

4CeeD Lecture Series

Lecture #1: Introduction and Overview

March 21st, 2023

Use of 4CeeD Services for Material Scientists

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A timely and trusted curator and coordinator of scientific data

Lecture Series Learning Objectives

- Lecture 1 (3/21): Overview of 4CeeD
 - Introduction to 4CeeD
 - Breakout Session #1: Log-In and Explore
 - Key 4CeeD Features: Templates for Fast Storage
 - Breakout Session #2: Creating and Using Templates
- Lecture 2 (3/23): Workshop (Cont.) & Advanced Features
- Lecture 3 (3/28): 4CeeD Backend Services
- Lecture 4 (3/30): SENSELET/MAINTLET

Introductory Questionnaire

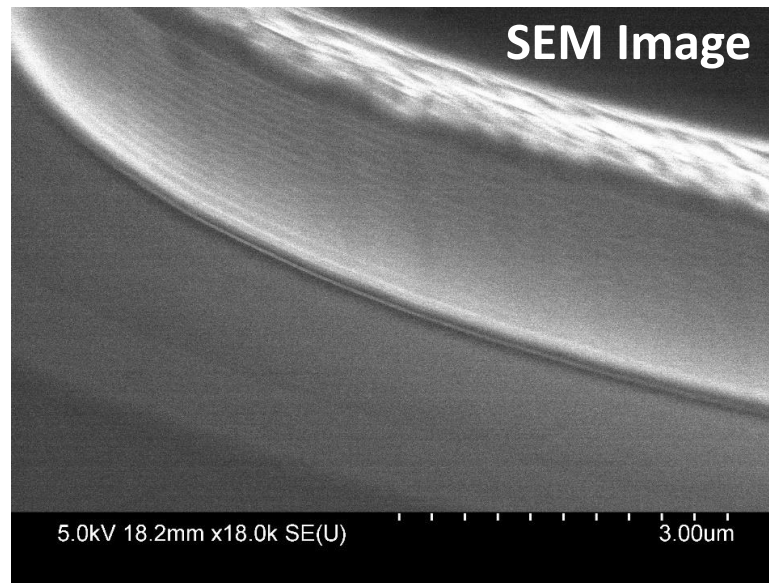
- Do you describe yourself more of a computer scientist or a material scientist?
- Do you conduct your research primarily on modeling/simulation or experimental research?

What is 4CeeD and its goals?

- Address Scientific **Digital Data Acquisition, Curation and Sharing** prior to Scientific Publication of Results via **Private Cloud Storage Facility**



Instrument
(in MRL/HMNTL/BI)



Sidewall View of AlGaAs DBR
Hitachi S4800 SEM

Experimental Setting

Time: 30 min

Temp: 425°C

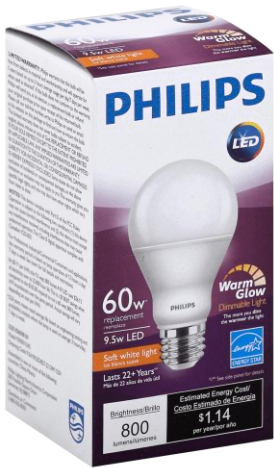
Observation Notes:

Oxidation depth is 12 μm
Oxidation layer is $\text{Al}_{0.98}\text{GaAs}$
 N_2 bubbler flowing steam
2" Quartz tube furnace

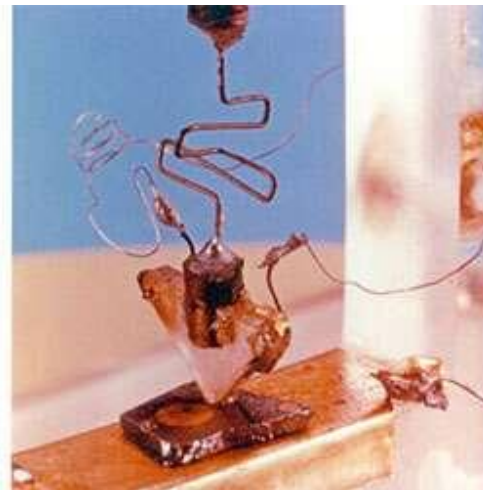
Sample Experimental Dataset from SEM Imaging

Why is current data collection an issue?

- Consideration of National Academy Studies: **20-year gap** from discovery of new materials to implementation of next-generation devices
- Necessitates **real-time** and **trusted** processing from **materials – to-devices digital data**



Red LED (1962) Holonyak, Jr.
Blue LED (1993) Nakamura



Transistor (1947) Bardeen



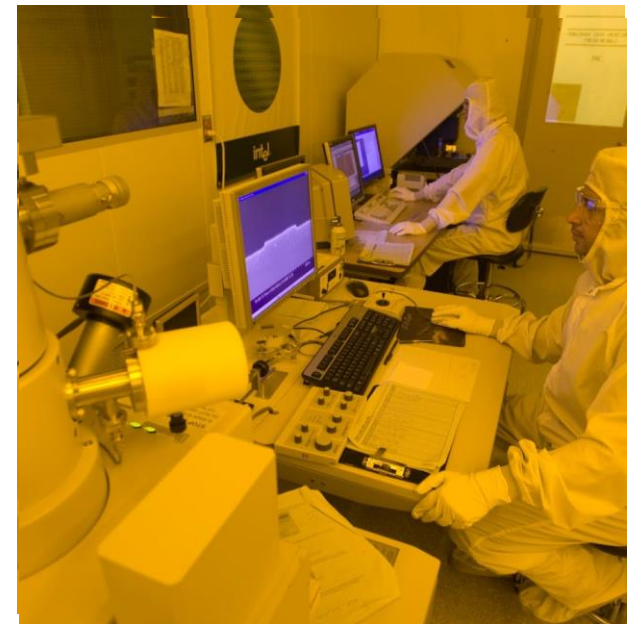
Graphene(2004) Geim and
Novoselov

Why is University data collection unique?

- Industry concentrates on scaling and improving reliability and manufacturability to deliver an end product (smartphone, cars)
- Academia concentrates on diverse and riskier research using older equipment to prove innovative ideas and concepts

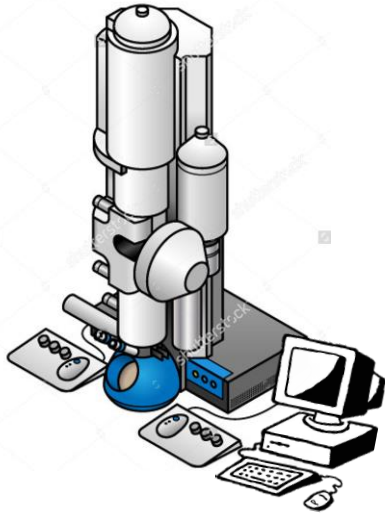


Industrial Wafer Fabrication Cleanroom



University Cleanroom
(HMNTL)

Current State of Data Capture

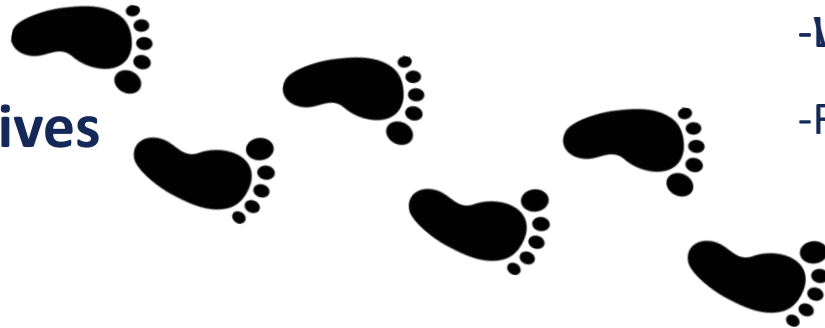


**Instrument
(MRL/HMNTL)**

- Fabricate experimental sample
- Prepare analytical sample
- Bring sample to instrument for analysis
- **Extract data (File conversion)**
- **Transport data to office computer**
- **Analyze data**



Flash Drives

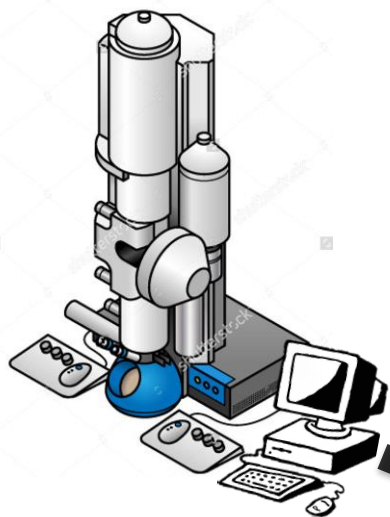


**Office
(MRL/MEB/MNMS)**

~~Standard workflow~~ **Standard workflow analysis**

- Excessively file oriented schemes
- Very limited access to data space
- What (if any) data is files, archives?
- Retroactive not reactive

Scenario with 4CeeD Integration



- Fabricate experimental sample
- Prepare analytical sample
- Bring sample to instrument for analysis
- **Extract data (NO FILE CONVERSION)**
- **Transport data to office computer (DIRECT)**
- **Analyze data (REAL TIME)**
- Repeat per iteration



**Instrument
(MRL/MNTL)**



Beneficial Data Interface

- No file conversion
- No data transport
- Real time reporting
- Easy data searching



Laptop



Campus PC



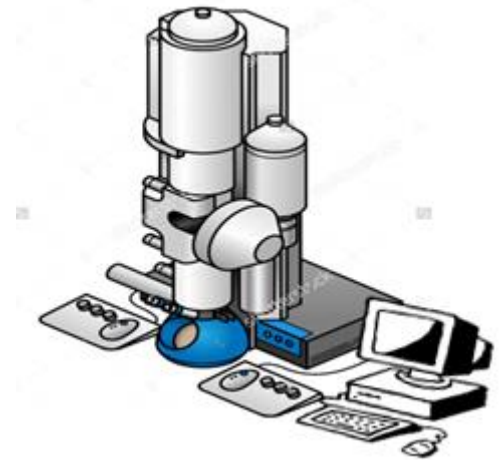
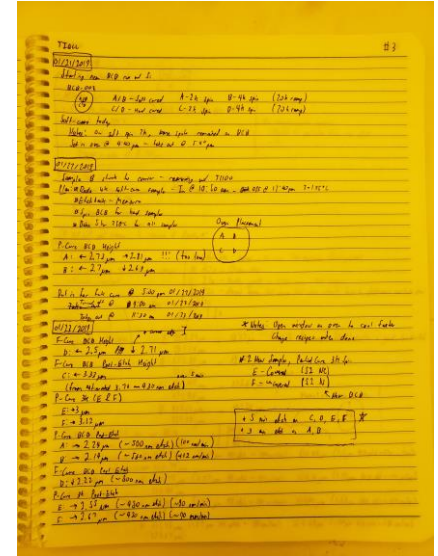
Collaborators



**Office
(ECEB)**

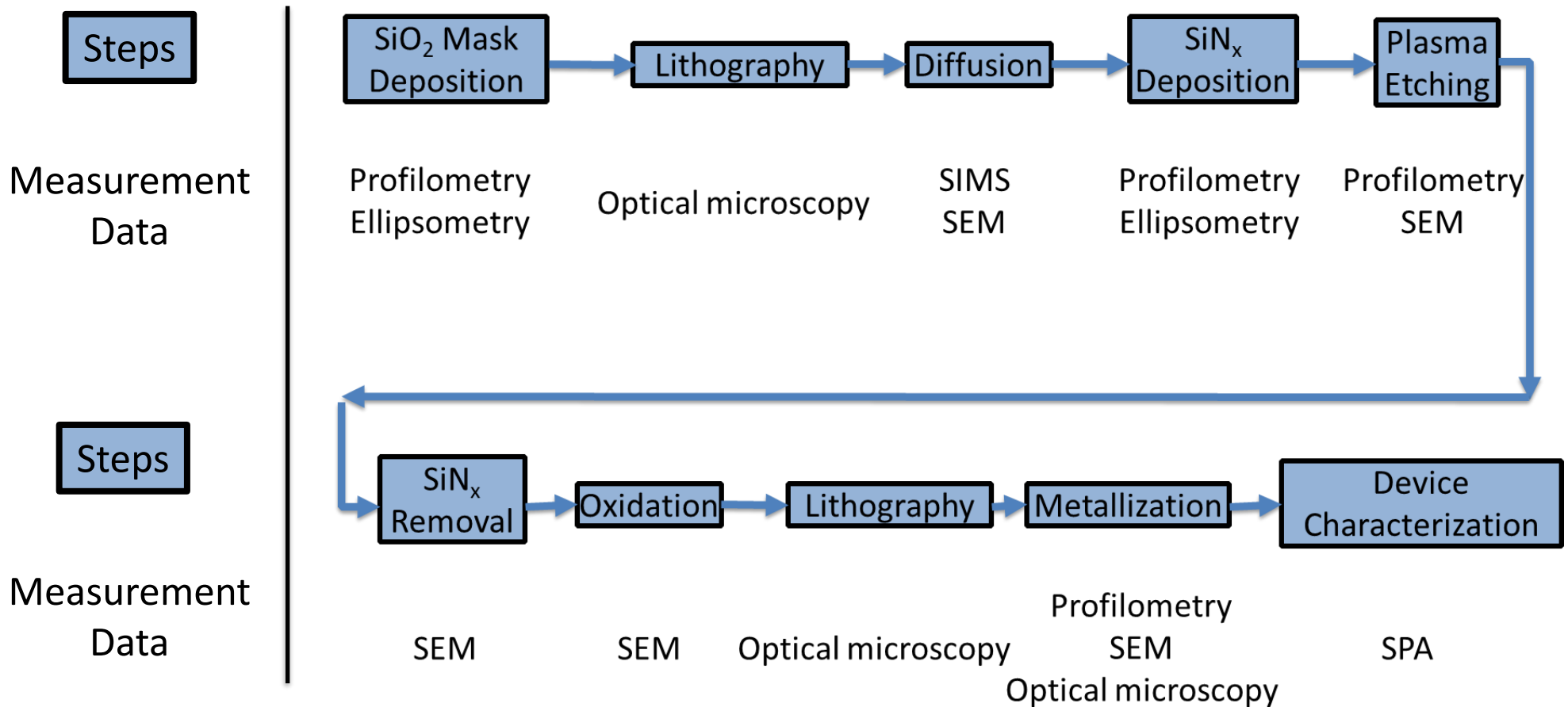
How is Metadata Currently Stored?

- Manual notetaking of complex experiments can lead to inconsistent or inadequate documentation
- Data transfer from tools is often done using flash-drive or emails that carry limitations and security risks
- Material research data is expensive and time intensive
 - Publication data is often documented well but remaining data is discarded

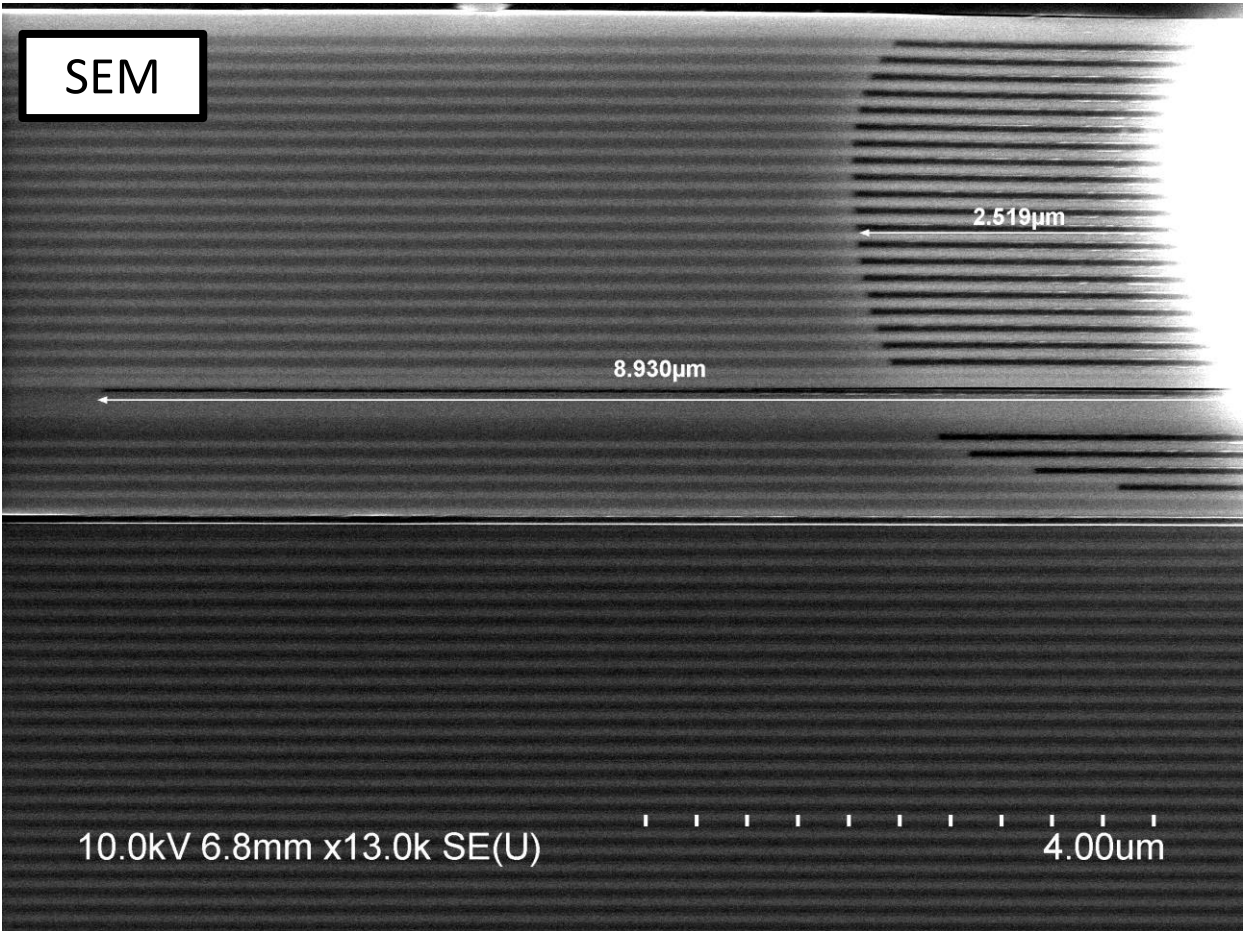


Metadata of Device Development Process

- Experiments can have multiple steps where each step is verified for success by various metrology methods



How is Metadata Currently Stored?



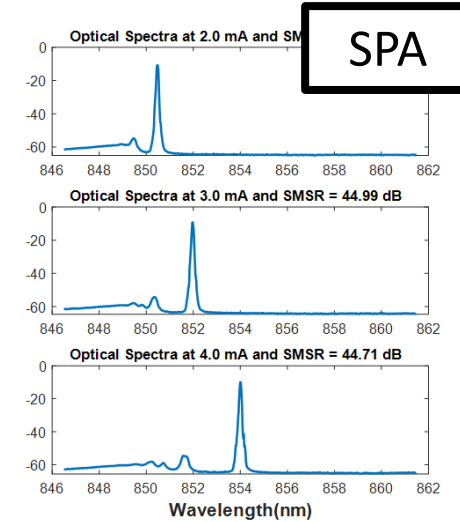
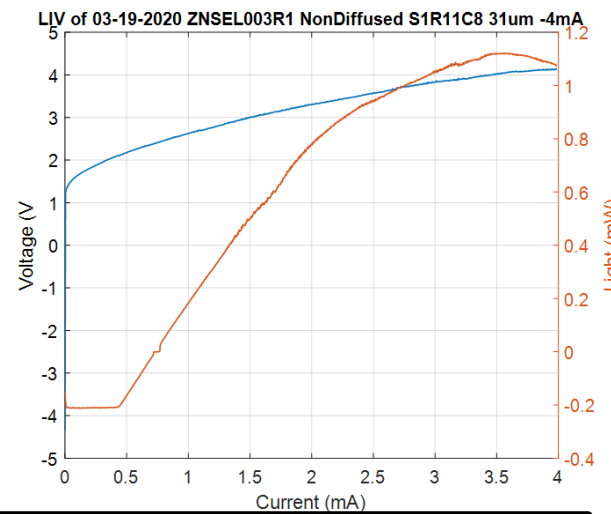
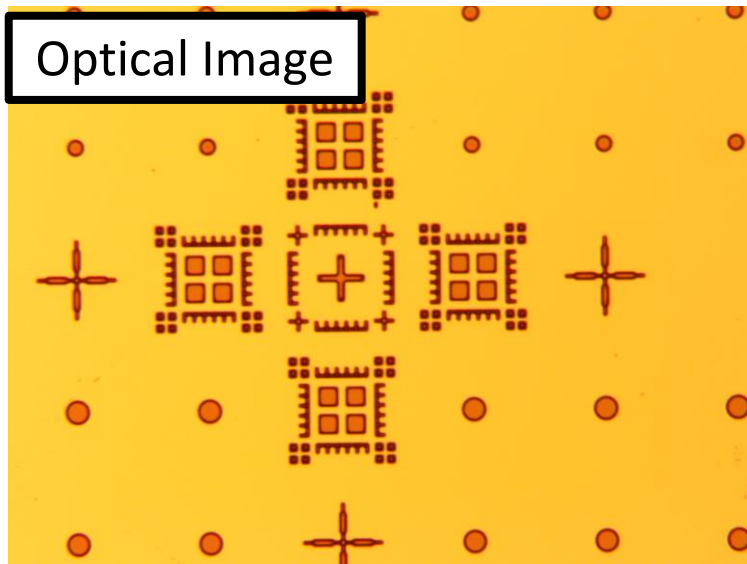
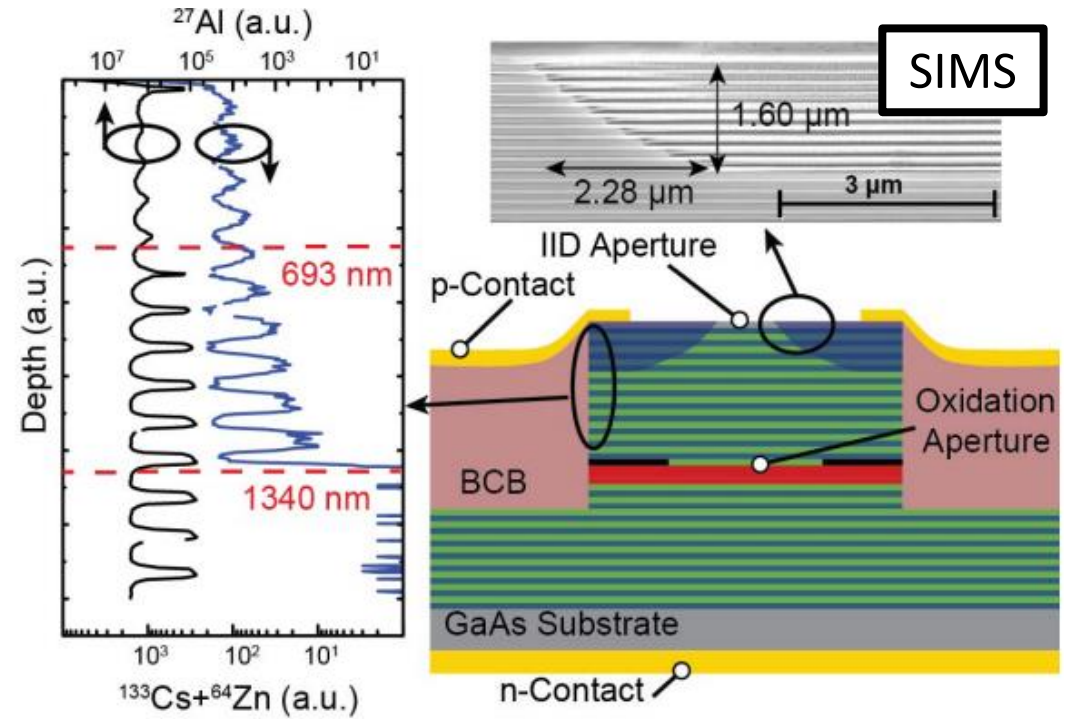
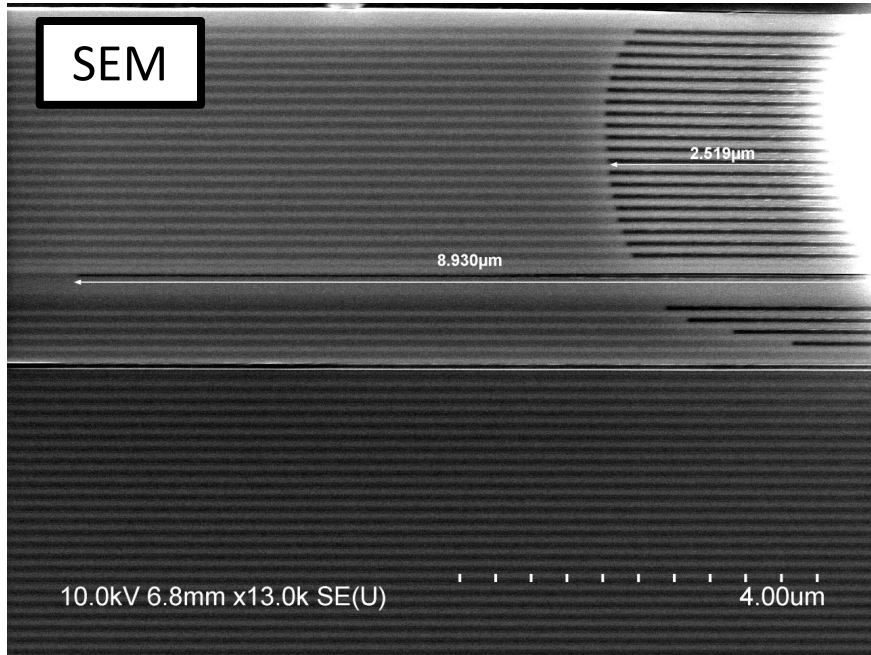
Experimental Setting:
Time: 11 minutes
Temperature: 425°C

Material Analysis:
Oxidation Depth: 8.93 μm
Oxidation Layer: $\text{Al}_{0.98}\text{Ga}_{0.02}\text{As}$
Furnace: N_2 Ambient, 2" Quartz

SEM Image Settings
Scale: 4 μm (10 divisions)
Acceleration Voltage: 10.0 kV
Working Distance: 6.8 mm

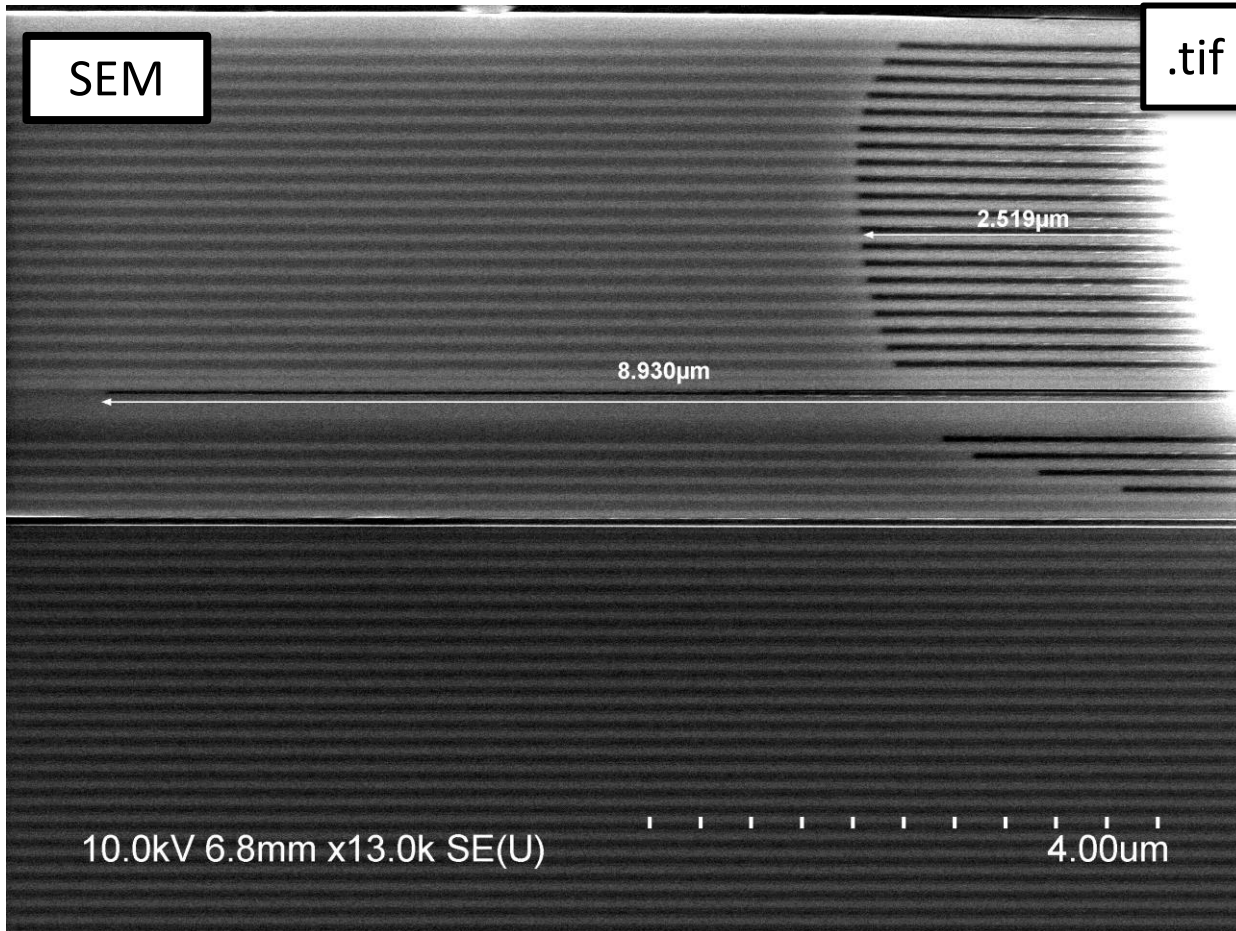
- Multiple text and image files are necessary to capture all the pertinent data of a single experiment

Example of Metrology Data (SIMS, SEM, OM, SPA)



Vastly different data formats for same device

Storing Multiple File Types



Experimental Setting:

Time: 11 minutes
Temperature: 425°C

.txt

Material Analysis:

Oxidation Depth: 8.93 μm
Oxidation Layer: $\text{Al}_{0.98}\text{Ga}_{0.02}\text{As}$
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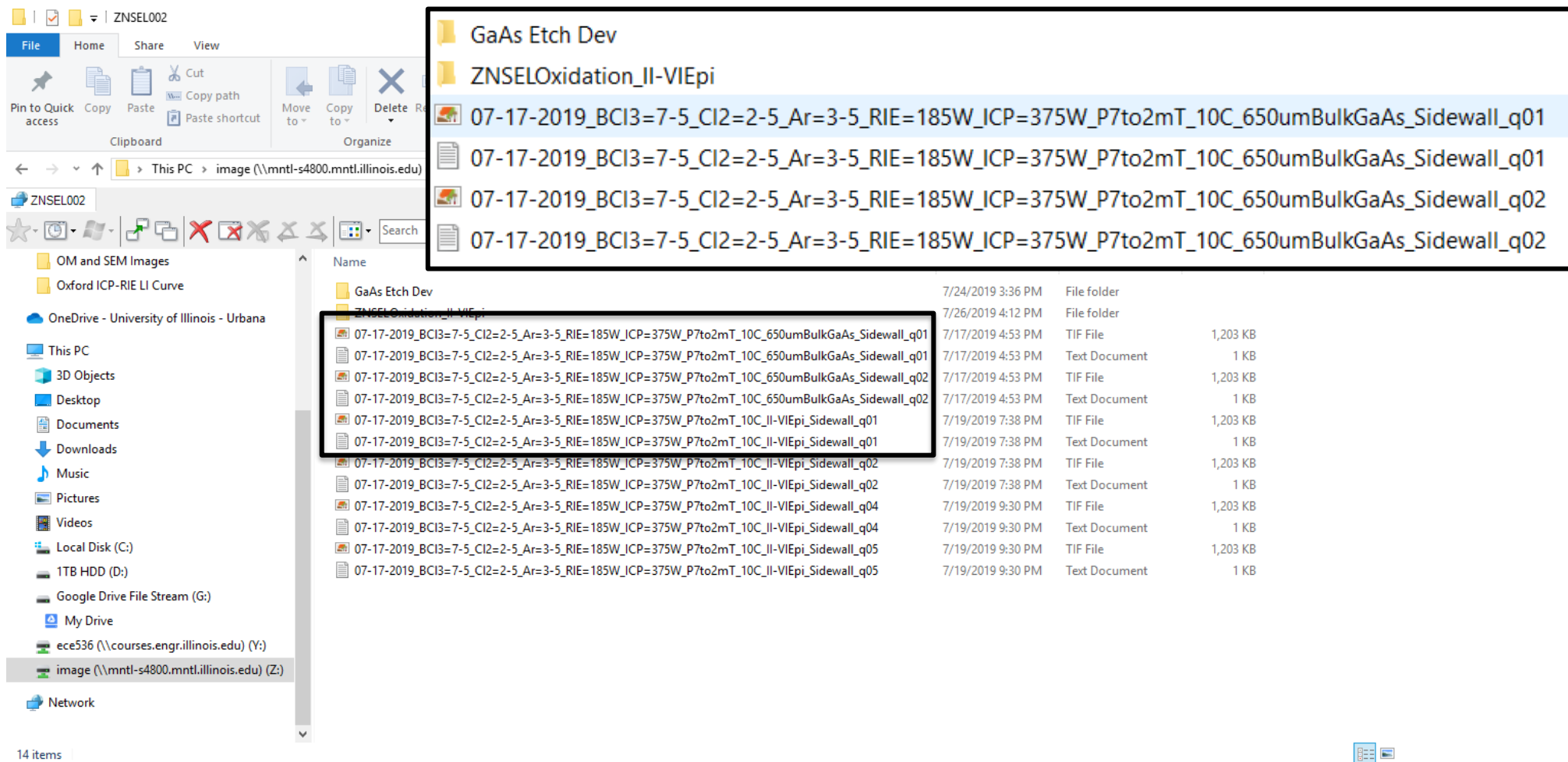
SEM Image Settings

Scale: 4 μm (10 divisions)
Acceleration Voltage: 10.0 kV
Working Distance: 6.8 mm

.txt

- Multiple text and image files are necessary to capture all the pertinent data of a single experiment

How this looks from File Explorer



- File explorer is limited to default “file list” where information is kept in long text names

How this look from 4CeeD [Datasets]

Patrick Su / Sample 1

VCSEL Etching Experiment

Created by Patrick Su

All Rights Reserved Patrick Su

Created on Jul 02, 2019

Access: Space Default (Private) Private

Public

Result image of 07022019-ICP-RIE Etching Experiment [↗](#)

[+ Add Files](#) [↓ Download All Files](#) [🗑 Delete](#)

Files

Metadata

Comments (0)



VCSEL GaAs Etch Sample 4CeeD.tif

image/tiff
Jul 02, 2019
1.2 MB

[Download](#)
[★ Follow](#)

👁 0 🗑 0 🗨 0

Space containing the Dataset

Select a Space

+ ADD

Collections containing the Dataset



GaAs Etching Development

1 dataset | [✕ Remove](#)

Select a collection

+ ADD

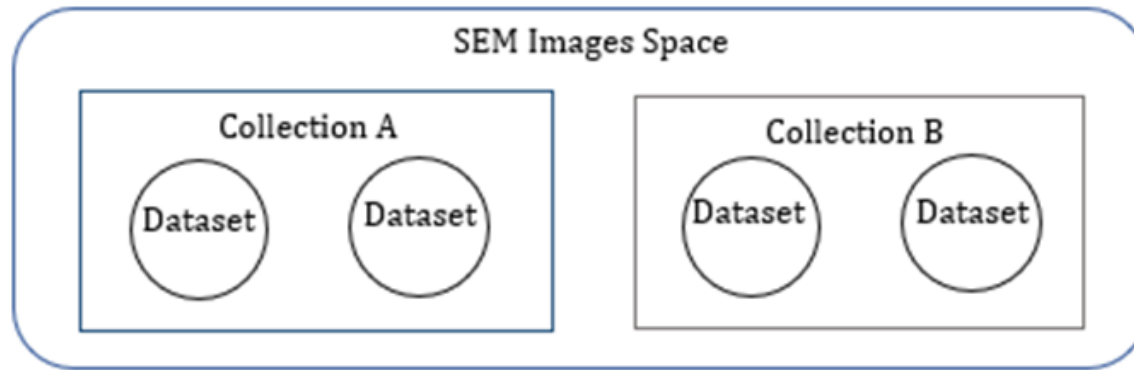
Tags

TAG

- 4CeeD is designed to present only pertinent information for quick understanding of the experiment

Data Hierarchy in 4CeeD

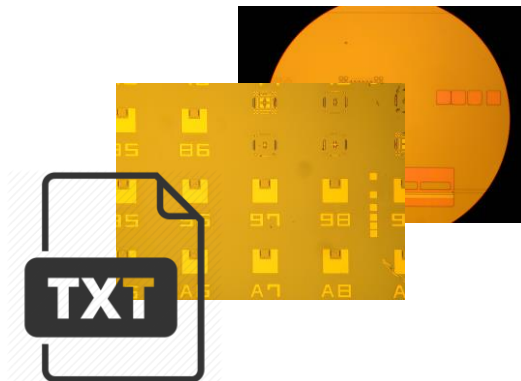
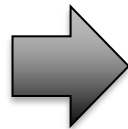
- “Spaces”, “Collections”, and “Datasets”



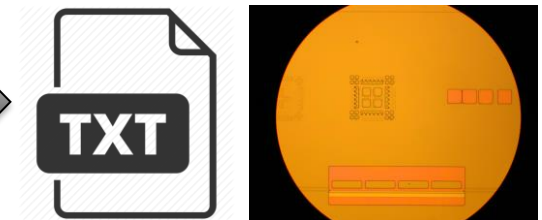
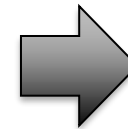
4CeeD Hierarchy



Space (Projects)



Collections (Experiments)



Datasets (Data)

Data Organization Structure

1) Space

Owner

Shared User

Shared User

Shared User


Shared User

Shared User

Shared User

2) Collection

3) Datasets



10. Base Zinc Diffusion

Process of diffusing Zn into the base region of the TI-QCL to increase doping and improve contact resistance.

Note: Due to instability of SiNx, the hardmask was redone with 100 nm SiO2.

Process (See detailed process on sheet in 2111):

1. Prepare tubes...

Owner: Robert Kaufman
Created on Apr 12, 2019



9. SiNx Diffusion Mask Definition Etch

NOTE! For future diffusions, do not use SiNx on iHP lattice matched materials as the mask does not hold up.

Open etch to define the diffusion mask.

Process (On Oxford Fraun REE):

1. Recipe session (Dateless-SiNx-Etch)
- 2 min...

Owner: Robert Kaufman
Created on Mar 26, 2019



8.b Diffusion Mask Lithography Exposure & Development

NOTE! For future diffusions, do not use SiNx on iHP lattice matched materials as the mask does not hold up.

Alignment, exposure, and development step of the lithography to define the emitter hard mask.

Process:

1. Align mask # 4 on MUB...

Owner: Robert Kaufman
Created on Mar 26, 2019



8.a Diffusion Mask Lithography Spin On


NOTE! For future diffusions, do not use SiNx on iHP lattice matched materials as the mask does not hold up.

Spin on process for the lithography to define the Zn diffusion hard mask.

Process:

1. Clean and O2 descum...

Owner: Robert Kaufman
Created on Mar 26, 2019



7. SiNx Deposition for Diffusion Hard Mask


NOTE! For future diffusions, do not use SiNx on iHP lattice matched materials as the mask does not hold up.

Deposition of SiNx using the STS to act as the hard mask for base Zn diffusion. The Zn diffusion is necessary to improve contact resistance but must only be in the base region to avoid shorting. Includes all TI-QCL samples (P14, #27, and KC#1). #14 is in quadrant "HP 1" in the photos...

Owner: Robert Kaufman
Created on Mar 26, 2019

2) Collection

3) Datasets



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Owner: Robert Kaufman
Created on Mar 26, 2019

2) Collection

3) Datasets



10. Base Zinc Diffusion


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Created on Mar 26, 2019



10. Base Zn Diffusion

Process of diffusing Zn into the base region of the TI-QCL to increase doping and improve contact resistance.

Process (See detailed process on sheet in 2111):

1. Prepare tubes
2. Flame off and dimple
3. Load diffusant (Zn3As2); load sample
4. Seal off...

Owner: **Robert Kaufman**
Created on Aug 21, 2019

★ Follow

📄 Download All Files

✕ Remove

Breakout Session #1: Log-In & Explore 4CeeD

learn.4ceed.illinois.edu

- "Sign Up" with Illinois email
- Note: Need to be on University connection to access (IllinoisNet or VPN)
- Try out 4CeeD yourself before next hands-on lecture
 - **Make an account**
 - Make a space, collection, dataset
 - Upload some image and add a template

Lecture Series Learning Objectives

- Lecture 1 (3/21): Overview of 4CeeD
 - Introduction to 4CeeD
 - Breakout Session #1: Log-In and Explore
 - Key 4CeeD Features: Templates for Fast Storage
 - Breakout Session #2: Upload your own data

Efficient Data Collection: Templates

- Templates and Extractors for Rapid Storage

Patrick Su / 03-11-2019 Zn D...


03-11-2019 Zn Diffusion Mask Lithography

Created by Patrick Su All Rights Reserved Patrick Su
Created on Mar 11, 2019
Access: Space Default (Private) Private
 Public

Zn Diffusion Mask Lithography Step
CLU-10HF 10 minutes -> 10 nm SiNx
Base Metal Mask Quadrant
HMDS/AZ 5214 E [10K/10K]
Expose 0 seconds (HP/ST) Flood 10 seconds
Develop AZ 400K 4:1 10 seconds (bulk clear at 10 seconds)


+ Add Files Download All Files Delete

Files Metadata Comments (0)

 **DSCN9748.JPG**
image/jpeg
Mar 11, 2019
898.6 kB

Download Follow

Space containing the Dataset
Select a Space + ADD

Collections containing the Dataset
 **TIQCL-005**
4 datasets | Remove

Select a collection + ADD

Tags
TAG

Templates are stored as Metadata

Efficient Data Collection: Templates

Experimental setting:

Time 13min
Temp 425 C

(Structured meta data)

Notes:

Oxidation depth is about 12um.
Oxidation layer composed of Al(0.98)GaAs with thickness of 30 nm. Furnace in 2111 MNT L, 2" diameter quartz.

(Free text)

- Free-text view can be unorganized, hard-to-read, and difficult to compare results

- Templates provide consistency, accessibility, and enables digital processing (ex. Jupyter Notebook)

Dataset Metadata

Select a template:
--Select One--

Key:	Value	Units:	
Time	13	min	REMOVE
Temperature	425	C	REMOVE
Oxide Depth	12	um	REMOVE
Oxide Layer	99	%	REMOVE
Oxide Thick.	30	nm	REMOVE

ADD NEW SUBMIT CLOSE

Breakout Session #2: Templates For Fast Storage

4CeeD You Shared Create Trash

Patrick Su / 03-11-2019 Zn D...

03-11-2019 Zn D

Created by Patrick Su
Created on Mar 11, 2019
Access: Space Default (Private) Public

Zn Diffusion Mask Lithography Step

Stored Key-Value Pairs

Dataset Metadata

Select a template:
MNTL: Lithography and Development (1 Stage)

Key:	Value	Units:	
Adhesion Prom	HMDS	Name	REMOVE
Spin Speed	100	RPM	REMOVE
Spin Time	20	Seconc	REMOVE
Photoresist	S1813	Name	REMOVE
Spin Speed	300	RPM	REMOVE
Spin Time	40	Seconc	REMOVE
Bake Temperat	115	Celsius	REMOVE
Bake Time	50	Seconc	REMOVE
Mask Name	TIQCL	Name	REMOVE
Key:	Value	Units:	

Obtaining the Dataset

QCL-005

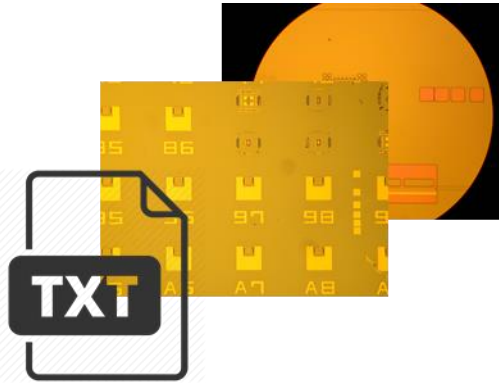
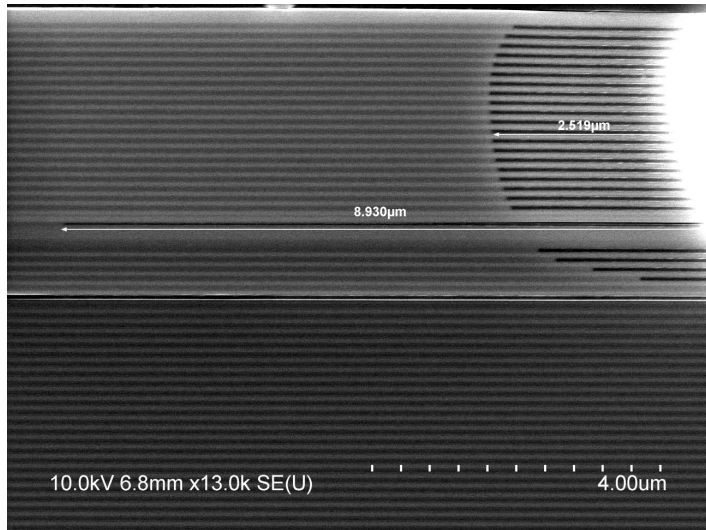
Remove

ADD

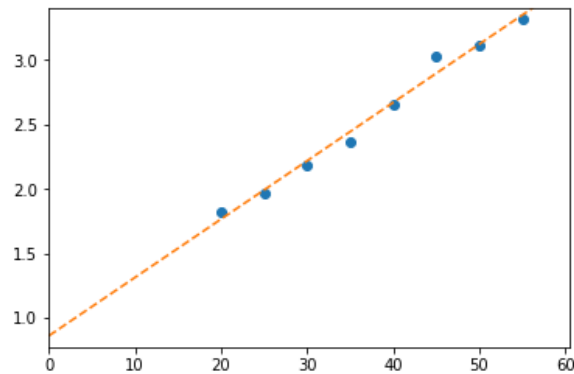
TAG

Incredibly useful for Jupyter Integration (Later Topic)

Questions?



0.993471835645128
 0.9876314375071126
 0.9940794194313601
 Pad Resistance: [1.0767903731516643e-05, 1.006055129797721e-05, 1.0414227514747174e-05]



TI-QCL (RBK) | TI-QCL 007 Process

TI-QCL 007 Process

Owner: Robert Kaufman
Created on Jul 22, 2019

Documentation of the process steps for TI-QCL 007 run. Includes samples #22 and #23.

Delete | Collaborators | Download All Files

Space containing the Collection

TI-QCL (RBK)
4 collections | Remove

Select a Space | Add

Parent collections

TI-QCL 007
1 collection

Select a Collection | Add

Datasets in the Collection

Create Dataset

12. SiO₂ Deposition for Isolation Trench Etch

Owner: Robert Kaufman
Created on Aug 21, 2019

11. SiO₂ Diffusion Mask Removal

Process (On Oxford Fracton RIE):

- Recipe season (Dalesasse-SiO₂-Etch)
- 2 min
- Etch samples
- Use dummies first to check rate (expect 262.5 nm/min)
- Expected time: <30 s
3. Clean (MNTL Clean)
- 2x Total Etch time...

Owner: Robert Kaufman
Created on Aug 21, 2019

10. Base Zn Diffusion

Process of diffusing Zn into the base region of the TI-QCL to increase doping and improve contact resistance.

Process (See detailed process on sheet in 2111):

- Prepore tubes
- Flame off and dimple
- Load diffusant (Zn3As2); load sample
- Seal off...

Owner: Robert Kaufman
Created on Aug 21, 2019

9. SiO₂ Diffusion Mask Definition Etch

Open etch to define the diffusion mask.

Process (On Oxford Fracton RIE):

- Recipe season (Dalesasse-SiO₂-Etch)
- 2 min
- Etch samples
- Use dummies first to check rate (expect 262.5 nm/min)
- Expected time: <30 s...

Owner: Robert Kaufman
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8.b Diffusion Mask Lithography Exposure & Dev

Alignment, exposure, and development step of the lithography to define the emitter hard mask.

Process:

- Align mask # 4 on MJB
- Base Metal Mask