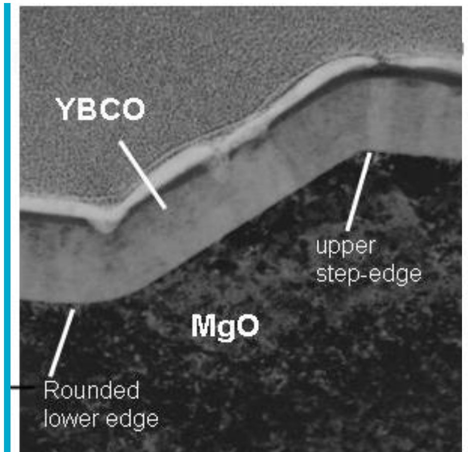
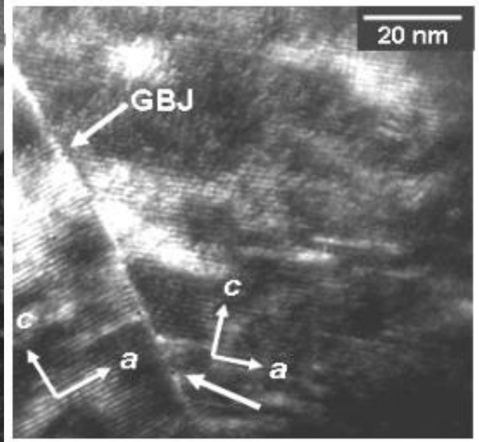
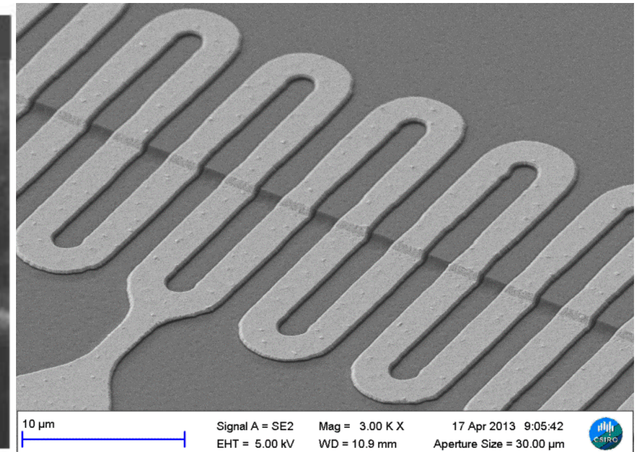
IEEE/CSC & ESAS EUROPEAN SUPERCONDUCTIVITY NEWS FORUM (global edition), October 2016.
Plenary presentation 4PL-01 given at ASC 2016; Denver,Colorado,USA, September 4 – 9, 2016.







One HTS Josephson Junction – An Array of Applications: Has anything come from HTS devices in the last 30 years?

C. Foley, J. Du, E. Mitchell, S. Lam, S. Keenan, J. Lazar, M. Bick, T. Zhang and K. Leslie

MANUFACTURING AND DATA61
www.csiro.au

(LaB)CuO T_c=36 K 1986

The New York Times ON THE WEB 18 March 1987

Discoveries Bring a 'Woodstock' for Physics

CSIRO


MAY 11, 1987
$1.95
TIME
CONTRA ARMS
The Widening Web
Wiring the Future
THE SUPERCONDUCTIVITY REVOLUTION

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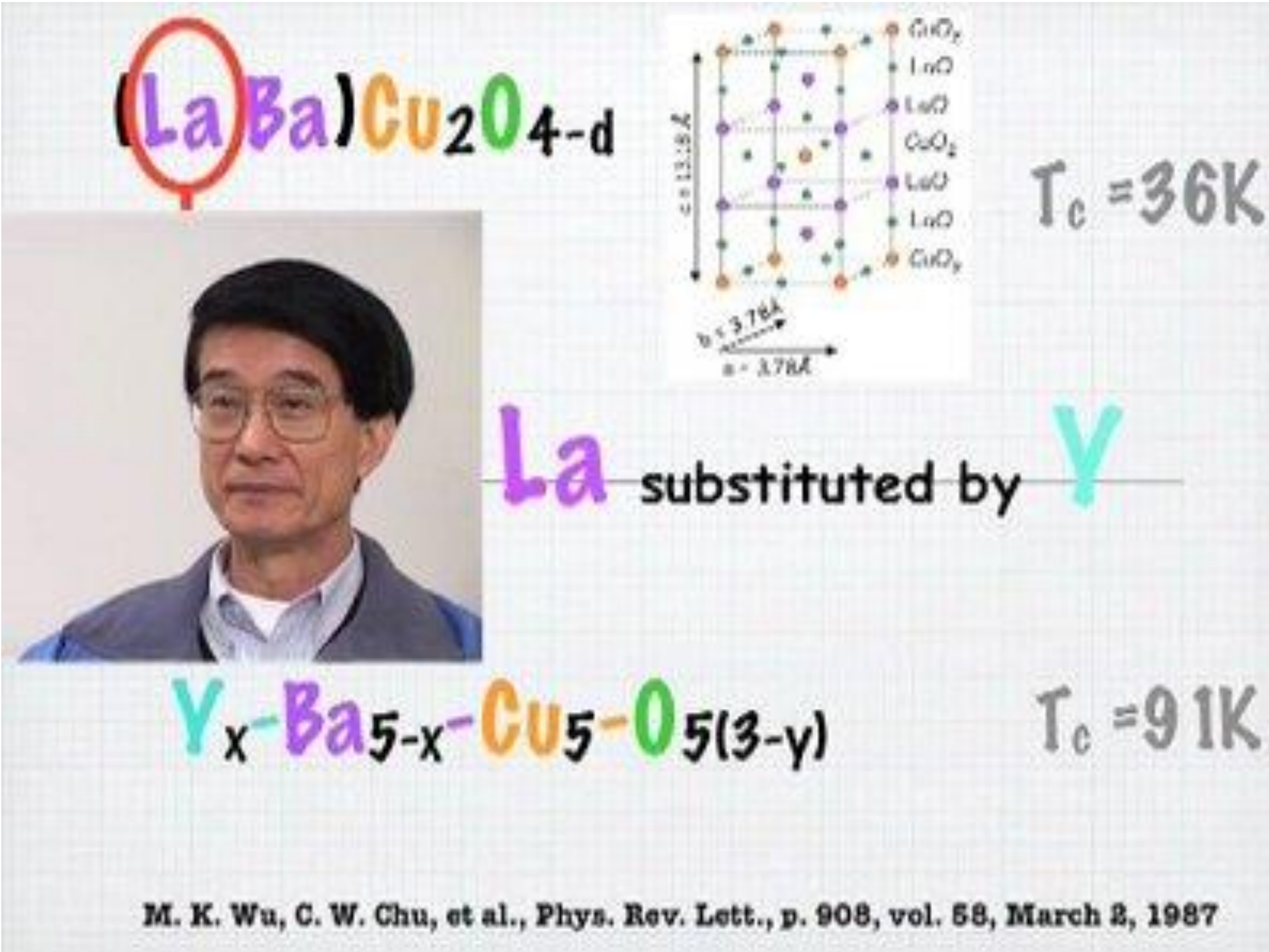
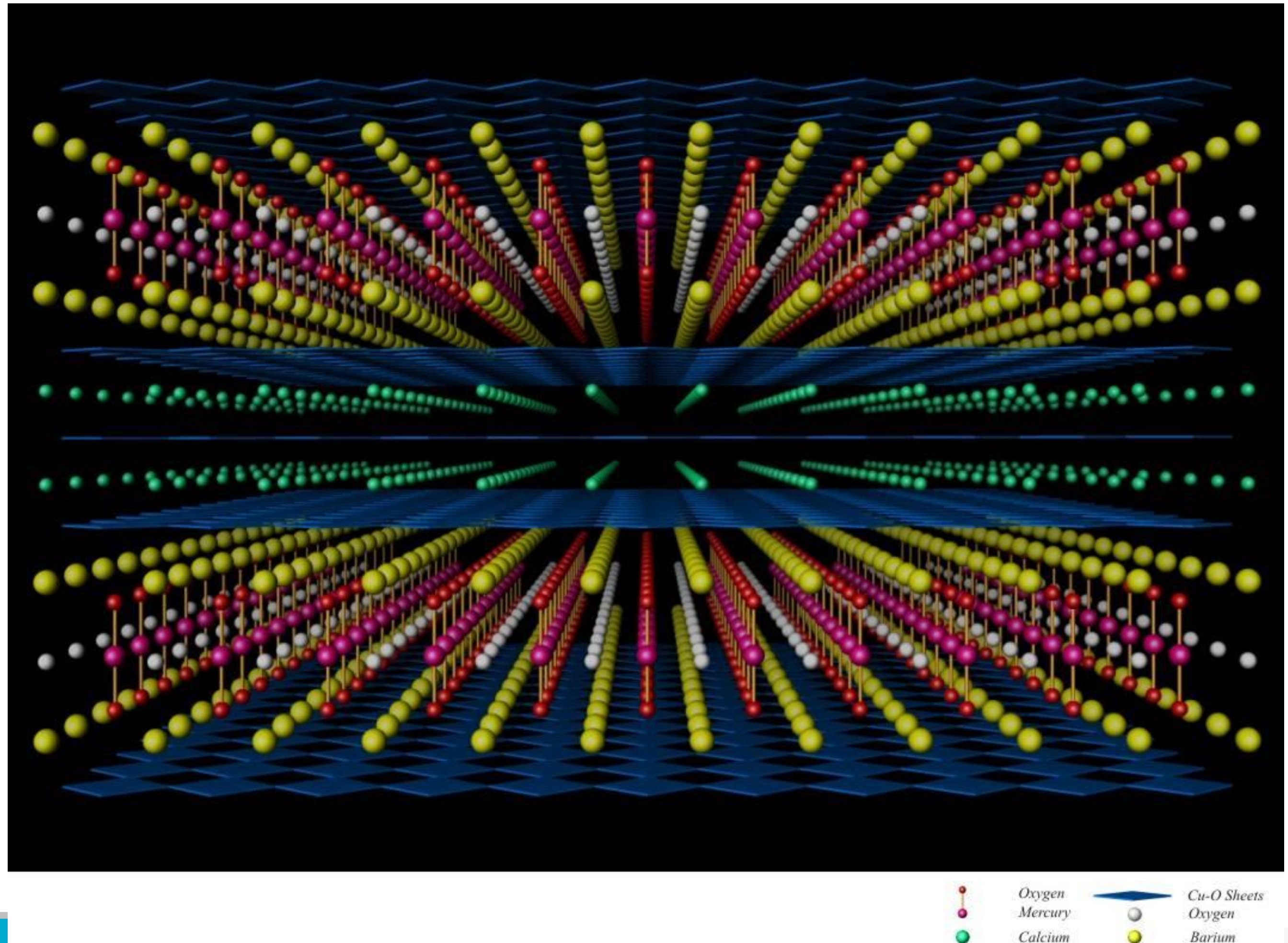
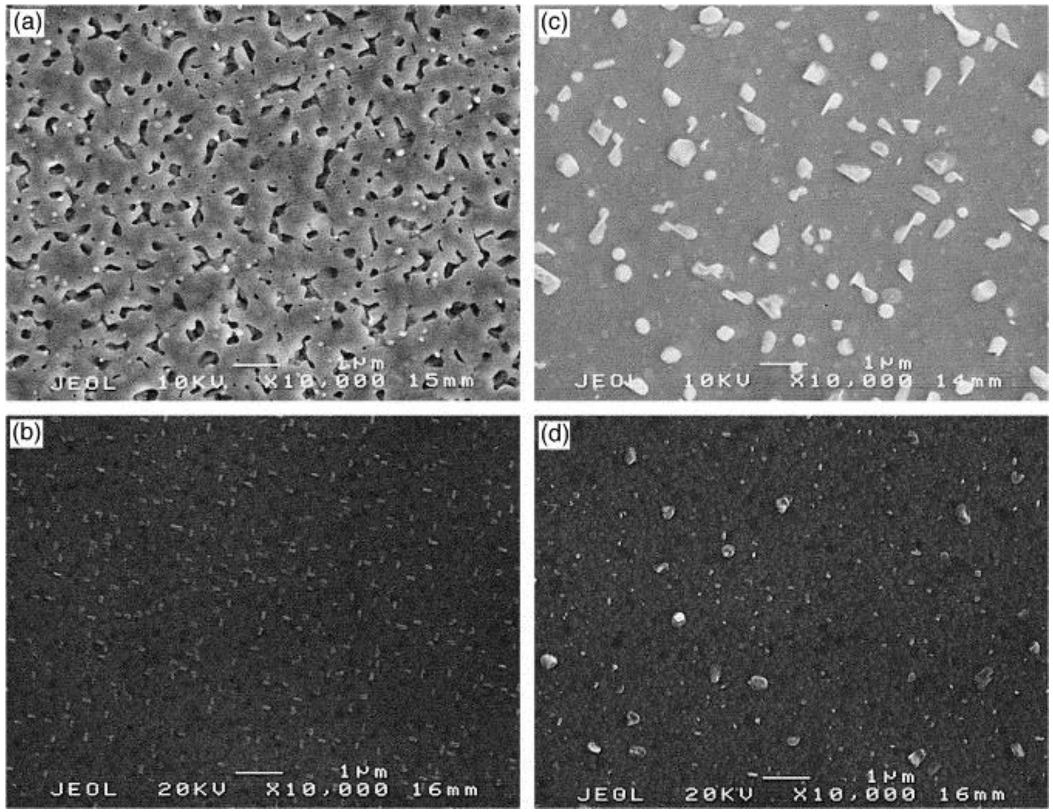
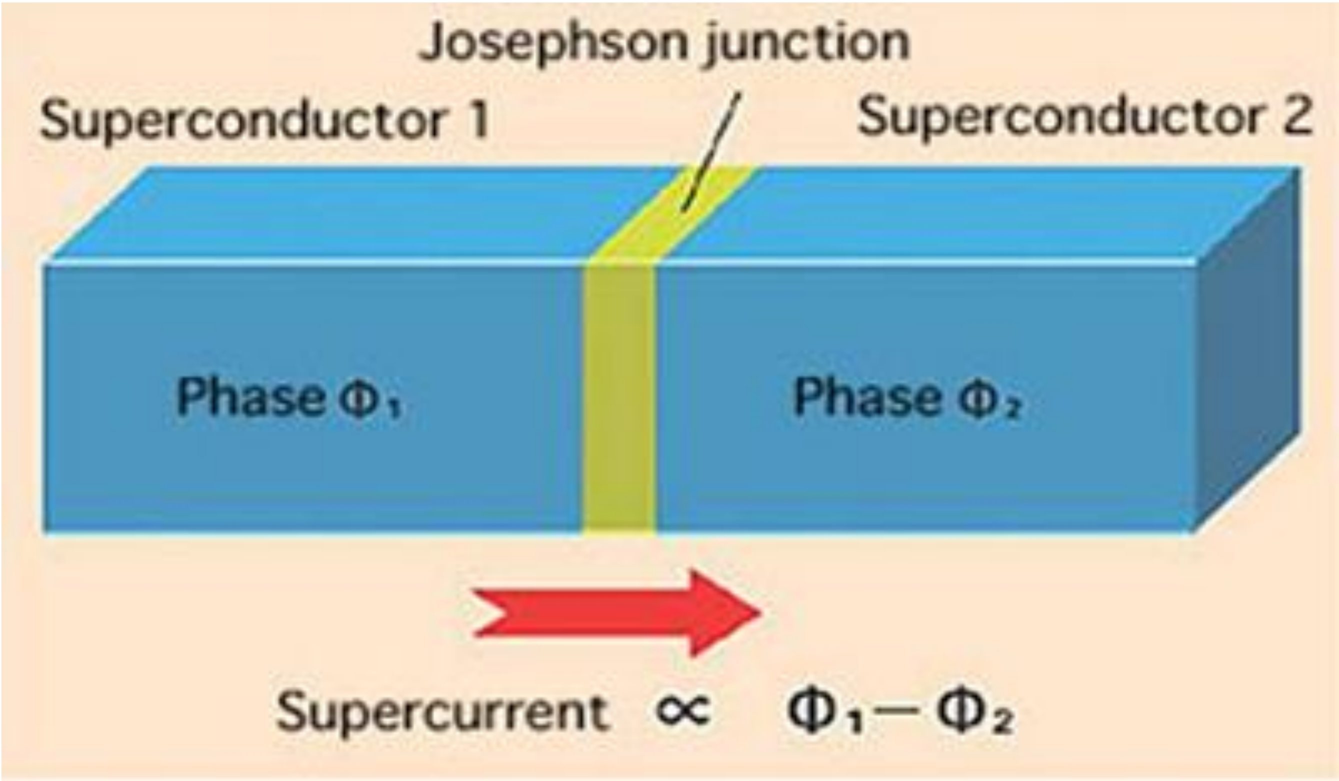
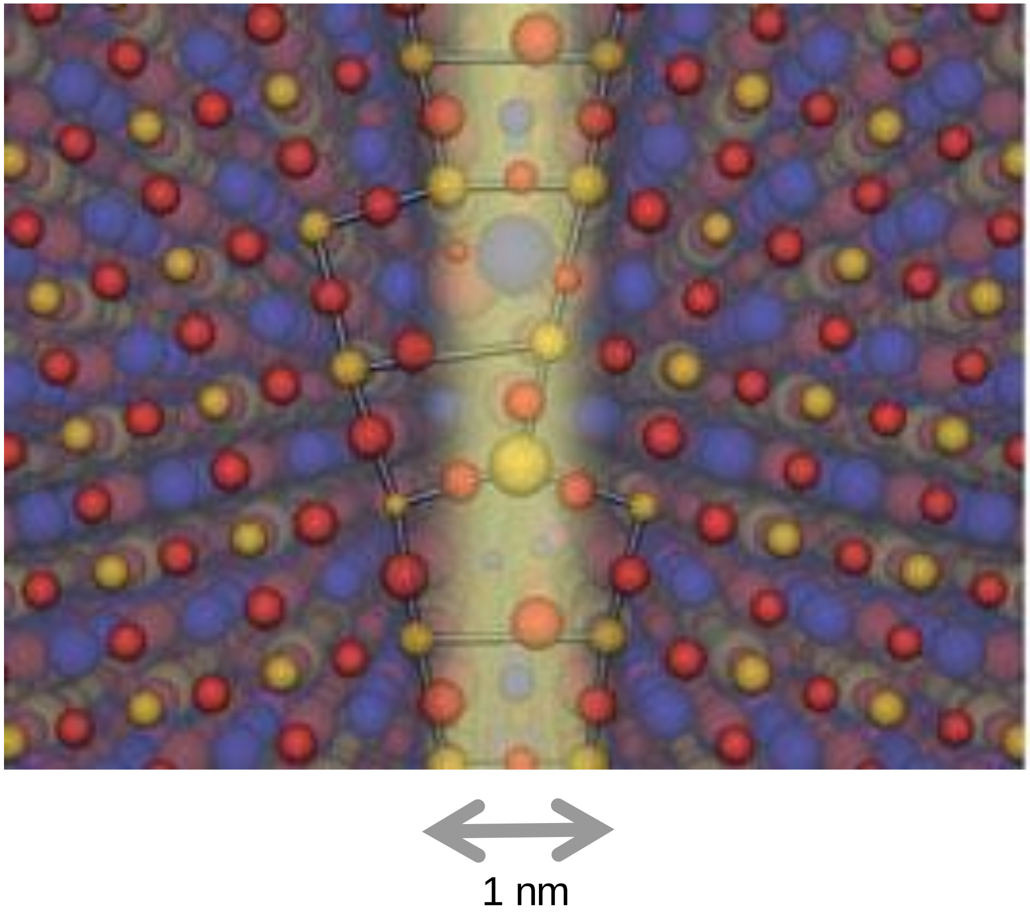

(La Ba)Cu2O4-d
Tc =36K
La substituted by Y
Yx-Ba5-x-Cu5-O5(3-y)
Tc =91K
M. K. Wu, C. W. Chu, et al., Phys. Rev. Lett., p. 908, vol. 58, March 2, 1987

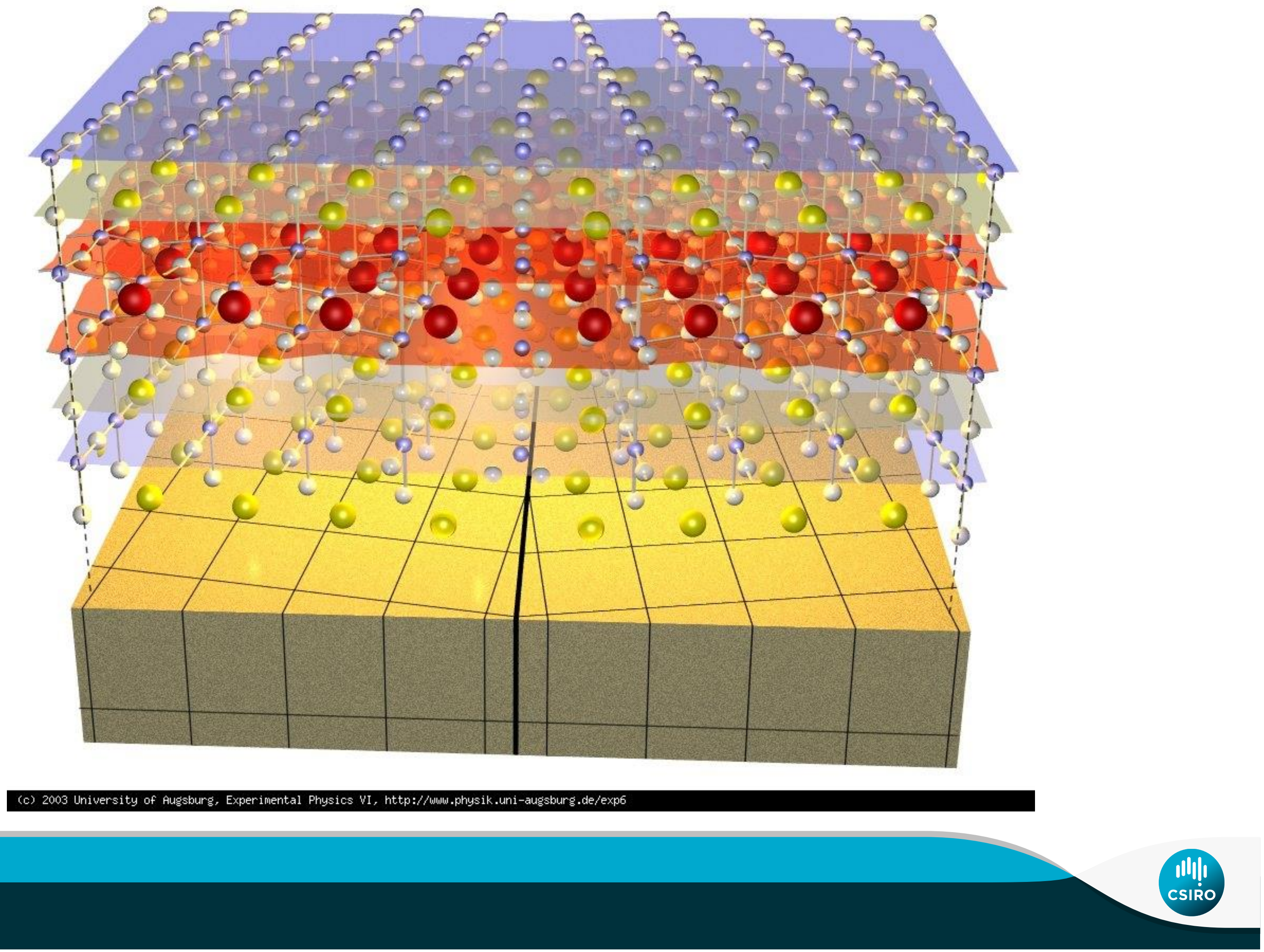

Oxygen
Mercury
Calcium
Cu-O Sheets
Oxygen
Barium
CSIRO


(a)
(c)
1μm
JEOL 10KV X10,000 14mm
(b)
1μm
JEOL 20KV X10,000 16mm
(d)
1μm
JEOL 20KV X10,000 16mm

Making a Josephson junction




1 nm


(c) 2003 University of Augsburg, Experimental Physics VI, http://www.physik.uni-augsburg.de/exp6
CSIRO

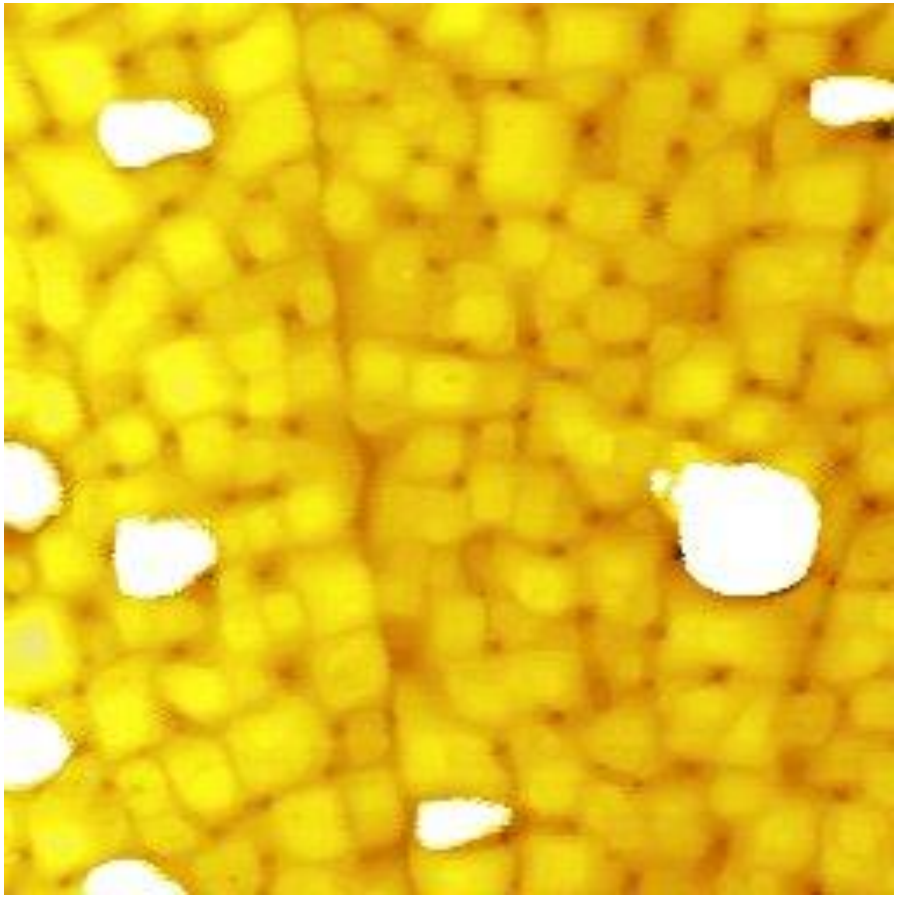
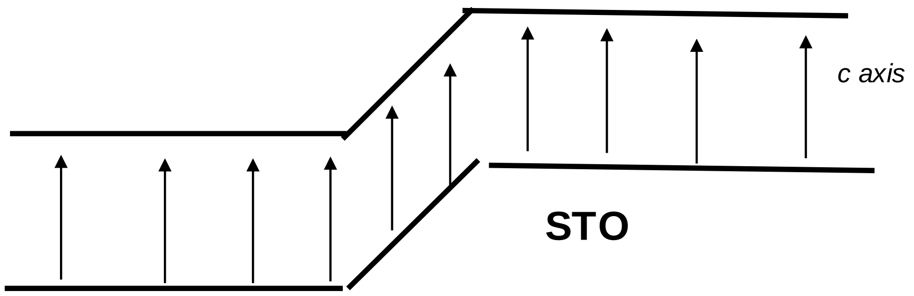


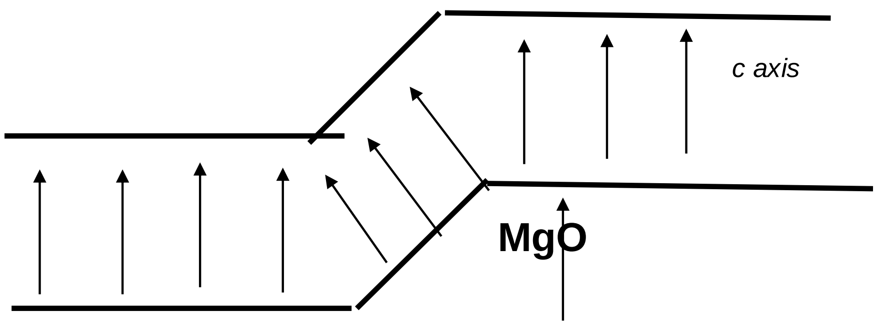
Image width: 2.5 µm

AFM

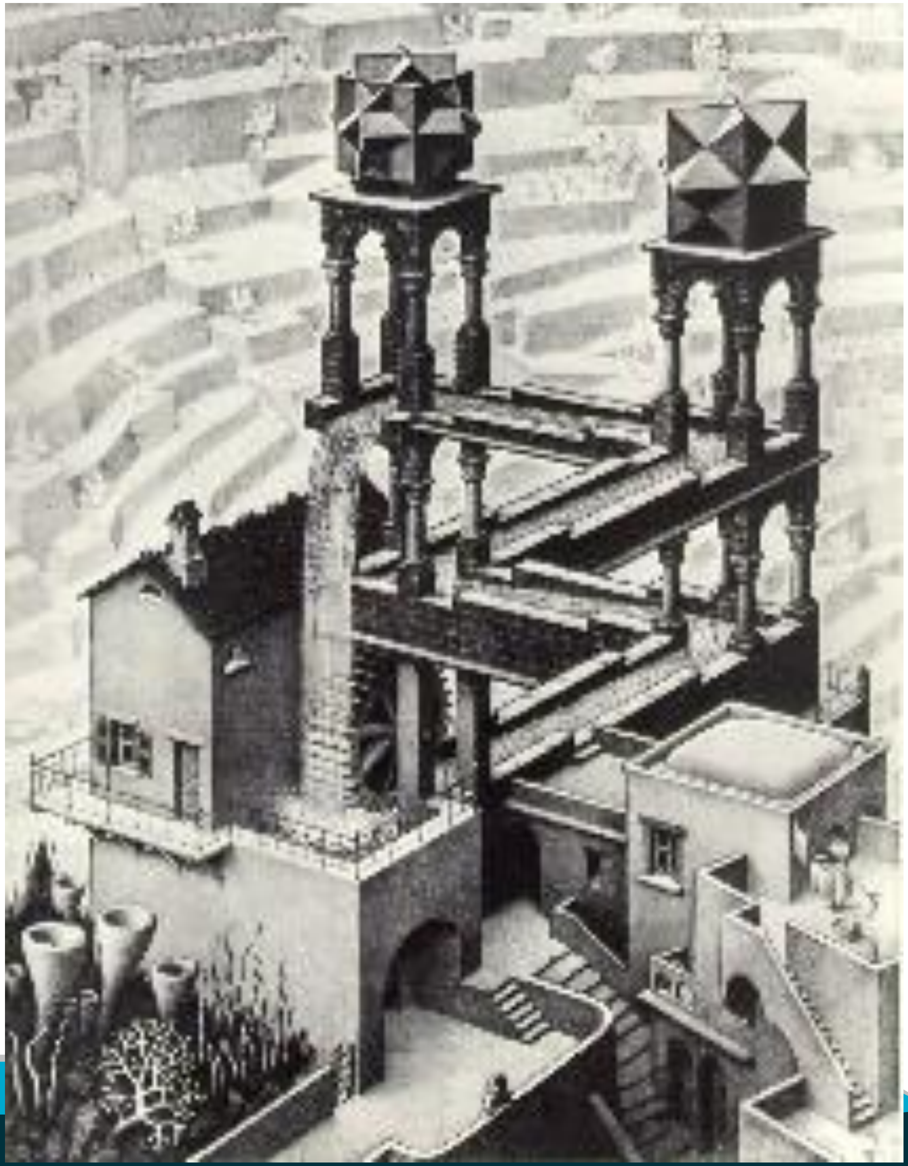
Can you create a grain boundary another way?

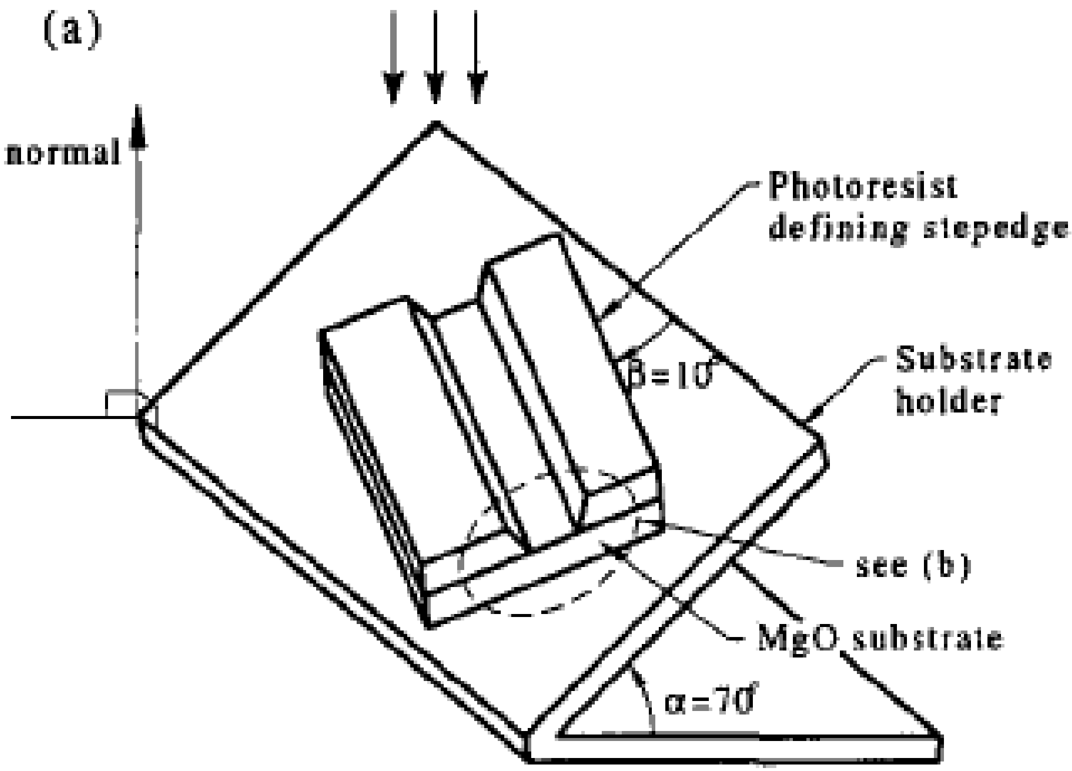
CSIRO


c axis
STO

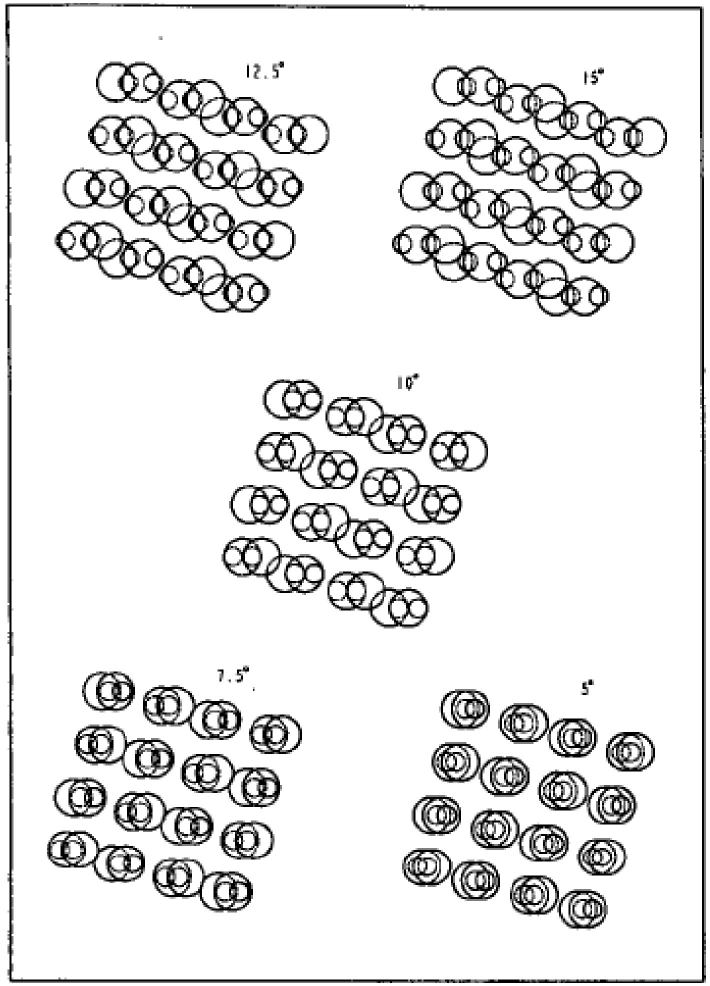

c axis
MgO

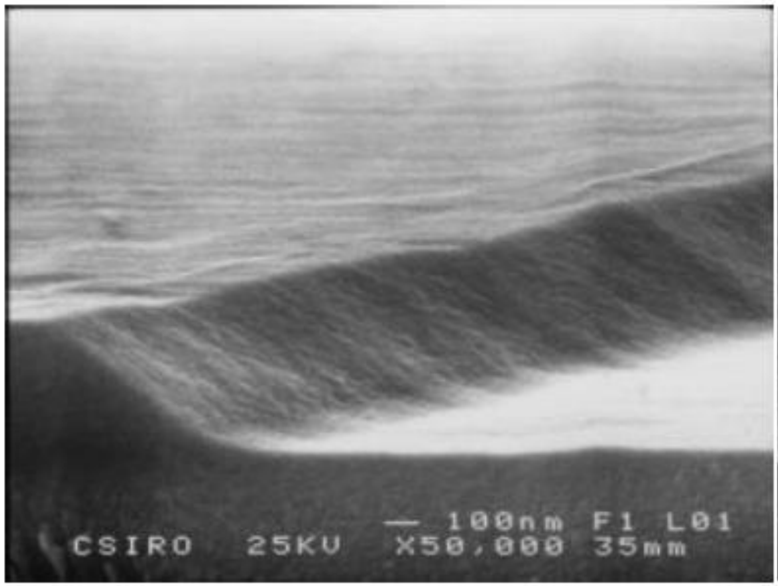
"Escher steps"

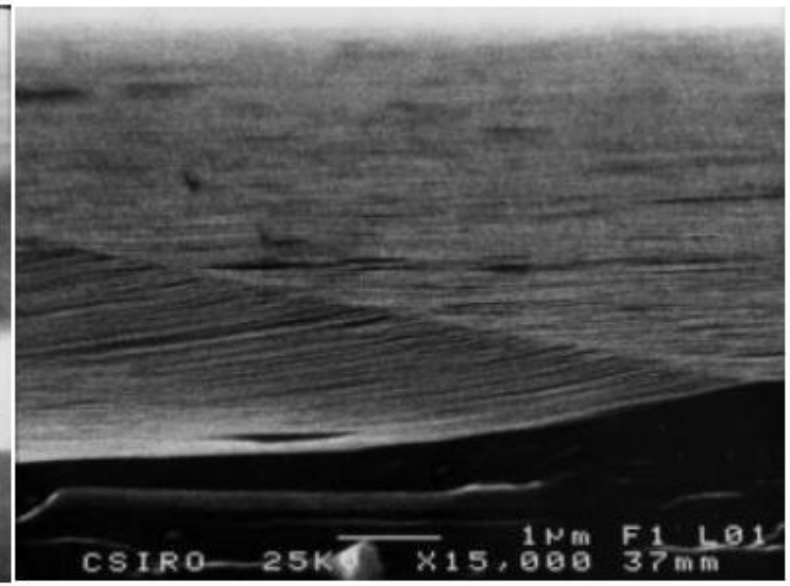


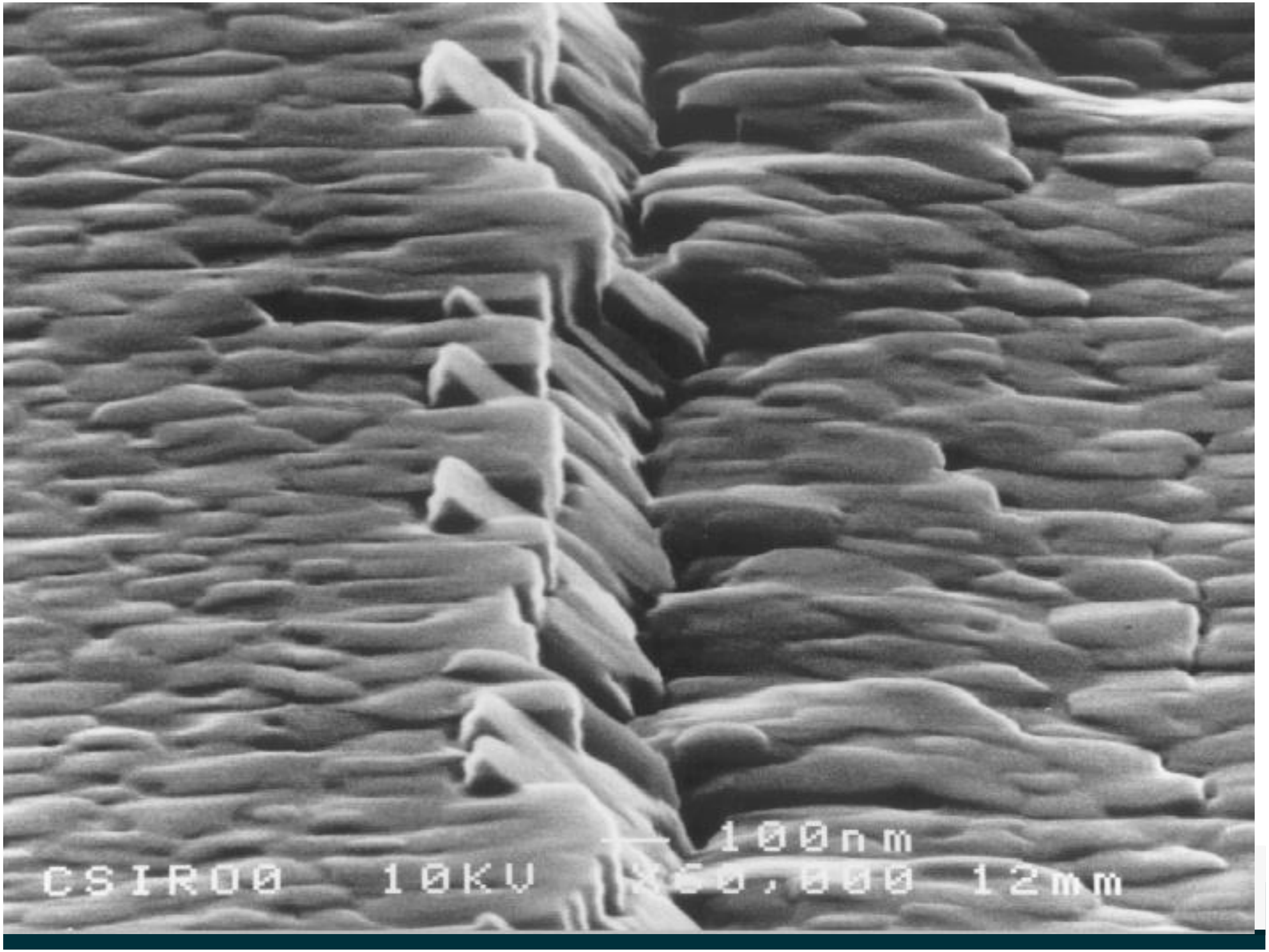

(a)
normal
Photoresist
defining stepedge
Substrate
holder
see (b)
MgO substrate
β=10°
α=70°

Schematic of the MgO lattice from different orientations for beta

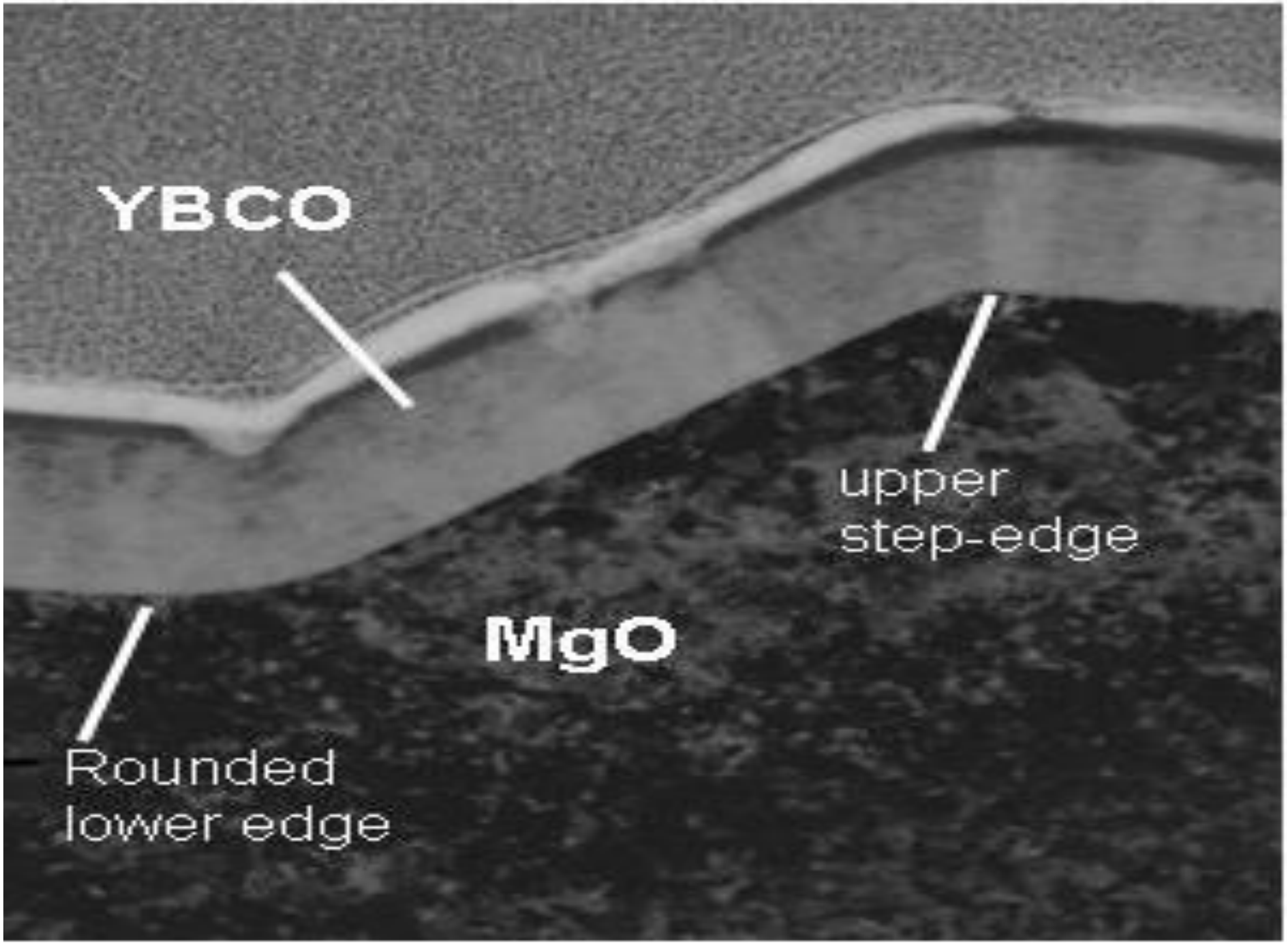


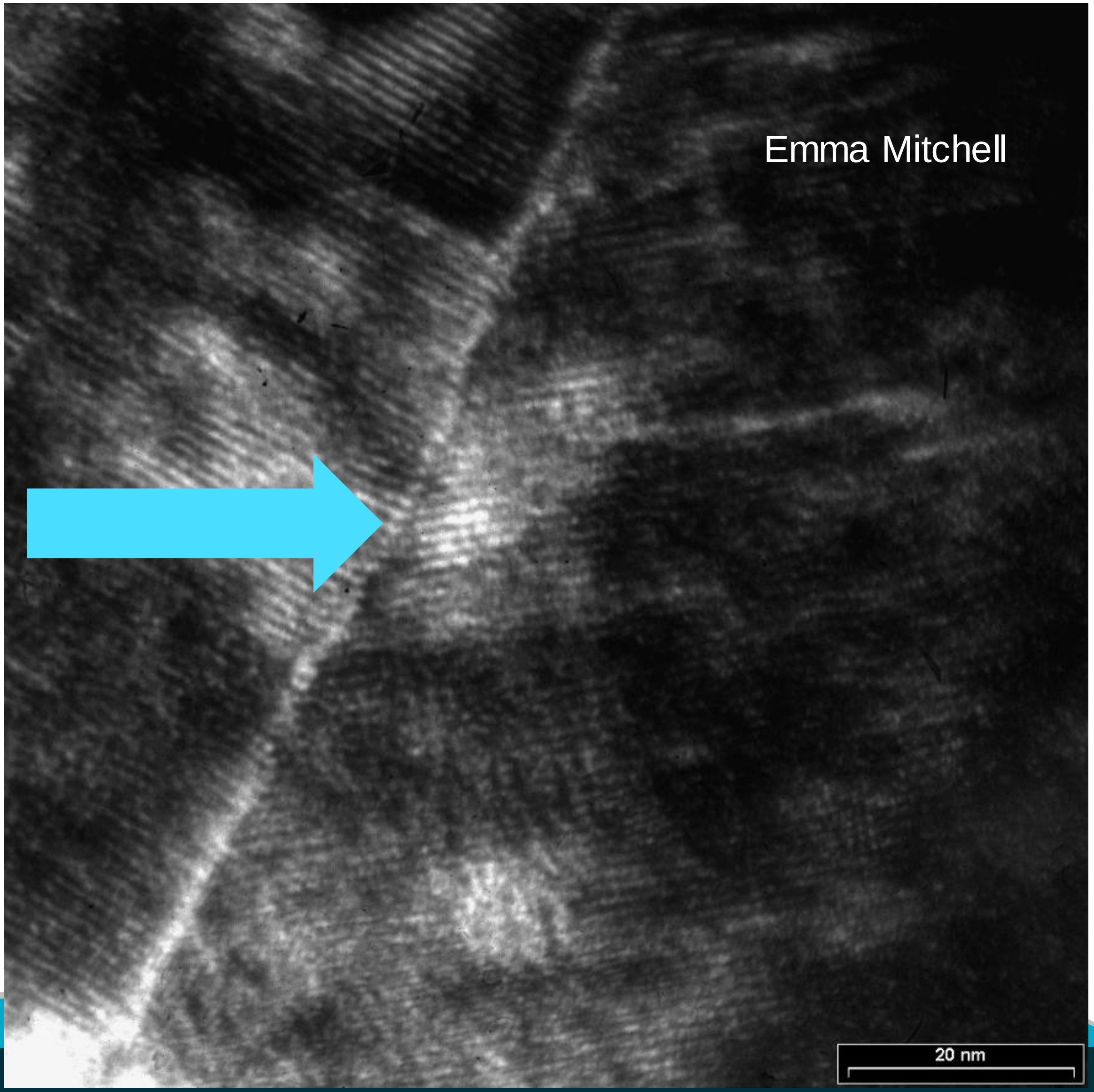

100nm F1 L01
CSIRO 25KU X50,000 35mm


1µm F1 L01
CSIRO 25K X15,000 37mm


100nm
CSIRO0 10KV
12mm

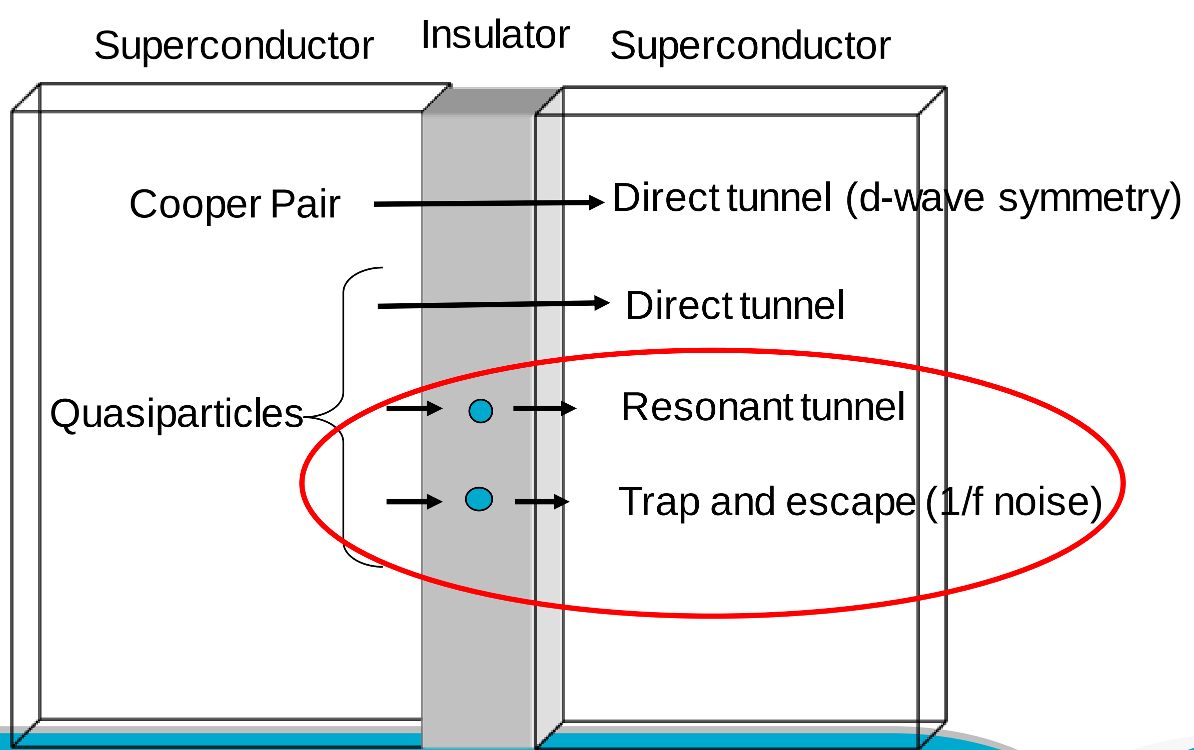

CSIRO
25KU
34mm


YBCO
upper
step-edge
MgO
Rounded
lower edge

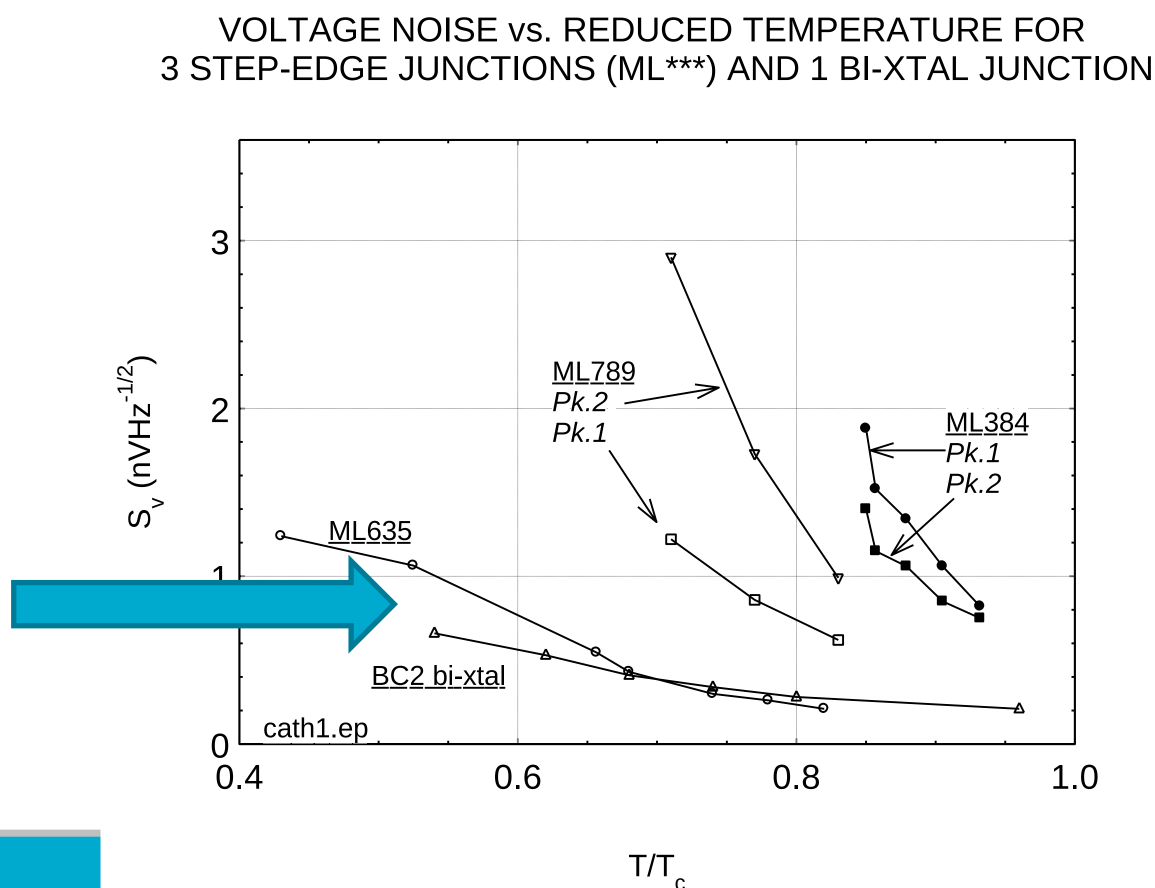

Emma Mitchell
20 nm

Enpuku and Minotani Simplistic Model

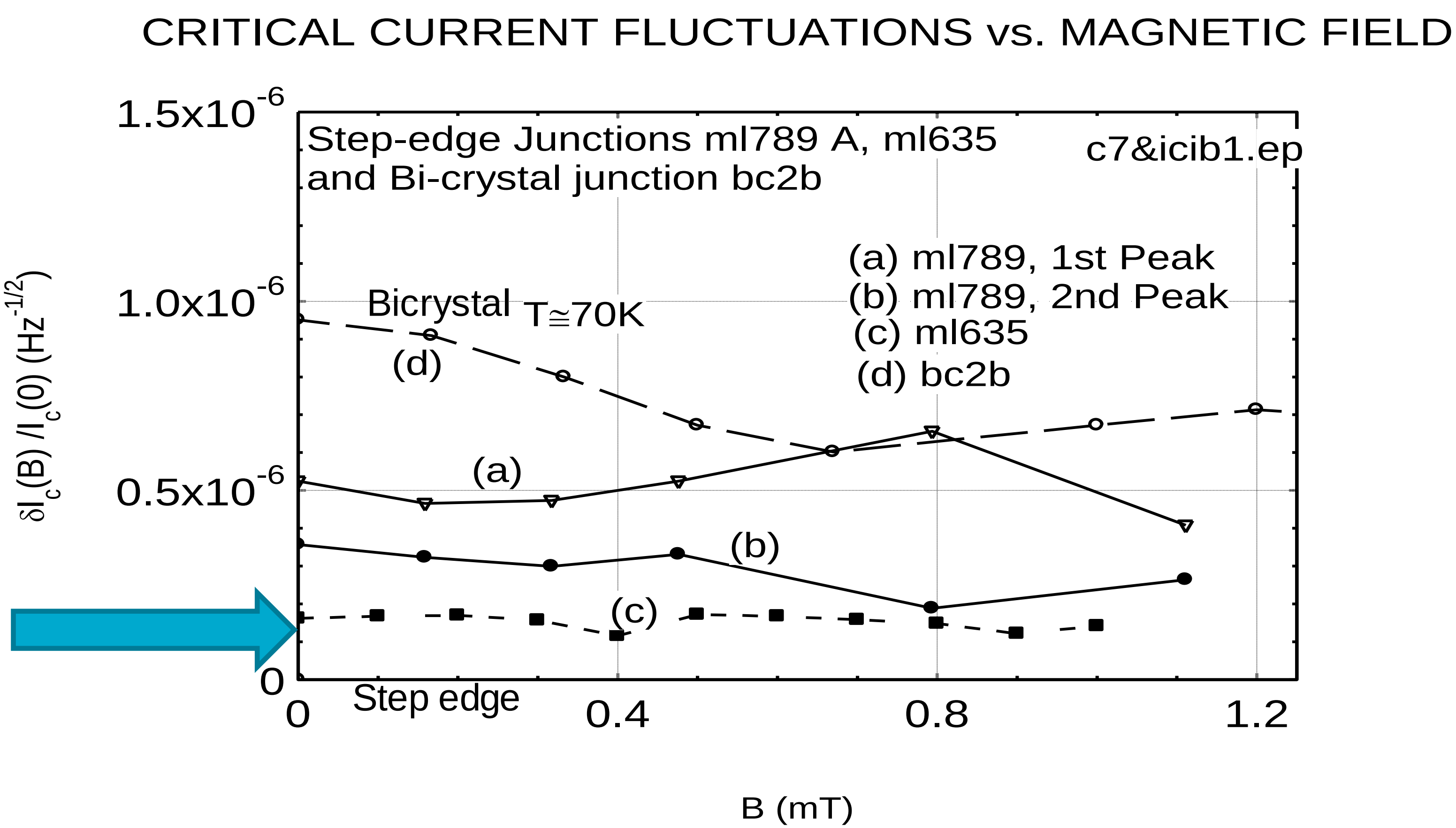
IEICE Trans Electron E83-C (2000) 34



Junction noise in a magnetic shield



Critical Current fluctuations in applied magnetic fields

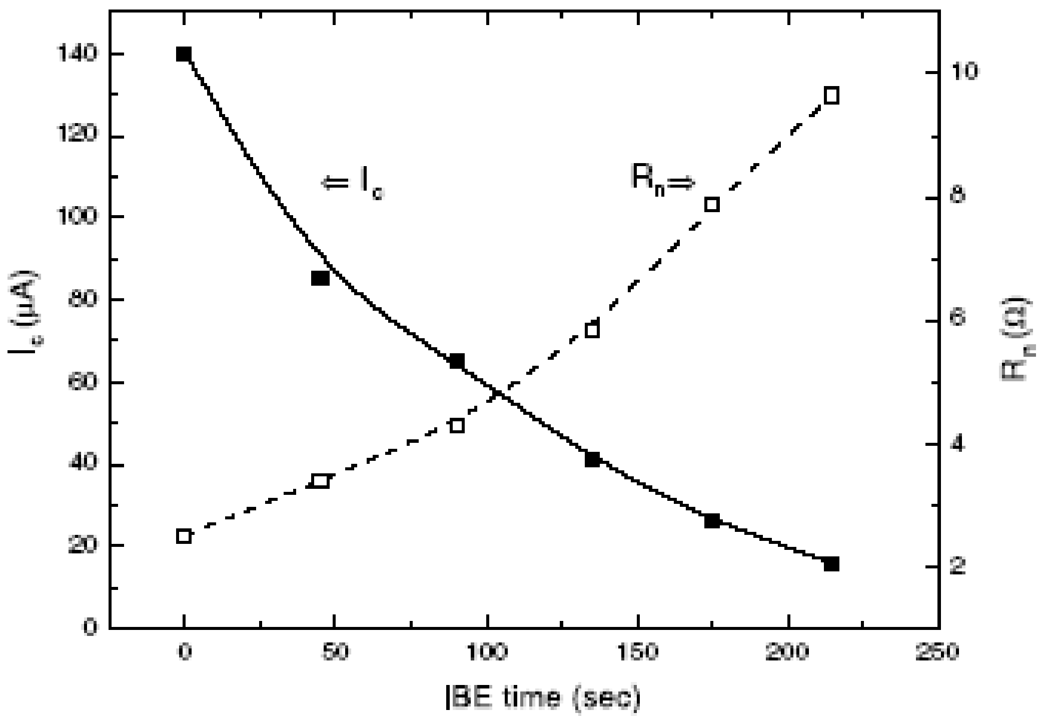


Controlling/trimming critical parameters: I_c and R_n

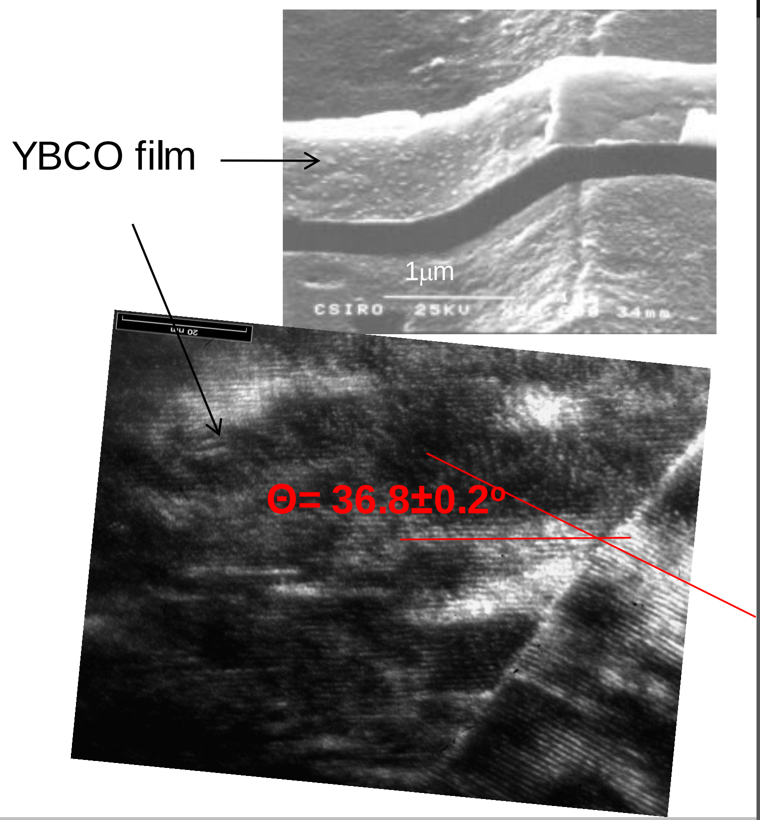
Use oxygen stoichiometry variability

- Heating
- Ion Beam etching

Du and Foley *Physica C* 391 (2003) 31



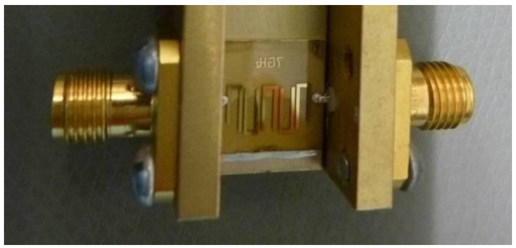
I. CSIRO HTS Step-edge Josephson Junction technology - many HTS electronic devices built upon

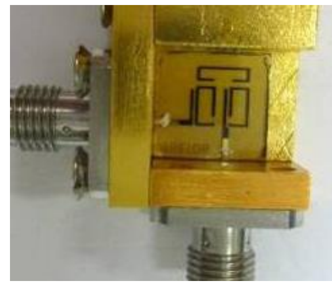


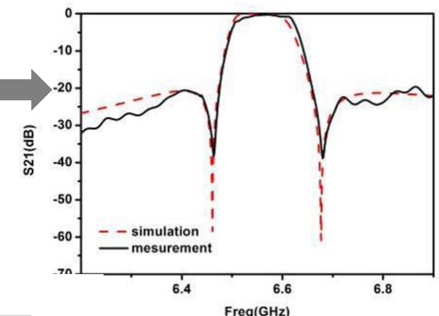
C. P. Foley et al, *IEEE Trans. Appl. Supercond.* **9** 1(999) 4281.
E.E. Mitchell and C.P. Foley, Supercond. Sci. Technol. **23** (2010) 065007

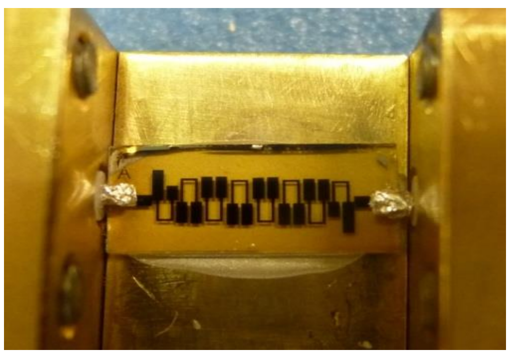
No junctions

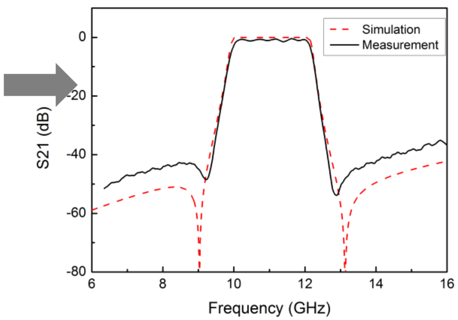
High-T_c superconducting band-pass and low-pass filters with superior performance



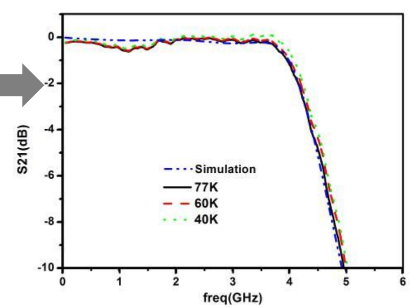








Insertion losses:
≤ 0.5 dB



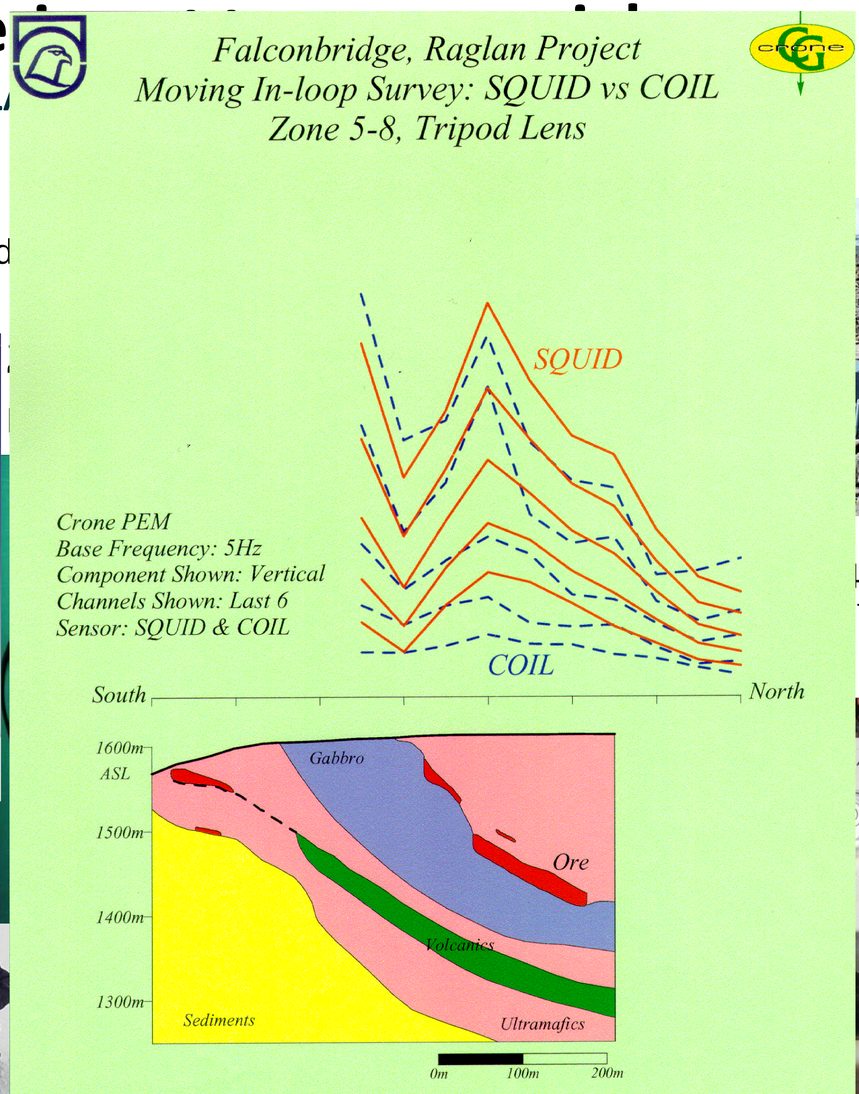
LPF 0-4 GHz

One junction

Expe

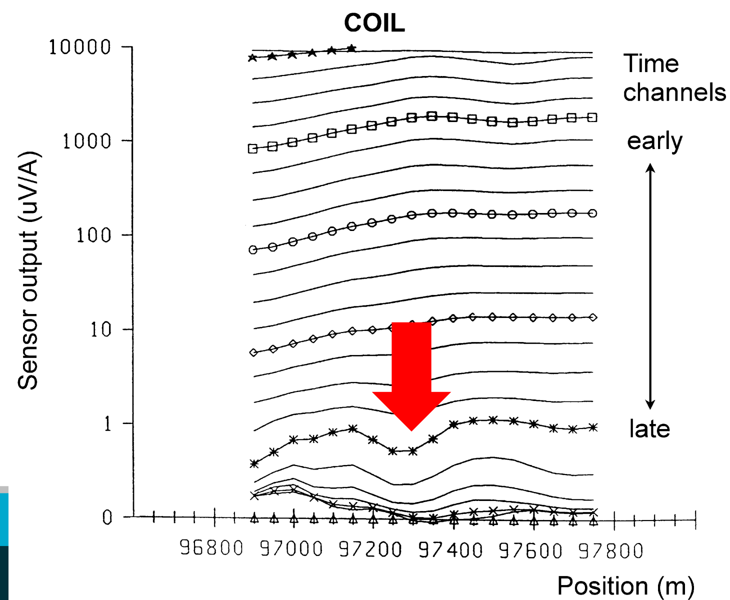
LA

1992-1993
First HTS Ground-based
BHPB



TM

Exploration Services

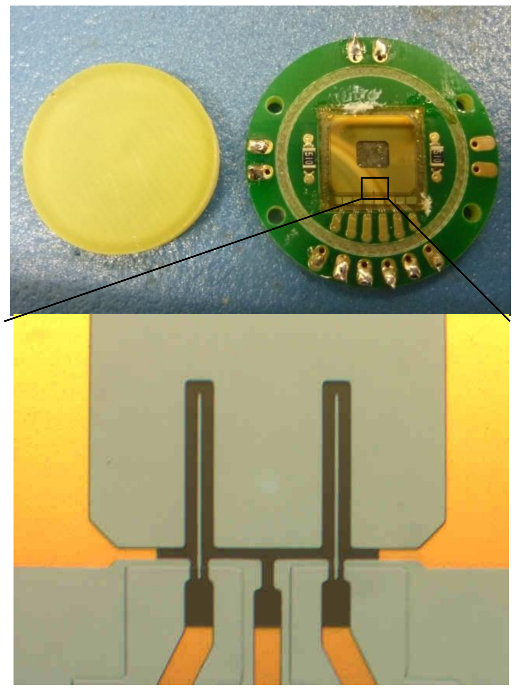

COIL
10000
1000
100
10
1
0
Sensor output (uV/A)
Time channels
early
late
96800
97000
97200
97400
97600
97800
Position (m)

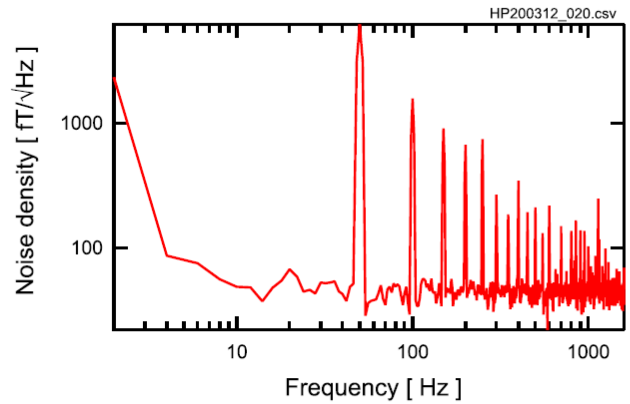

1992


Cannington Silver Mine
$2B Silver - biggest in the world

2 junctions

CSIRO HTS DC SQUIDs

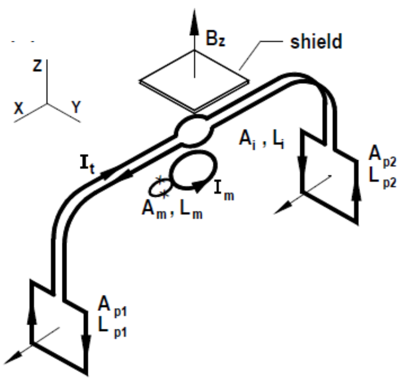


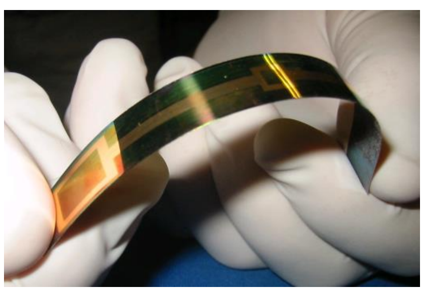


Field noise ~ 30 fT/root Hz (white)
or Flux noise ~ 5 μΦ/root Hz

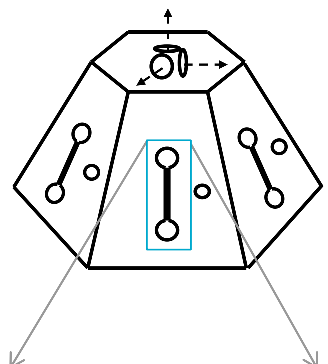
Rotating Gradiometers Systems using High T_c Junctions

1. Rotating axial gradiometers
Sensitivity – 10 pT/m/√ Hz at 0.5 Hz unshielded

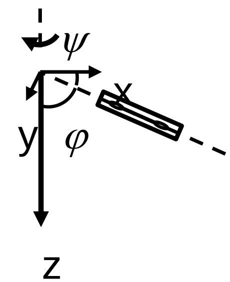


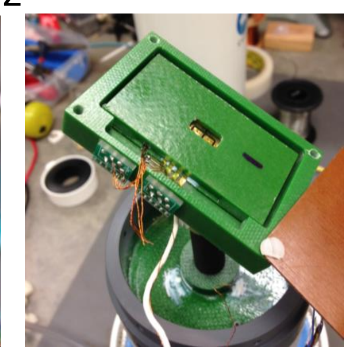


2. Static planar gradiometers (hexagonal-prism)
Sensitivity – 2 pT/m/√ Hz at 10 Hz unshielded



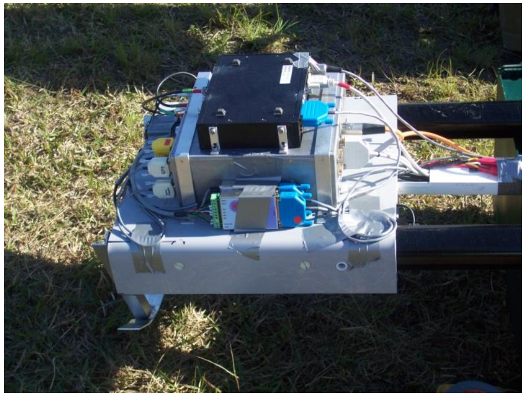
3. Rotating planar gradiometer- initial results; continuing improvement
Sensitivity ~ 10-20 pT /(m.√Hz) in rotation at 2nd harmonic (25 Hz)
Stable operation in Earth's field



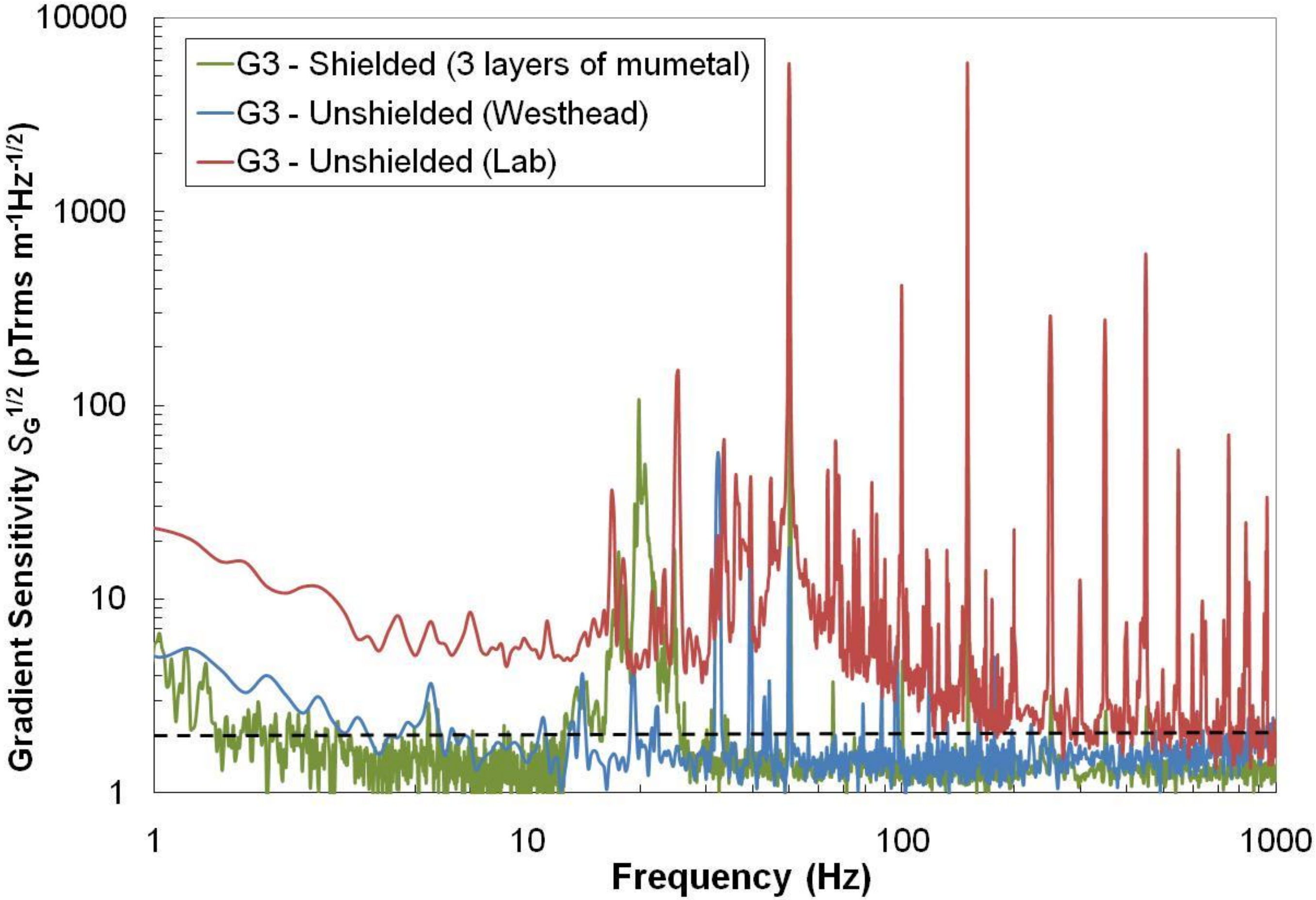


Ground trial at Tallawang

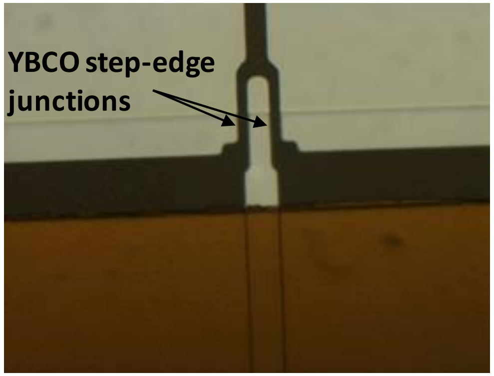
Helicopter trial over a magnetic target

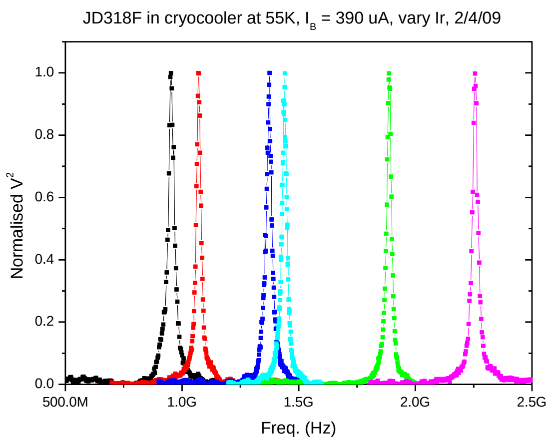


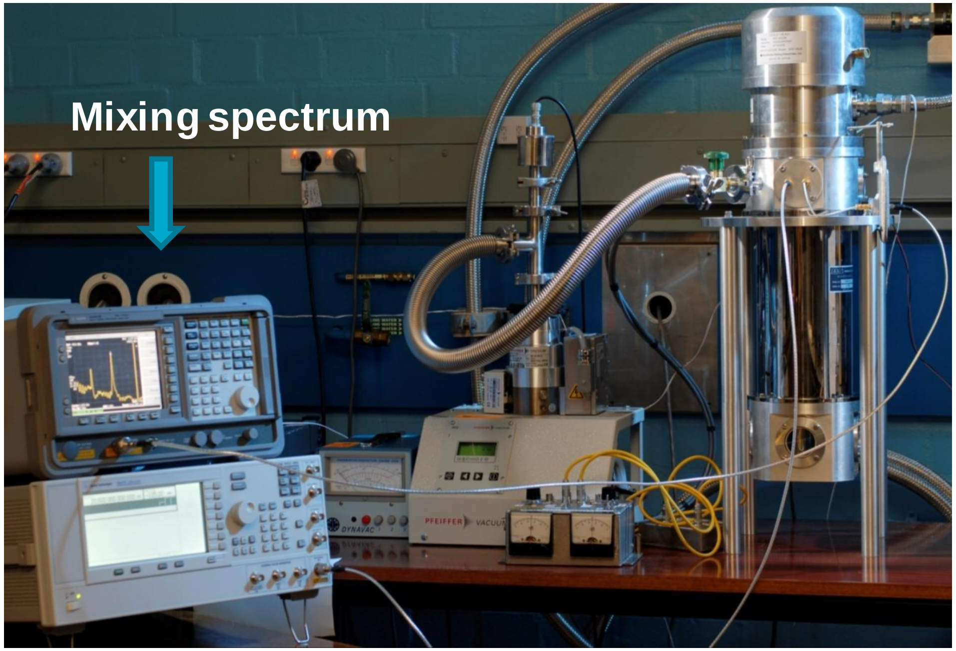
Background gradient noise



HTS resistive-SQUID heterodyne GHz oscillator with tuneable frequency



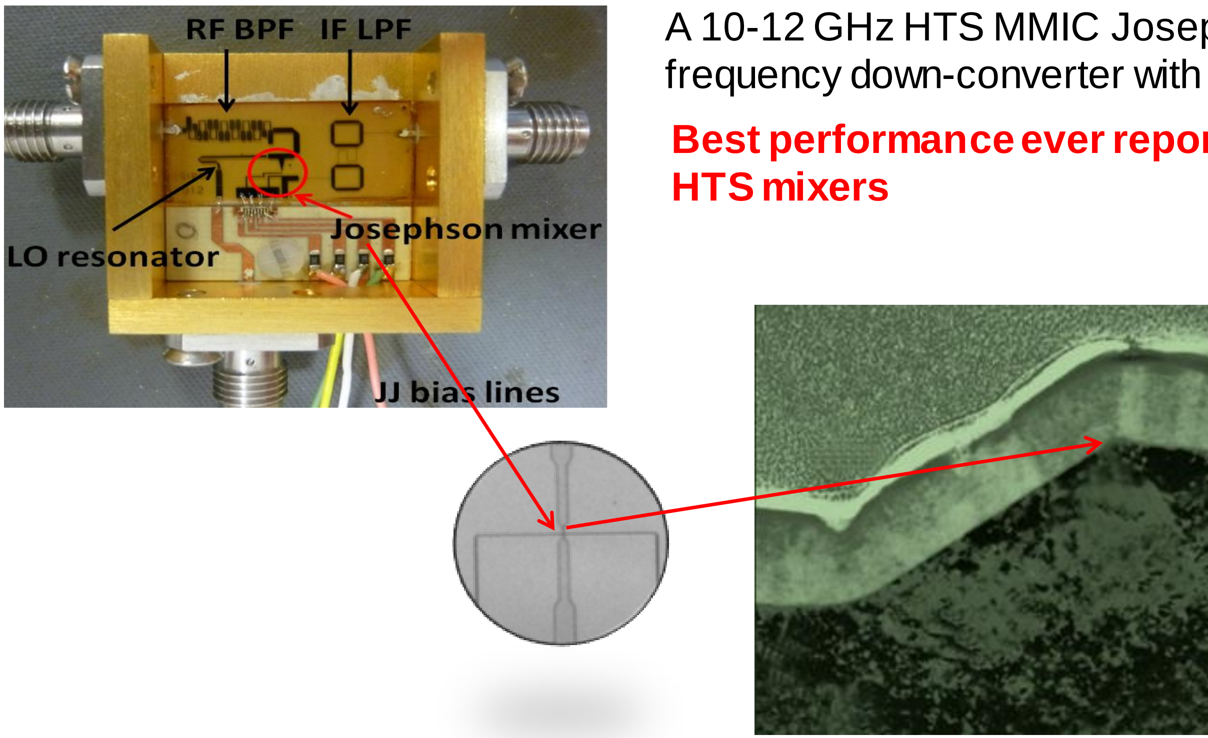




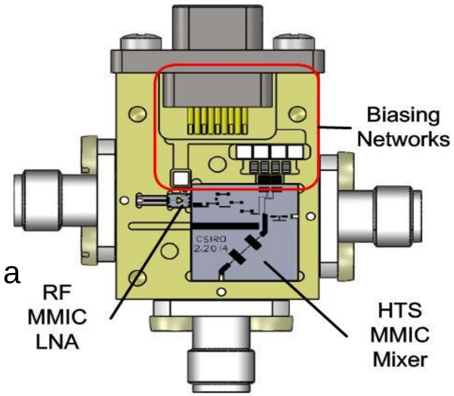
HTS Monolithic Microwave Integrated Circuits (MMIC) for Communication Receiver Front-ends

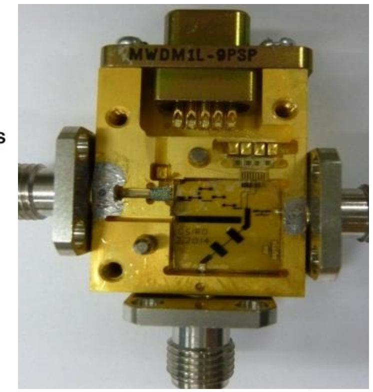
A 10-12 GHz HTS MMIC Josephson frequency down-converter with ~ zero loss

Best performance ever reported for HTS mixers



Advanced High-T_c Superconducting Receiver Technology for Ka band high-speed, long-range communications



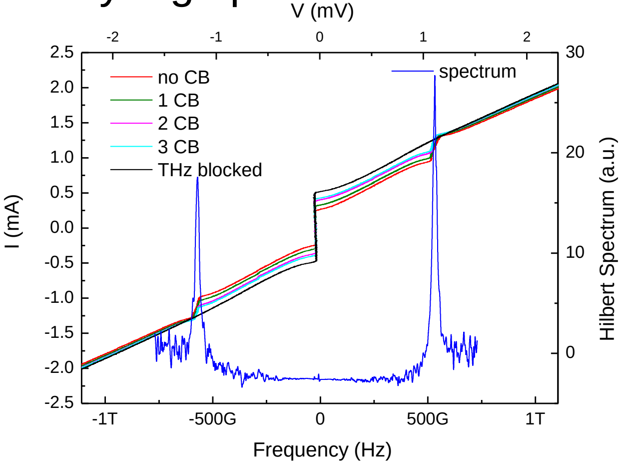


Demonstration of a HTS receiver integrated with a mini cryocooler – a cryogen-free portable instrument box

The latest CSIRO demonstrator of a compact (2.5 x 2 x1.5 cm^3), high-gain (40 dB) and low noise (~ 0.1 dB) Ka band HTS receiver front-end module.

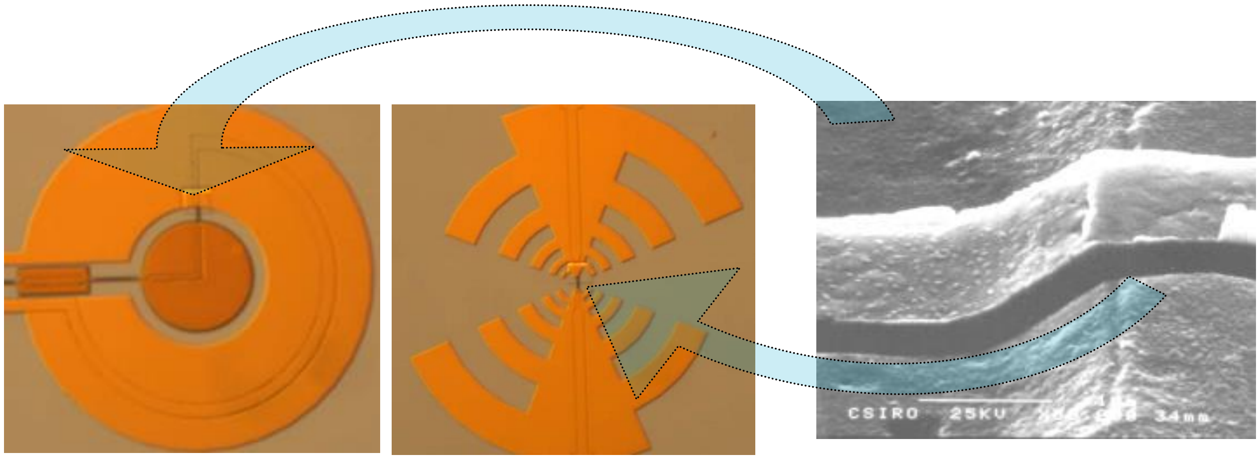
Josephson Junctions for High Frequency Applications

- **AC Josephson Effect**: $f = (2e/h)V_o$, $2e/h = 0.4836$ GHz/μV
  V_0 from μV to mV, *f* falls into the microwave, mm, sub-mm/THz bands
  - Generate rf signal of variable frequency controlled by a voltage;
  - Detect an incoming rf signal;
  - Measure and detect voltage with extremely high precision.
- **Advantages of SC active devices**:
  - extremely low noise,
  - low power consumption (nWs),
  - high freq and wide band operation (due to high-energy gap).

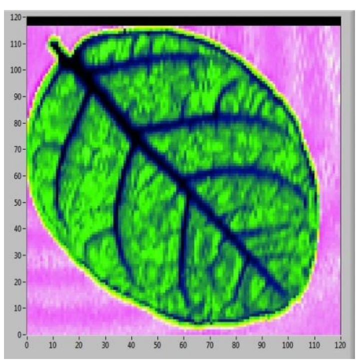


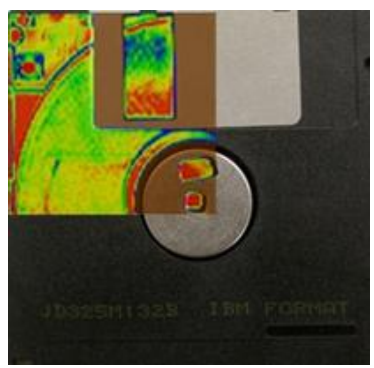
➡ Recent development in uW and THz Devices

High-T_c Superconducting Detectors for THz Imaging



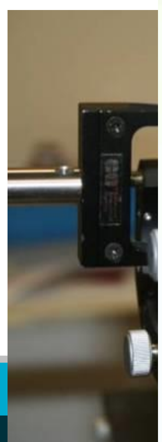
Ring-slot & log-periodic antennae- coupled HTS Josephson detectors.

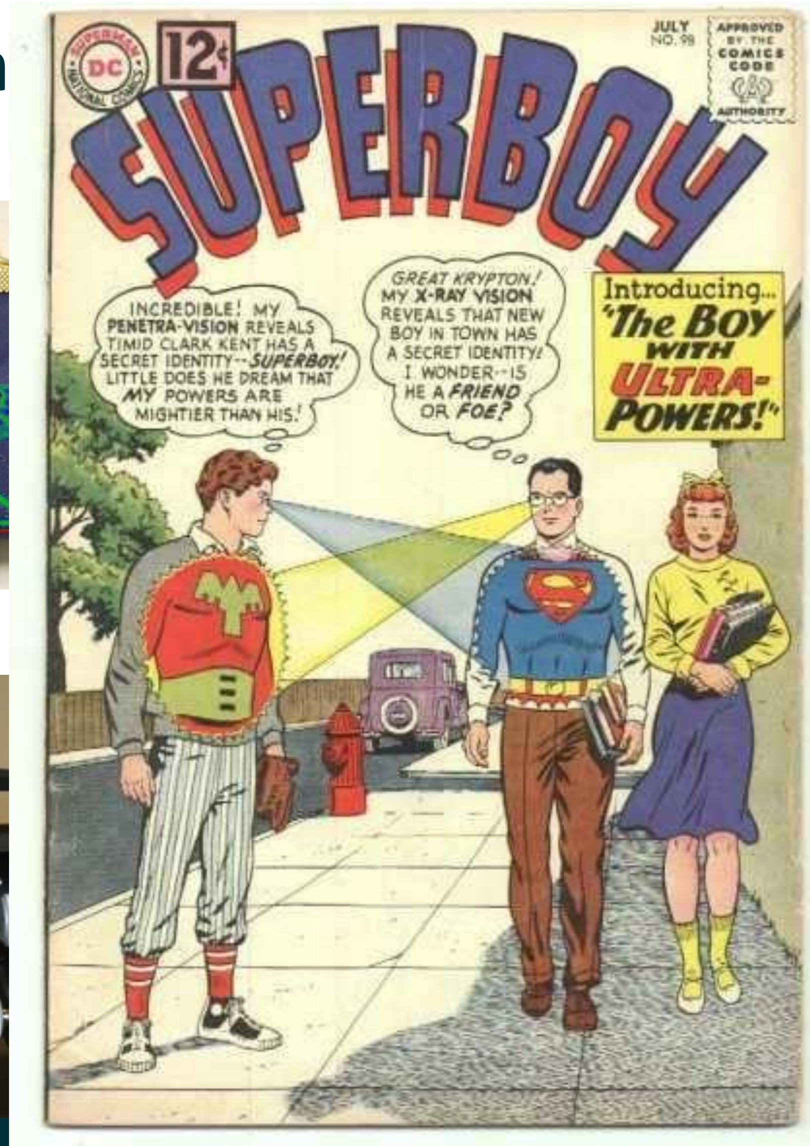


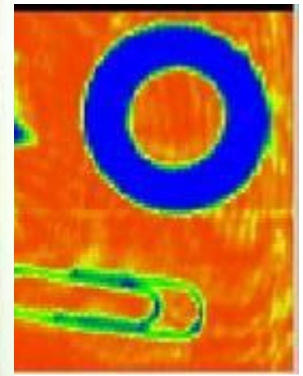


CSIRO

More im

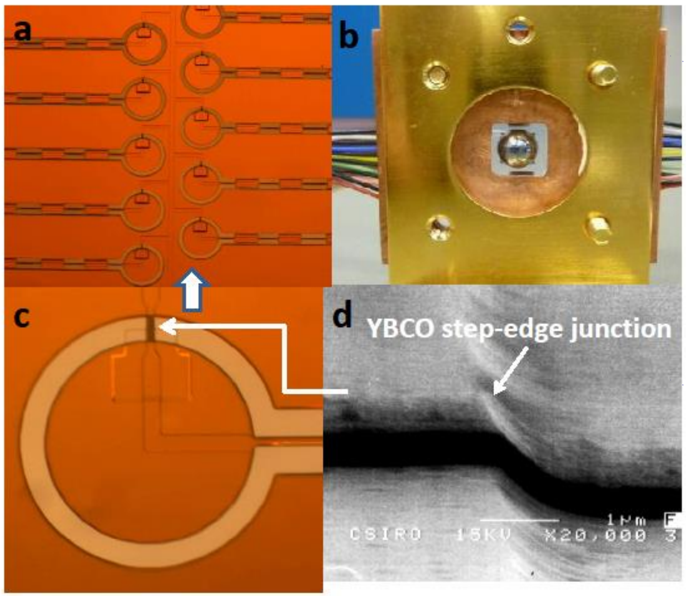



SUPERMAN DC NATIONAL COMICS
12¢
JULY NO. 98
APPROVED BY THE COMICS CODE AUTHORITY
SUPERBOY
INCREDIBLE! MY PENETRA-VISION REVEALS TIMID CLARK KENT HAS A SECRET IDENTITY--SUPERBOY! LITTLE DOES HE DREAM THAT MY POWERS ARE MIGHTIER THAN HIS!
GREAT KRYPTON! MY X-RAY VISION REVEALS THAT NEW BOY IN TOWN HAS A SECRET IDENTITY! I WONDER--IS HE A FRIEND OR FOE?
Introducing... "The Boy with Ultra-Powers!"

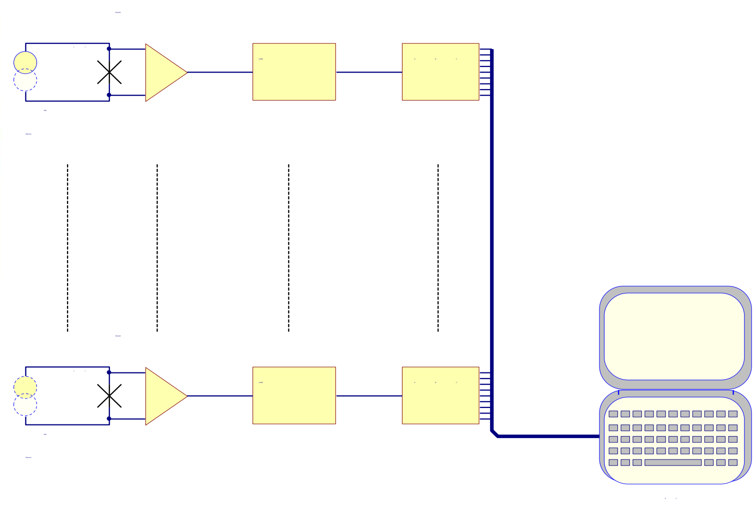


Several junctions

Development of an array HTS detectors

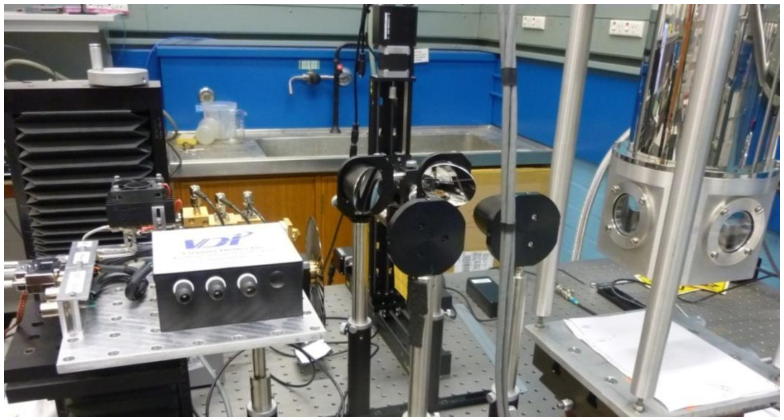


10 antenna-coupled detector array with a 6mm silicon lens

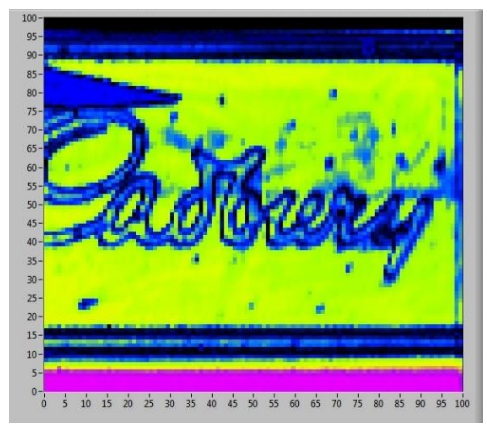


Schematic of the multi-channel biasing and read-out electronics

Cryogen-free HTS JJ detector-based THz imager



THz image of chocolate bar in paper wrapper: Resolution improves with decreasing temp due to improved HTS JJ detector sensitivity and SNR (signal-to-noise ratio) - **advantage of using cryocooler: adjustable temp for optimising junction parameters and image quality**



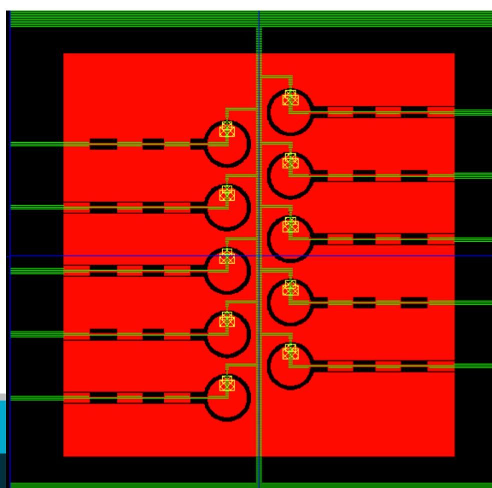
At 60 K

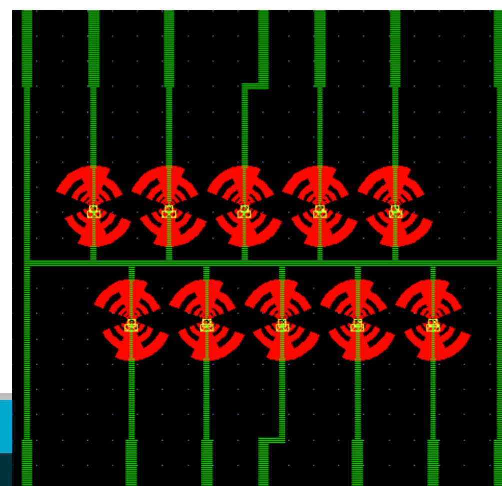
At 77K

CSIRO

Future goals

- HTS JJ detector arrays under development
  - improve image resolution and reduce scanning time
- Pursue applications of the technology – imaging of skin cancer
- THz spectroscopy

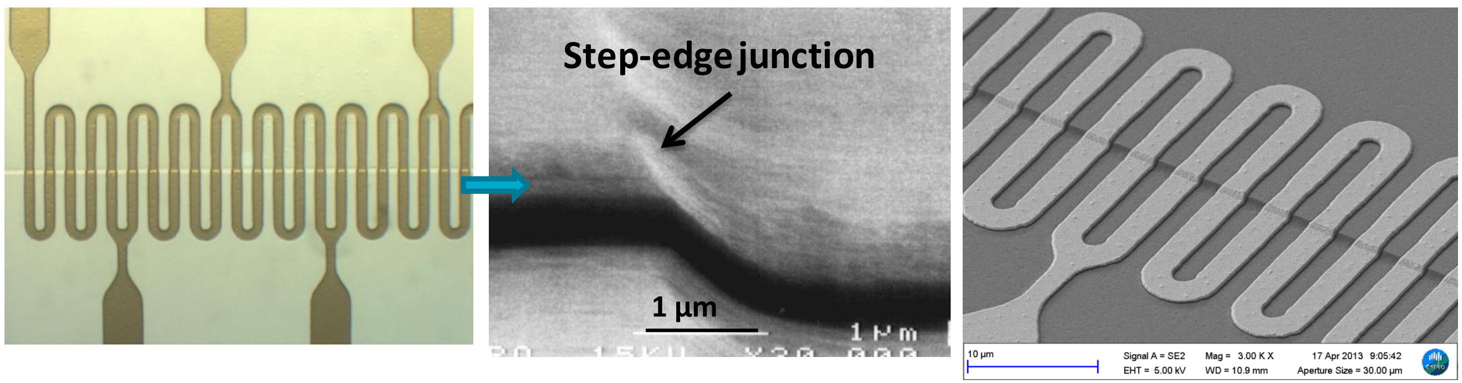




LOTS of junctions

Josephson Junction Arrays – CSIRO

In-house design, fabrication and characterisation
Stable operating on PT cryocooler. 1000 junctions operational.

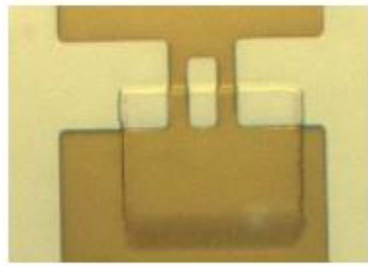


Photograph and SEM micrograph of 2-μm wide step-edge series junction array.

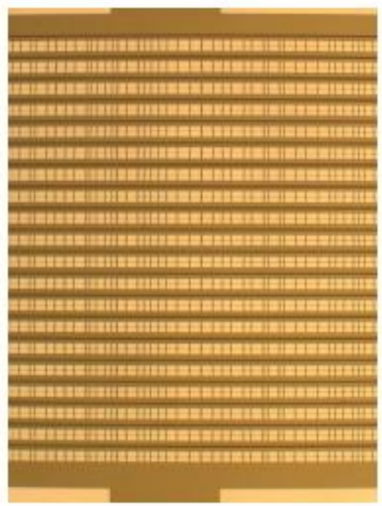
- 50x20 (1000) junction arrays demonstrate expected performance (May 2014)
- Fabricated 8 samples of 50 series junctions with junction widths of 2, 3, and 4 μm from two film batches.
- Achieved a 100% yield of working JJs of the 8 array samples
- Stable operation of the array device on a commercial two-stage PT cryocooler.

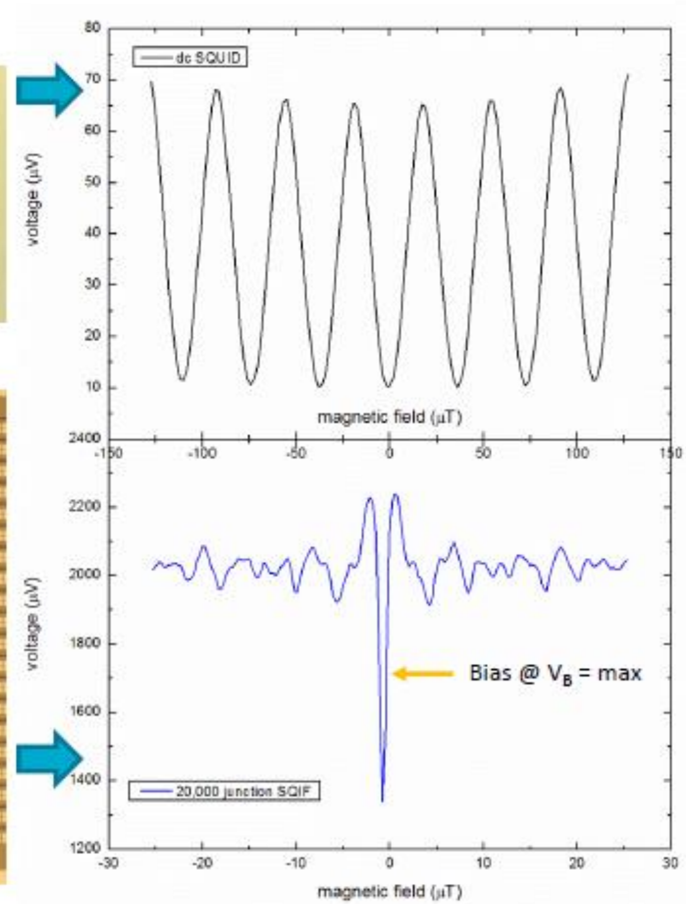
4. SQIFs: Overview

- SQUID = superconducting loop with 2 Josephson junctions
- *V-B* response = periodic with flux (*B*-field)
- Period is ∝ 1/Area



- SQIF = array of SQUID loops joined in series and/or parallel
- Loops have a range of areas
- *V-B* response = single anti-peak at zero field
- Sensitivity depends on loop areas, spread, *N*, inductance, critical current
- Bias device on steepest point

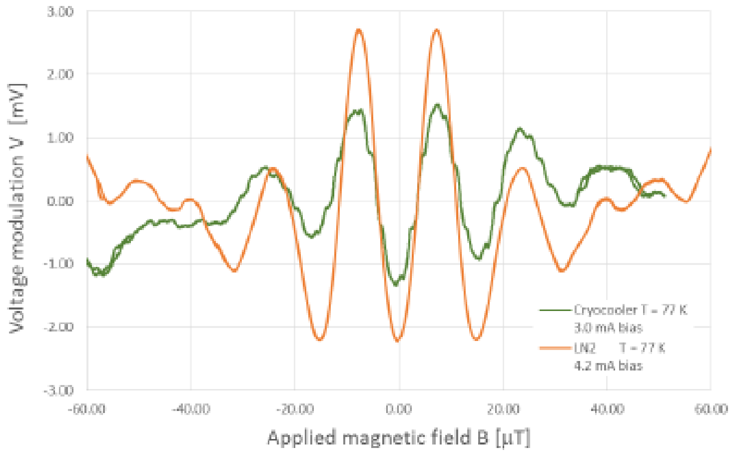


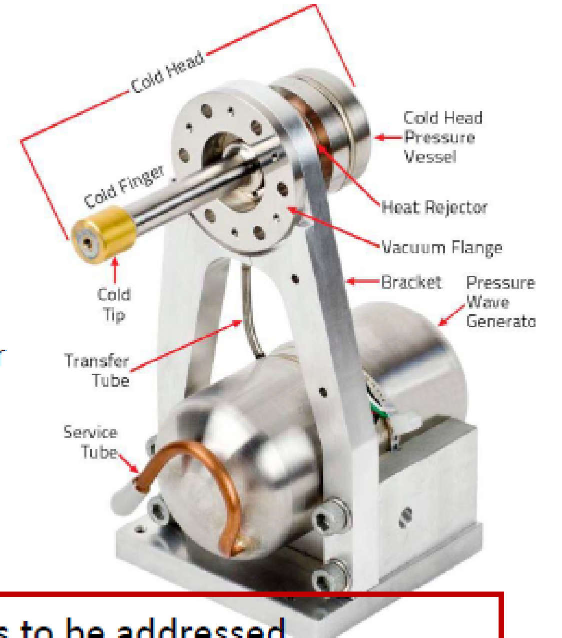


5. Cryocooler operation for mobility

- Mini-cryocooler from Sunpower (CryoTel Model DS 1.5)
- Lightweight (cooler mass: 1.2 Kg) and compact (outer diameter of 50 – 60 mm), low input power (30 W)
- 1.4 W of cooling power at 77 K.
- Base Temperature ~ 40 K (< 23°C reject temperature).

Demonstrated - highly sensitive 3 mm SQUID magnetometer + 54,000 SQUID array



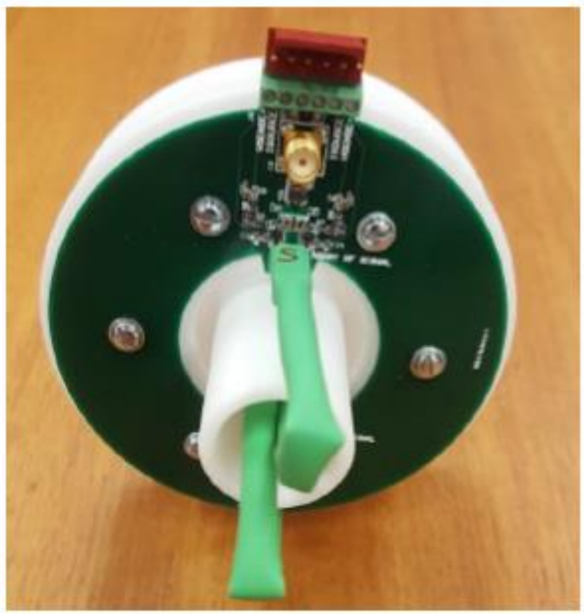
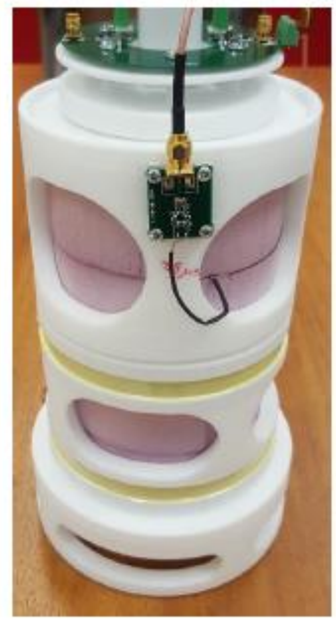


Issues to be addressed

- Magnetic noise
- Vibrational noise
- Poor vacuum longevity

5. RF Antenna- whole system development

- Design, fabricate and characterise RF probe and package for SQIFs.
  - Probe characteristics measured up to 300 MHz and used to calibrate VNA.
  - 1 MHz to 300 MHz -greatly reduced cross talk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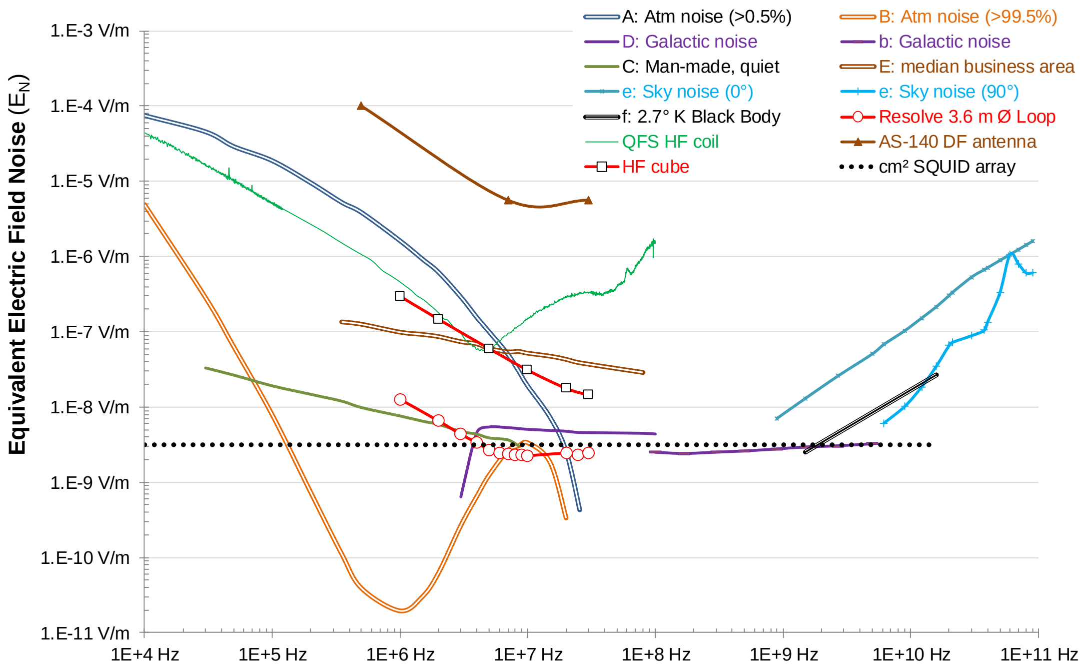
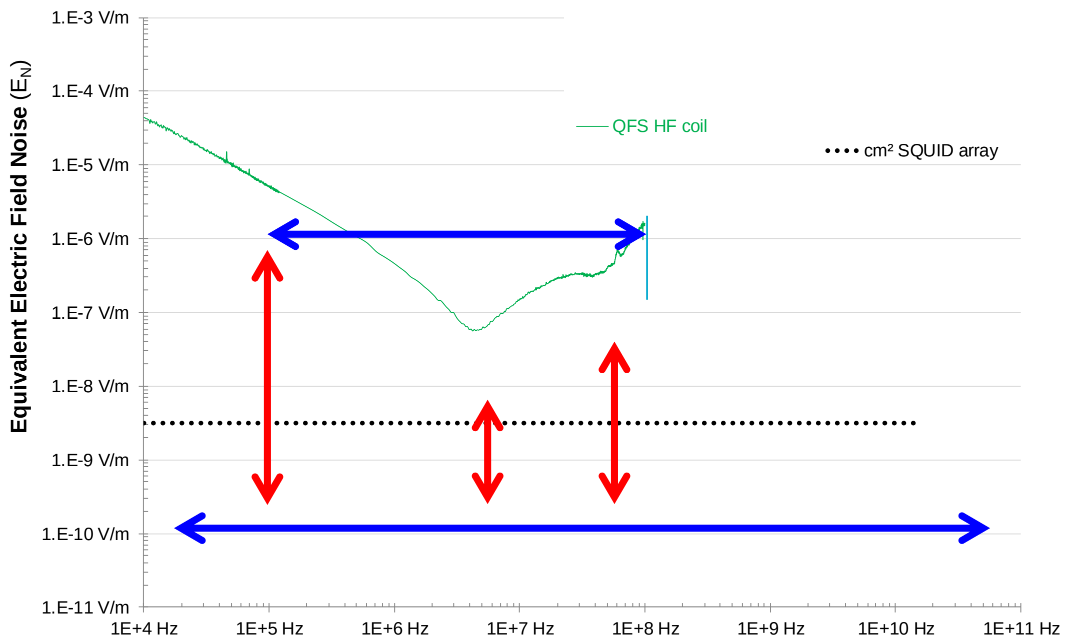
Sensitivity and Noise

- SQUID Arrays offer sensitivities at quiet environment levels

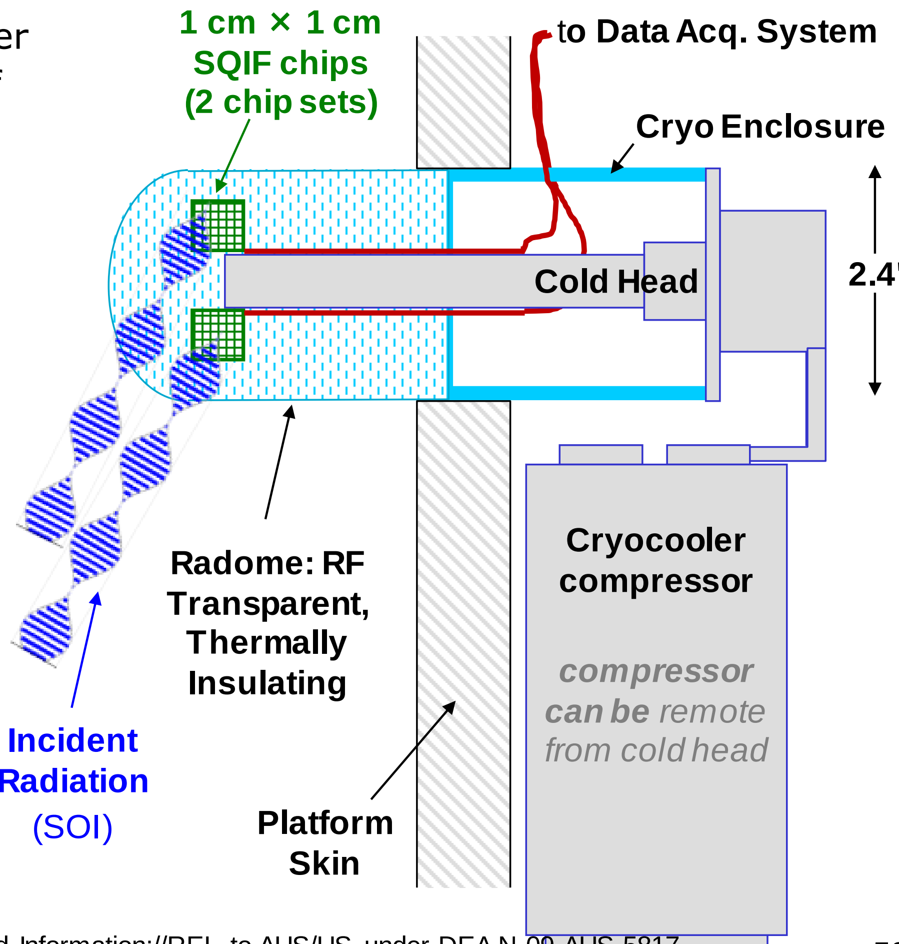


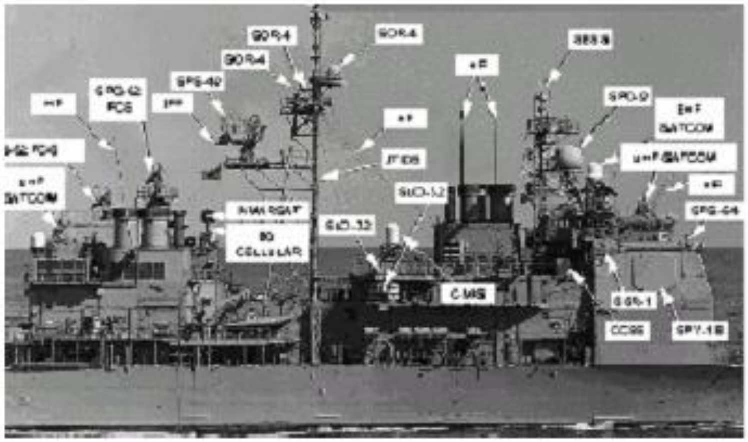
SQUID Arrays will offer Superior:

- Sensitivity: 26 to 40+ dB improvement
- Useable Bandwidth: 6 decades vs. 2~3



- Two element SQIF Interferometer
- Phase Detection and/or Angle of Arrival (AOA)
- Use tactical 77 K cryocooler
- SWaP: < 5 lbs, < 100 W




SATCOM
CELLULAR
CMS
SPQ-9
SPY-1B

The wicked problems!

- Reproducibility
- Device yield
- Unshielded operation
- Cost
- Noise
- Performance
- I_c spread
- Formation of a clean single grain boundary

All need to be solved if HTS Josephson junction devices are to be mass market

So far…….

- Reproducibility - ok
- Device yield – 100%
- Unshielded operation – possible with the correct RF shielding
- Cost - coming down
- Noise - improving
- Performance – always want better!
- I_c spread – a major focus – 18%
- Formation of a clean single grain boundary - revisiting

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www.csiro.au

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Design Rules for YBCO Step-Edge Josephson Junction Devices

April 2013

J. Du
C.P. Foley
S.K.H. Lam
E.E. Mitchell
Jeina Lazar

Commercial- in-Confidence

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Conclusions

- Make HTS devices
  - Low noise
  - Broad band
  - High TRL full systems
- Have been used for many applications
- Excellent THz and mm wave frequencies
- 100% yield
  - Different quality
- CSIRO Design Rules and Foundry
- Device price is coming down
- Next steps to improve I_c variation across the chip
- Compact coolers – close to “black box” use