UK Transition Edge Sensor Arrays for SAFARI

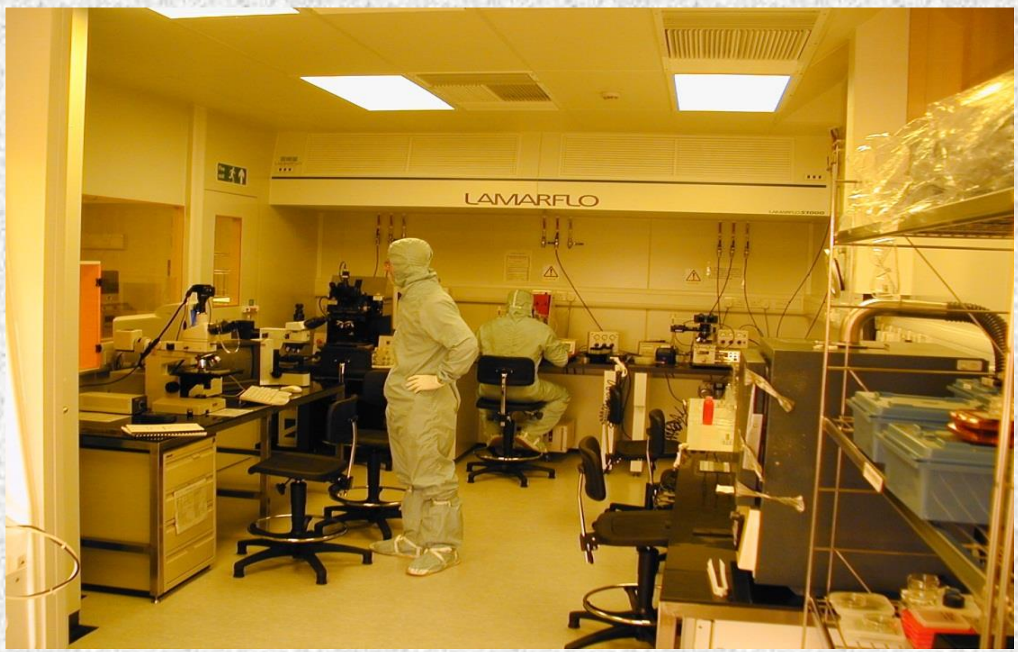
Stafford Withington

On Behalf of FIR ESA CTP Consortium

UNIVERSITY OF CAMBRIDGE

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

- Transition Edge Sensors with FDM based on SQUIDs is baseline for SAFARI
- Active European Consortium Working on Ultra-Low-Noise TES Arrays since 2009
- Current principal members are Cambridge Univ., Cardiff Univ. and SRON
- Supported by ESA, largely in context of SAFARI, but not SAFARI specific
- No SAFARI-specific UK funding during this time, but programme has drawn heavily on large STFC investment in infrastructure in superconducting detector technology

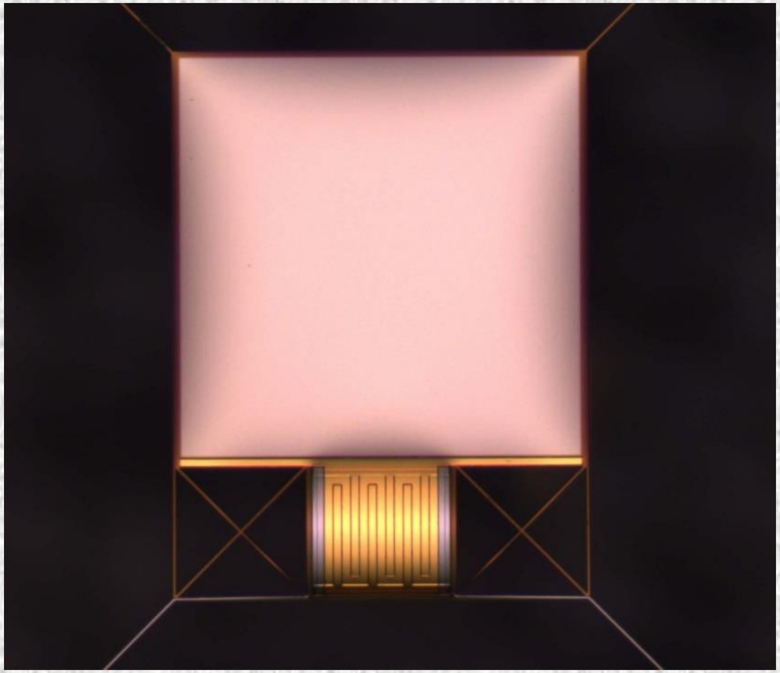


- In 2013 status changed from TRP to CTP, with UK and SRON developments running in parallel, rather than a single funded programme
- Very strong collaboration continues with SRON on all aspects of SAFARI instrument
- Entering last phase of funded work on CTP, which will finish Dec 2016
- Over last 10 years numerous workshops, meetings and progress reviews
- UK has substantial capability in low-noise FIR TES arrays (NEP 10^{-17} to 10^{-19} $WHz^{-1/2}$)

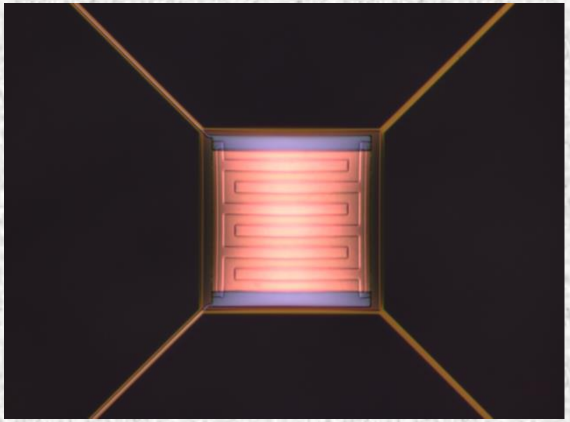
Transition Edge Sensors:

β-phase Ta absorber with Tc of 860 mK
200 nm SiN (high heat capacity due to TLSs)
MoAu bilayers with Tc of 110 mK
G ~ 0.2 pW K^{-1}
NEP ~ 2 to 4 x 10^{-19} $WHz^{-1/2}$
τ ~ 10 mS
Psat ~ 20 fW

Low Psat and NEP means measurement challenges

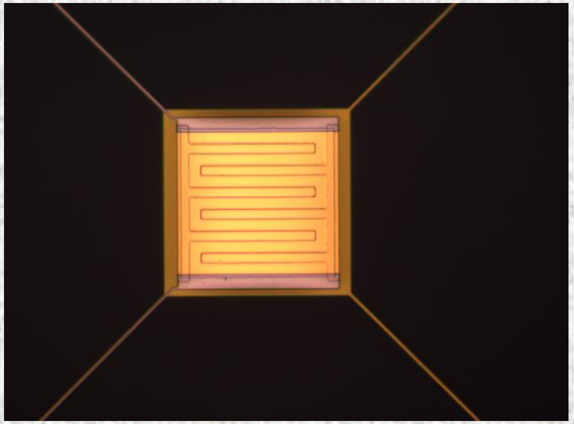


Bilayer technologies needed to achieve Tc - all make good TESs



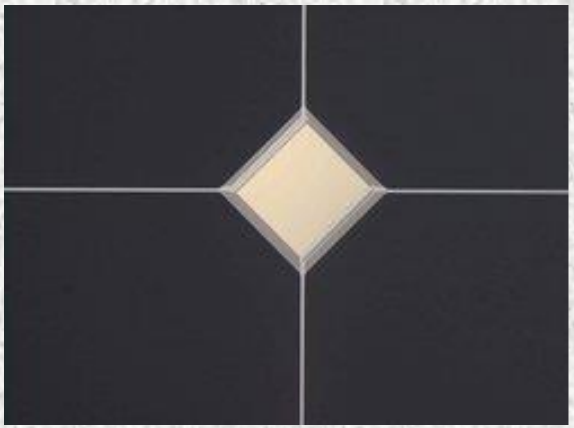
Cambridge MoCu – 200nm (40/106nm)

- Especially difficult to manufacture
- Need SiO_2 passivation layer to protect Cu
- High stress – thin (200nm) nitride - <1µm curvature



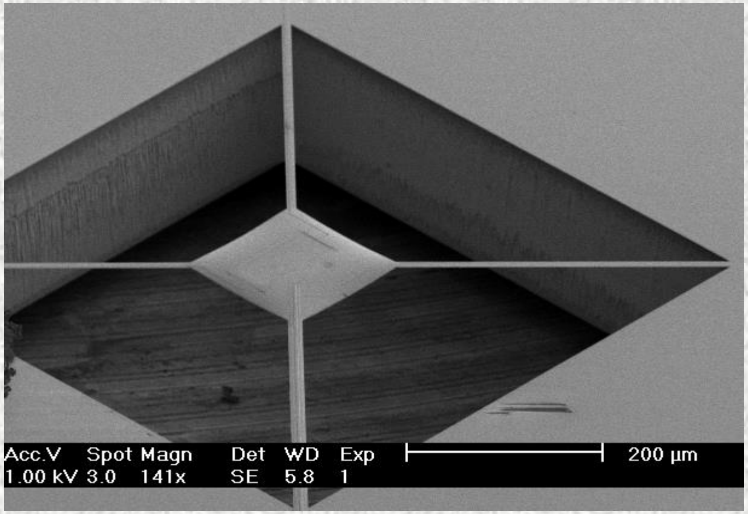
Cambridge MoAu – 200nm

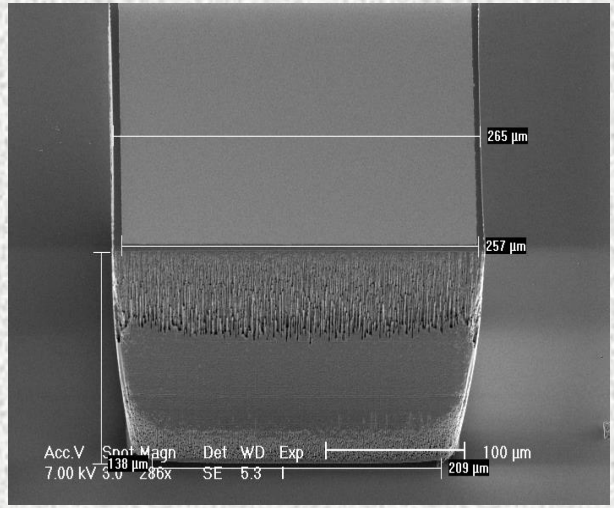
- Self passivating - low C
- Good inter-diffusion stability
- Low stress – good for thin nitride – < 100nm curvature

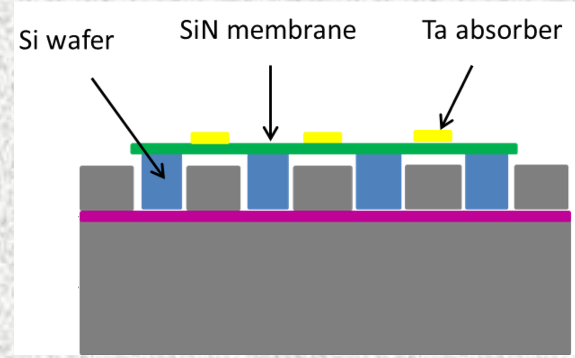


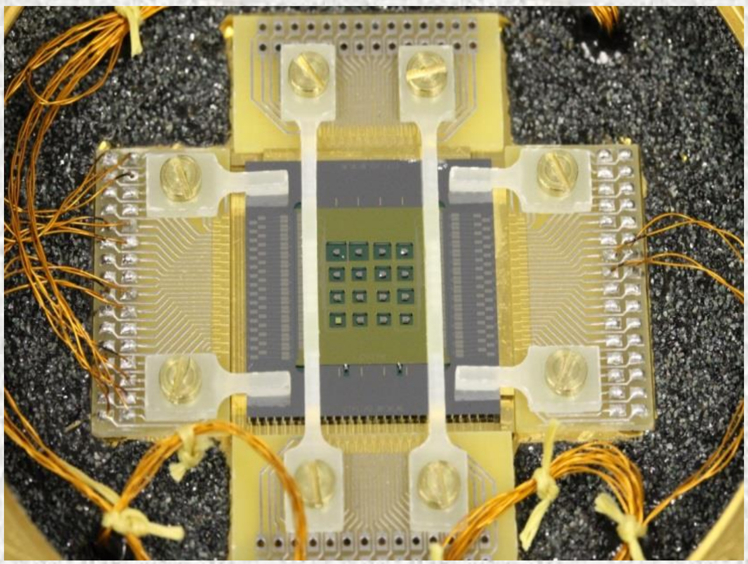
SRON TiAu – 500nm (16/85)

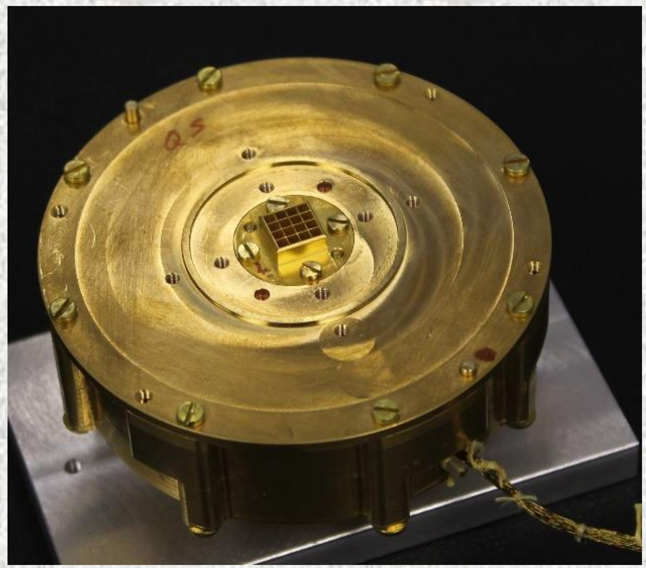
- Self passivating
- Good inter-diffusion stability









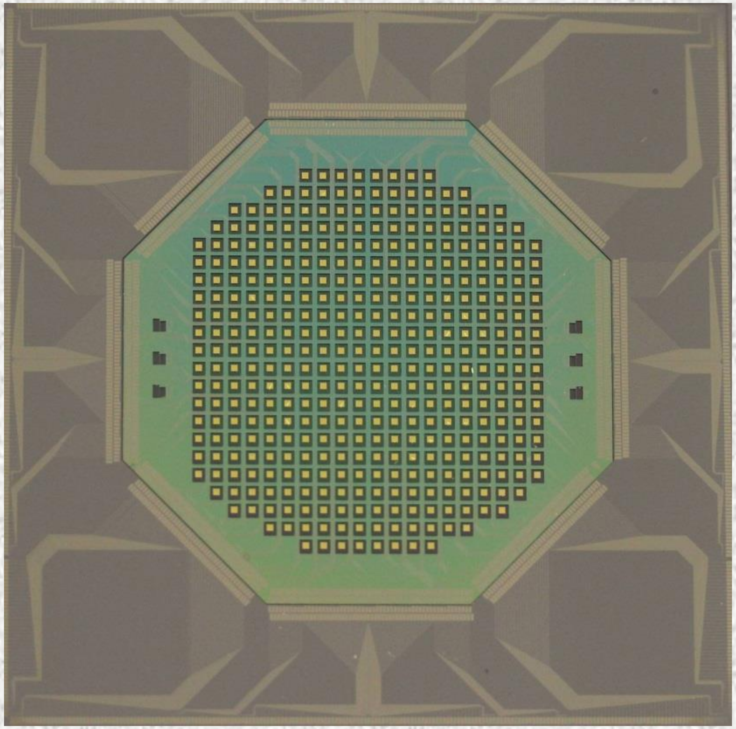


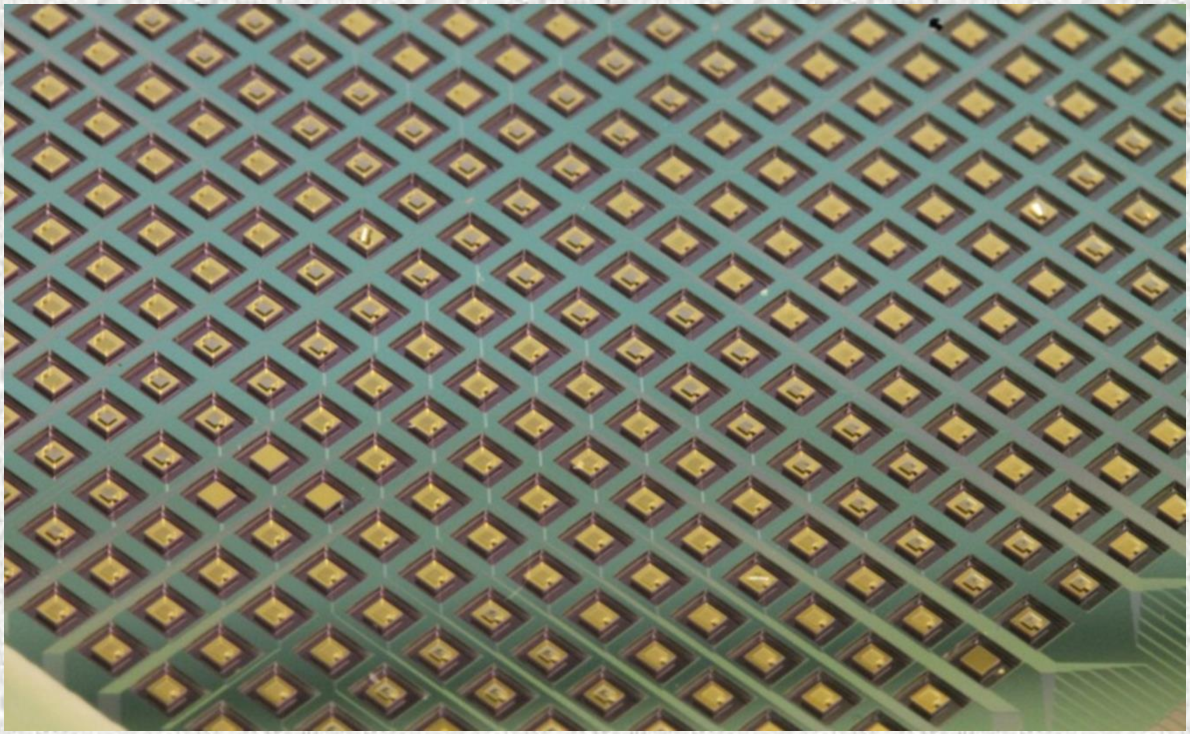
Small-format 16 element test arrays with integrated optical backshorts
Few-mode, 10-20, lightpipe coupling (developed frabrication technology for S and L Band)

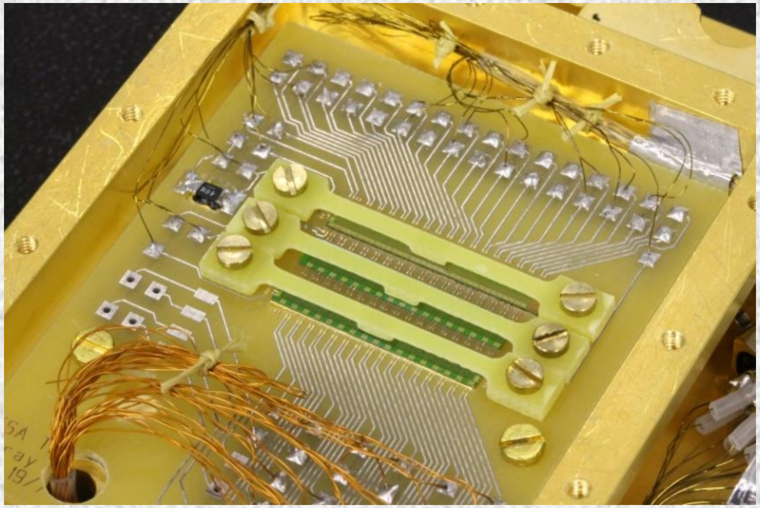
First phase (TRP):

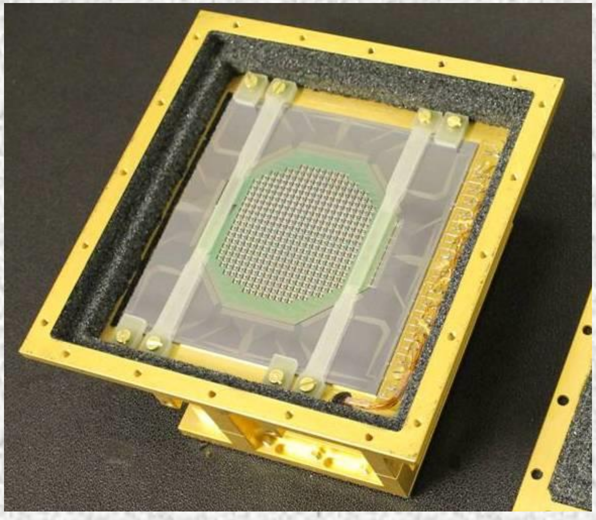
- UK work concentrated on large-format L-Band imaging arrays (200-100 μm)
- SRON concentrated on large-format S-Band imaging arrays (30-60 μm)
- No M-Band work (60-110 μm) – most difficult
- Development of fabrication techniques
- Exploration of basic device physics (what determines noise, speed, etc.)
- Demonstration of laboratory-based measurement techniques (variable temperature load, passband defining optical filters)
- Only limited optical tests – proven, but very difficult
- Few-mode system and so work was needed to set up data analysis models of test system

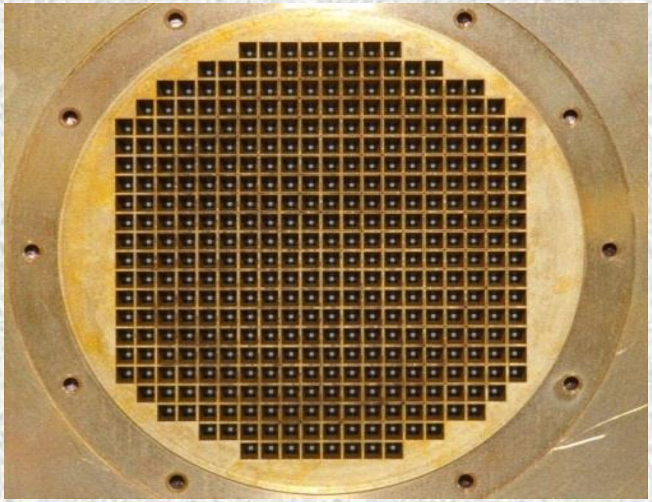
ESA TRP L Band 388 pixel imaging array as off 2013:









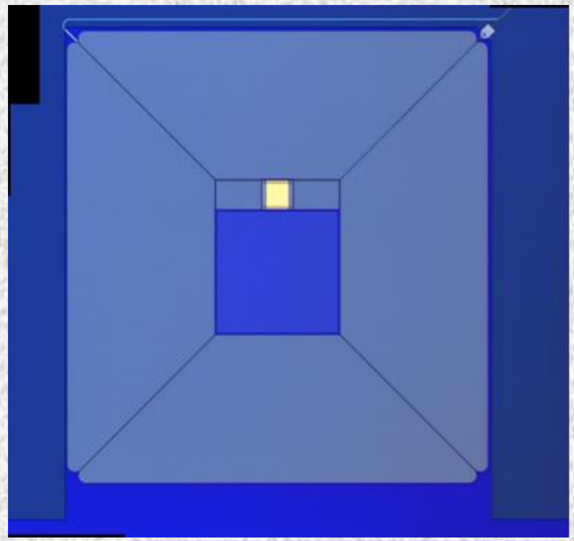


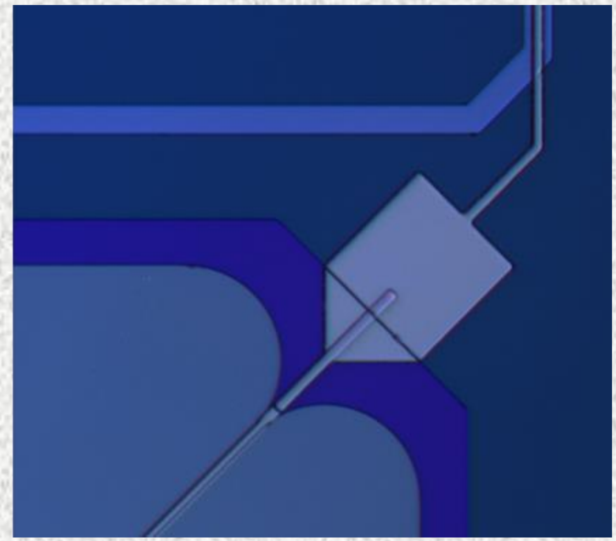
Second phase (CTP):

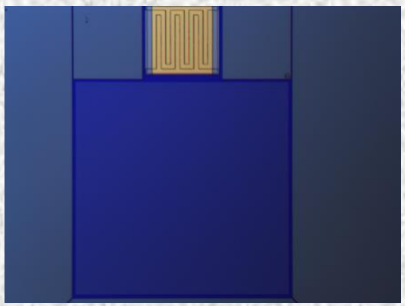
- UK worked on small-format L-Band, M Band and S-Band arrays 200-30 μm
- Extensive work on modelling, device processing, more sophisticated designs
- Development of profiled lightpipe manufacture, camera integration, metrology
- Measurements of dark noise and device dynamics
- Accurate optical efficiency measurements – development of bandpass optical filters
- Designed and fabricated complete sets of `high G' devices having same physical forms of `low-G' devices.
- Now have spectral and spatial measurements using room temperature FTS and beam scanning system (test systems set up at Cardiff)
- Excellent imaging array technology available for utilitarian purposes as by-product

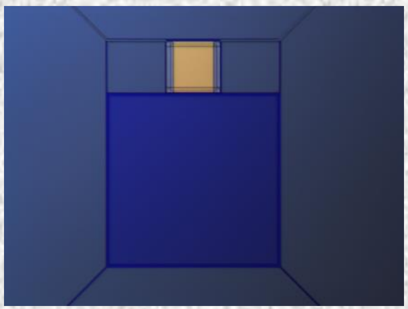
TES array chips:

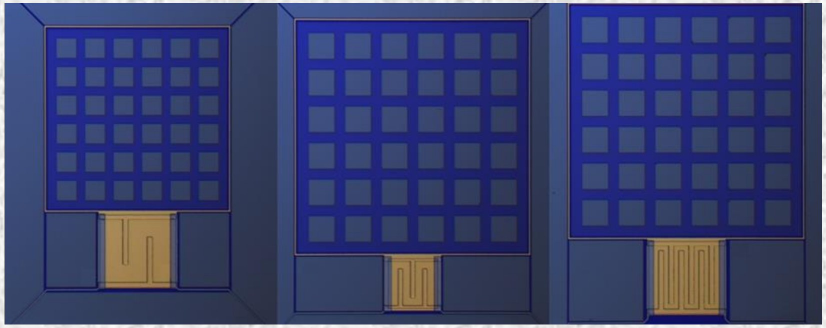
- Extreme range of leg geometries:
  - 1500µm long and 1.5µm wide
  - 200 µm long and 100µm wide
  - 4um long and 500 nm wide
- Bilayer variations (size, Au bars)
- Absorber variations (meshed)
- Au rim / no rim









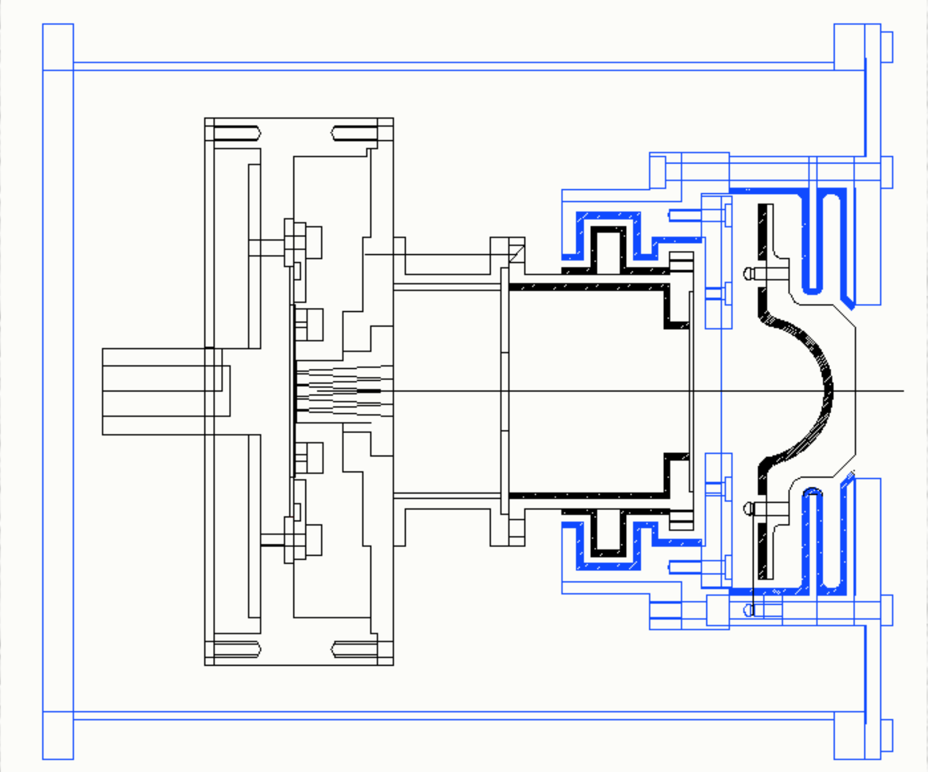


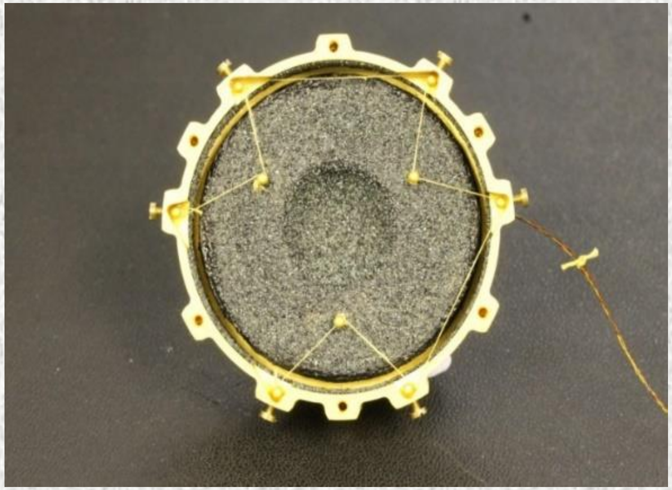
Microstrip Nb wiring:

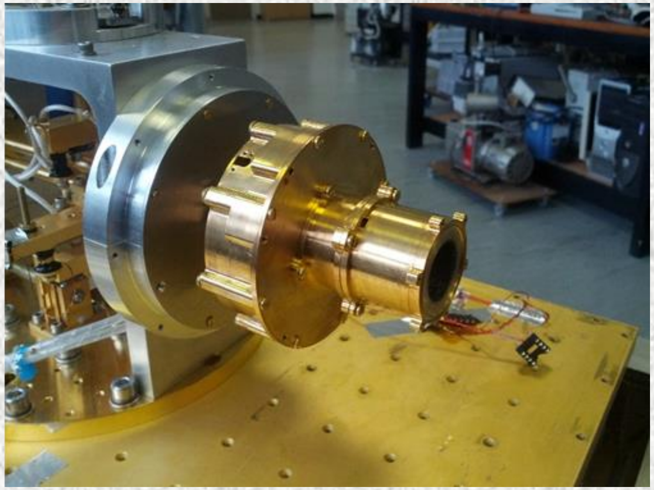
- Fully integrated process $Nb/SiO_2/Nb$
  - track width 2µm
  - space between tracks 2µm
  - 250 tracks/mm density
- Breakout to standard wiring on legs
- Excellent alignment on legs

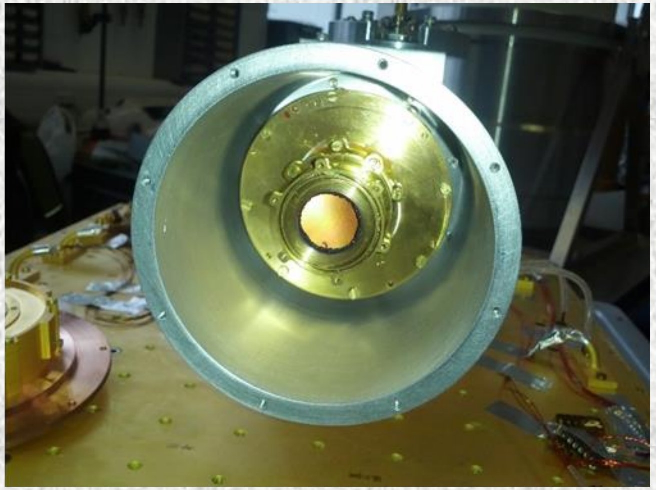
Optical efficiency measurements(Cambridge)

- Thermal and bandpass optical filters
- Aperture defined throughput
- Detailed modal analysis
- Clean few-mode illumination
- Black absorber throughout
- Variable temperature hot load:
  - 3.5 – 25 K range (3 heaters)
  - 200 μK temperature stability
  - < 10 s time constant set by wire
- Extremely high straylight rejection



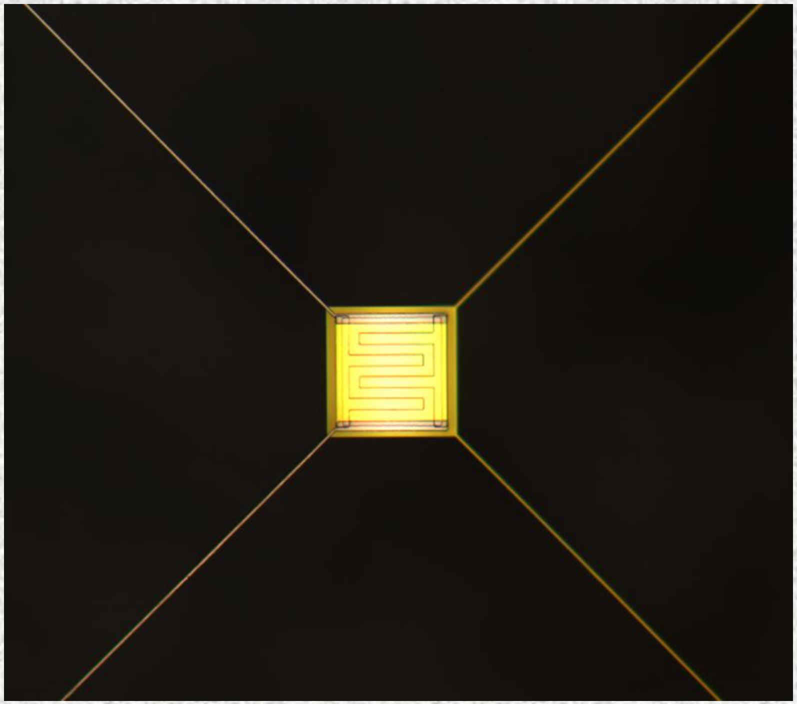


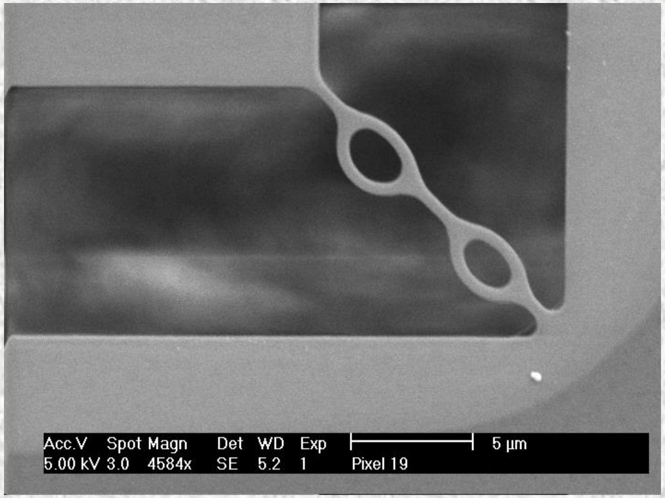


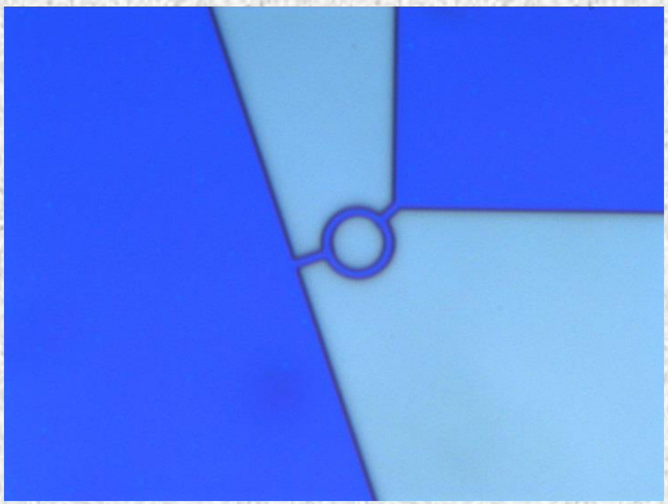


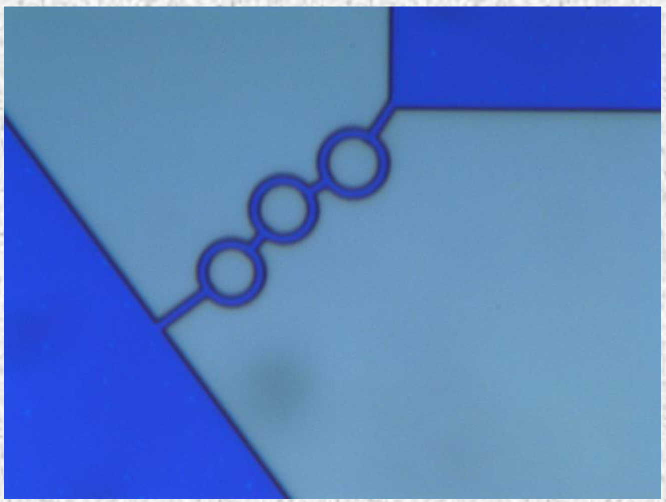
Many development opportunities available.

- Improved sensitivity – lower NEPs, uniformity
- Move to SoI rather than SiN to avoid heat capacity of TLSs and increase speed, higher uniformity
- Ballistic phononic legs (optical lithography and EBL)
- Excellent results already demonstrated for quantum thermal conductance limited TESs









Coming year (2016):

- Manufacture and test demonstration of M Band linear arrays (60-110 μm)
- Concentrate on mass-producible linear arrays for grating readout
- Refine profiled lightpipe manufacturing techniques and camera assembly techniques
- Understand optical efficiency measurements in greater detail

Proposed that UK should contribute to SAFARI mission:

- UK expertise in TES technology can make a major contribution to the SAFARI instrument (not just device processing, which is only a small part of an imaging spectroscopic sub-system, also need metrology and array integration)
- Current working arrangement that UK would provide detector arrays (not just devices) for at least one, possibly two, wavebands: M and/or S Band being the most likely
- Excellent if the UK could make a key high-tech contribution to a major, high profile space mission, working with international colleagues
- SRON and potential US partners have agreed to work with us in context of the UK providing detector technology for SAFARI
- Would place UK in position of being a major player in developing and providing technology for the mission and a beneficiary of the resulting science