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Development of thin films for superconducting RF cavities in ASTeC

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on behalf of collaboration team

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Motivation

- The aim is to develop the PVD and CVD coating technologies of superconducting materials for RF cavities and apply it on the RF cavities
- Objectives:
  - a systematic study of
    - Deposition parameters
    - Film morphology, structure, chemistry
    - AC and DC superconductivity characteristics such as T_c, B_c, RRR, etc.
    - RF evaluation of samples
    - Cavity deposition and test

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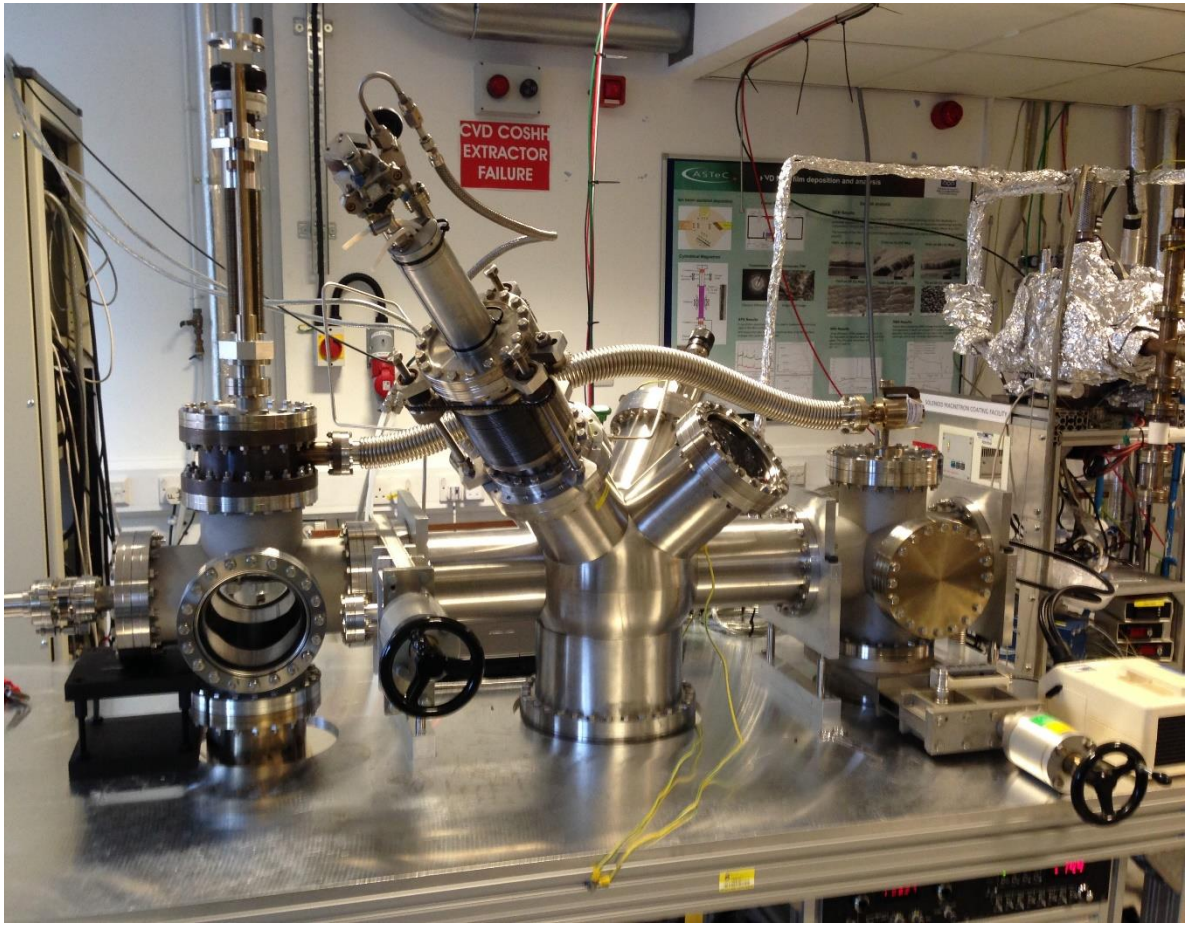
UHV PVD facility

- Bakeable
- Load-lock chamber
- DC and RF bias
- Three planar concentric targets with the variable distance to the substrate: 10-15 cm
- Substrate rotation
- Ion beam assist,
- $20 \leq T_s \leq 950$ °C
- Differential RGA pumping to analyse the sputter gas.



- HiPIMS and Pulsed DC,

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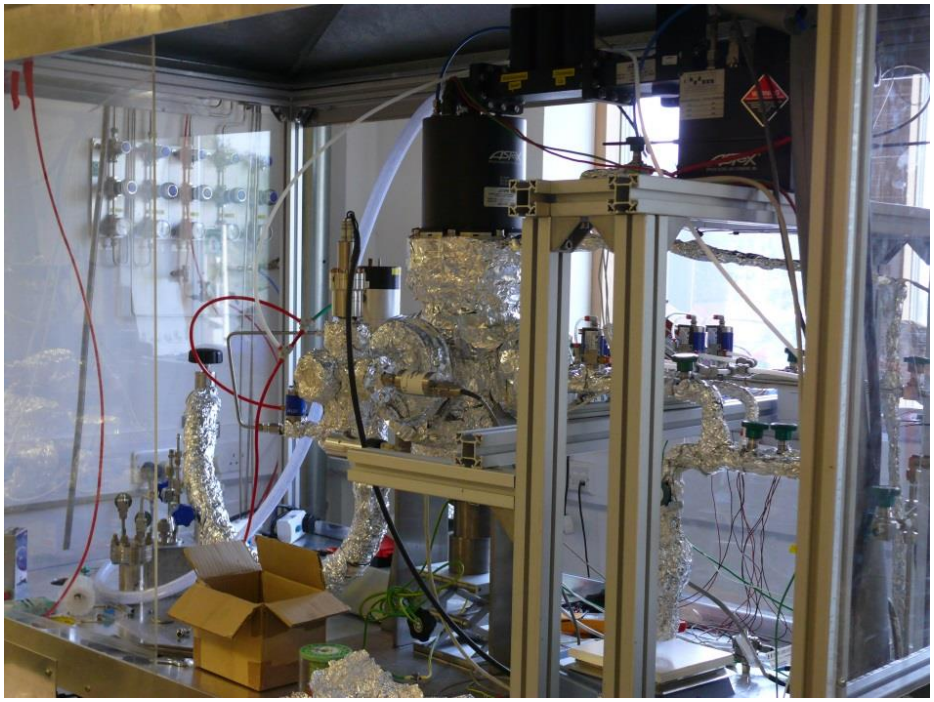
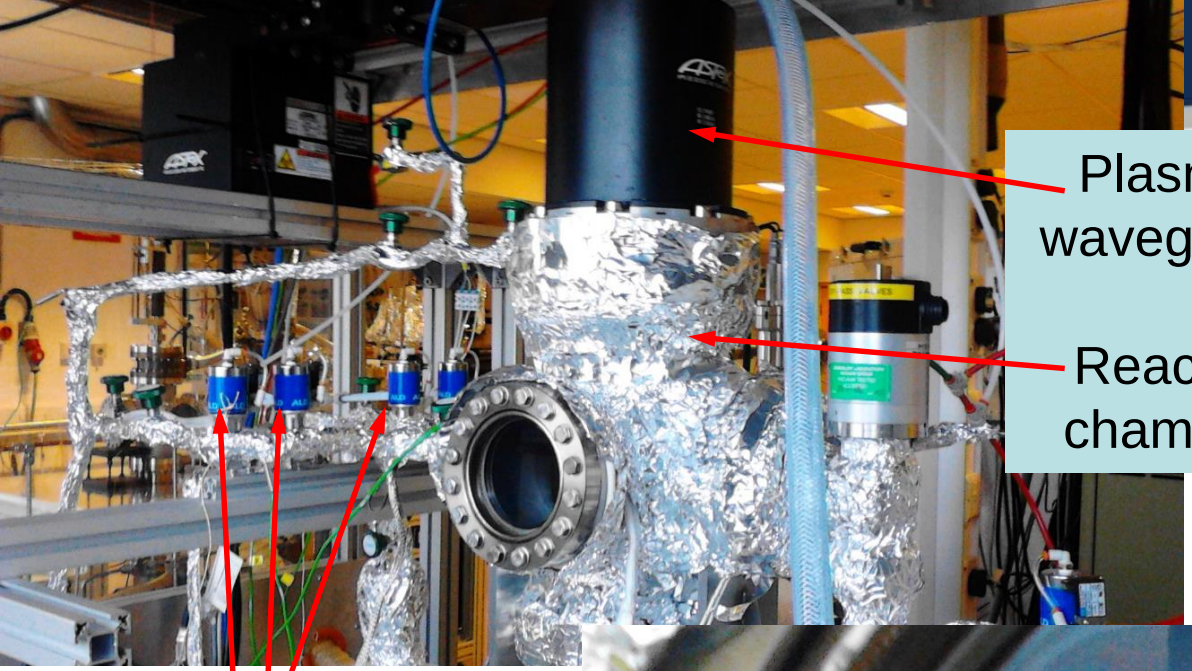
PECVD/ALD deposition

- Base pressure:
  - 1.5 x 10^{-5} mbar at 120 ºC
- Gas flows:
  - Argon, Max 5 l/min, 200 sccm MFC
  - Hydrogen, Max 1 l/min, 100 sccm MFC
- Heater tested up to 700 ºC (could go 950 ºC)



ALD rig

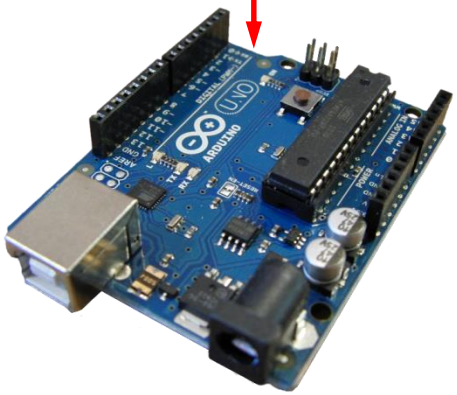


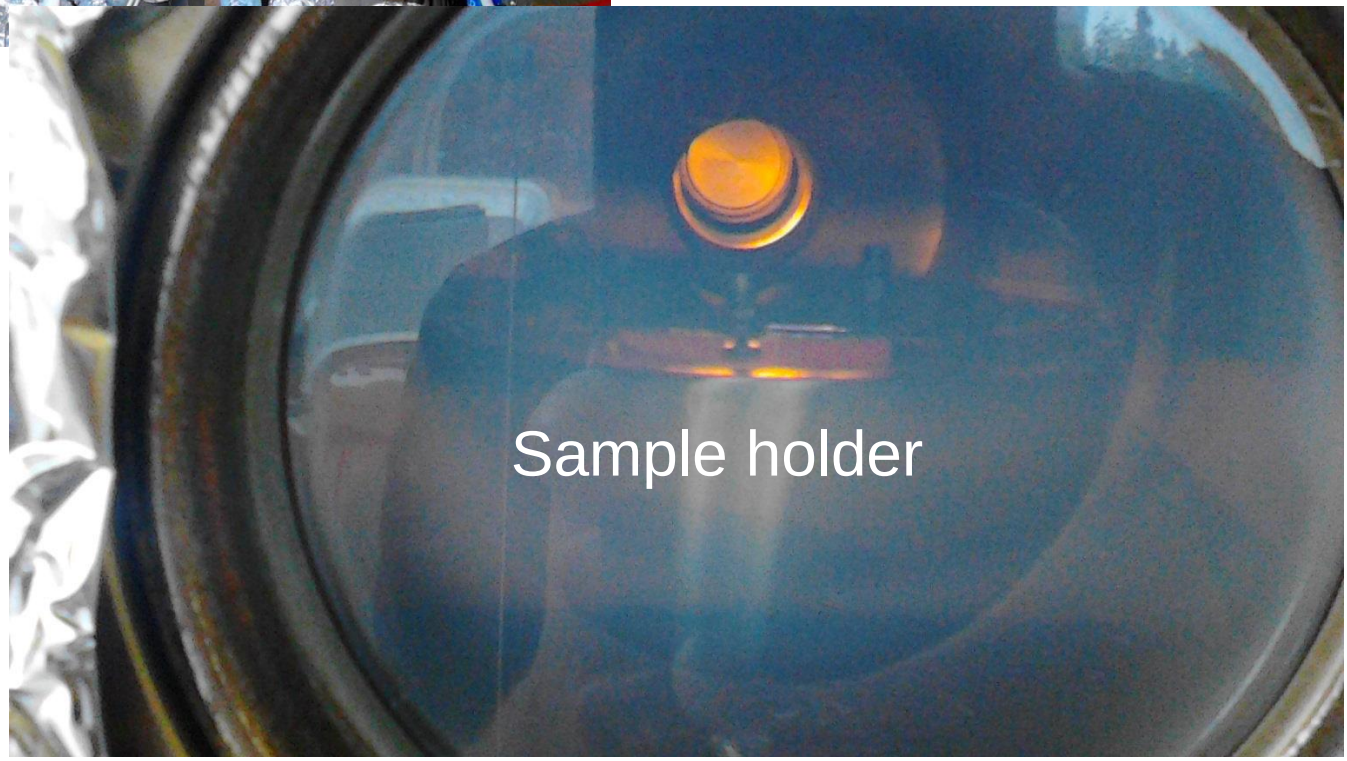
Plasma waveguide

Reactor chamber

SAES gas purifiers

ALD valves: tested with Arduino control, switching <1 ms





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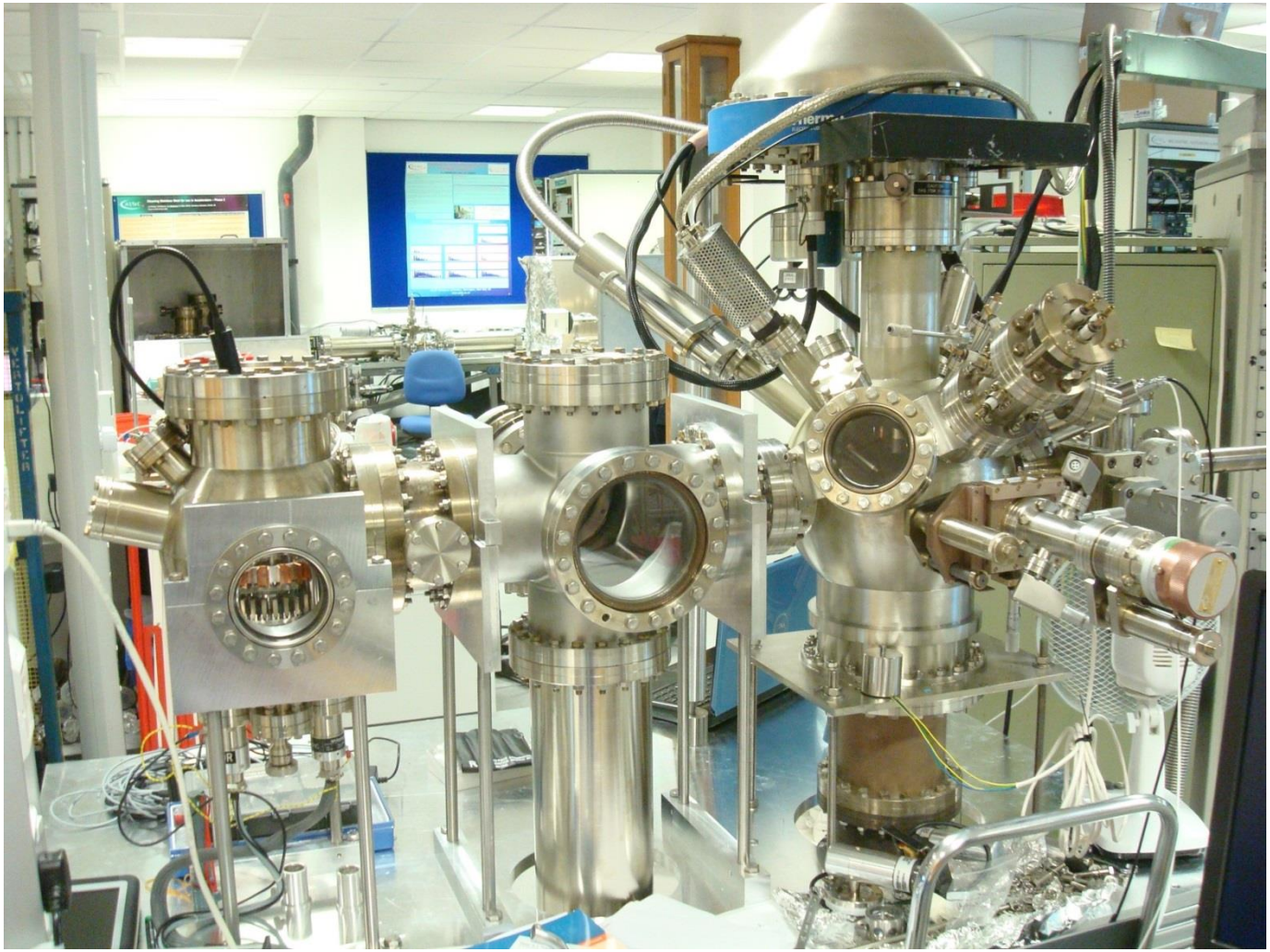
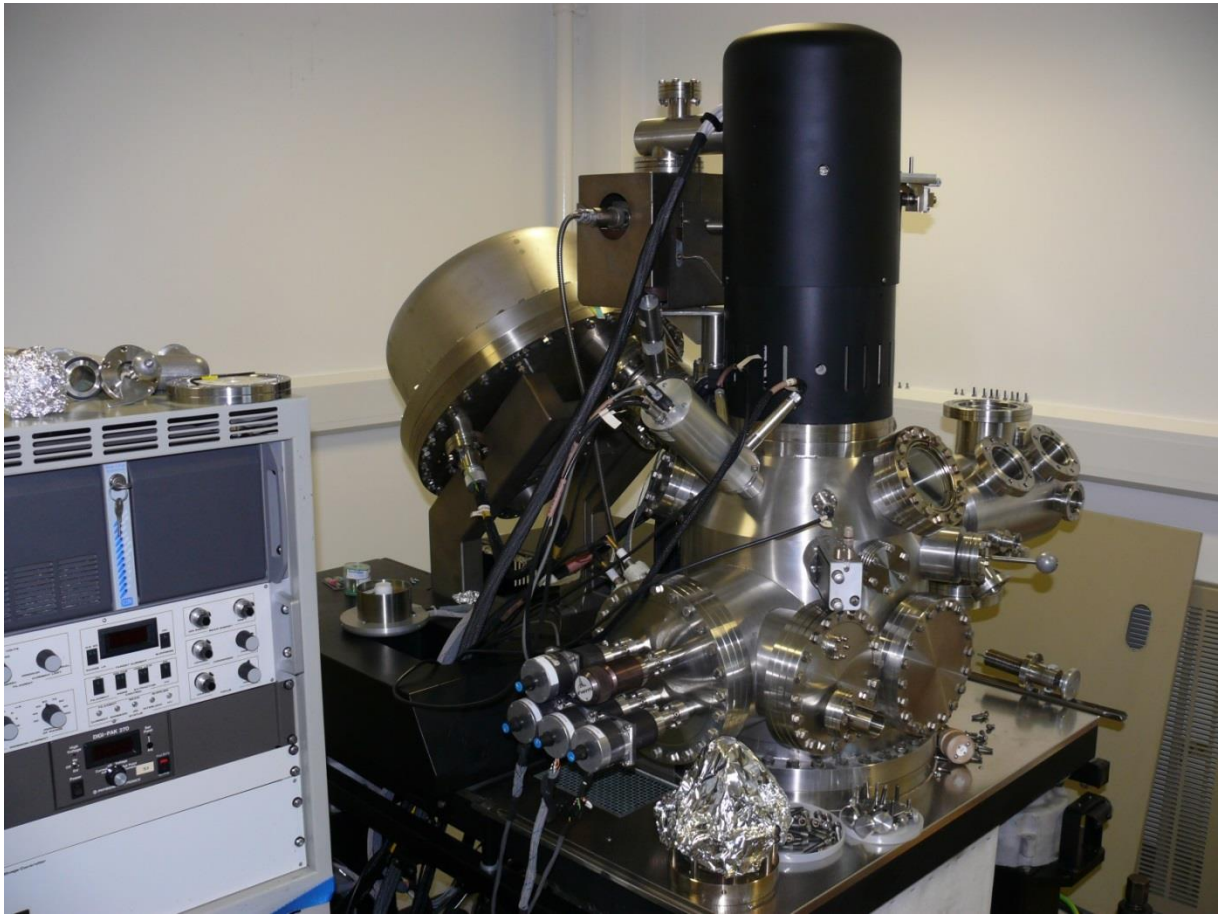
Multi-Probe UHV XPS, AES, AFM, STM, LEED and ISS



New surface analysis rigs: Auger microscope

- Spatial distribution of the elements (Auger maps or analysis in lines, points and areas) Secondary electron images with spatial resolution down to 200 nm.
- XPS facilities with energy resolution ~ 0.9 eV.
- AES and XPS depth profiling.



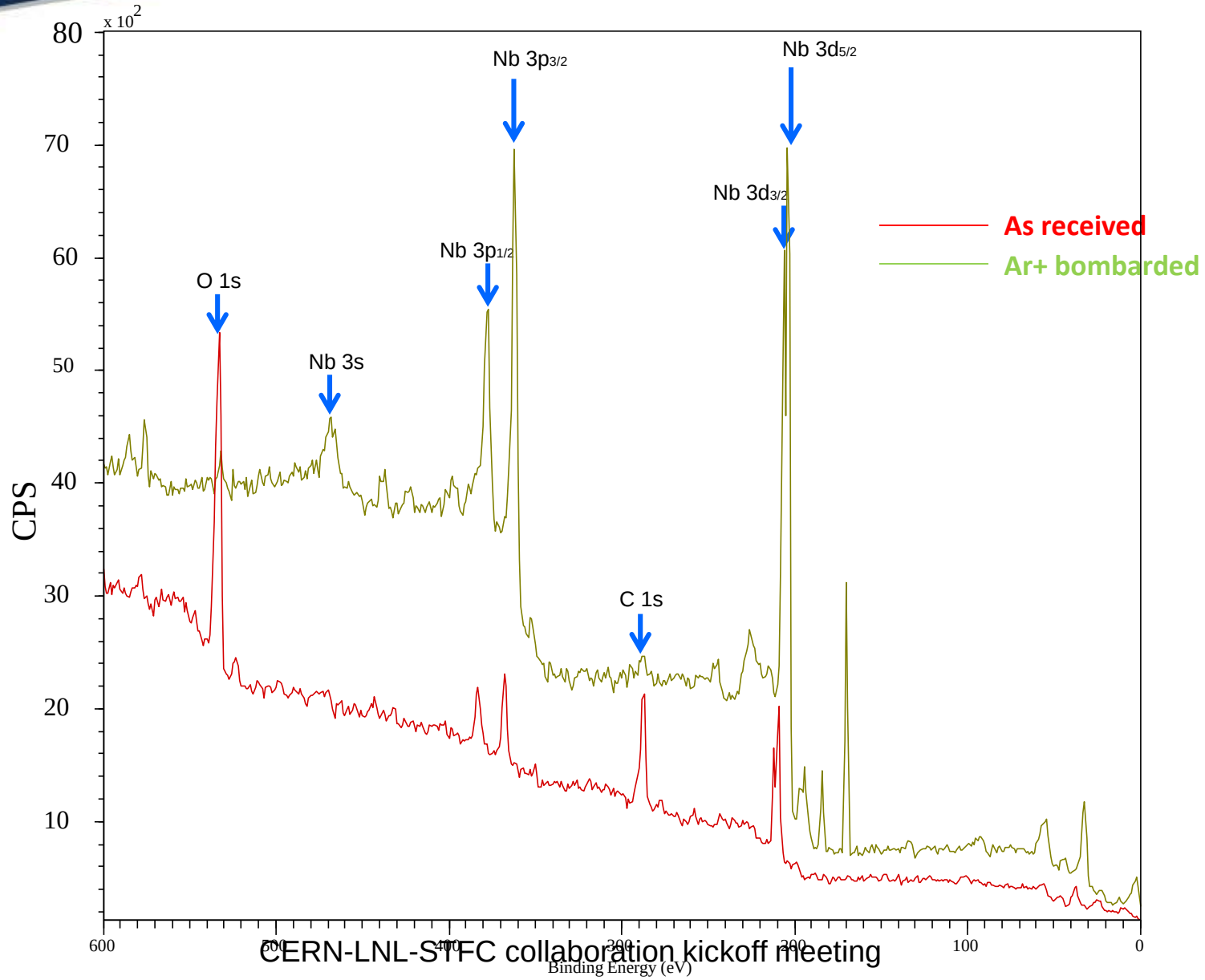
New surface analysis rigs: SNMS

- Secondary neutral mass spectrometry

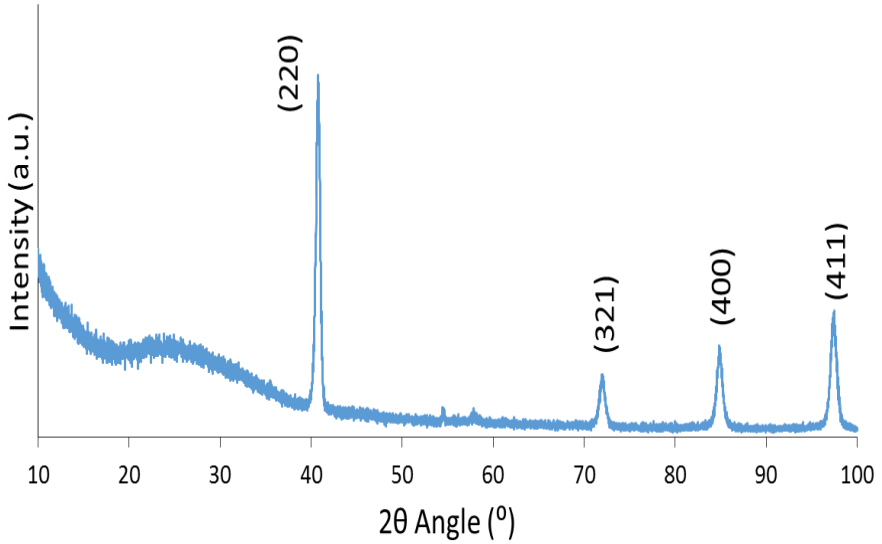
- Isotope elemental depth profiling.

- Good sensitivity for hydrogen using Hydrides

XPS analysis



Film Morphology: XRD



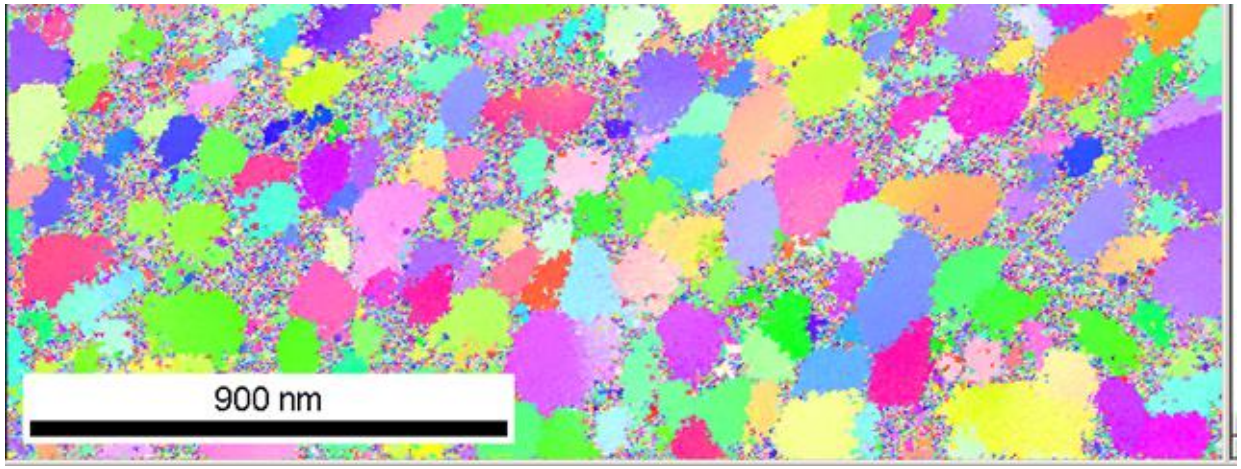
- Nb grain sizes within our films:
  18 -73 nm
- This is similar in size to the grains produced in other studies.
- The films are polycrystalline

and highly textured with the prefered direction of growth depending on the substrate orientation and deposition condition

- RRR values shows no dependence to a preferred orientation

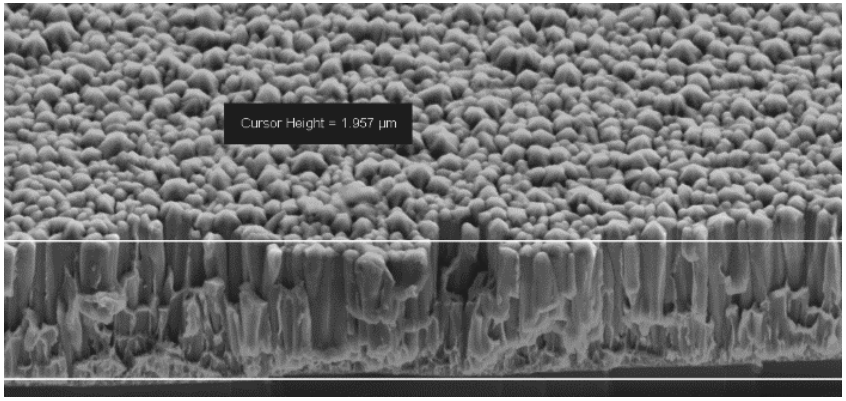
Film Morphology: EBSD

- Only one sample has been analysed using EBSD
- EBSD data shows grains larger than 18 nm present in the sample, the largest of which are of the order 250 nm across their longest axis. The larger grains are surrounded by a matrix of smaller grains of a similar size to those described by XRD.

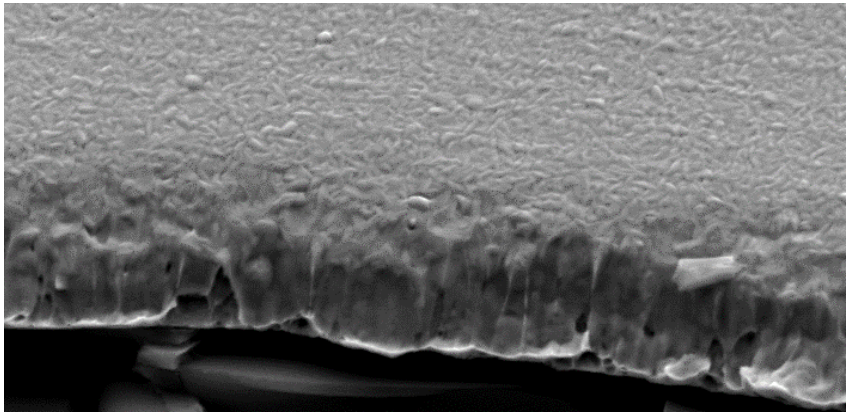


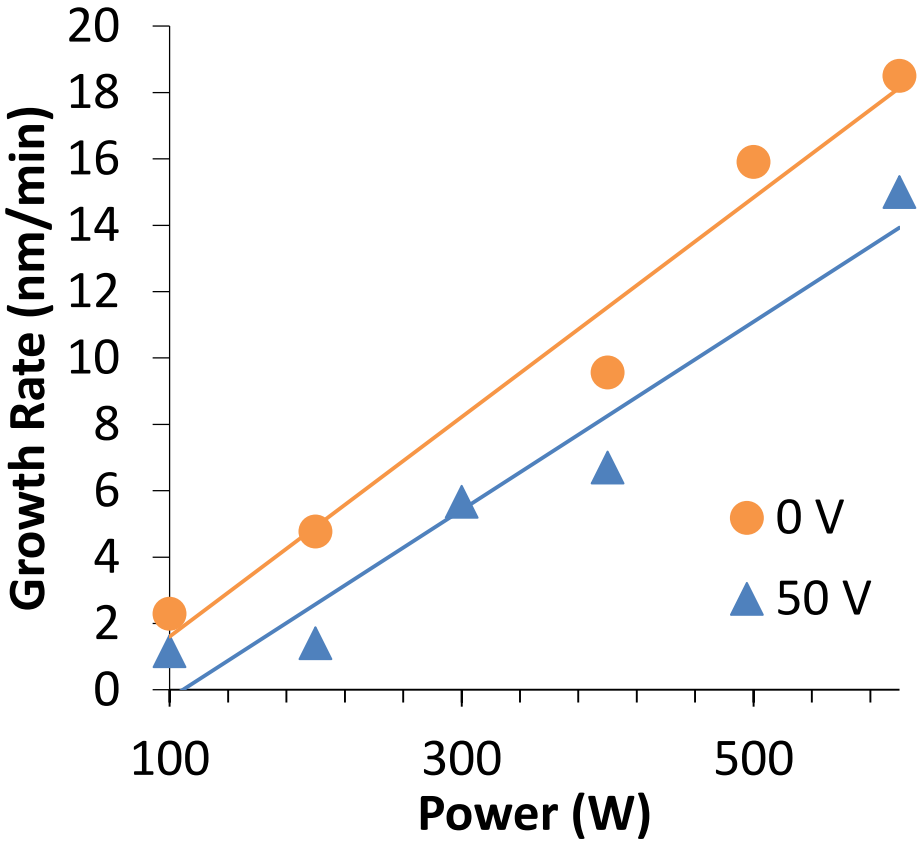
Film Morphology: SEM

samples deposited without a bias



samples deposited with a 50-V bias





Superconductivity evaluation

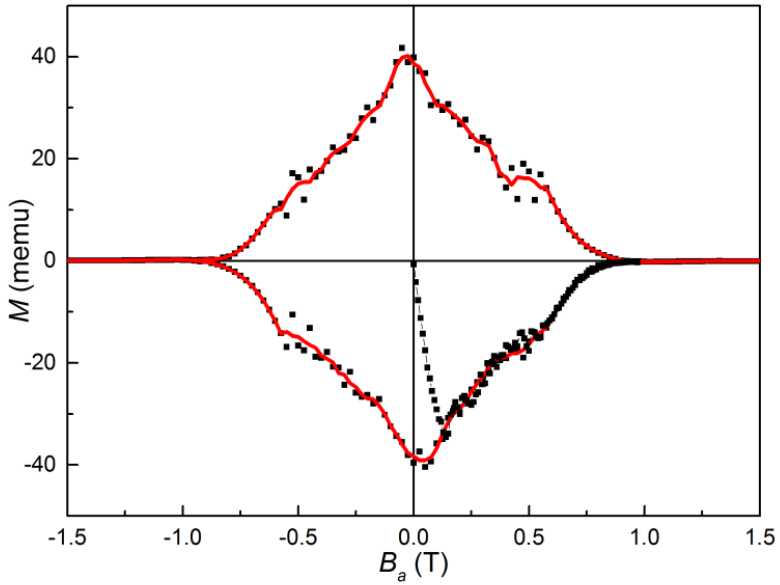
- **RRR** measurements
  - have been performed using a purpose built cryostat housing a four point probe.

- **DC SQUID** measurements
  - The measurement gives values for both the first and second critical fields, H_{c1} and H_{c2}.

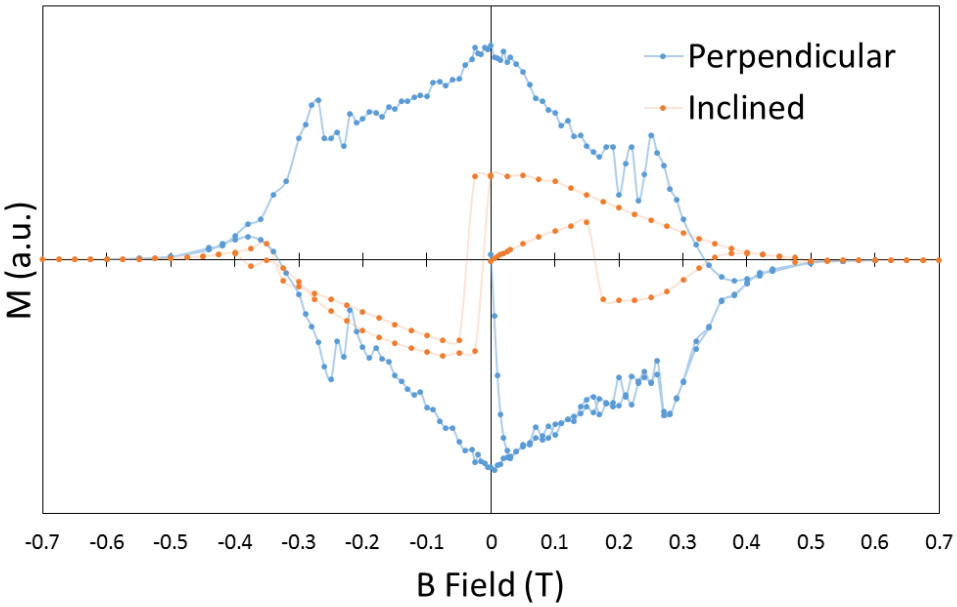
Superconductivity evaluation: DC SQUID

- 5 samples studied for B perpendicular to the sample surface
- 2 samples studied for B parallel to the sample surface

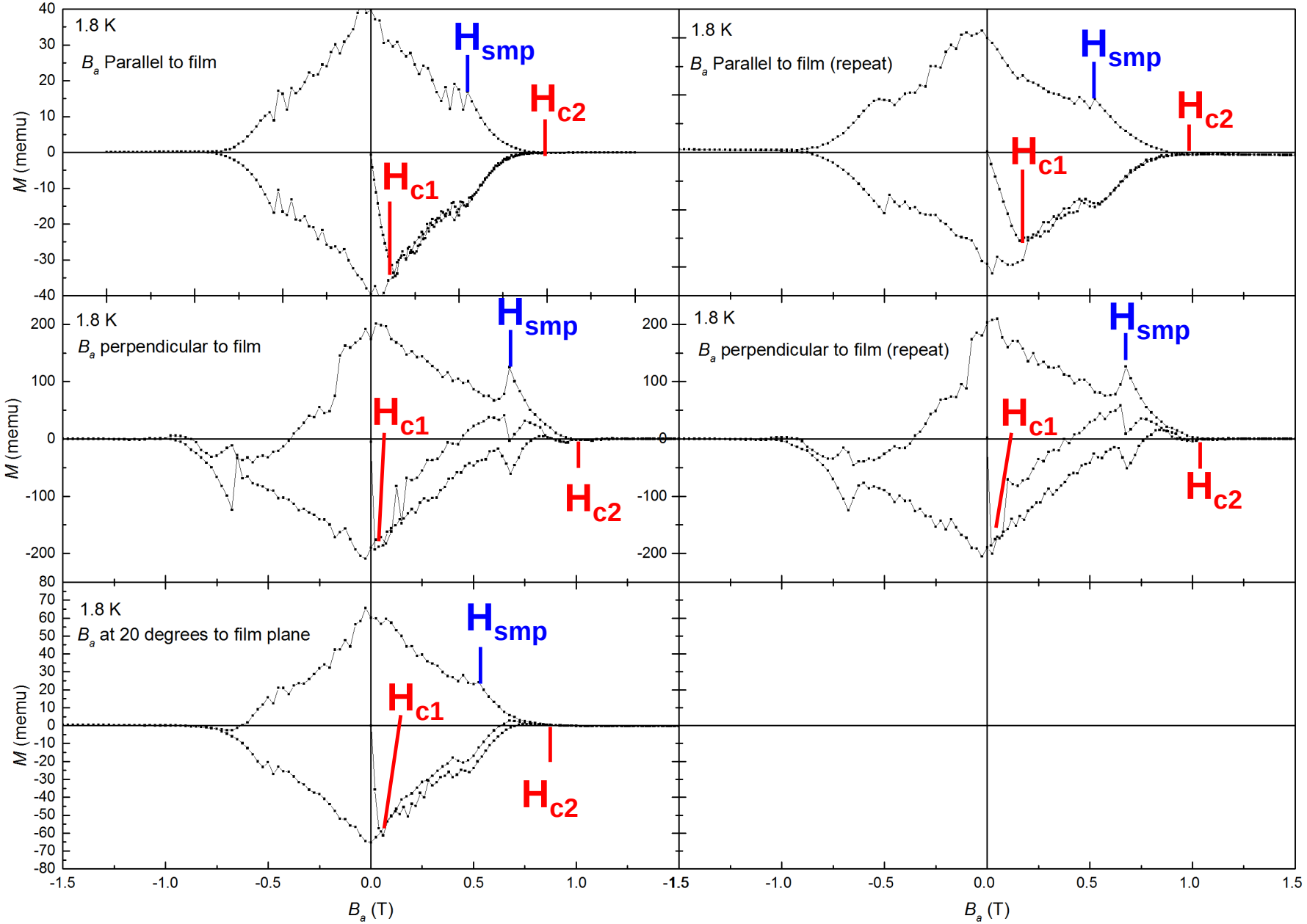
A typical DC magnetic susceptibility measurement with the sample parallel to the magnetic field.



Some results are quite unexpectable

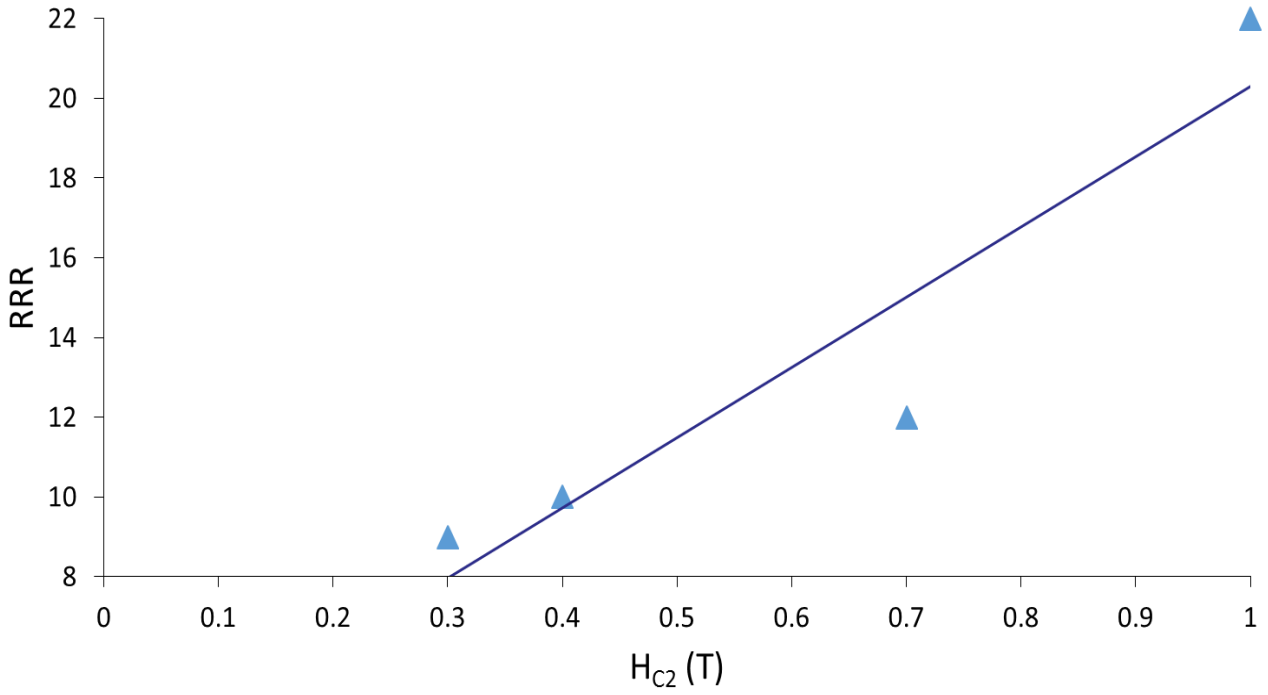


Superconductivity evaluation: DC SQUID

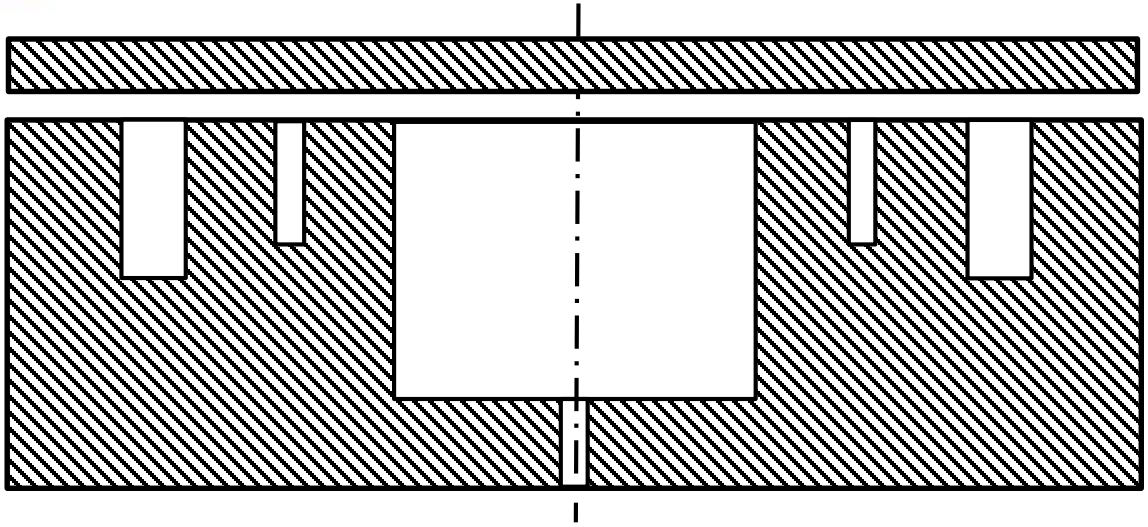


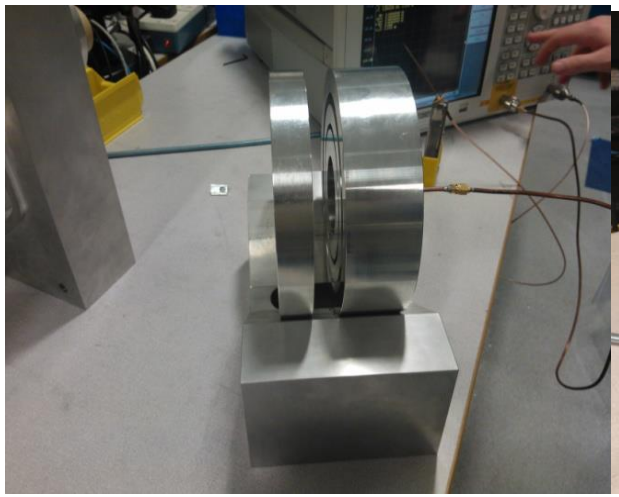
RRR vs H_{c2} fim deposited on Silicon

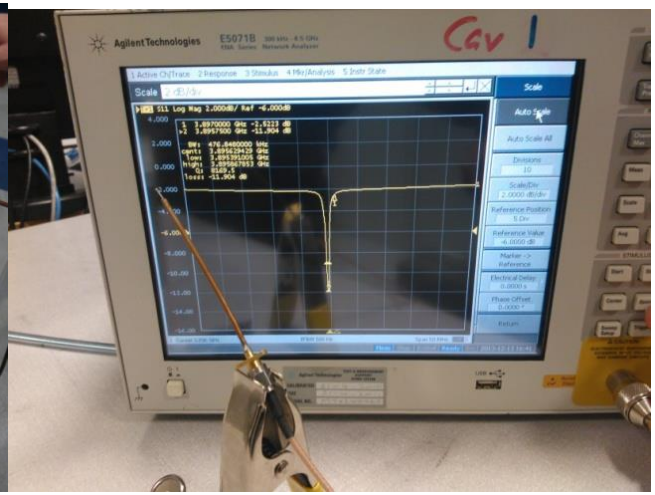
H_{C2} increases with RRR at T = 6 K



Pill BOX Cavity: Aluminium mock up RF cavity test

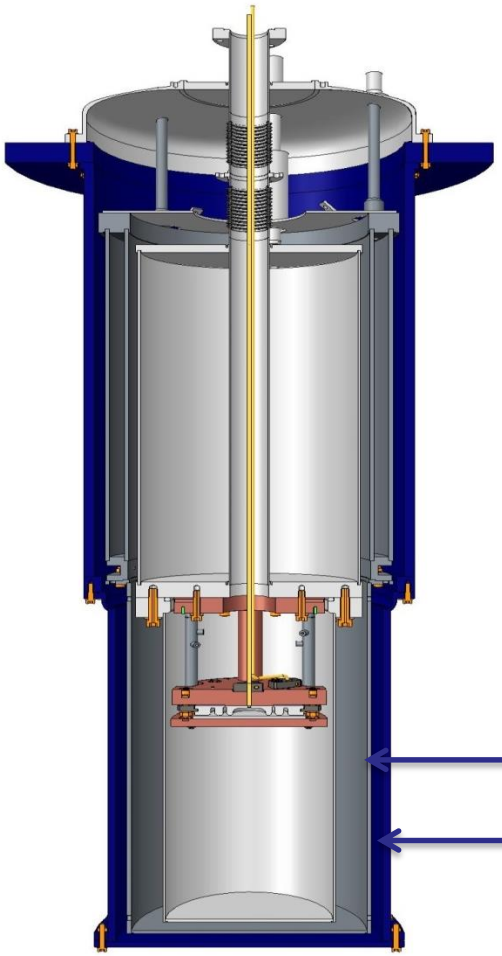






- Mock up 3.9 GHz pill box cavity has been fabricated to validate the simulation results obtained with Microwave Studio.
- Samples:
  - a 100-mm diam. Nb disk
  - a 100-mm diam. copper disk with thin films of Nb deposited on the surface.

LHe CAVITY CRYOSTAT



Outer Vacuum Chamber

Liquid Nitrogen Chamber

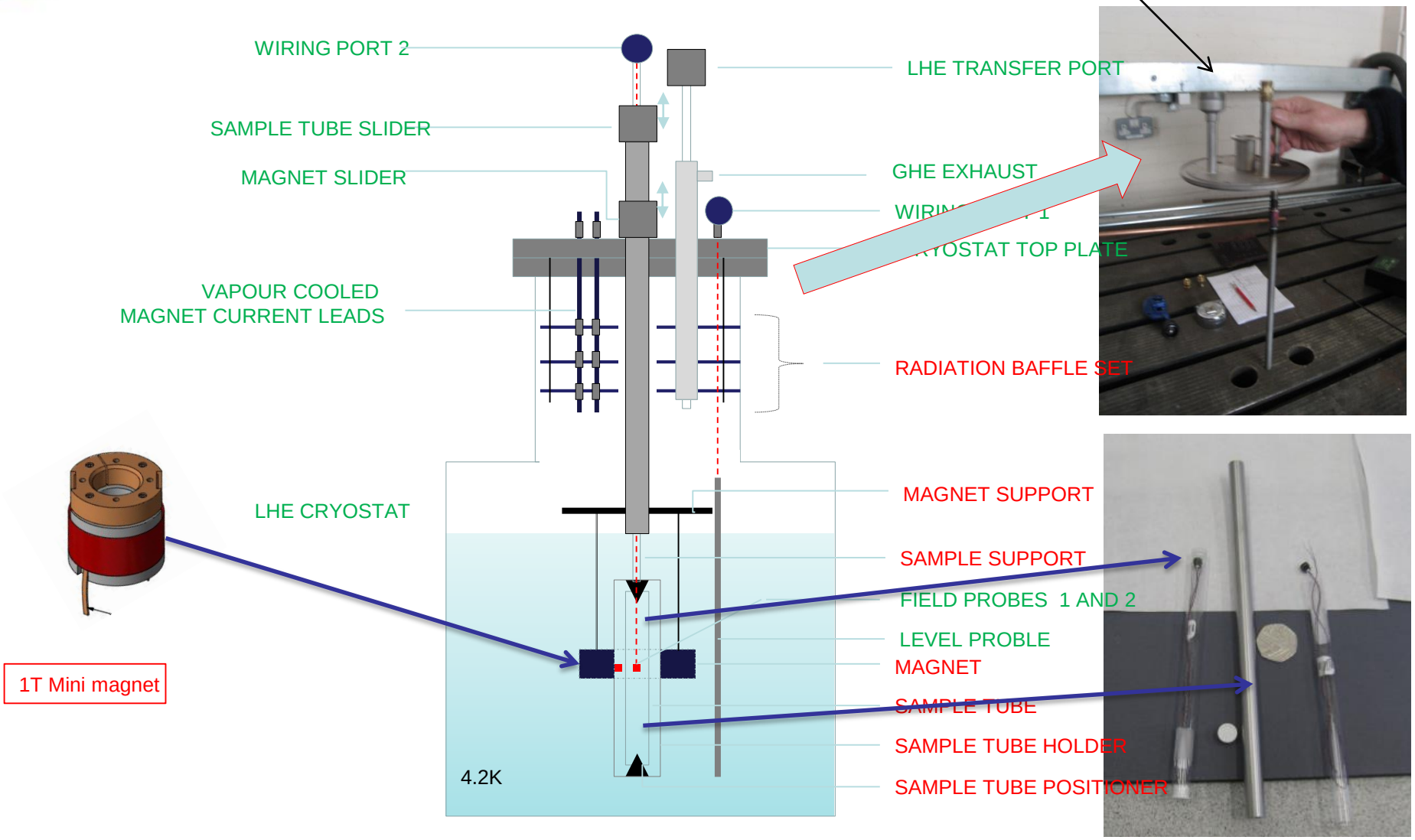
Liquid Helium Chamber

Cradle Assembly

Sample Chamber

Radiation Shield

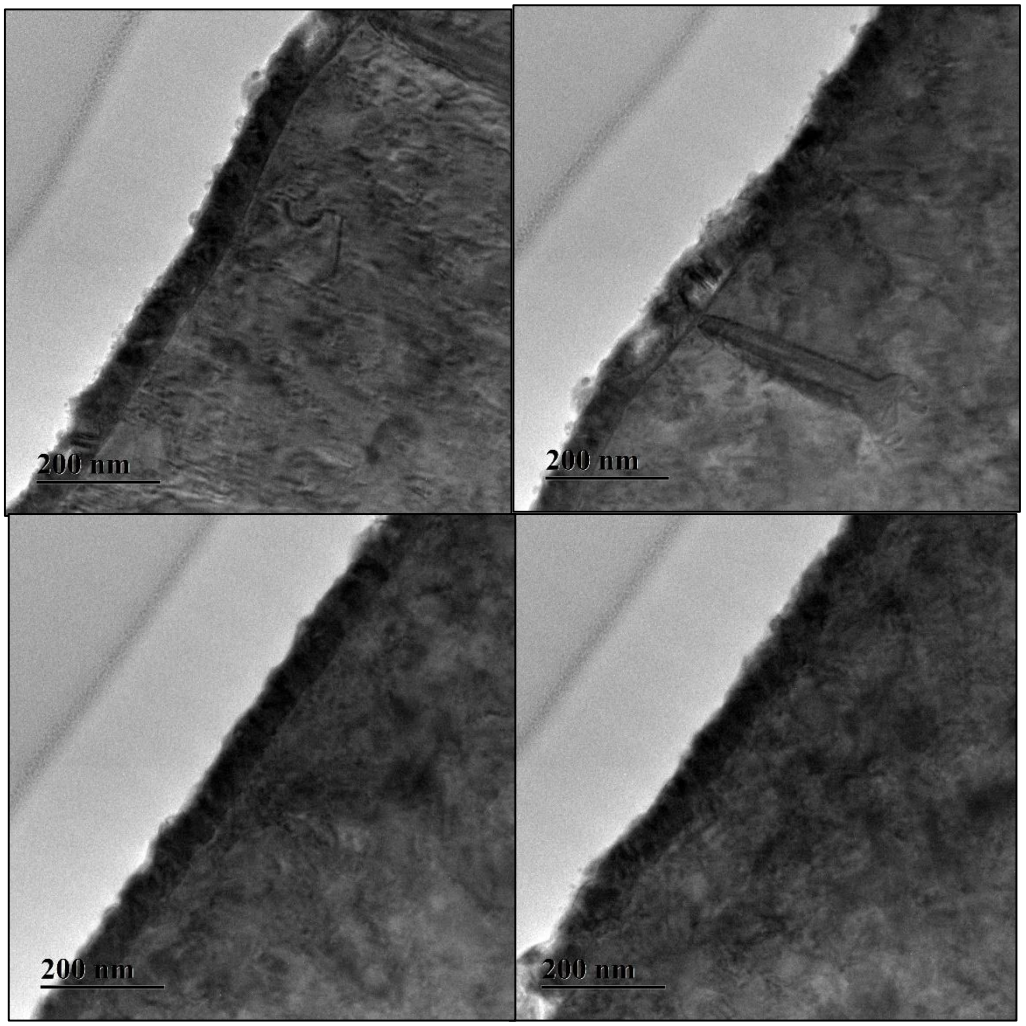
Magnetic field penetration measurement experiment suggseted by A.Gurevich



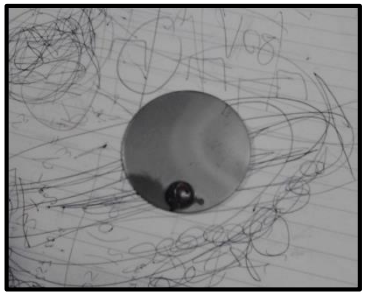
PVD SUMMARY of RESULTS

- Largest grains of 73 nm deposited by HiPIMS on MgO
- Increasing gain size expected to increase Hc1
- Hc1 has ranged from 0.1 to 0.18 T on Cu and Si substrate
- Hc2 for films deposited by HiPIMS has been approx. 0.4 T and lower than for DC sputtered films
- Low Hc2 expected of large grain films and is approaching values expected of bulk Nb (approx. 0.27 T)
- More stable pinning for films deposited onto Cu substrate when compared to Si substrate
- Films deposited onto Si show large flux jumps
- RRR approximately doubles for films deposited onto Cu when compared to Si however no correlation between RRR and Hc2
- Films with higher RRR showed fewer flux jumps

CVD deposition of Nb on Cu



- Nb(v) Cl
- Deposited at 650°C
- Tc = 9.3K
- RRR = 31



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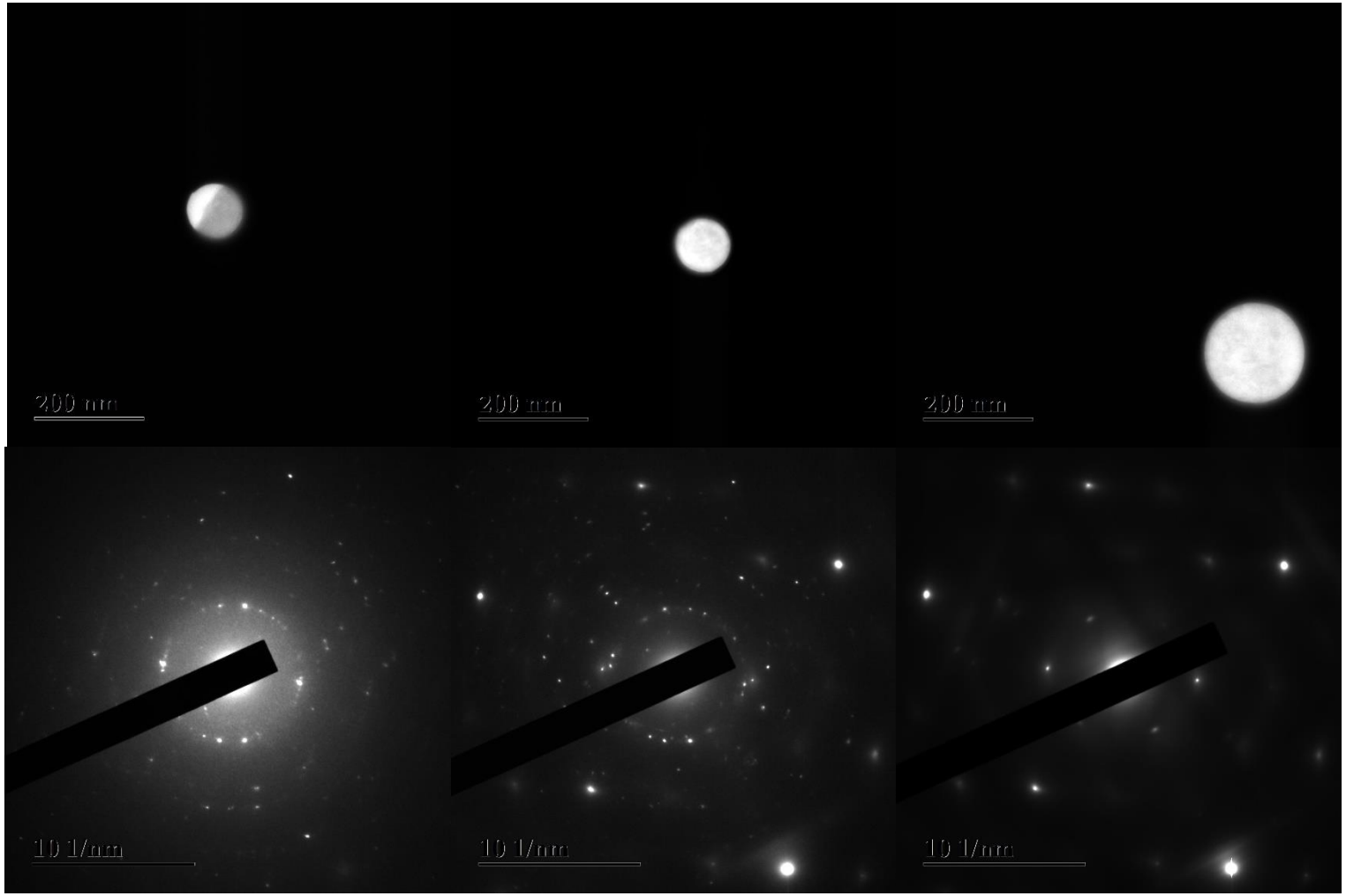
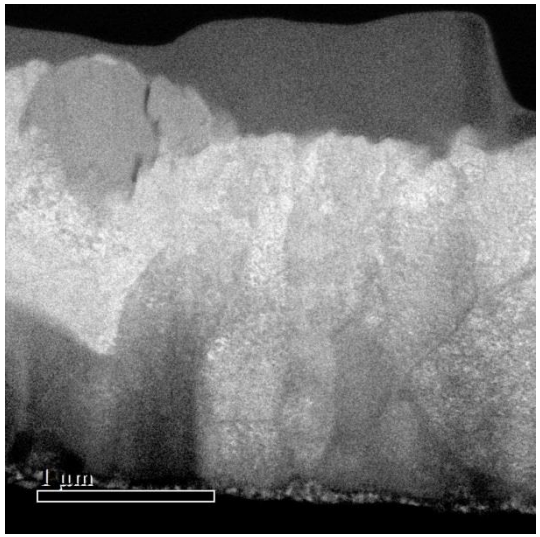
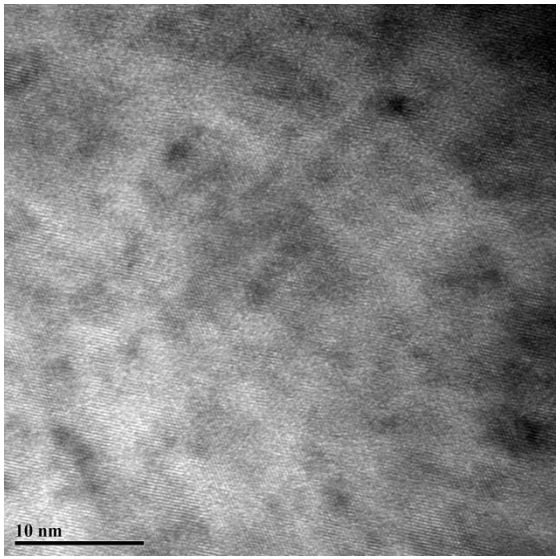
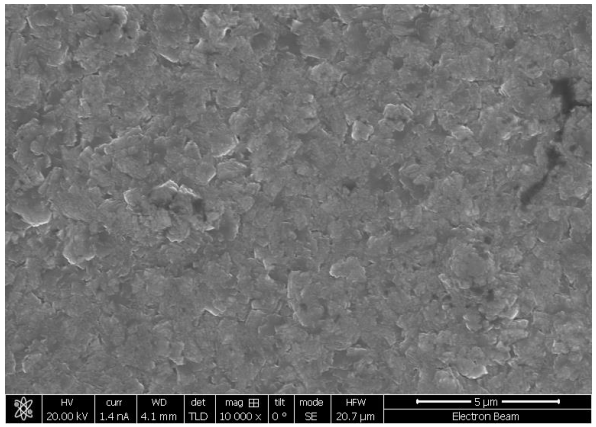
CVD Nb – Electron diffraction

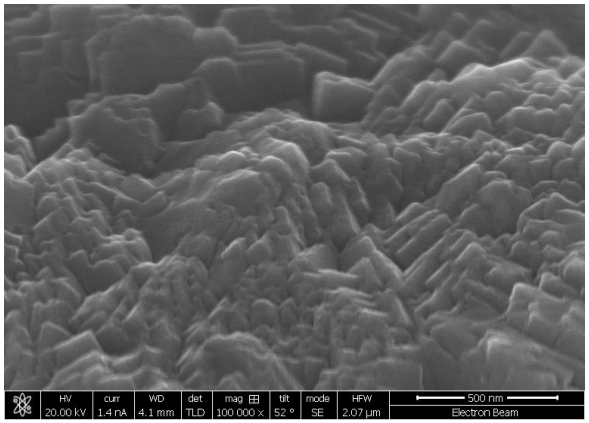


SEM and TEM of PECVD of Nb









Conclusions

- Quality of the film (morphology, RRR, H_{c2}) depends on
  - deposition parameters such as
    - Substrate temperature,
    - Ion/atom arrival ratio,
    - Substrate bias,
    - Plasma generation at the target
      - DC pulsed or DC
      - HiPIMS
    - Substrate crystallography
    - For CVD/ALD precursor and deposition Temperature

Conclusions (2)

- Sample evaluation
  - RF pill-box cavity is the best, however
    - High Cost of manufacturing and cost of LHe,
    - Time consuming
  - AC and DC susceptibility:
    - Not direct for RF (H_{c1} and H_{c2}) and a cost of LHe
    - Quicker
  - T_C and RRR is an initial of evaluation
    - RRR > 10-73, but does not corrollate with RF
    - Quick, cheap
  - Surface analysis to determine:
    - Dense or columnar
    - Grain size,
    - Composition and impurity
    - Defects density

Future plans

- HiPIMS sample deposition for
  - Nb, NbN, NbCN, Nb_3Ge MgB_2
- Plasma ALD deposition
  - Nb, NbN, NbCN, MgB_2
- Continuing RRR measurements
- AC and DC magnetisation measurements
- Magnetic field penetration SCI multilayer layer
- RF pill-box test facility
  - Testing with a bulk Nb disk (July 2015)
  - Sample measurements (August 2015)
- 3D coating (2016)

The UK's SRF collaboration team

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