Quantum Nano Fabrication and Characterization Facility

6/6/24

IAFL Open House and RAC Capabilities

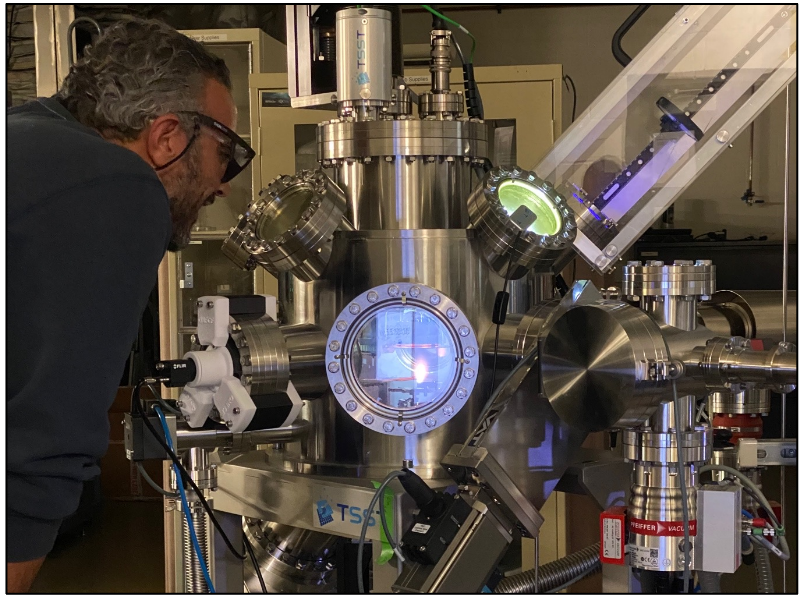
Nathan Nelson-Fitzpatrick

QNFCF
Quantum Nano Fabrication and Characterization Facility

The Quantum Colaboratory

UNIVERSITY OF WATERLOO

JEOL



INTRODUCTION AND LAB USE UPDATE

Core facility nanofabrication/characterization lab

- Resources in **QNC Cleanroom**, **QNC Metrology** and **RAC1/2 buildings**
- 14 staff – 11 provide technical services

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214 users / year from 84 groups (FY24)

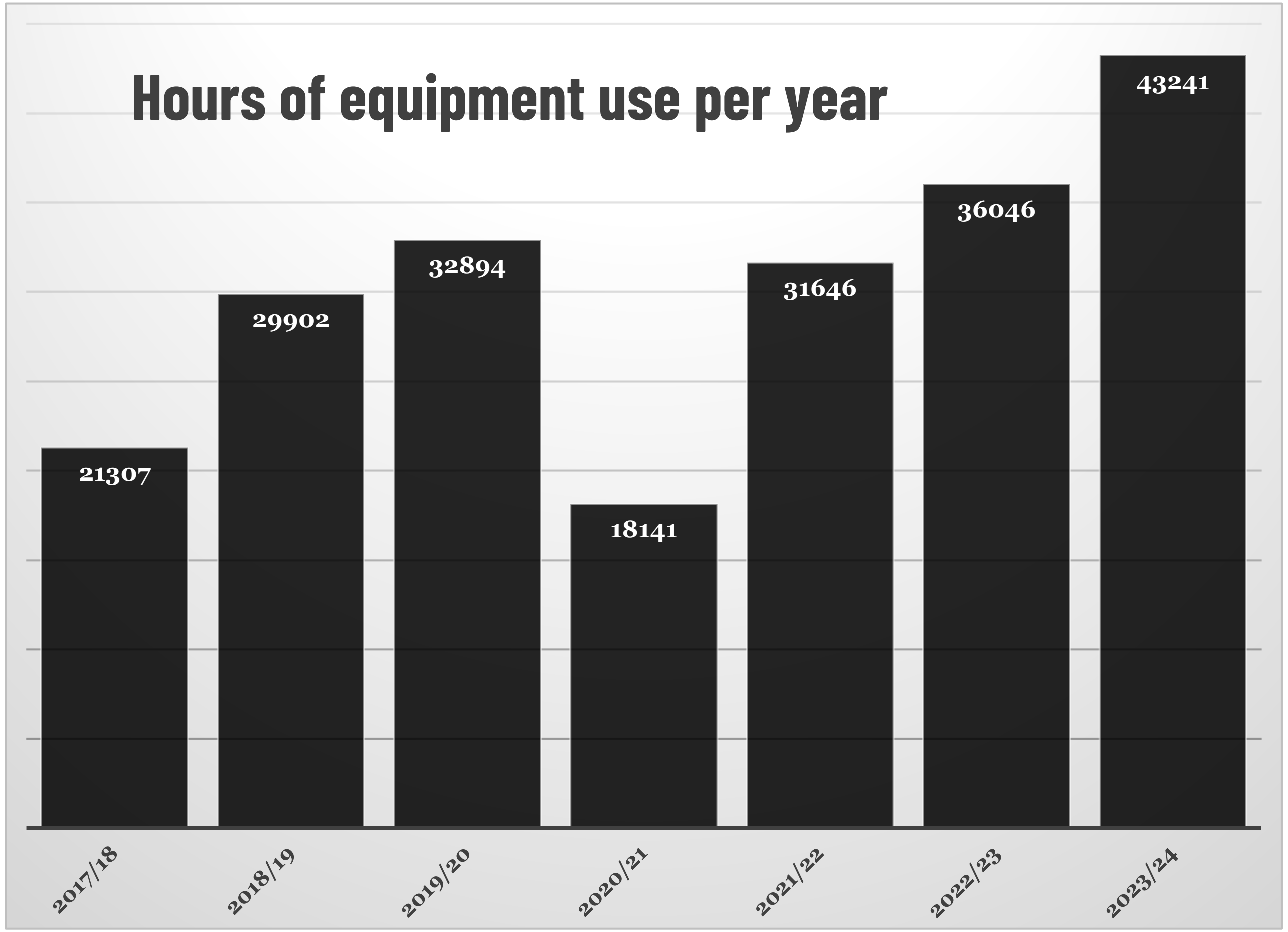
- 73% UWaterloo internal
- 17% SME / industry
- 10% External academic

> 43000 hours invoiced / year (FY24)

- >$2.0M generated/year to support maintenance
- SME users accounted for 47% of revenue

Open to academic and industrial/SME users

- QNFCF members own their own IP



QNFCF Quantum Nano Fabrication and Characterization Facility
UNIVERSITY OF WATERLOO

COMMUNITY & HQP DEVELOPMENT

<u>**Individual training is part of our DNA**</u>

- >1000 hours of training delivered per year
- Over 95% of equipment available for user training
    - Including 100kV EBL and S/TEM
- 1-1 staff driven training for equipment
- Regular opportunities for learning from staff, industry professionals and other lab users
- Professional staff resources for guidance in troubleshooting and process development

Top: TEM "Lunch and Learn" lecture
Bottom left: WIN-Bristol summer school
Bottom right: BEAMER CAD software workshop

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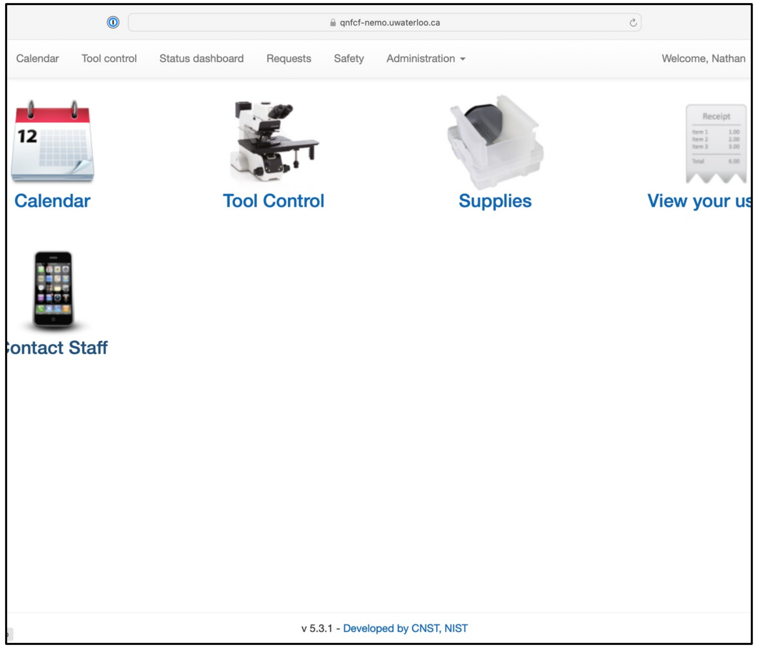
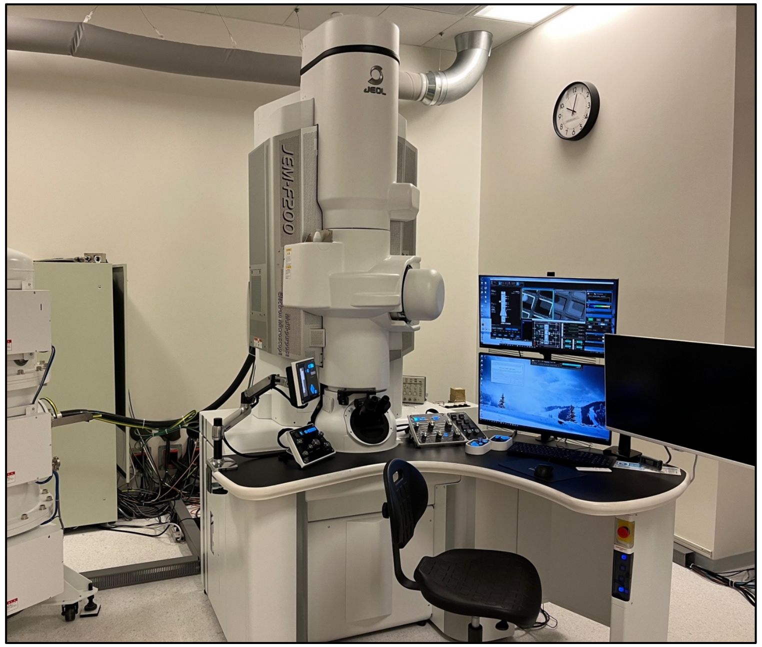
QNFCF 2024 MAJOR PROJECTS REVIEW



NEMO lab management

Project lead: **Greg Holloway**
Supporting staff: Nicki Shaw, Nathan Nelson-Fitzpatrick, Guillermo Gomez



S/TEM, FIB, sample prep

Project lead: **Nicki Shaw**
Supporting staff: Sandra Gibson, Greg Holloway, Daphene Wen (co-op)

Inert Atmosphere Fabrication Lab

Project lead: **Taso Alkiviades**
Supporting staff: John Nugent, Greg Holloway, Lino Eugene, Nathan Nelson-Fitzpatrick

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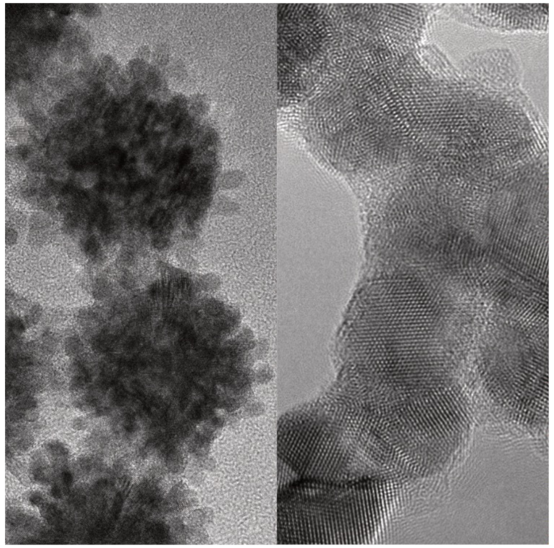
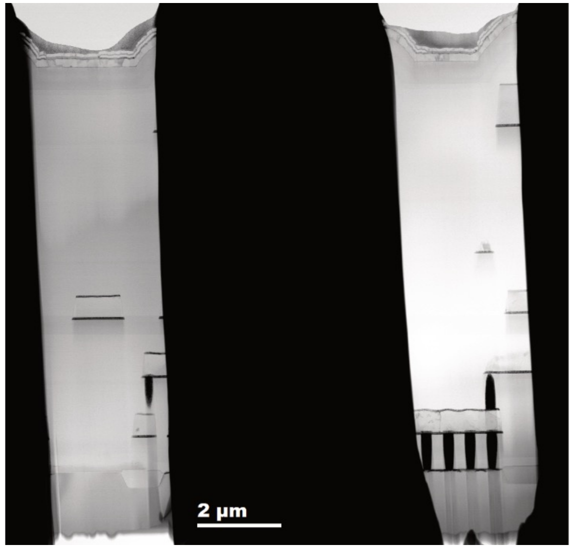
TEM

(L) **Vasily Panferov**, Professor Juewen Liu
(R) **Mohamed Okasha**, Professor Vivek Maheshwari
Department of Chemistry, University of Waterloo



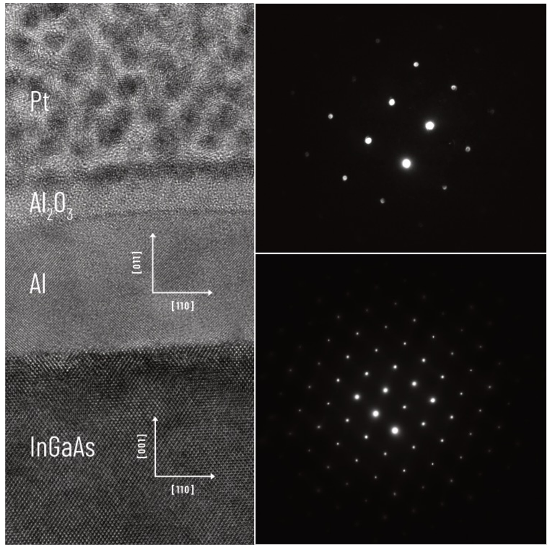
STEM

Yu Shi, Professor Guoxing Miao, Department of Electrical and Computer Engineering, University of Waterloo



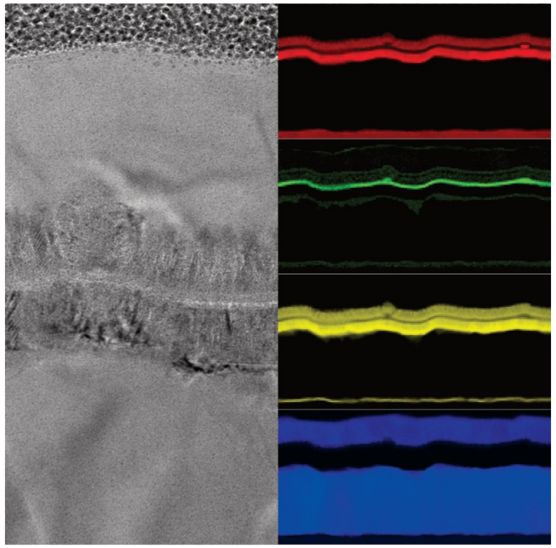
Diffraction

Ahmed Elbaroudy, Professor Zbigniew Wasilewski, Molecular Beam Epitaxy Research Group (MBE), University of Waterloo



Spectroscopy

Yu Shi, Professor Guoxing Miao, Department of Electrical and Computer Engineering, University of Waterloo

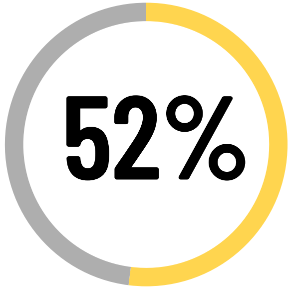


16 **TRAINED TEM USERS**
Since launch in October 2023

300 **Hours of use**
Since July 2023

6 **DEPARTMENTS**
Across campus

105 **Training hours delivered**
Since October 2023



OF TEM USERS ARE **TRAINED** TO OPERATE THE TOOL

JEOL

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Quantum Nano Fabrication and Characterization Facility

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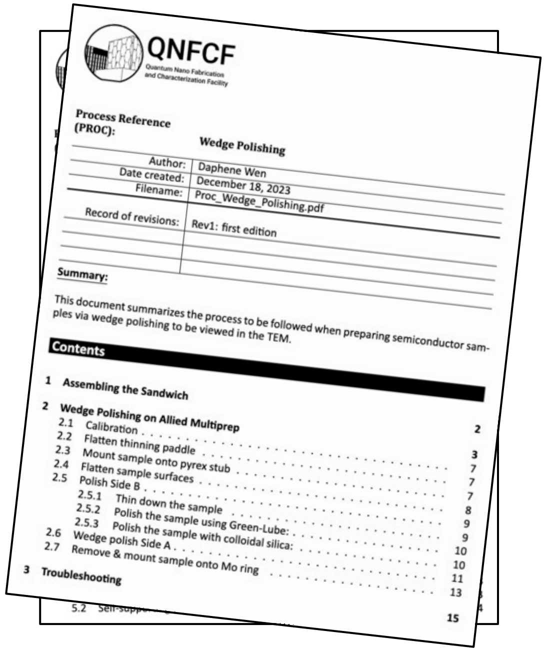
QNFCF TEM TEAM


QNFCF
Quantum Nano Fabrication and Characterization Facility

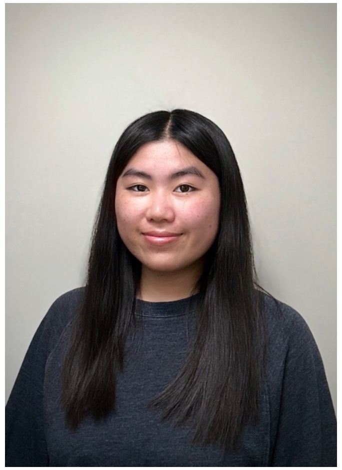
Process Reference (PROC): Wedge Polishing

Author:	Daphene Wen
Date created:	December 18, 2023
Filename:	Proc_Wedge_Polishing.pdf
Record of revisions:	Rev1: first edition

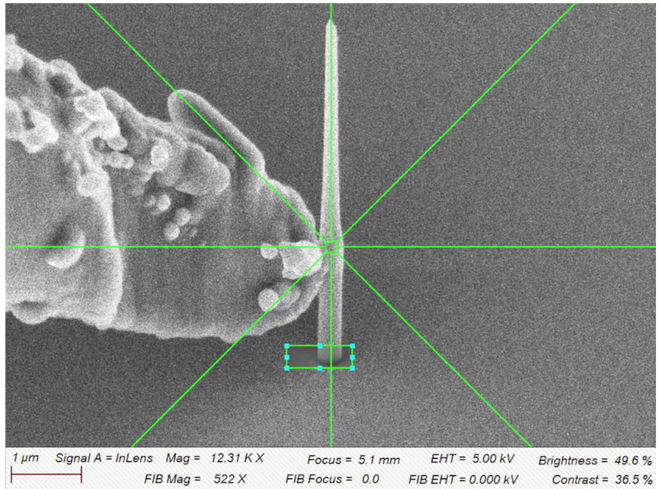
Summary:

This document summarizes the process to be followed when preparing semiconductor samples via wedge polishing to be viewed in the TEM.

Contents

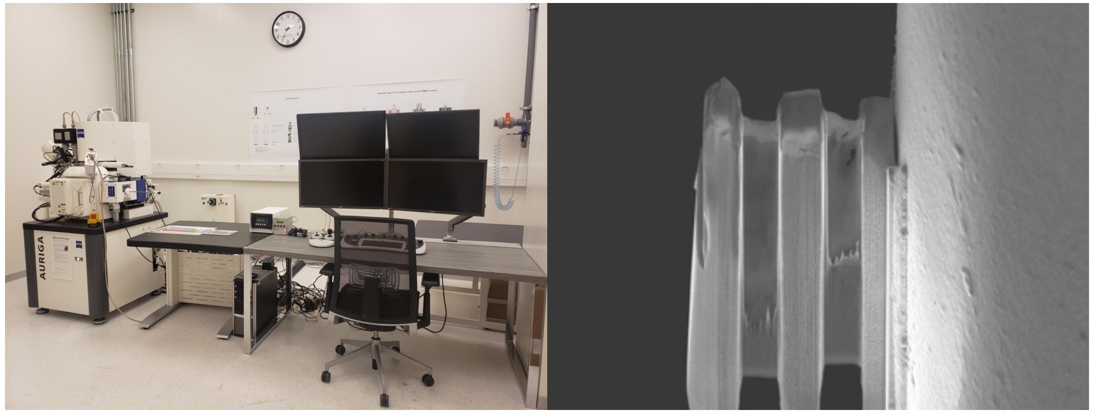


Co-op Daphene Wen

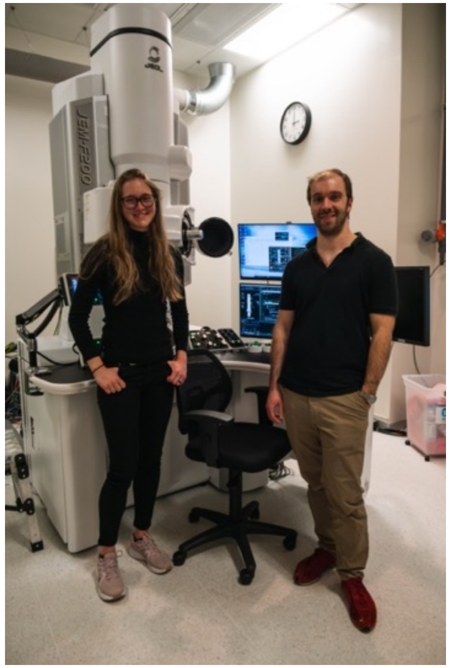


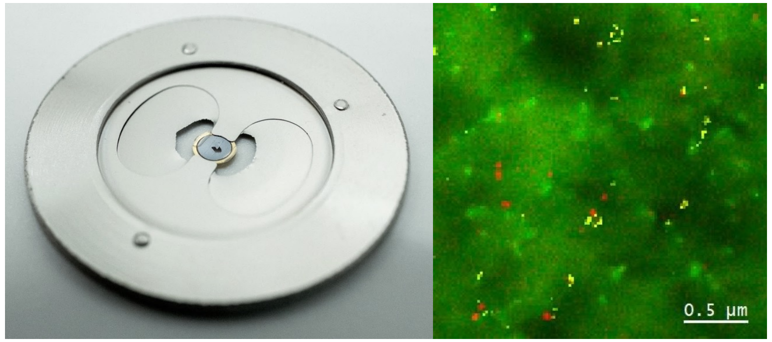
FIB manipulation of InP nanowire

Top: Sandra Gibson
Right: Nicki Shaw and Greg Holloway



Zeiss FIB & example TEM lamellae





Mechanical sample prep project

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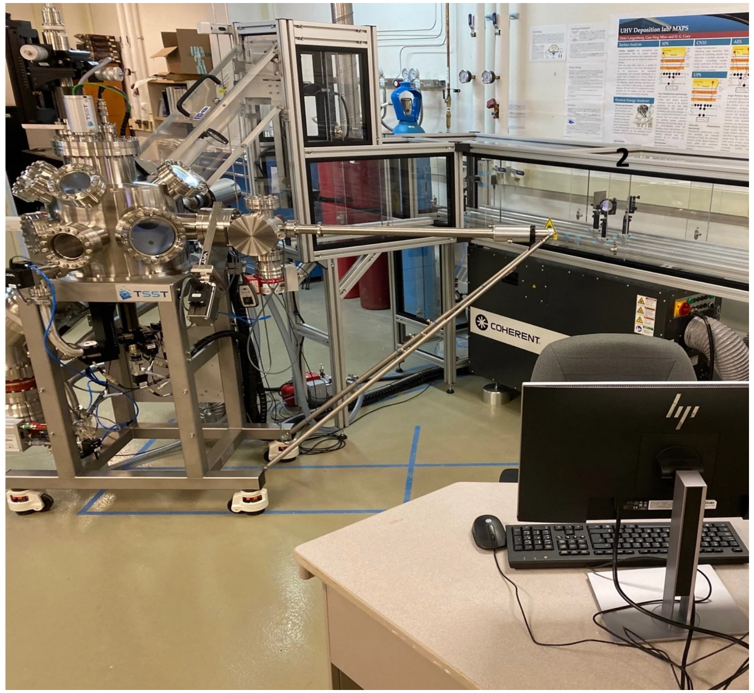
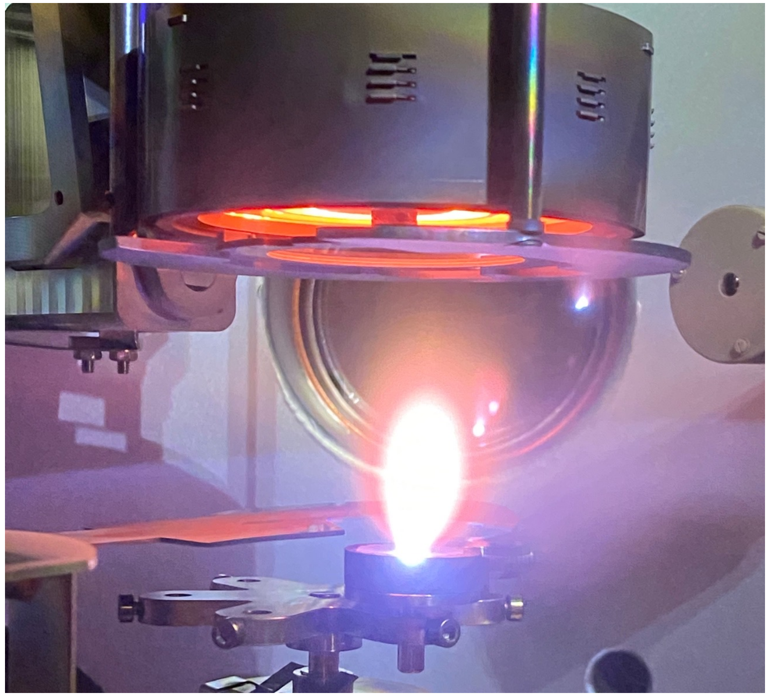
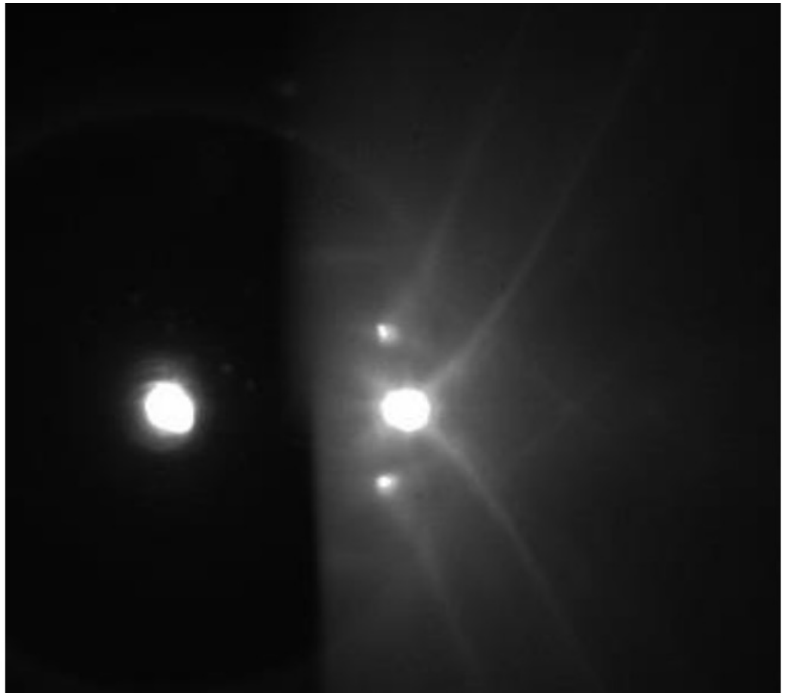
EXTRA RAC RESOURCE – PULSED LASER DEPOSITION

TQT Transformative Quantum Technologies







Pulsed Laser Deposition

- UHV construction
- 900℃ stage with X-Y and tilt control
- Laser raster (enhanced uniformity)
- O_2 environment w. pressure control

Why PLD?

- Very high KE of deposition flux
- Advantageous for complex oxide films: YBCO, STO, VO_2
- Relatively easier to maintain stoichiometry
- Tradeoff with uniformity

RHEED analysis

In-situ monitoring of film morphology
- Pattern gives clues as to growth model/type
- Intensity oscillation used to monitor thickness

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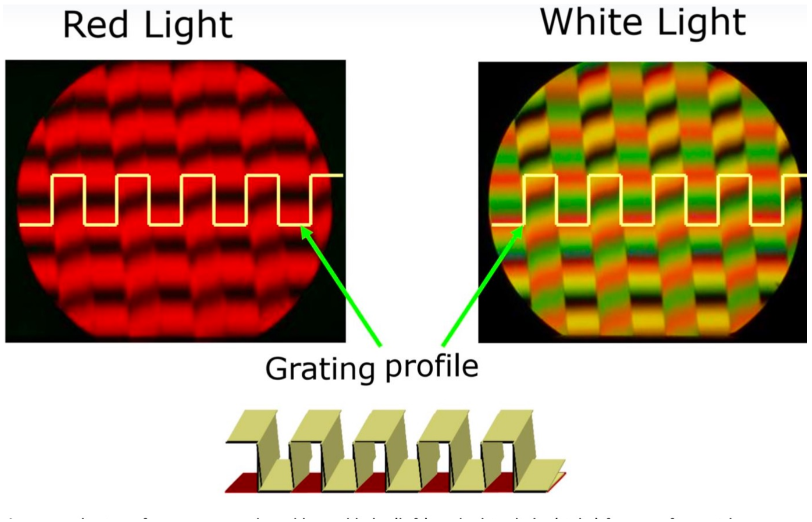
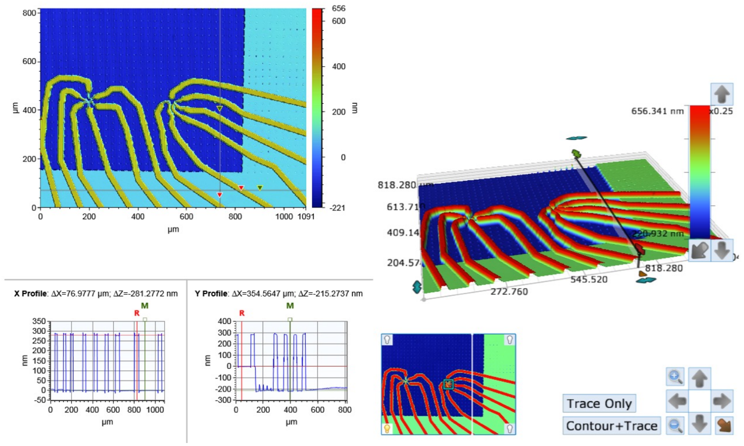
EXTRA RAC RESOURCE – CONTOUR 3D PROFILER

Transformative Quantum Technologies





Non-contact profiler

- 3 nm resolution in VSI mode
  - Step height limited only by objective and microscope stage
- 0.1 nm resolution in PSI mode
  - Step height <λ/4 or 130 nm

Why Contour?

- No contact
- Fast
- Very high Z resolution

Example applications

Suitable for:
- Micron scale devices
- Microelectromechanical systems (MEMS)
- Gently varying optical features, lenses

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INERT ATMOSPHERE FABRICATION LAB

2024

QNFCF

UNIVERSITY OF WATERLOO

TQT Transformative Quantum Technologies

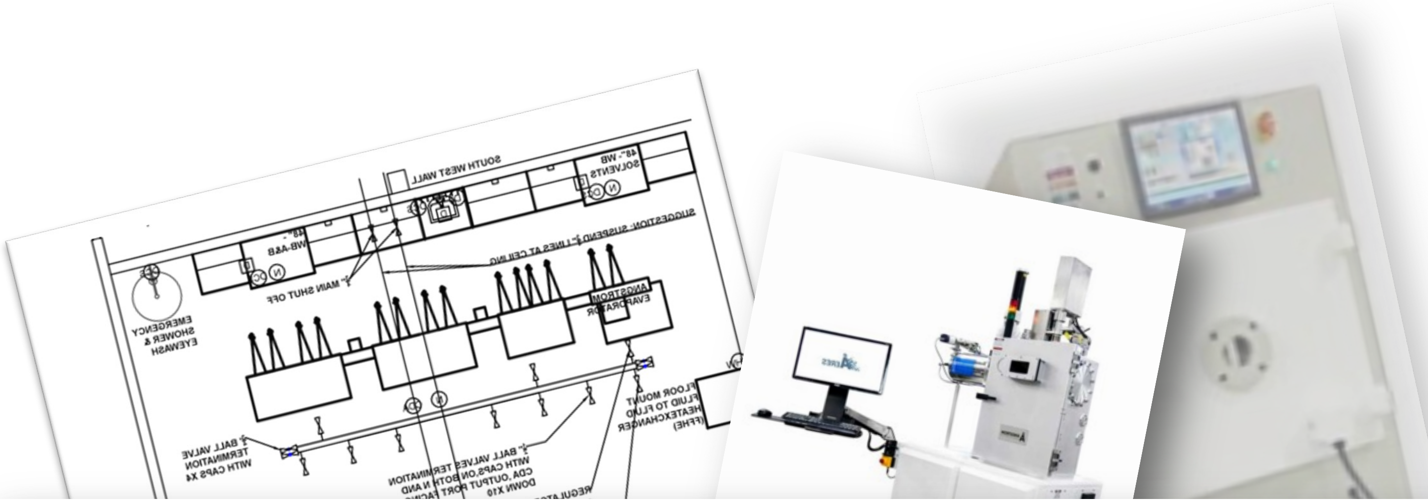
Prepared by Taso Alkiviades

QNFCF

Our goal is to extend our core facility platform into the 2D material device fabrication field and elevate the capabilities our 2D material research groups.

QNFCF

Guided by our core principals we developed a plan that encompasses the specific research requirements which were provided by Prof. Adam Wei Tsen and Dr. Tarun Patel and through our experience in designing professional lab spaces we set on developing a world class fabrication facility to serve our community.

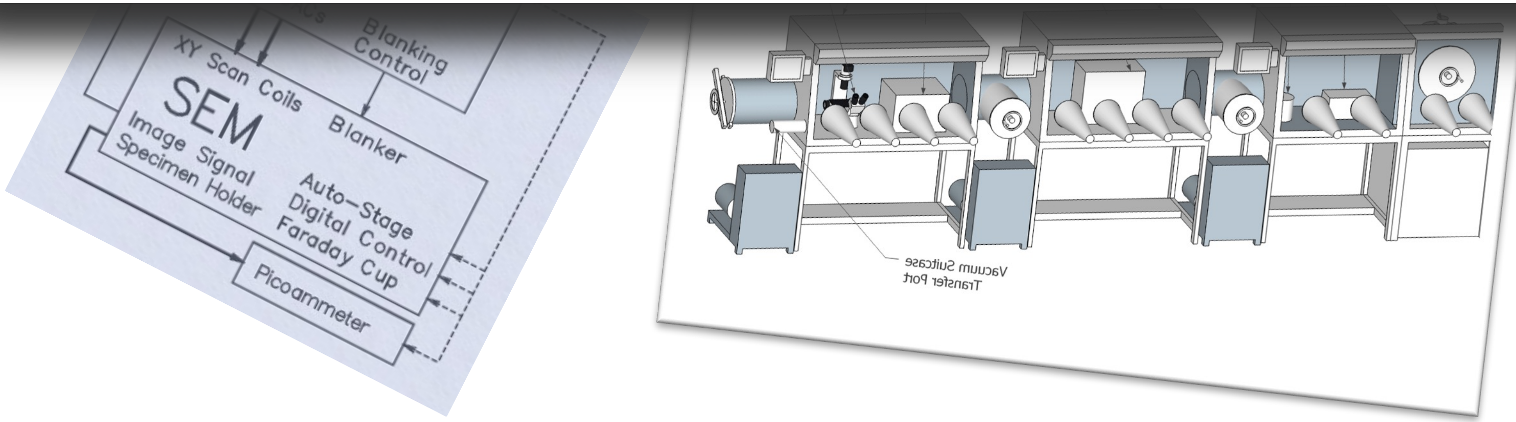


Vision

Enabling world-class research via state-of-the-art facilities and professional operations

Mission

We are committed to operating a world-class nanofabrication and characterization facility to professional standards, to the combined benefit of the University of Waterloo's stakeholders, researchers and collaborators



TASK IN HAND

To develop a complete nanofabrication fabrication suit entirely integrated in an inert environment and include all the critical equipment pertaining to 2D material assembly

RUSSIAN NESTING DOLL – LEVEL OF INTEGRATION

APPROPRIATE FACILITY REQUIRMRNTS

SPECIFY SICIENTIFIC EQUIPMENT

DESIGN OUR GLOVEBOX

INTEGRATE EQUIPMENT

TESTING OF EQUIP & PROCESS

PROCEDURES & TRAINING FRAMEWORK

ANGSTROM ENGINEERING

JEOL

BRUKER

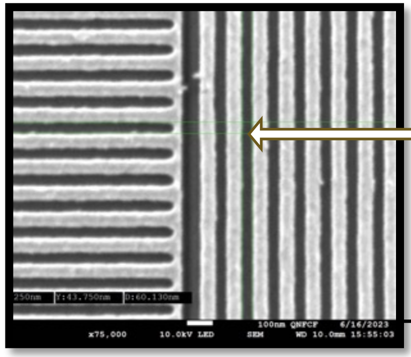
TQT Transformative Quantum Technologies

QNFCF

UNIVERSITY OF WATERLOO

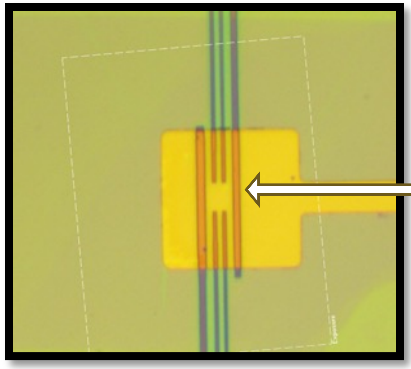
KEY COMPONENTS OF INERT ATMOSPHERE FABRICATION LAB

- Nanofabrication equipment
- 2D Material assembly microscope
- Glovebox system



Pre glovebox test
43nm features

NPGS Software



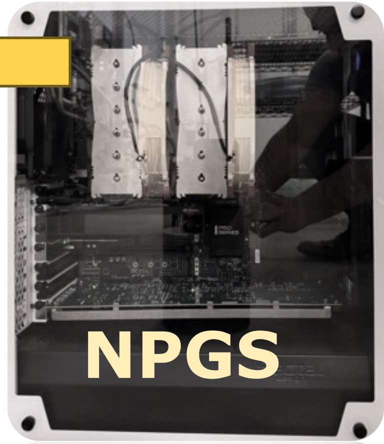
Post glovebox
500nm features
on H-BN

Lithography System

Dr. Lino Eugene
Nanofabrication and process engineer -QNFCF

Dr. Greg Holloway
Electron Beam lithography Scientist - QNFCF

JEOL IT510 SEM



Joe Napaity, Nanometer Pattern Generation System

Requirements

To write micron scale features for generating electrical contacts to interface with our 2D flakes and it needed to be a maskless lithography system to generate custom patterns.

Design Specifications

JEOL IT510 scanning electron microscope, couples with a Nanometer pattern Generation System. 500nm features to date.

SEM

- 30KV Tungsten filament electron gun
- 5 Axis stage
- Large sample chamber, up to 2” wafers
- A user-friendly software interface

NPGS

- 16bit DAC
- Deben beam blanker – 50nS
- Keithley 6485, Pico ammeter

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JEOL IT510 Delivery

JEOL IT510 + NPGS setup

Mating JEOL IT510 to glovebox day

Tong Liu, Chief Service Engineer, JEOL USA

Mixing concrete for SEM base

Our team has years of experience in Nanofabrication and can tailor the exact equipment to the process

Metal Deposition

Dr. Nathan Nelson Fitzpatrick,
Director - QNFCF

ANGSTROM ENGINEERING

System requirements

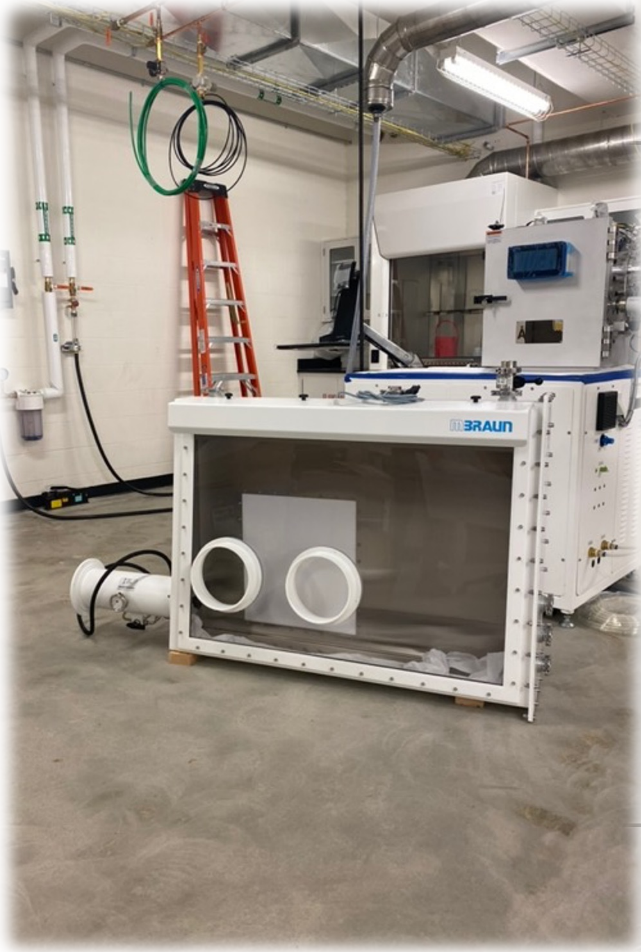
Capable of depositing thin films of Ti, Pd, Al, Ni and Au, to metalize our contacts.

System Specifications

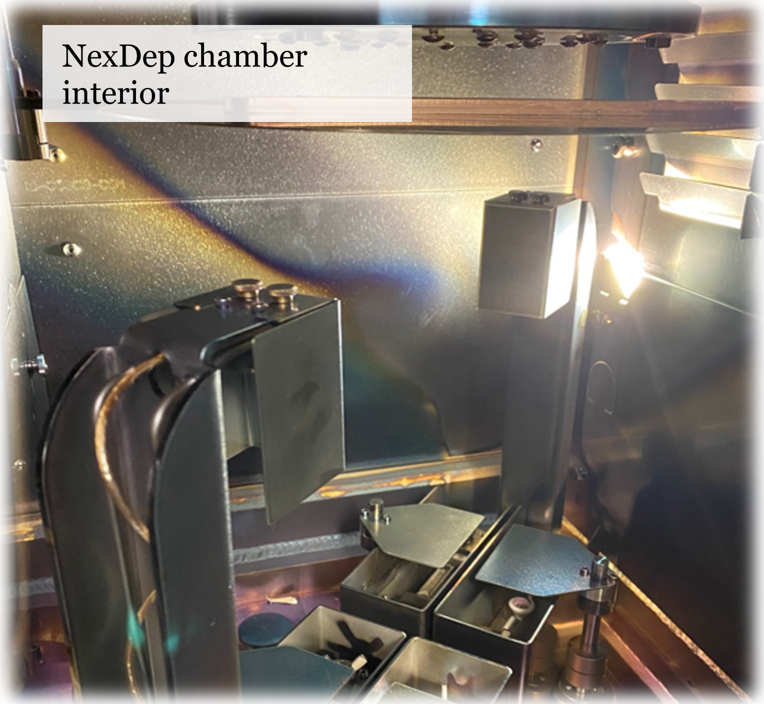
Angstrom engineering NextDep thermal evaporator with dual door access via glovebox and standard atmosphere.

- 4-source thermal evaporator with single cooled source for long and rapid deposition rates in high melting point material
- Rotating heated substrate stage at 50RPM and 300°C
- 2x –cooled QCM deposition monitors

- We are currently setup for Au, Ti and Ni



Sean Campbell,
Service Manager,
Angstrom Engineering



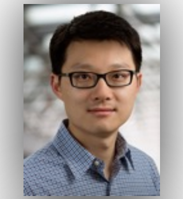
NexDep chamber interior

OLYMPUS

QNFCF has access multi-skilled individuals who have come together to recreate and create new capabilities

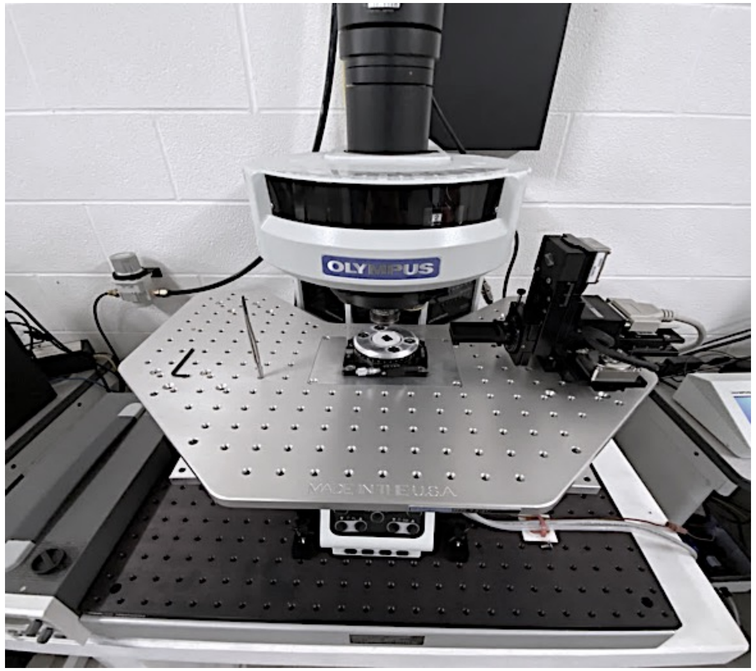
SUTTER INSTRUMENT

2D Materials assembly microscope



Prof. Adam Wei, Tsen
Associate Professor

Dr. Tarun Patel
Postdoctoral Researcher



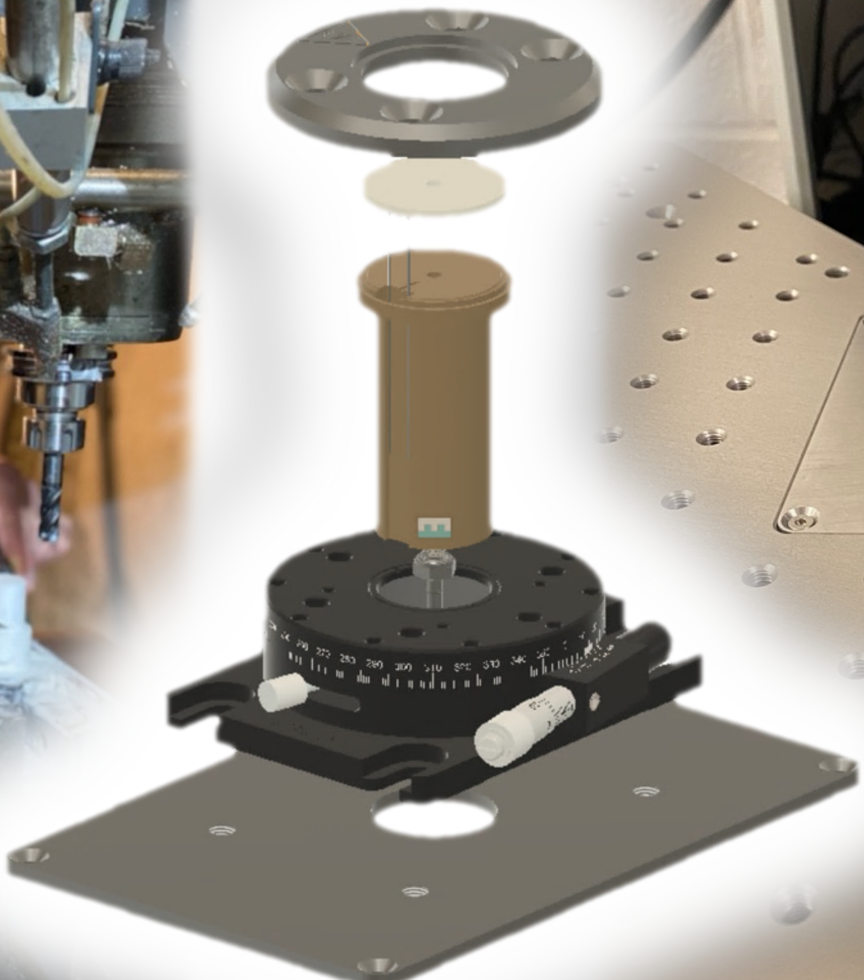
System requirements

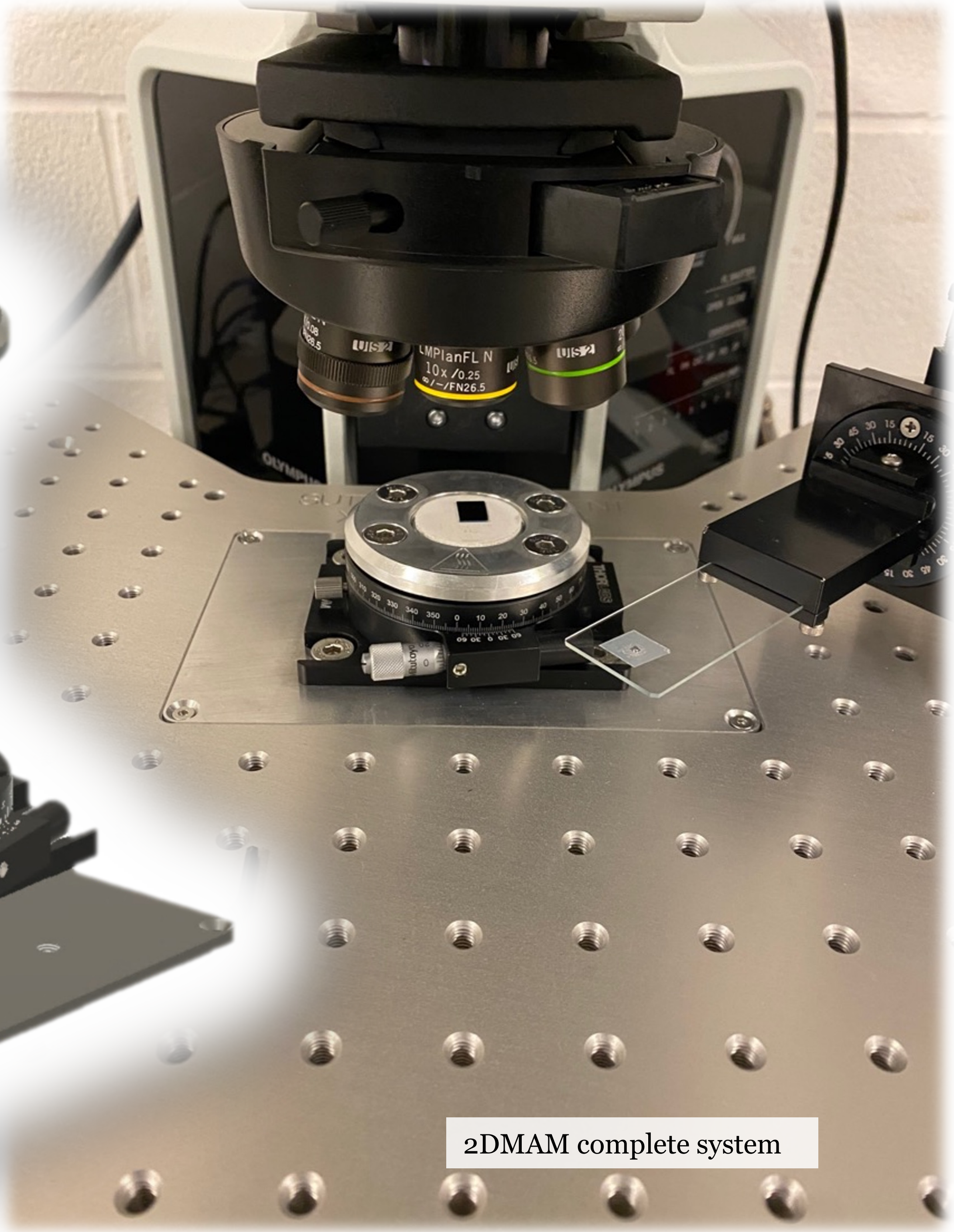
“Pick and Place” 10-200μm 2D material flakes in order to stack them or place them on electrical contacts.

System Specifications

Vacuum stage with ultra fast heating for substrates and devices at 60°C per min up to 200°C. Micromanipulator with 62.5 nm/step precision. Vibration isolation platform.

Alex Mitrovic, Precision Machinist, milling a delicate ceramic component for our heater stage.


In-house design 2D material assembly heater stage



2DMAM complete system

Integration of existing characterization tools into the inert glovebox environment.

AFM Characterization

Dr. Sandra Gibson, Nanofabrication and Characterization Scientist - QNFCF

System Specifications

Characterize 2D material repeatedly measure up to 0.3nm in step height in inert environment

- Large area scanner 90µm x 90 µm, Z-range 7.5 µm
- Small area scanner 5 µm x 5 µm, Z-range 1.5 µm

BRUKER

UNIVERSITY OF WATERLOO


Vibration isolation testing


Support new user
IMPACT HAZARD!
WARNING

ANGSTROM ENGINEERING

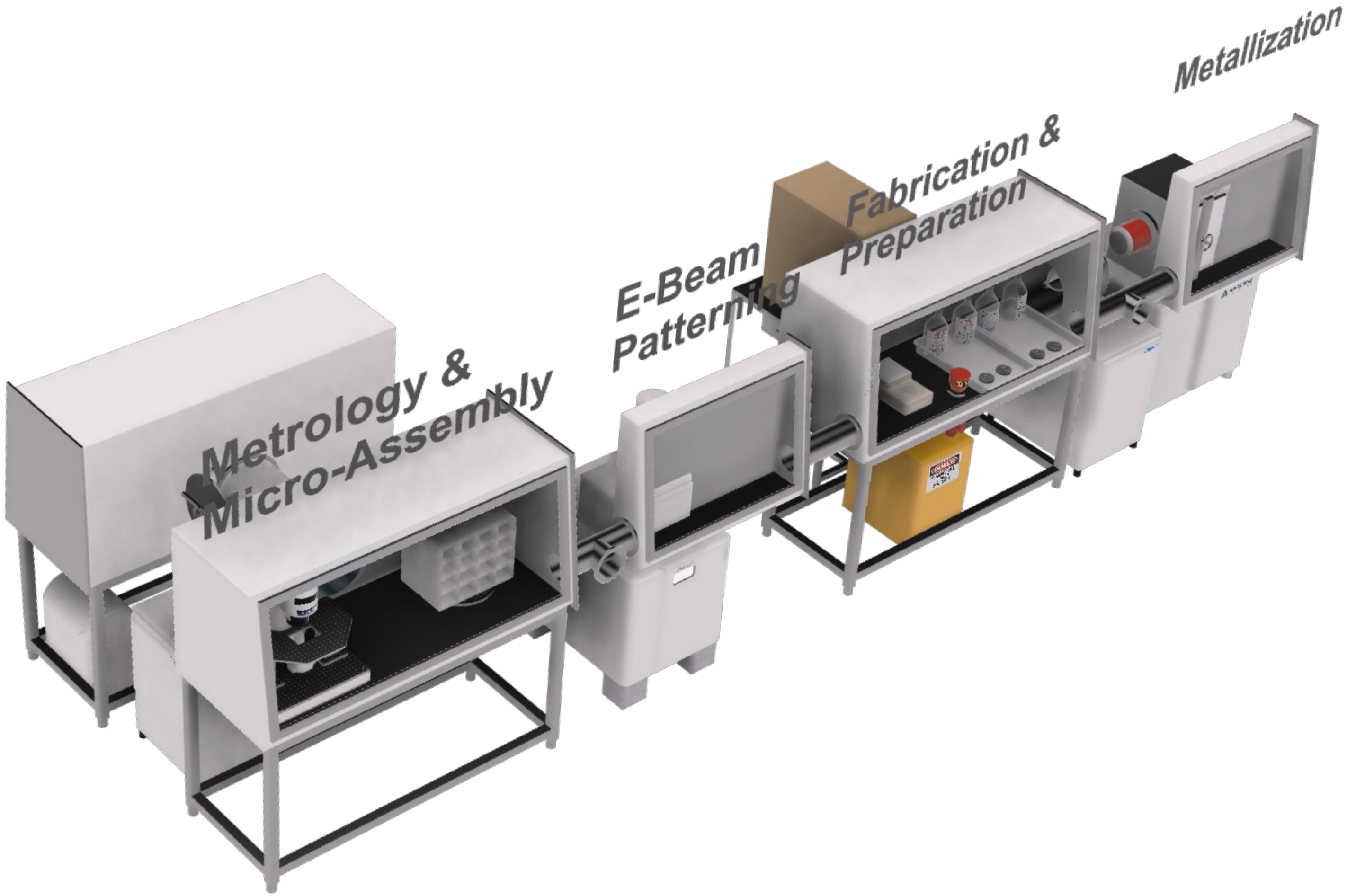
Glove Box

System requirements

The goal is to perform device fabrication in a stable inert environment to protects air sensitive material from oxidising. Allows multiple users to working on the system simultaneously

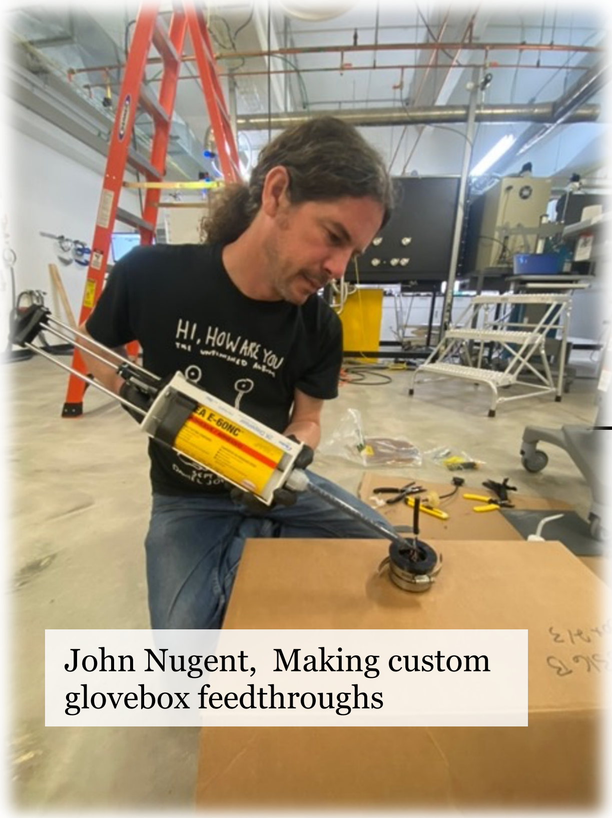
System Specifications

- 2x Quick load antechamber
- 2x large antechamber for bulk items
- Angstrom custom design doors to interface with large vacuum chamber equipment
- Two zone purification purification systems
    - Fabrication zone includes solvent scrubber

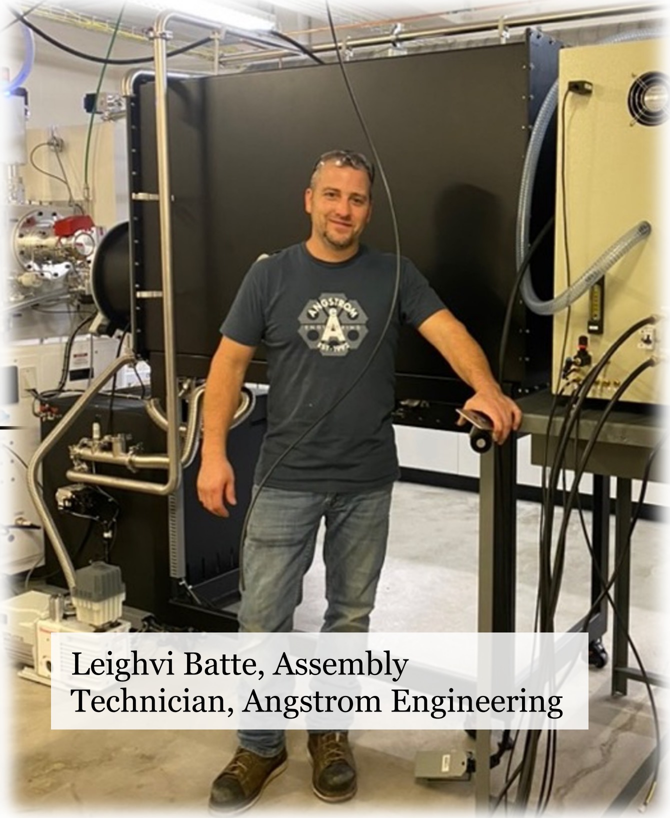



inert
ANGSTROM ENGINEERING
INTEGRATED SYSTEMS SOLUTIONS
inert
PURE LAB
NITROGEN
inert
500
Oxygen
Level
0
ppm
1000
< 0.1 ppm
500
Moisture
Level
0
ppm
1000
< 0.5 ppm

Delivery



John Nugent, Making custom glovebox feedthroughs



Leighvi Batte, Assembly Technician, Angstrom Engineering

Scott Flynn, Test & Process Specialist, Angstrom Engineering

Andre Labelle, Test & Process Manager, Angstrom Engineering

TQT Transformative Quantum Technologies

IQC Institute for Quantum Computing

UNIVERSITY OF WATERLOO

THANK YOU

ANGSTROM ENGINEERING

JEOL

RAC1 – CLEAN ASSEMBLY LAB

6/12/24

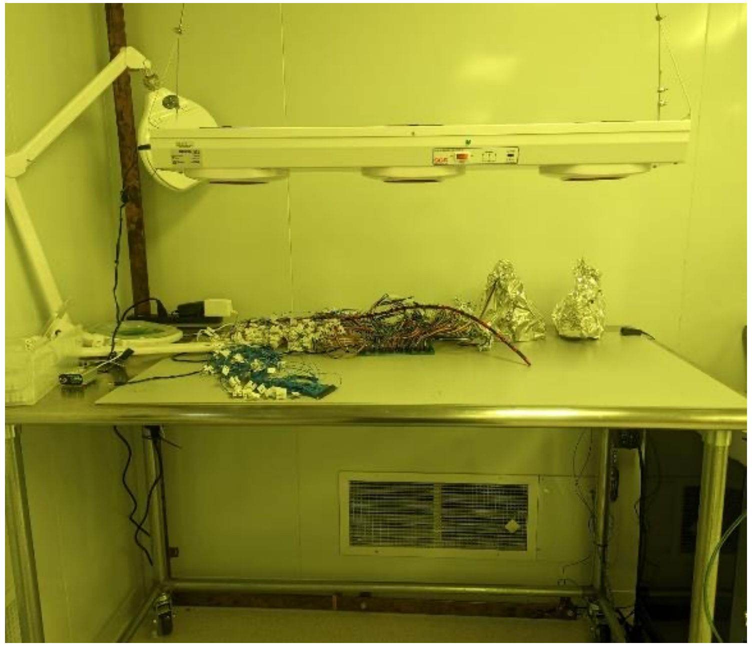
John Nugent,
Quantum Nano Fabrication and Characterization Facility

UNIVERSITY OF WATERLOO

CLEAN ROOM

Clean Room

975 sq ft
ISO 7 (Class 10,000)



Assembly Stations

ESD Safe clean assembly

Thermal Chamber

Test feedthrough
-73C to 200C

WET CHEMISTRY

Solvents

General purpose, cleaning and prep

Acids & Bases

Acid or base processes, non-HF

Hydrofluoric Acid

Wet silicon oxide etch, HF solutions only

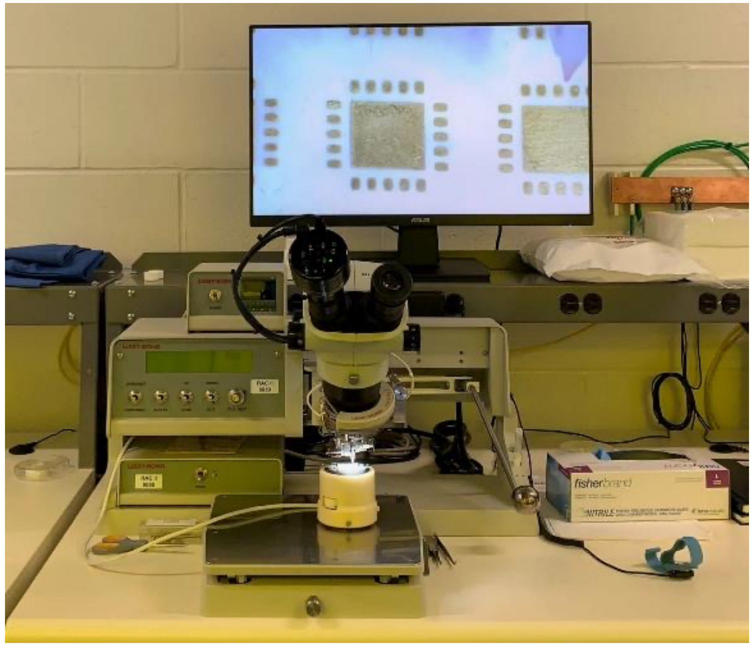
FABRICATION TOOLS

Diamond Saws

Precision, low speed <300rpm

Optical Microscopes

Leica, 5x-100x Bright/Dark Field
EvoVision Stereo



Wire Bonder

45deg wedge
25-micron aluminum or gold wire

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YOU+WATERLOO

Our greatest impact happens together.

ADDITIONAL RAC1/RAC2 RESOURCES

2024

UNIVERSITY OF WATERLOO

scientaomicron

LT-SPM LAB

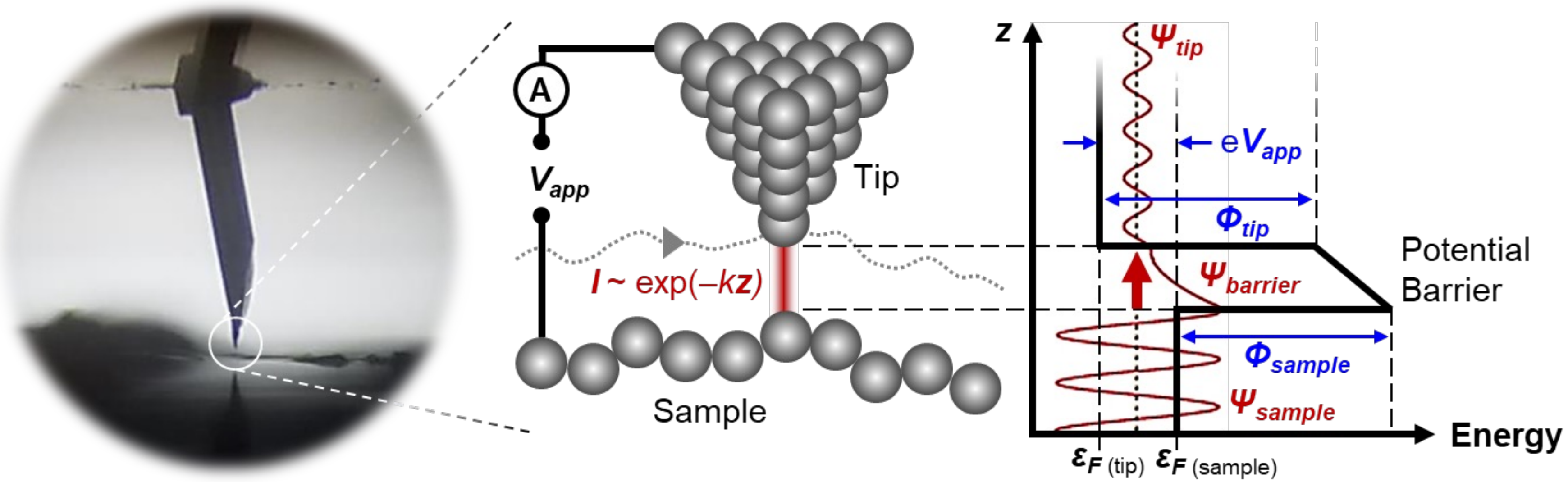
- STM with QPLUS AFM option
- Location: RAC 2 Room 1124

SCANNING TUNNELING MICROSCOPY

STM principle of operation

The tunneling current is highly sensitive to sample topography (i.e. z) and the local density of states (LDOS) of the sample.

- Atomic-scale imaging
- Probing of novel quantum states



Ref: https://www.spectraresearch.com/april-current-amplifiers-bring-may-ultra-low-current-stm/

CRYOGENIC UHV SCANNING CHAMBER

- Ultra-low vibrations

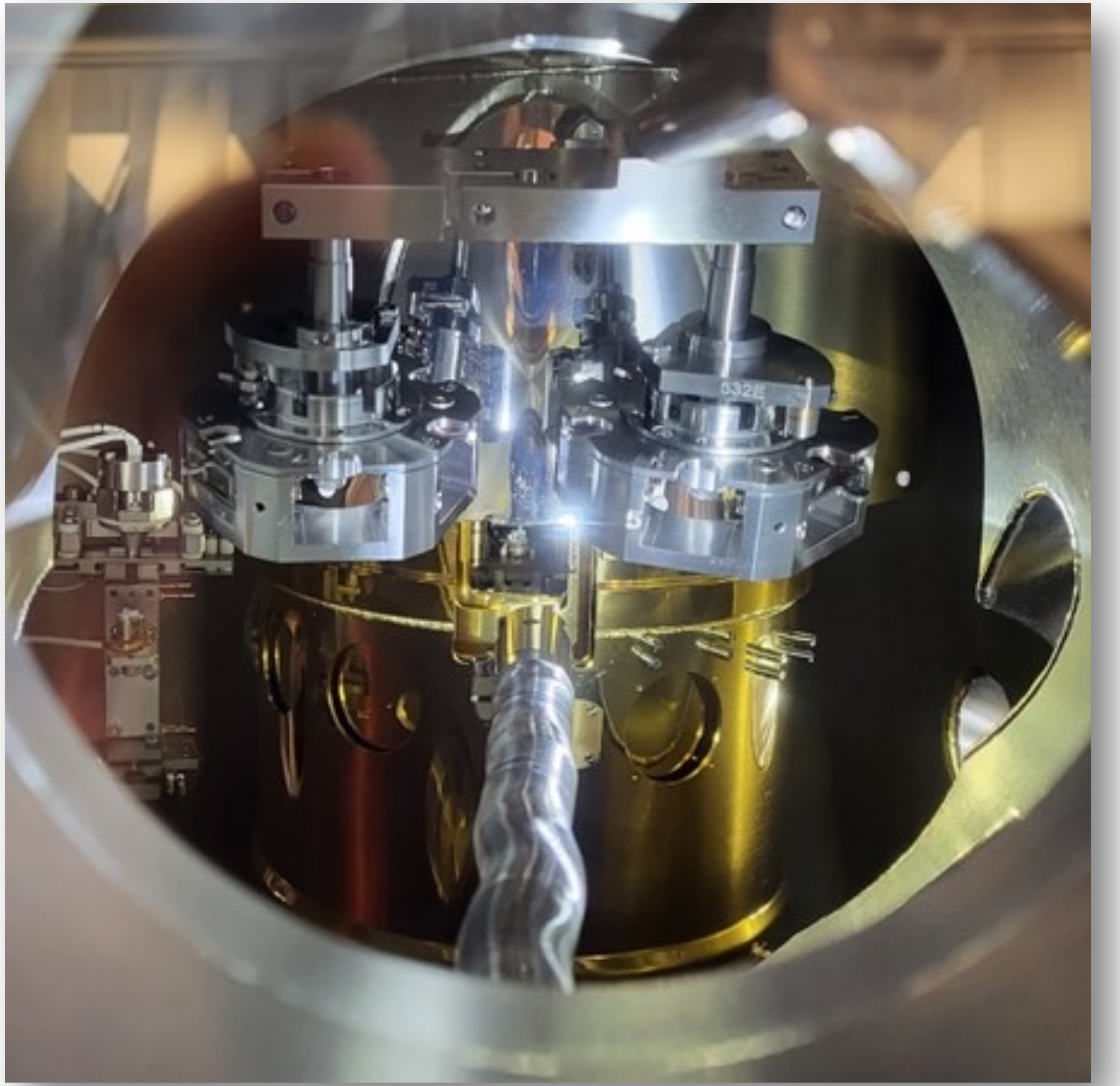
(isolation + low temperature)

3 scanner calibrations:

Room T, 77 K (LN2) and 5 K (LHe)

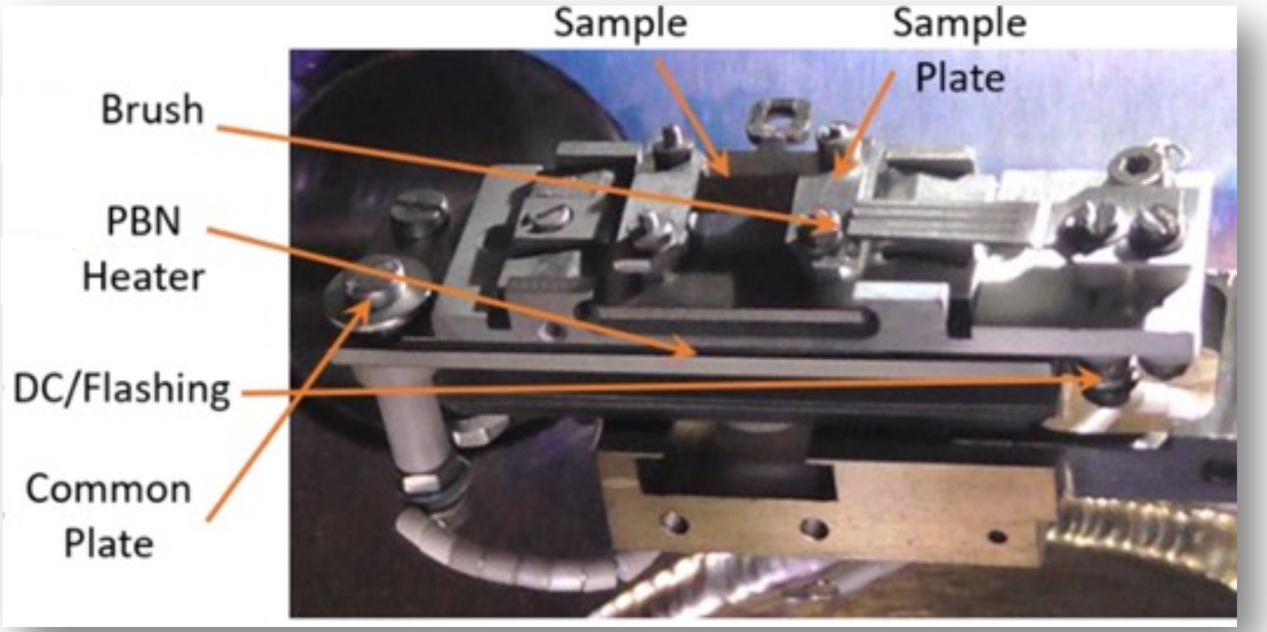
- Piezo scanner with ~pm level stability
- Sub-nA current amplifier

Rotating cryostat door access

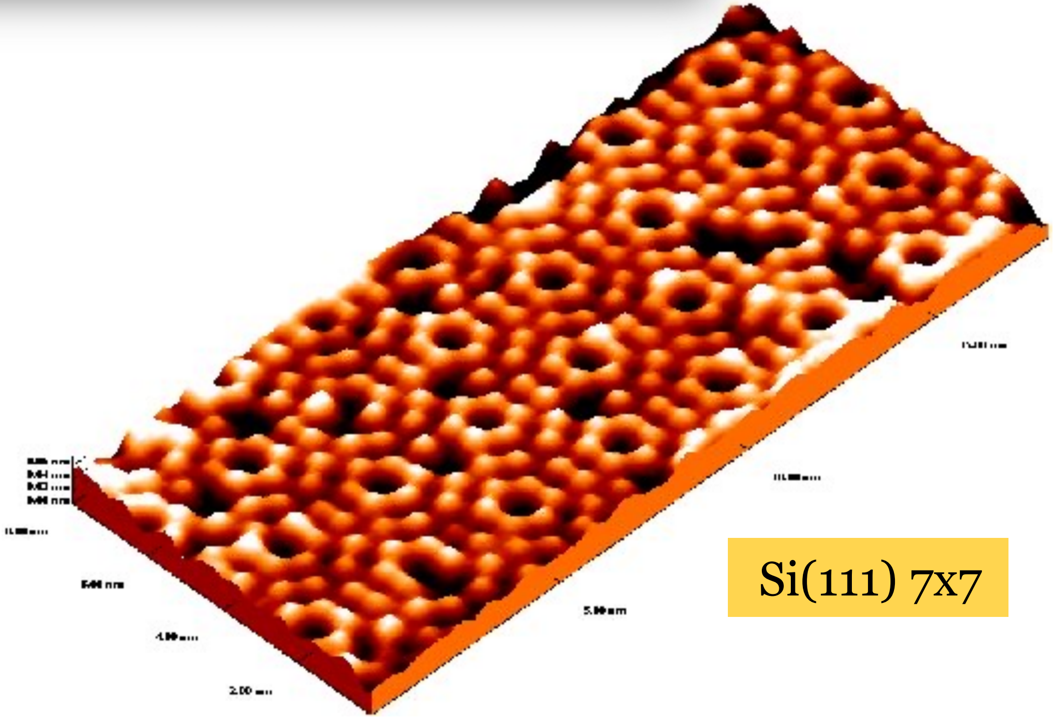


UHV
PREPARATION CHAMBER

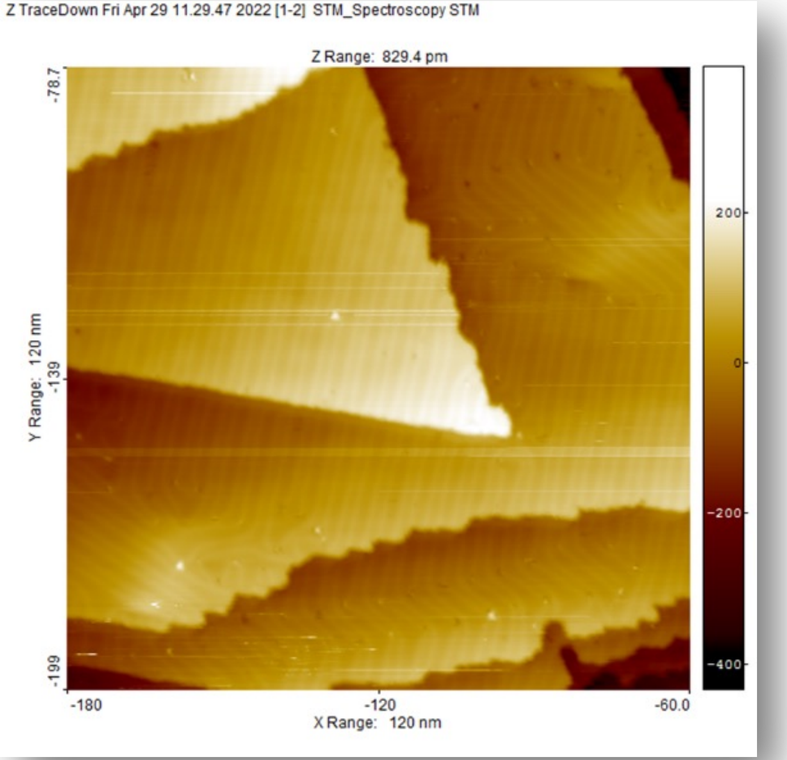
- Resistive heating stage
- Direct current annealing (specialized sample holder)
- Argon-ion RF sputtering gun
- In-situ sample cleaving tool



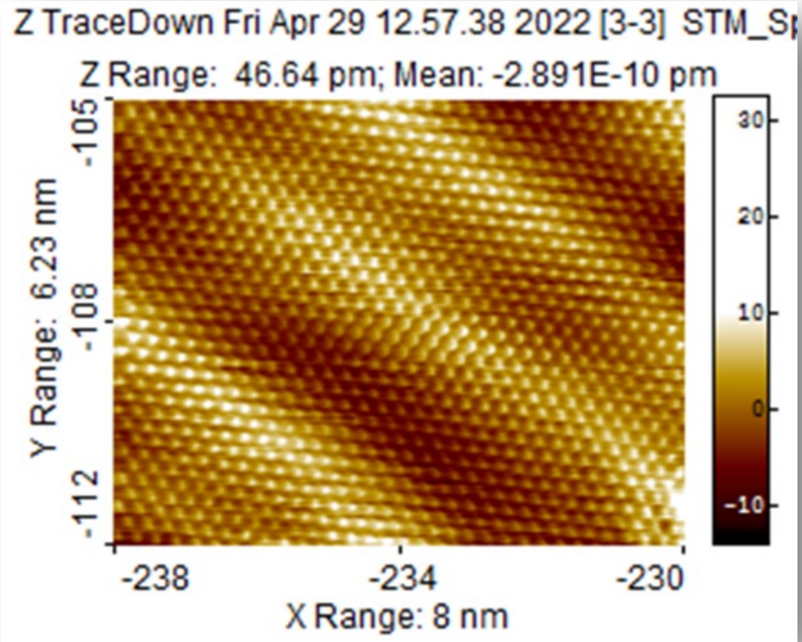
- Remove contamination/oxidation
- Surface reconstructions



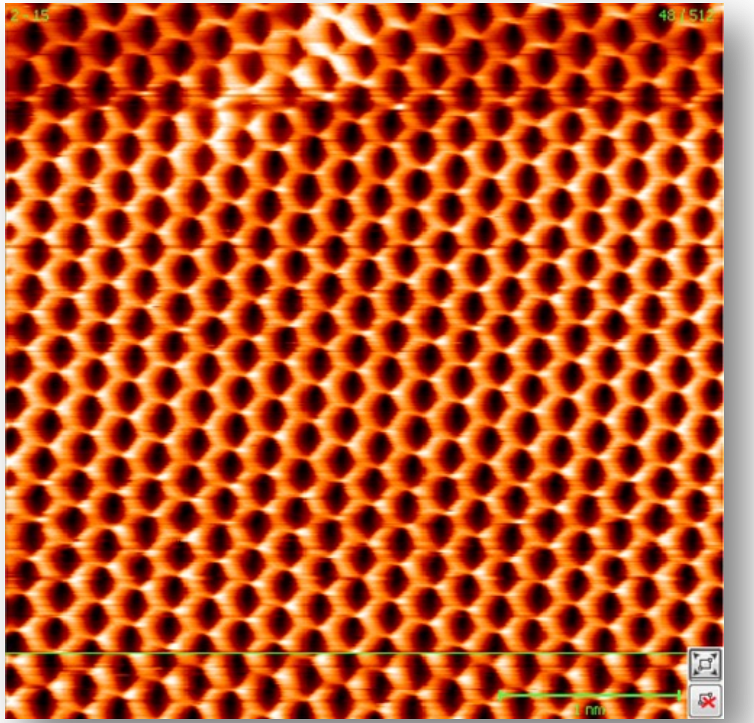
EXAMPLE RESULTS - STANDARDS



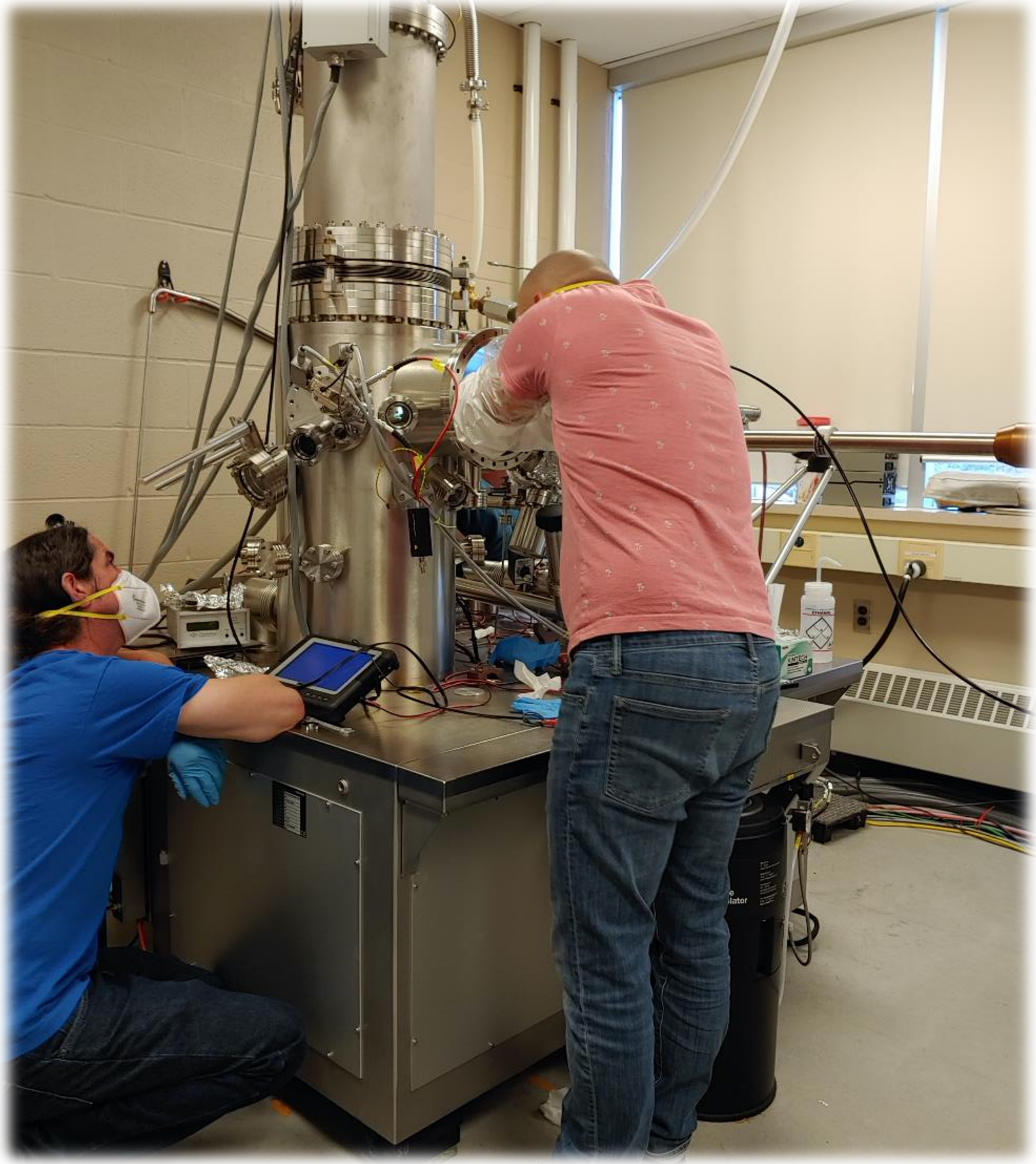
Terraces of Au (111) on Mica

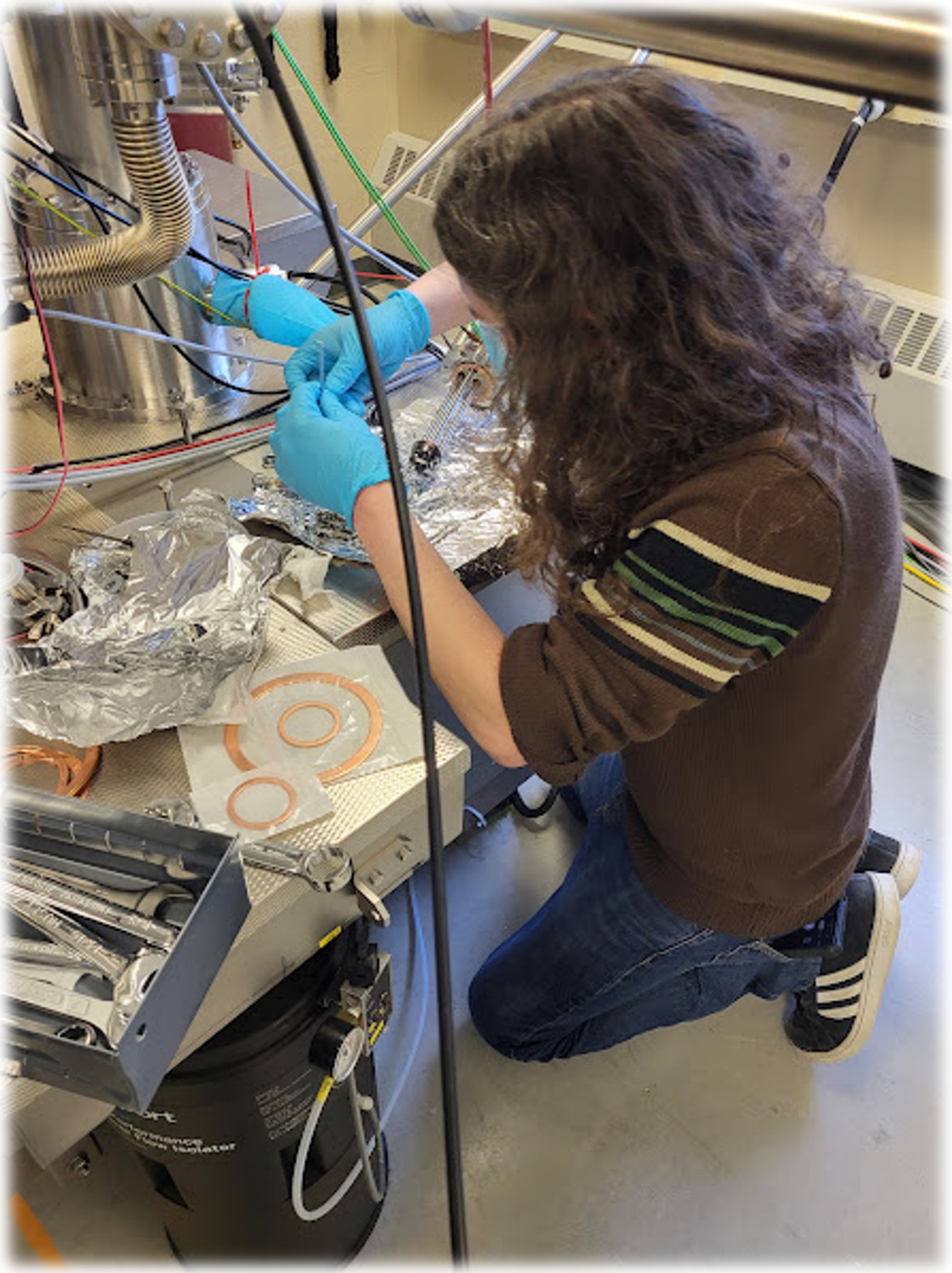


Atomic resolution of Au (111)



HOPG honeycomb lattice
(4 nm scale)





HIGH RESOLUTION XRD

D8 Discover

- Location: RAC 2 Room 2112

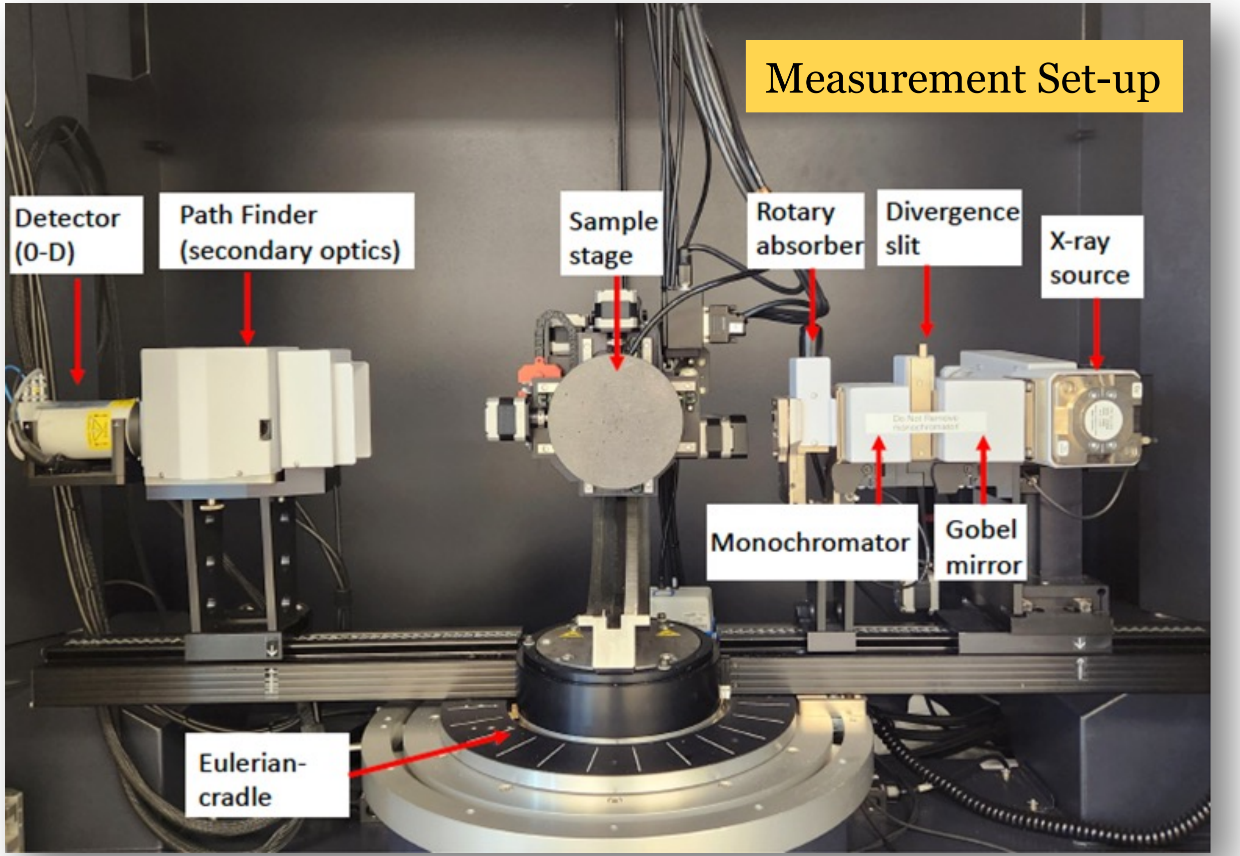
THIN-FILM HR-XRD

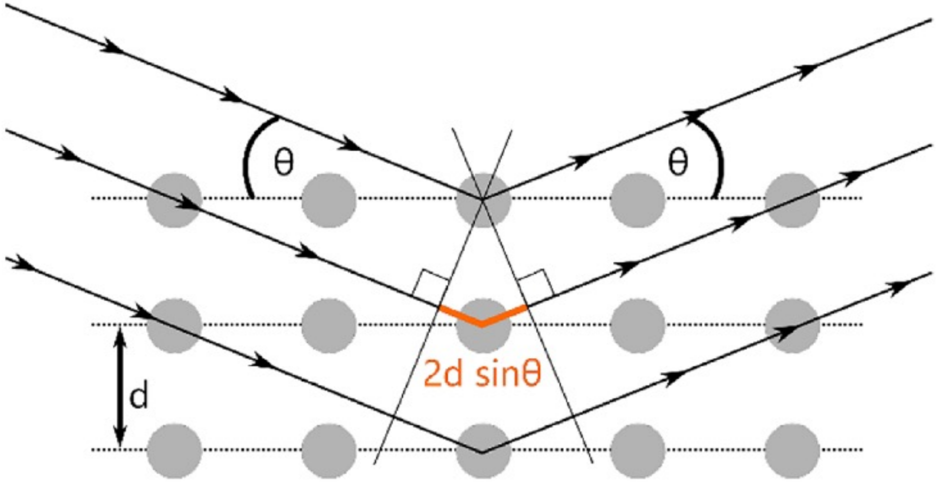
- Cu-source X-ray tube
- Centric Eulerian-cradle

Psi, Phi and X-Y-Z translation

- 1 cm □ to 5” Ø wafers
- Vacuum chuck
- 1.0 x 6.0 mm beam

Measurement Set-up





Diffraction from crystal planes

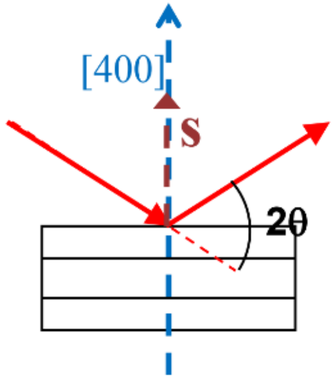
UNIVERSITY OF WATERLOO

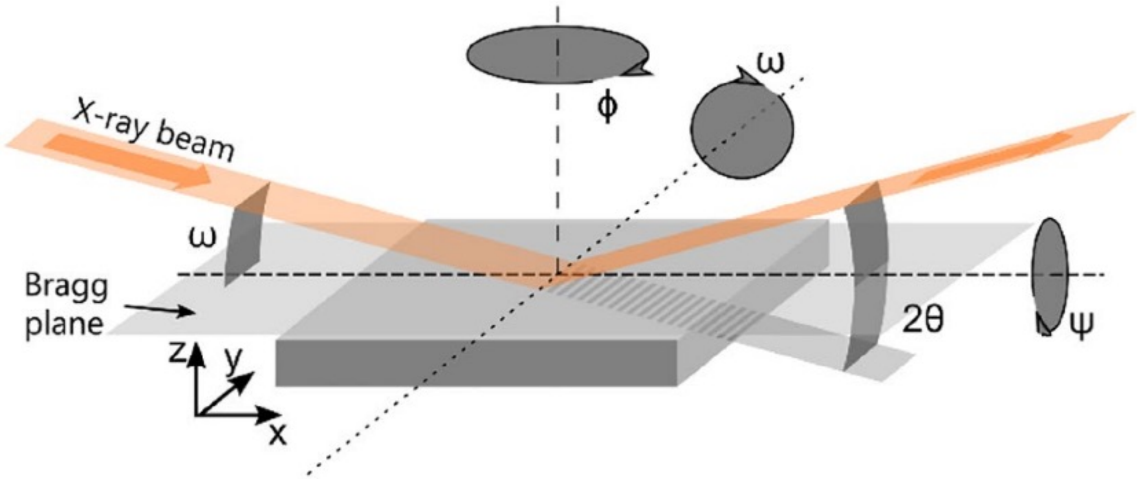
(2θ/ω)

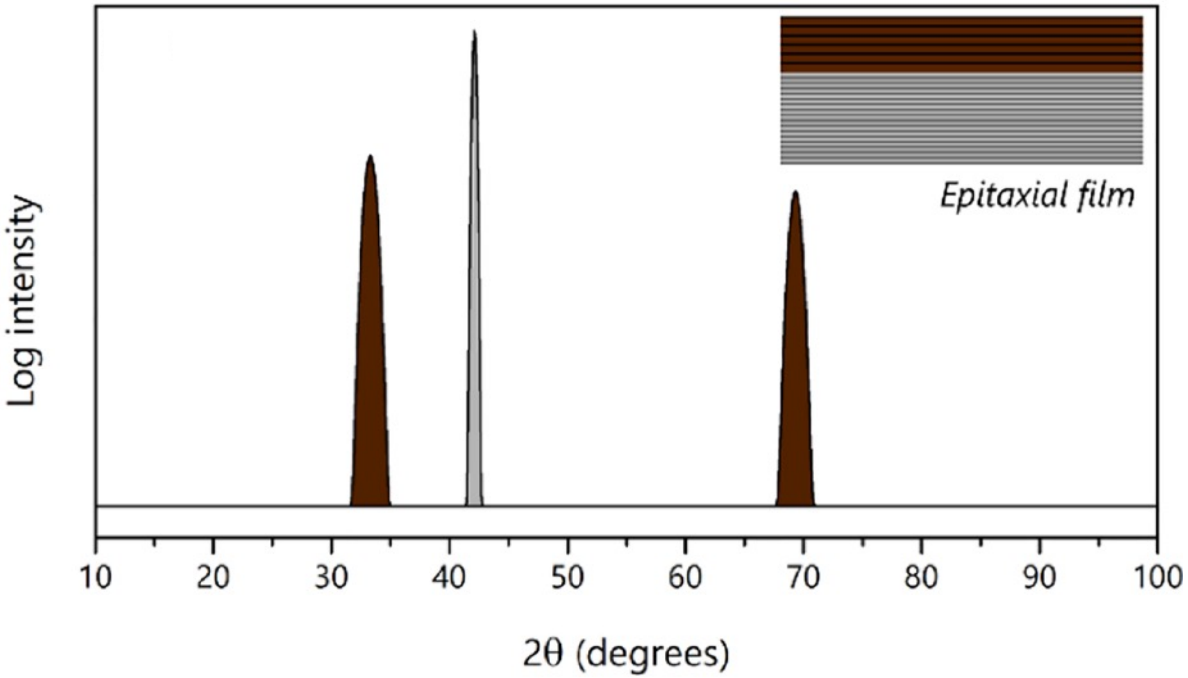
SYMMETRIC SCAN

Film orientation/crystallinity

- Maintain ω = ½ (2θ) + offset
- Diffraction vector is always aligned ⊥ to substrate
- Peaks occur for all 'out-of-plane' *hkl* reflections







Ref: Harrington & Santiso, J. of Electroceramics (2021) 47:141–163

(2θ/ω)
SYMMETRIC SCAN

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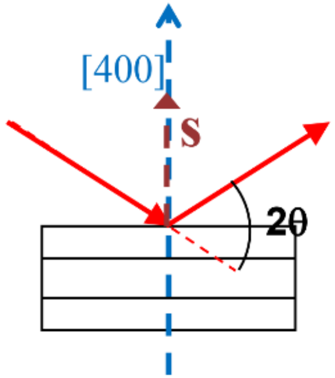
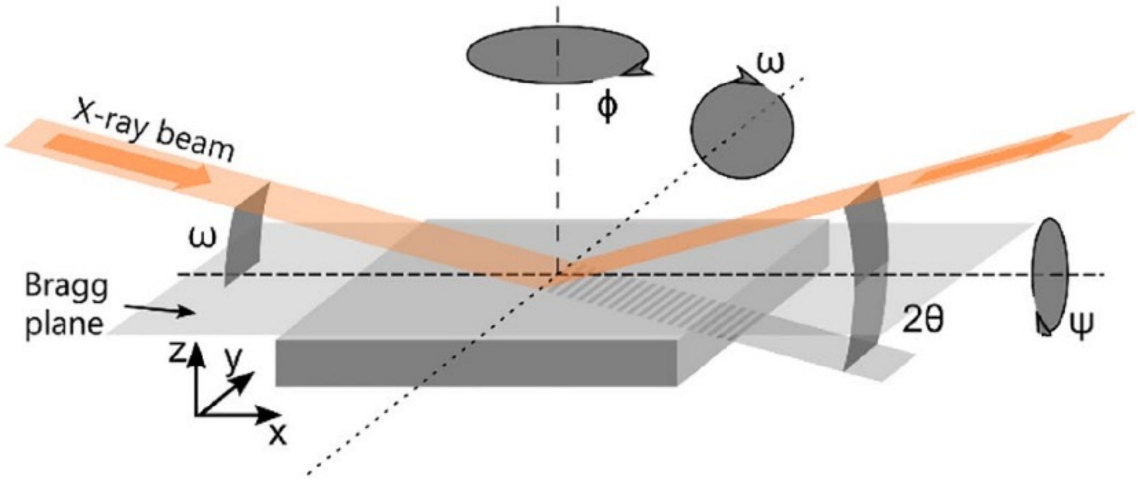
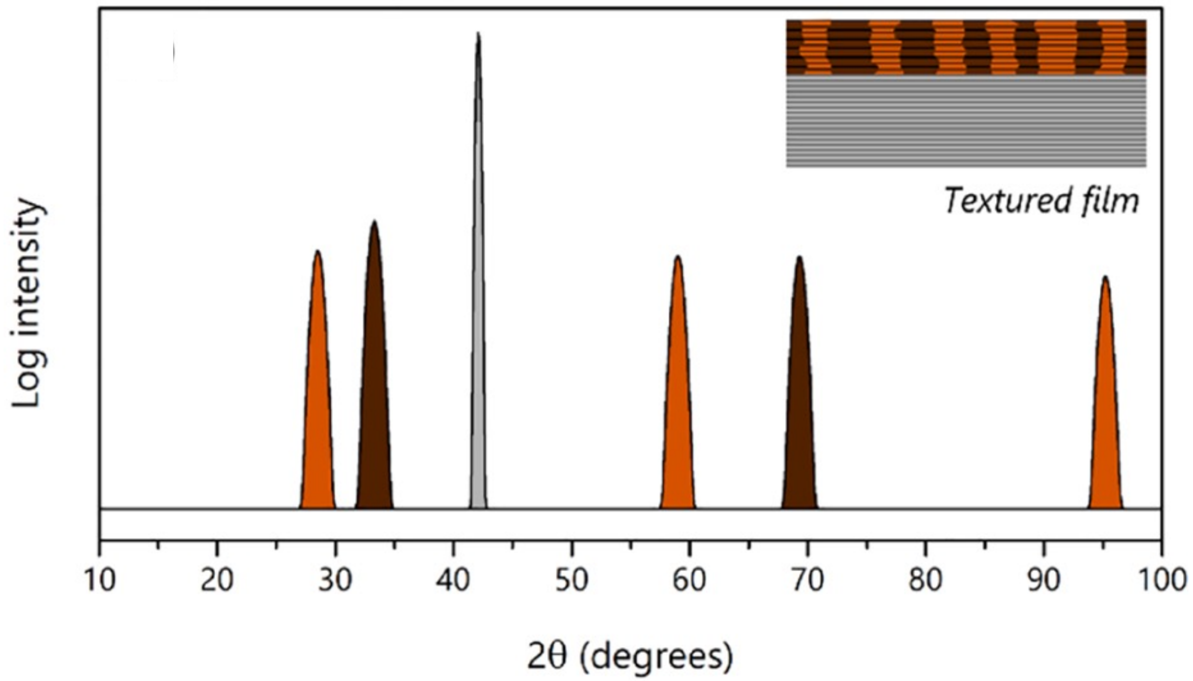
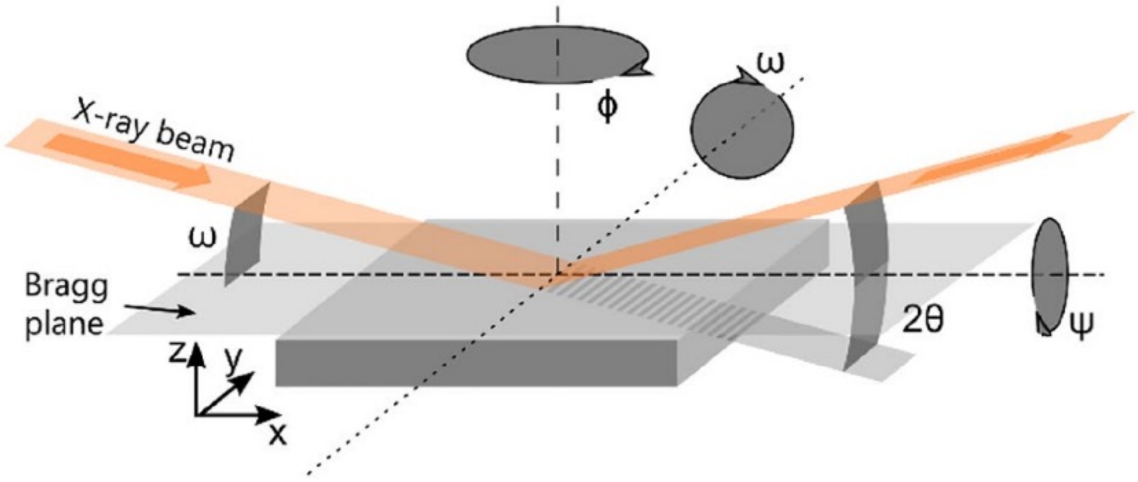




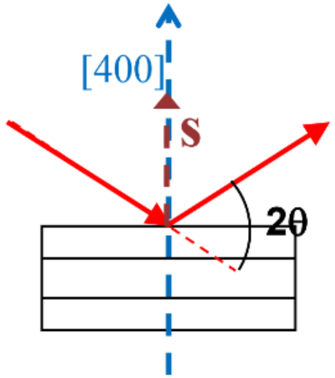


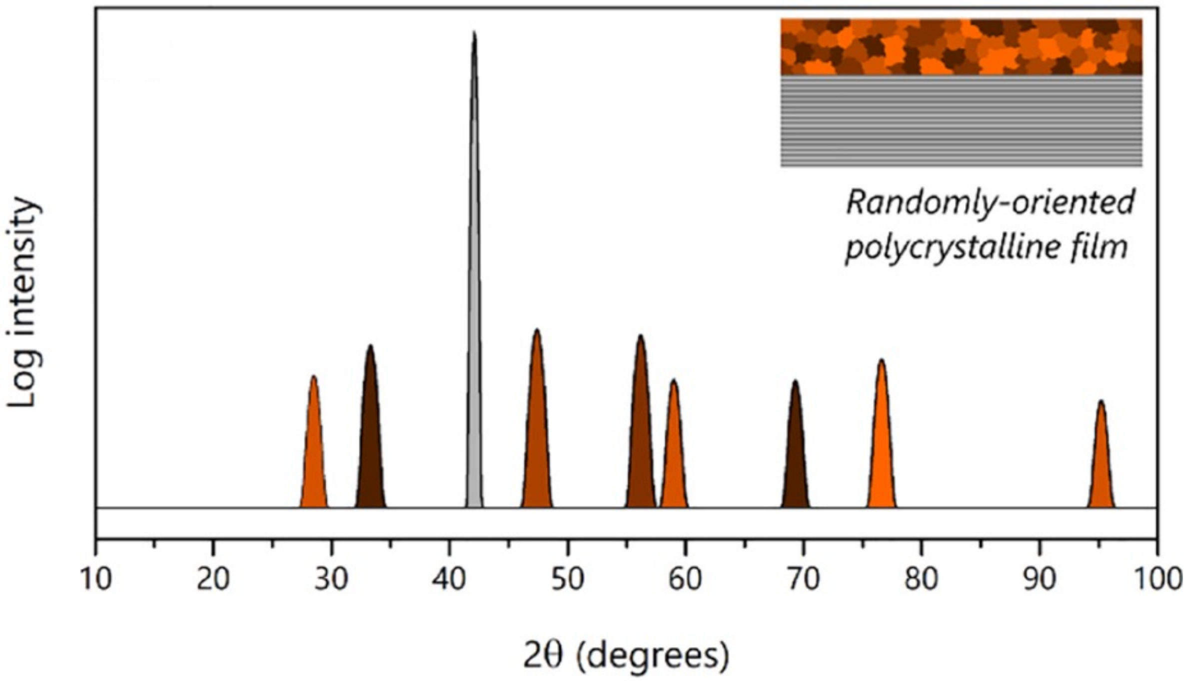
(2θ/ω)
SYMMETRIC SCAN



Film orientation/crystallinity

- Database of powder diffraction data for analysis

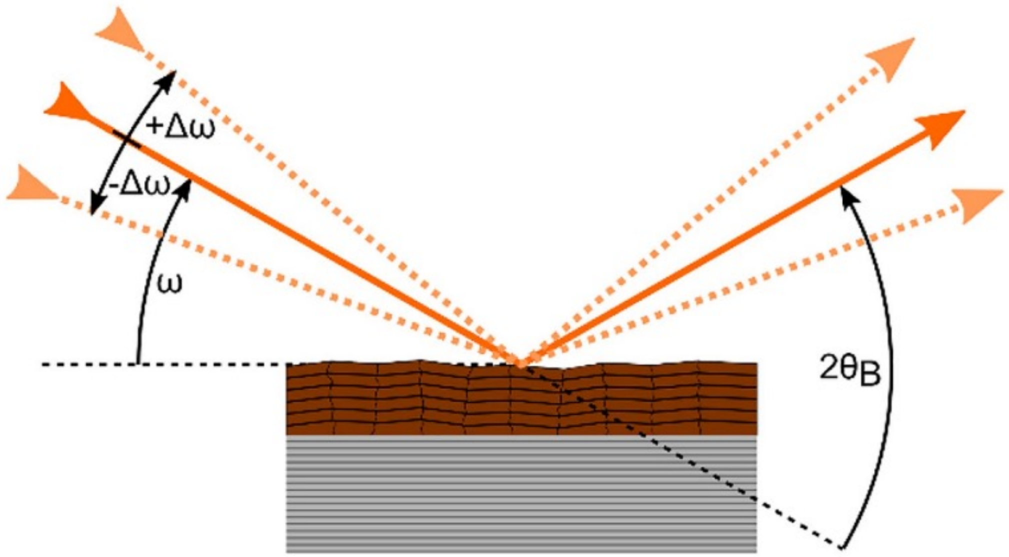


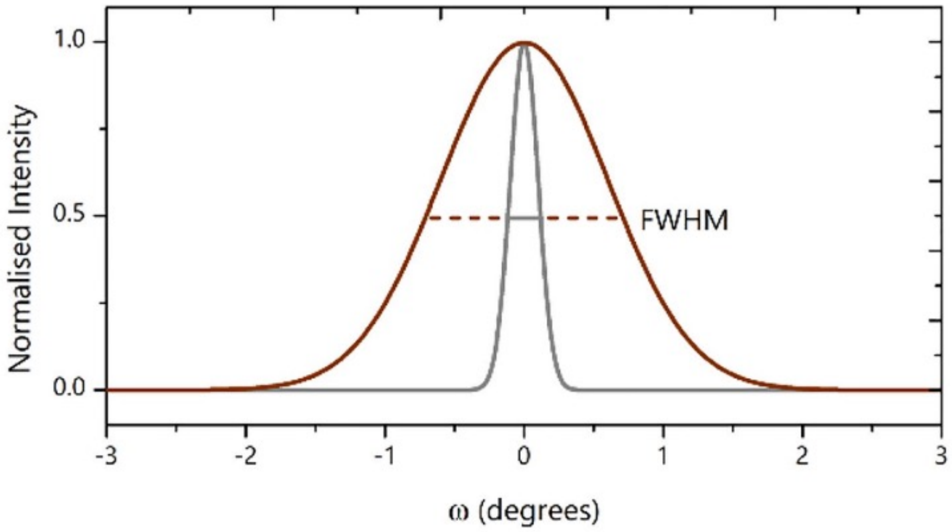


(XRD) ROCKING CURVE

The FWHM depends upon:

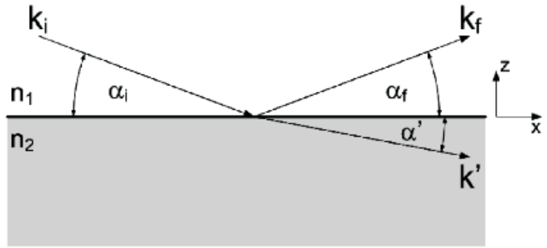
- the ‘mosaic spread’ of the grains
- density of dislocations
- substrate curvature

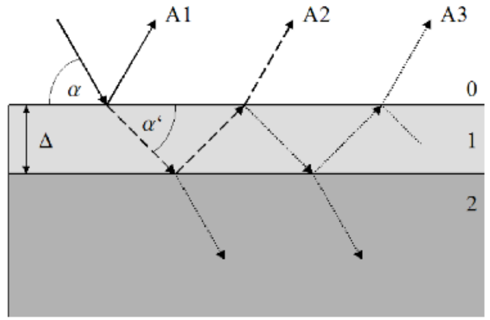


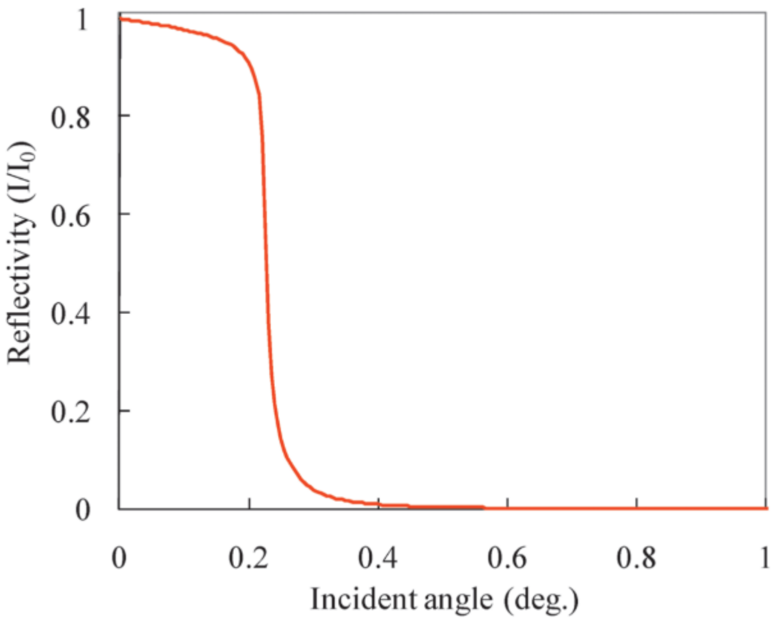


(XRR) REFLECTIVITY SCAN

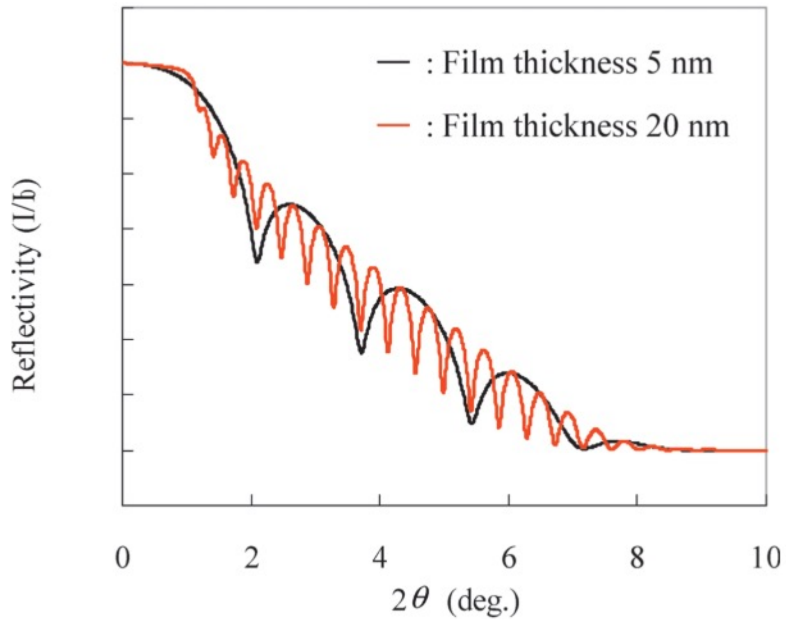
- Measure X-ray intensity at grazing incidence
- Crystalline <u>or</u> amorphous film stacks
- Model oscillations to extract film properties
- ~ nm to 1 µm thick







Substrate



Film Thickness

Ref: M. Yaaska, The Rigaku Journal **26**(2)2010

(XRR) REFLECTIVITY SCAN

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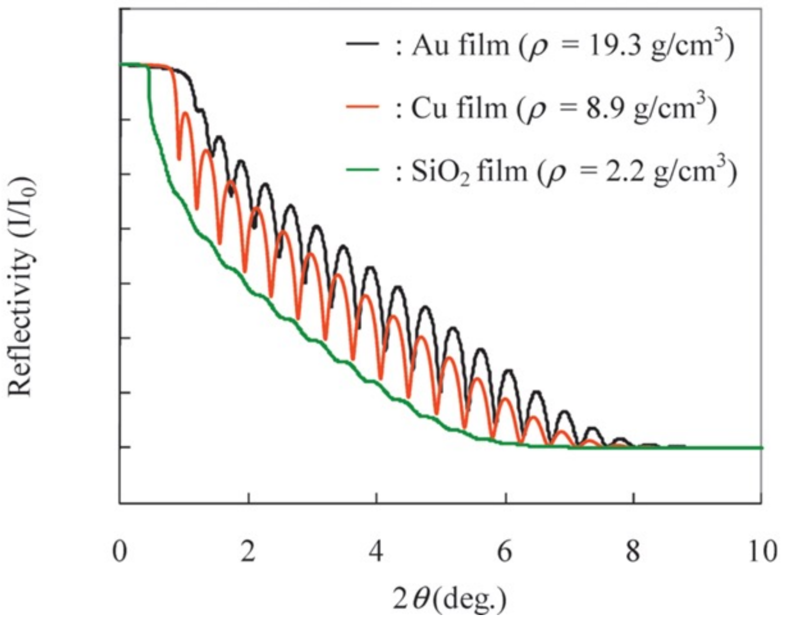
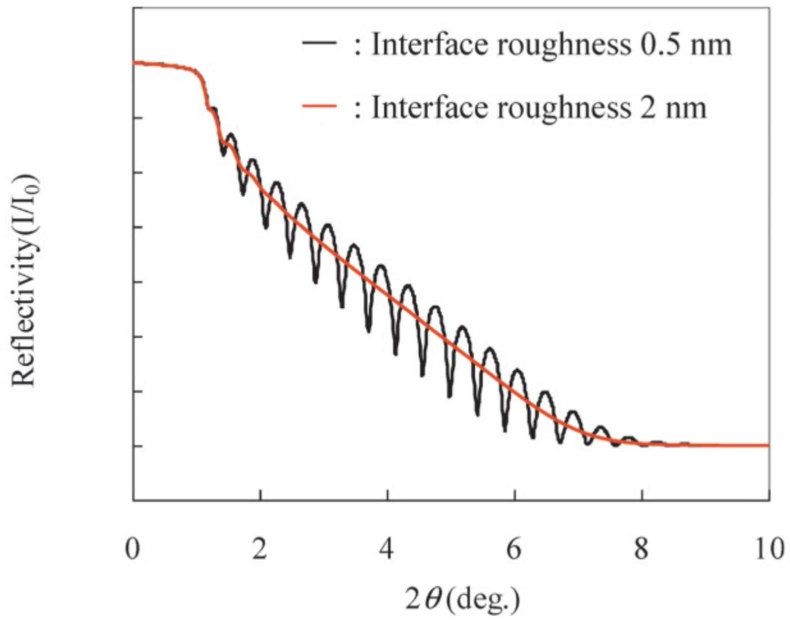


Density



Roughness