microstrip feedline
- inspired by SPTpol 90 GHz design
  - demonstrated optical performance (Chang et al. 2012)
    - > 85% co-polar coupling
    - < 1% cross-polar leakage

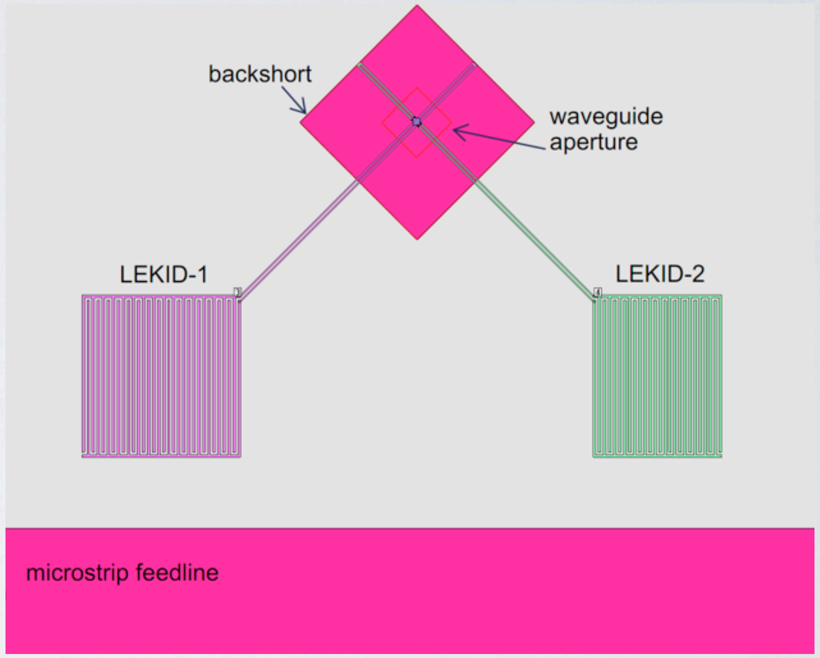
SIMULATED PERFORMANCE

Waveguide coupling



Hubmayr et al. 2012

Cross-talk simulation geometry



negligible microwave cross-talk

- HFSS simulation of 1.2 THz pixel
- perfectly conducting walls
- no gap between waveguide and absorber
- absorbed power determined by integrating the Poynting flux over the surface of inductors

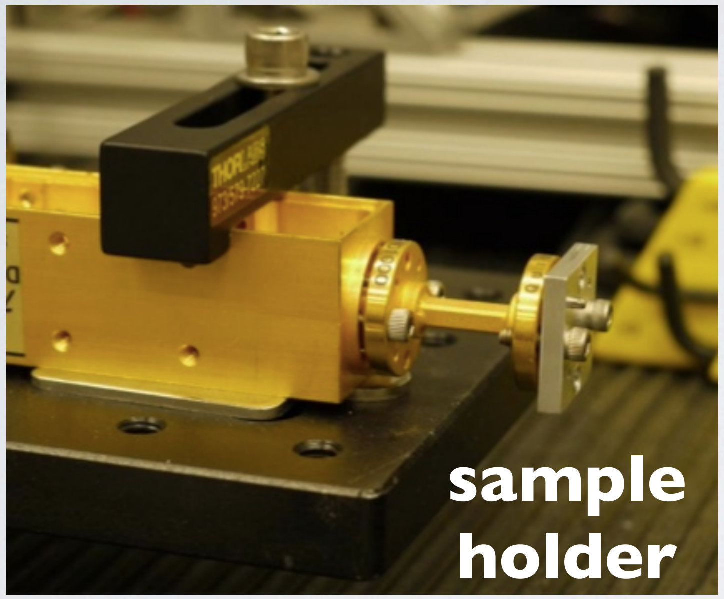
- X/Y resonators separated by 300 MHz
- Find resonances using internal ports

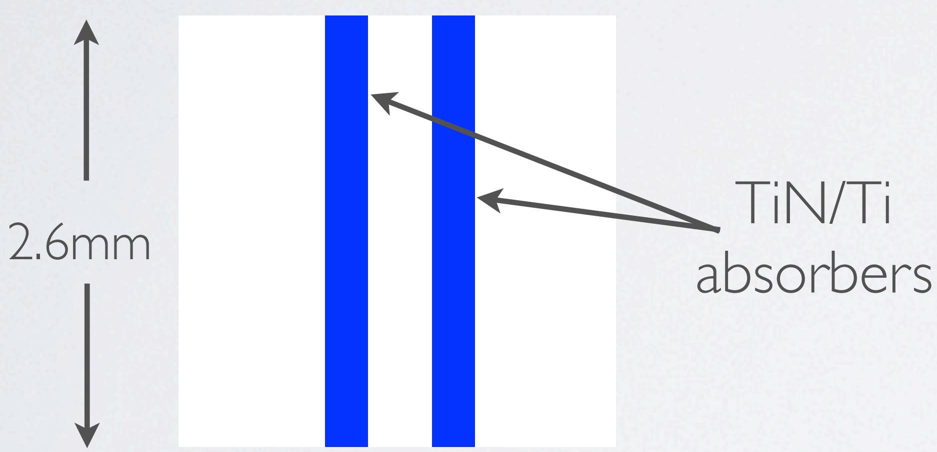
“New Method for Determining the Quality Factor and Resonance Frequency of LEKIDs and CPW Resonators”
David Wisbey, Tuesday 2:45pm Poster 304

$$\kappa_{\mathrm{cr}} = \frac{\delta f_2/f_2}{\delta f_1/f_1} = (0.8 \pm 4.6) \times 10^{-5}$$

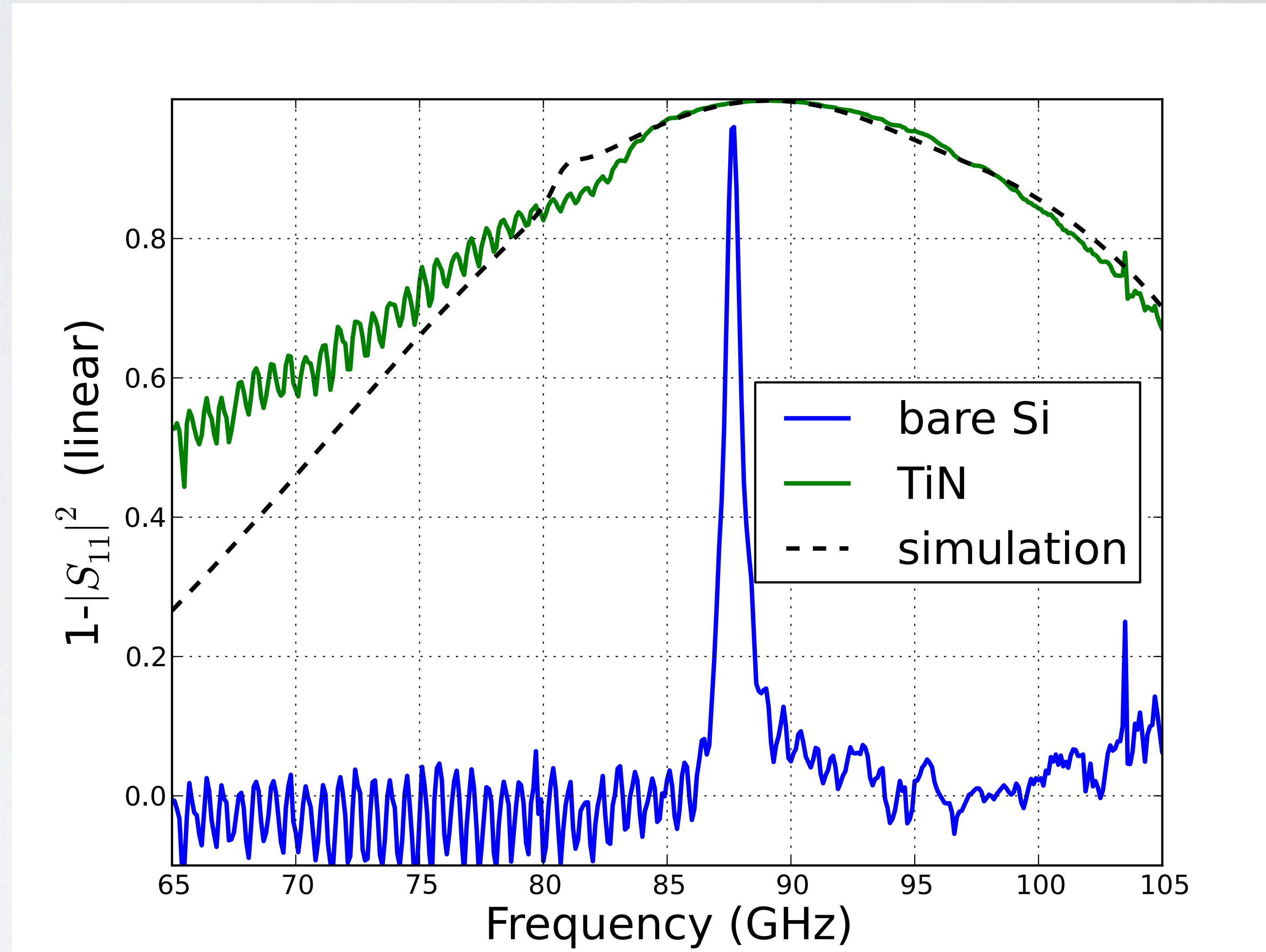
ROOM TEMPERATURE ABSORPTION MEASUREMENT

W-band reflection measurement





Absorption



- RRR of TiN ~ 1
- films are TiN/Ti proximity sandwich
- W-band scaling allows measurement with existing infrastructure

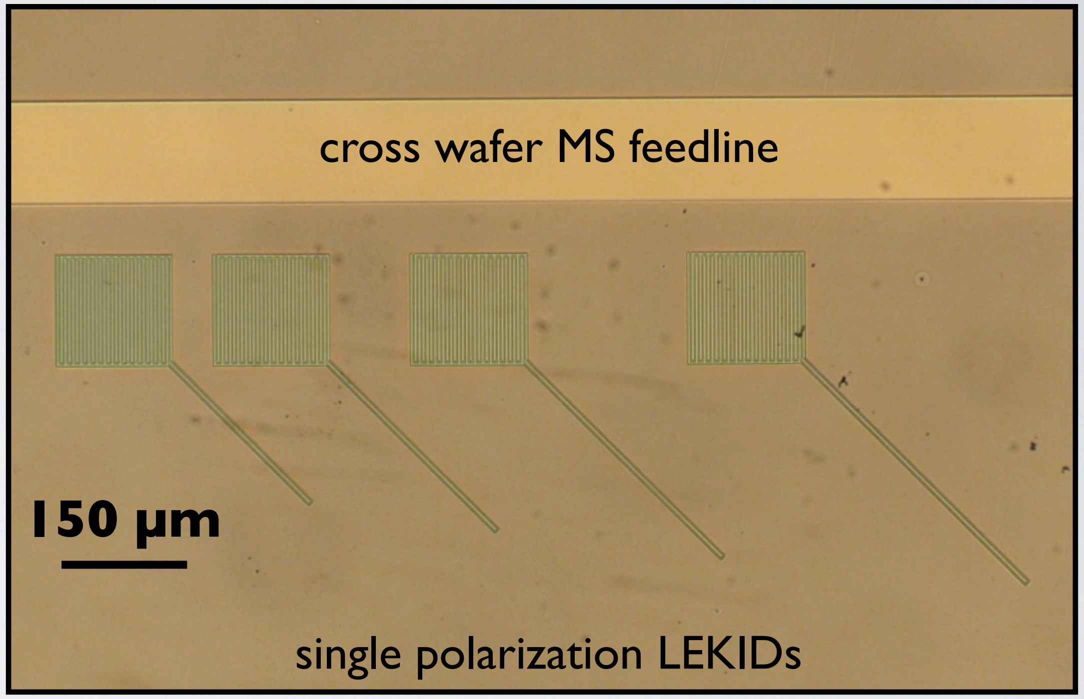
- $|S_{11}|^2 \neq 1$ implies absorption
- data matches model assuming $R_s = 130\ \Omega/\square$

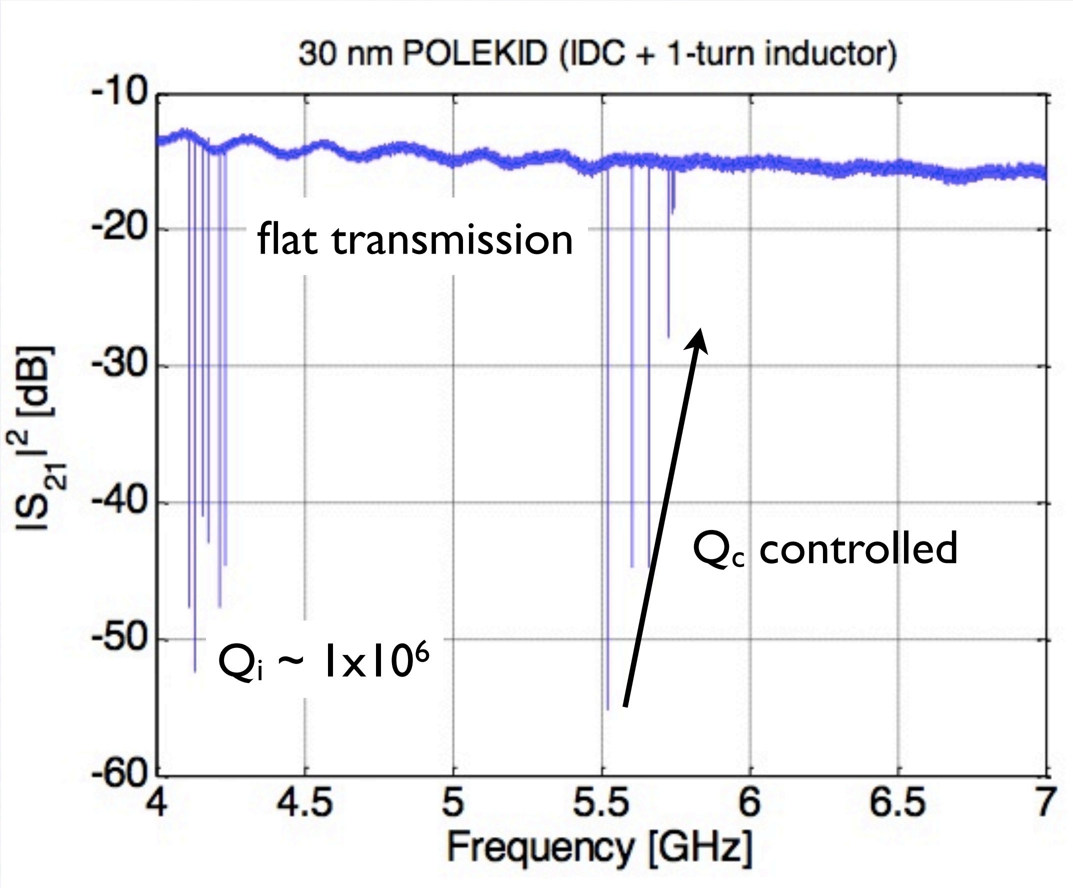
TEST DEVICES

- 3 single-layer resonator test wafers
- 4.5 K TiN 20, 30 and 40 nm thick
- single polarization resonators
- design parameters determined

t	T_c (K)	RRR	R_s	L_s
17.5 nm	4.4 K	1.08	27 Ω/□	8.5pH/□

- non-uniform etch induced large scatter in resonant frequencies
  ➡ exploring wet and dry etch



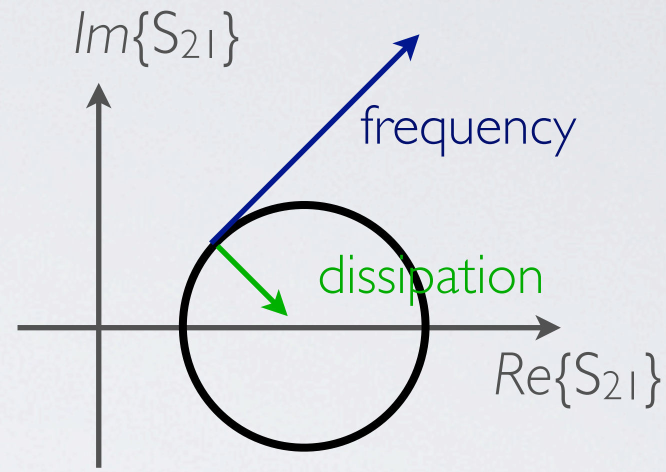


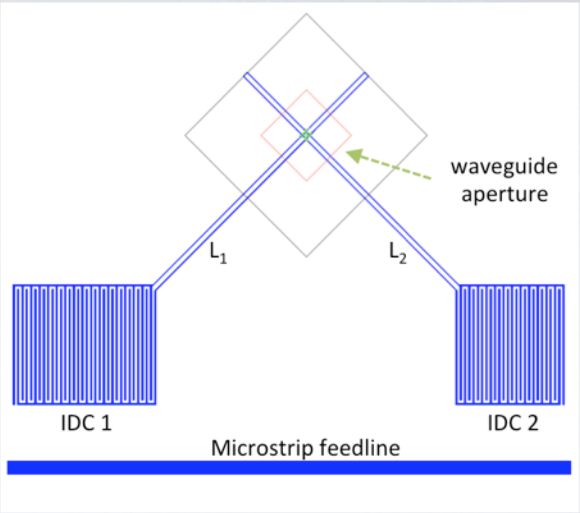
SENSITIVITY OF 4.5K TIN WITH DISSIPATION READOUT

$$NEP^2_{diss} \sim \frac{k_b T_{amp}}{P_g}$$

$$P_g < 0.8 \frac{Q_c \omega_r E_*}{2Q_r^3}$$

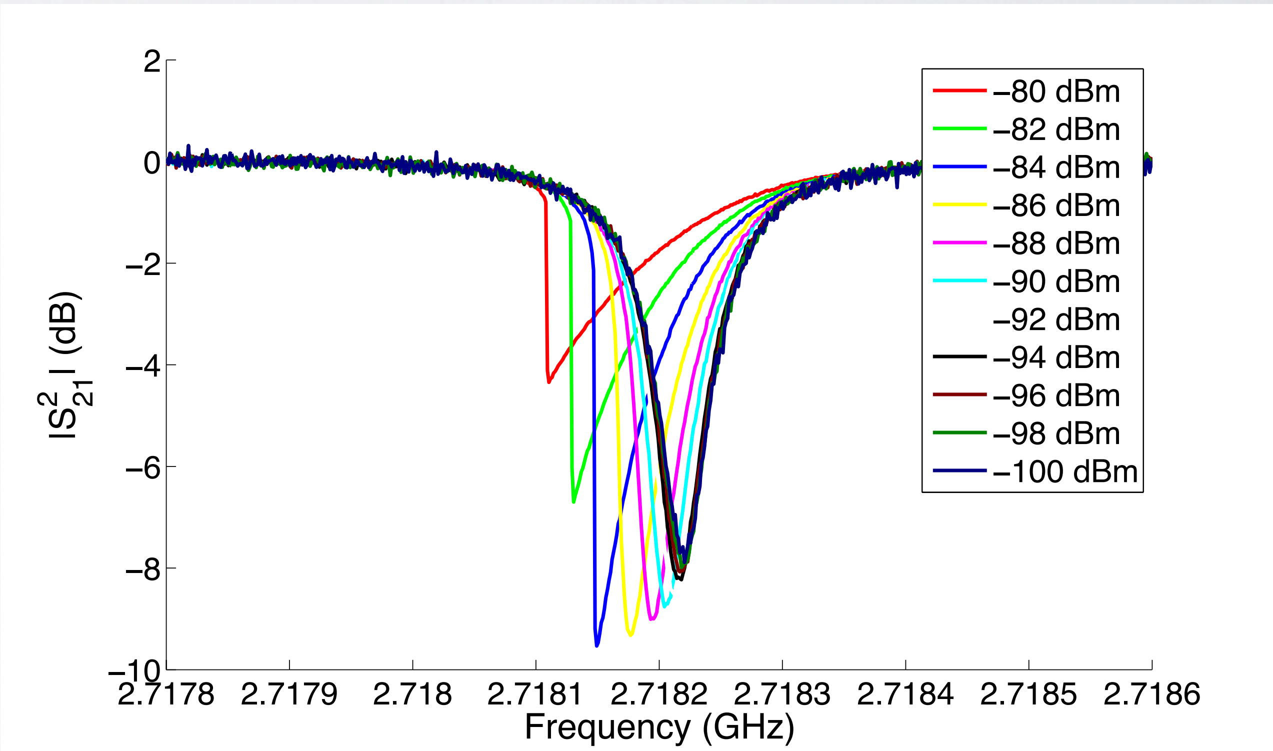
McKenney et al 2012





- intrinsic resonator noise in dissipation quadrature below standard quantum limit (Gao et al 2011)
- NEP limited by amplifier noise
- practical limit on P_g set by avoiding bifurcation
- $P_{g,bif}$ @ critical coupling
  - 2 pW predicted
  - ~7 pW measured
  - $P_{g,bif}$ (measured) > $P_{g,bif}$ (calc) observed by MAKO group as well (Swenson et al 2012)

bifurcation near critical coupling



prediction:
(T_{amp} = 4K, f = 1.2 THz)

$$\frac{NEP^2_{diss}}{NEP^2_{photon}} = 1.4$$

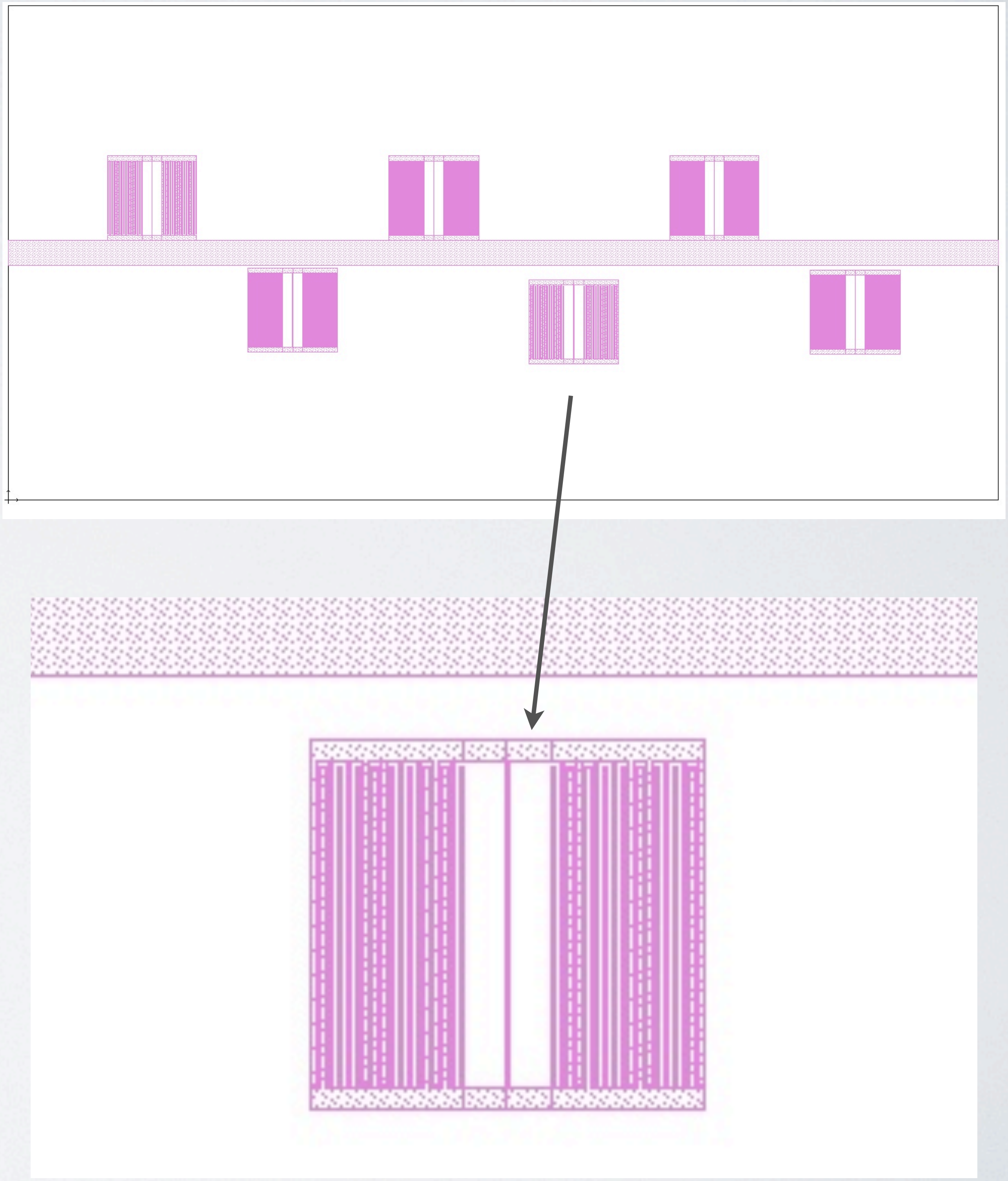
FUTURE DIRECTION

- move to Tc = 1.5 K
- dissipation readout
  - f_o > 3 GHz
  - predict background limited performance
- frequency readout
  - f_o < 1 GHz ala MAKO (Swenson 2012, McKenney 2012)
  - ~ 1mm^2 IDCs (allowed because of feedhorn coupling

$$\frac{NEP_{freq}^2}{NEP_{ph}^2} \sim T_c^5$$

- Tc = 1.5K test pixels fabricated
  - what is the best noise performance we can achieve?
  - explore frequency noise versus IDC geometry

low T_c, low f_o test chip



SUMMARY

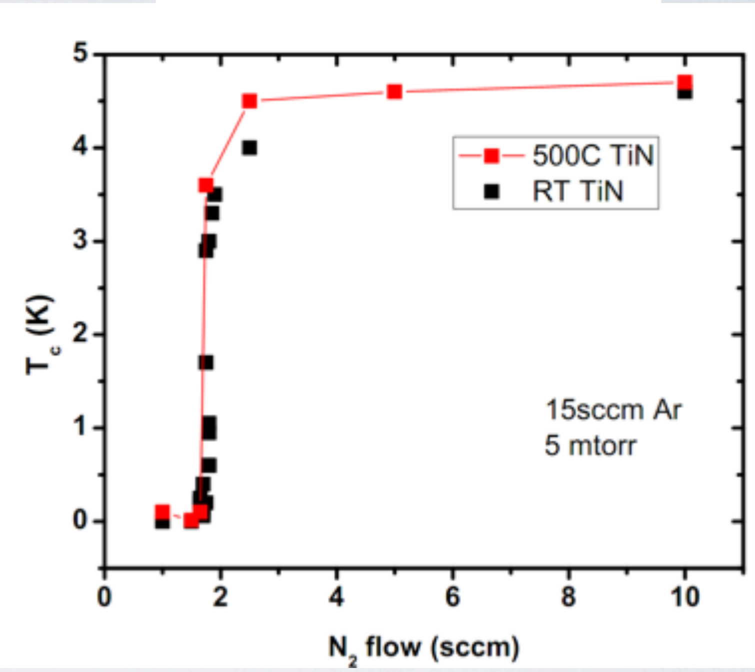
- first use of feedhorn-coupled mkids
- dual polarization sensitivity within one spatial pixel
- TiN/Ti/TiN tri-layer achieves uniform T_c = 1.5 K across 75 mm wafer
- promising results with waveguide coupling
- research of TiN material properties on-going
- noise properties focus of future work

EXTRA MATERIAL

TITANIUM NITRIDE

- High resistivity facilitates optical coupling
- High kinetic inductance fraction
- Tunable transition temperature (Tc)
- Good uniformity of stoichiometric films

Tunable Tc



Tc uniformity