Diamond Fabrication

Zhang Chuheng, CQI, IIIS, TSU
6 Apr 2017

Overview

- Fabrication Methods in S-102
- Current Low Temperature Fabrication Scheme
- Notice and Problems in Each Step

Fabrication Methods

Patterning	EBL / Optical Lithography (with Spin Coating / Baker) FIB
Layering & Etching	Sputter / Electron Beam Evaporation / ALD ICP / Plasma Clean
Observing	Optical Microscopy / Step Profiler / Film Thickness Gauge / AFM / SEM
Others	Chemical Process / Annealing

Current Fabrication Scheme: Overview

Prepare	NV Density Estimation > Piranha Clean > ICP Etch
Chipname & Marker	Evaporation of Al > FIB > Clean after FIB
NV Location	NV Location and SIL Calculation
SIL Fabrication	Piranha Clean > Al Evaporate > FIB Fabrication > Clean and Remove Al > Three-acid Clean to Remove Carbon > ICP Etch
Test	Test for Efficiency

continue on next slide …

Current Fabrication Scheme: Overview

Waveguide	Piranha Clean > PMMA Spin-coating and Baking > Evaporate Al 20nm > EBL and Develop > Plasma Clean > Evaporate Ti+Au > Liftoff
Waveguide Thickening	Waveguide Thickening
AR Coating	Antireflection Coating by ALD
Mount	Fix by Cryogenic Colloid > Wire Bonding

NV Density Estimation

Prepare	NV Density Estimation > Piranha Clean > ICP Etch
Chipname & Marker	Evaporation of Al > FIB > Clean after FIB
NV Location	NV Location and SIL Calculation
SIL Fabrication	Piranha Clean > Al Evaporate > FIB Fabrication > Clean and Remove Al > Three-acid Clean to Remove Carbon > ICP Etch
Test	Test for Efficiency
Waveguide	Piranha Clean > PMMA Spin-coating and Baking > Evaporate Al 20nm > EBL and Develop > Plasma Clean > Evaporate Ti+Au > Liftoff
Waveguide Thickening	Waveguide Thickening
AR Coating	Antireflection Coating by ALD
Mount	Fix by Cryogenic Colloid > Wire Bonding

NV Density Estimation

- Ideal case:

  >1NV per 100um*100um area @ depth 5~8um

- Problem:

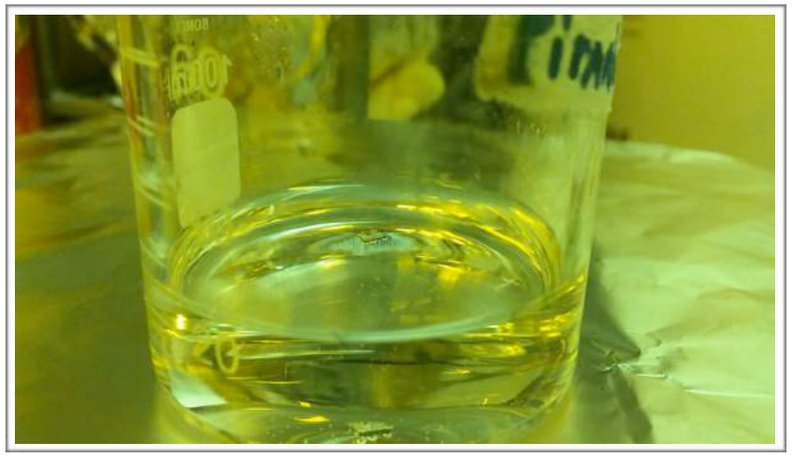
  few shallow NVs -> ICP etch several microns

  (deep NV leads to inefficient SIL fabrication)

Piranha Clean

Prepare	NV Density Estimation > Piranha Clean > ICP Etch
Chipname & Marker	Evaporation of Al > FIB > Clean after FIB
NV Location	NV Location and SIL Calculation
SIL Fabrication	Piranha Clean > Al Evaporate > FIB Fabrication > Clean and Remove Al > Three-acid Clean to Remove Carbon > ICP Etch
Test	Test for Efficiency
Waveguide	Piranha Clean > PMMA Spin-coating and Baking > Evaporate Al 20nm > EBL and Develop > Plasma Clean > Evaporate Ti+Au > Liftoff
Waveguide Thickening	Waveguide Thickening
AR Coating	Antireflection Coating by ALD
Mount	Fix by Cryogenic Colloid > Wire Bonding

Piranha Clean



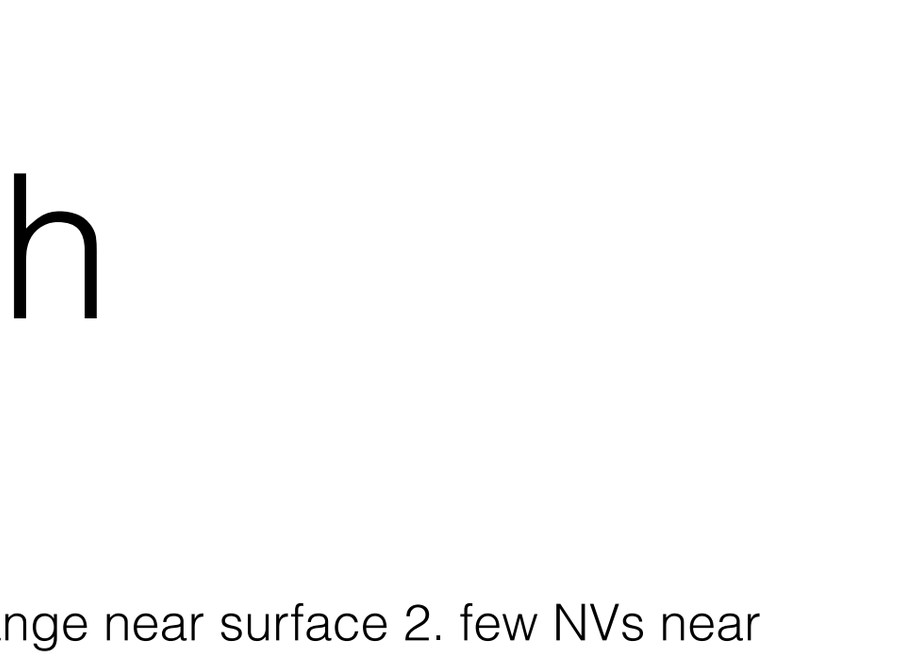
- Purpose: remove organic residual, especially oil
- Notice:
  - Use microscope dark field mode to see whether it is clean after piranha
    - Operation side up all the time (111 strip sample will roll during piranha clean)
    - Nitrogen blow from inside, do NOT blow sample away
- Problem: time consuming -> multiple sample clean
- Link: http://sealzhang.tk/experimental%20physics/2016/11/23/Piranha-Clean

ICP Etch

Prepare	NV Density Estimation > Piranha Clean > ICP Etch
Chipname & Marker	Evaporation of Al > FIB > Clean after FIB > No ICP here
NV Location	NV Location and SIL Calculation
SIL Fabrication	Piranha Clean > Al Evaporate > FIB Fabrication > Clean and Remove Al > Three-acid Clean to Remove Carbon > ICP Etch
Test	Test for Efficiency
Waveguide	Piranha Clean > PMMA Spin-coating and Baking > Evaporate Al 20nm > EBL and Develop > Plasma Clean > Evaporate Ti+Au > Liftoff
Waveguide Thickening	Waveguide Thickening
AR Coating	Antireflection Coating by ALD
Mount	Fix by Cryogenic Colloid > Wire Bonding

ICP Etch

- Purpose:
  - Remove several microns of surface (for 1. strain is strange near surface 2. few NVs near surface)
  - Remove Ga+ ion after FIB
  - Improve surface properties (eg. get a distinguished surface peak / a smooth surface)
- Notice:
  - Careful piranha clean before a deep etch
  - Outcome is quite recipe related
- Problem:
  - Gullies after ICP



- Link: http://sealzhang.tk/experimental%20physics/2016/11/23/ICP

ICP Etch

- Machine: Oxford Instruments - Plasmalab System 100
- Link: http://www.oxfordplasma.de/systems/100ll.htm

Electron Beam Evaporation

Prepare	NV Density Estimation > Piranha Clean > ICP Etch
Chipname & Marker	Evaporation of Al > FIB > Clean after FIB
NV Location	NV Location and SIL Calculation
SIL Fabrication	Piranha Clean > Al Evaporate > FIB Fabrication > Clean and Remove Al > Three-acid Clean to Remove Carbon > ICP Etch
Test	Test for Efficiency
Waveguide	Piranha Clean > PMMA Spin-coating and Baking > Evaporate Al 20nm > EBL and Develop > Plasma Clean > Evaporate Ti+Au > Liftoff
Waveguide Thickening	Waveguide Thickening
AR Coating	Antireflection Coating by ALD
Mount	Fix by Cryogenic Colloid > Wire Bonding

Electron Beam Evaporation

- Purpose:
    - Avoid charge accumulation on the surface during FIB (20nm Al)
    - Serve as the master mask of waveguide (Ti60nm+Cr60nm+Au60nm)
- Notice:
    - Make sure the samples are well clipped
- Link: http://sealzhang.tk/experimental%20physics/2016/11/23/Electron-beam-Evaporation-Deposition

Electron Beam Evaporation

- Machine: PLASSYS MEB 550S4
- Link: https://plassys.com/evaporation-hv-uhv/

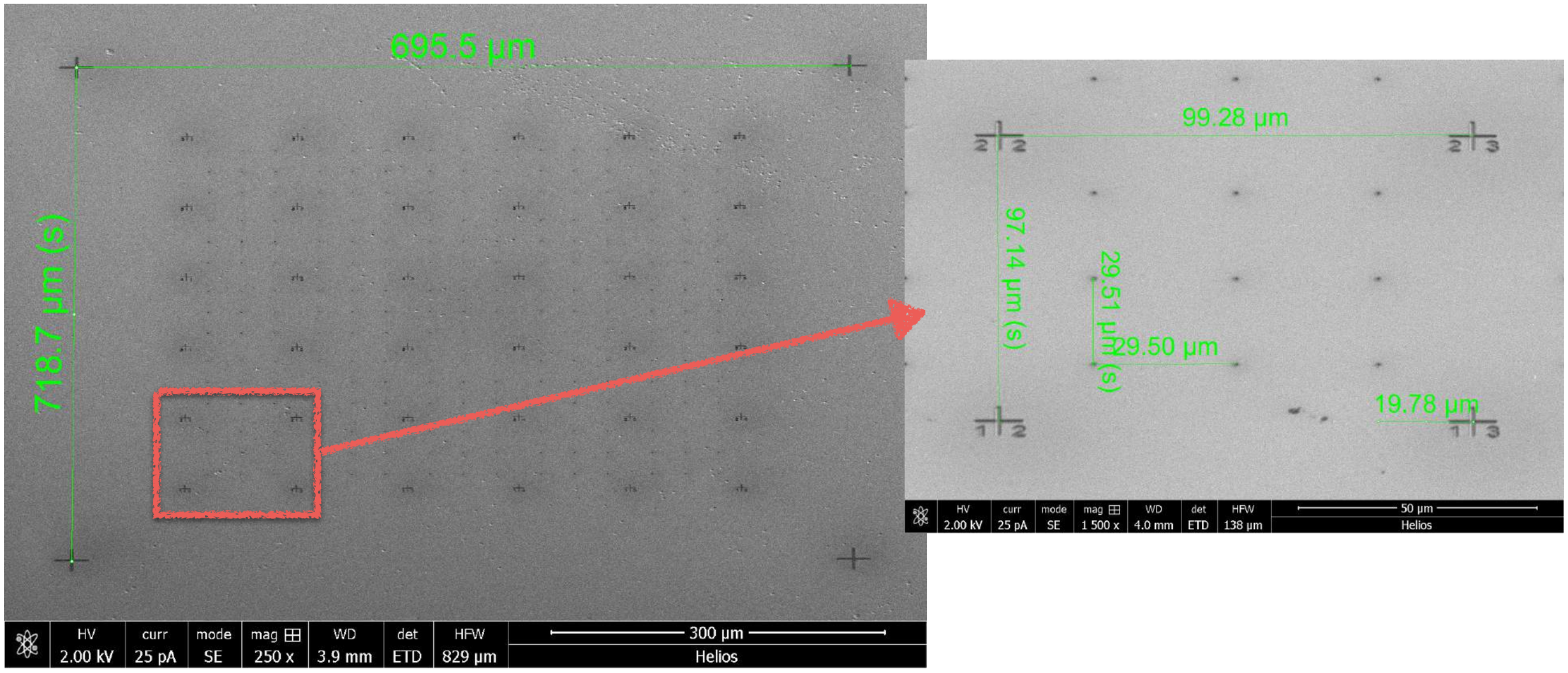
Focused Ion Beam

Prepare	NV Density Estimation > Piranha Clean > ICP Etch
Chipname & Marker	Evaporation of Al > FIB > Clean after FIB
NV Location	NV Location and SIL Calculation
SIL Fabrication	Piranha Clean > Al Evaporate > FIB Fabrication > Clean and Remove Al > Three-acid Clean to Remove Carbon > ICP Etch
Test	Test for Efficiency
Waveguide	Piranha Clean > PMMA Spin-coating and Baking > Evaporate Al 20nm > EBL and Develop > Plasma Clean > Evaporate Ti+Au > Liftoff
Waveguide Thickening	Waveguide Thickening
AR Coating	Antireflection Coating by ALD
Mount	Fix by Cryogenic Colloid > Wire Bonding

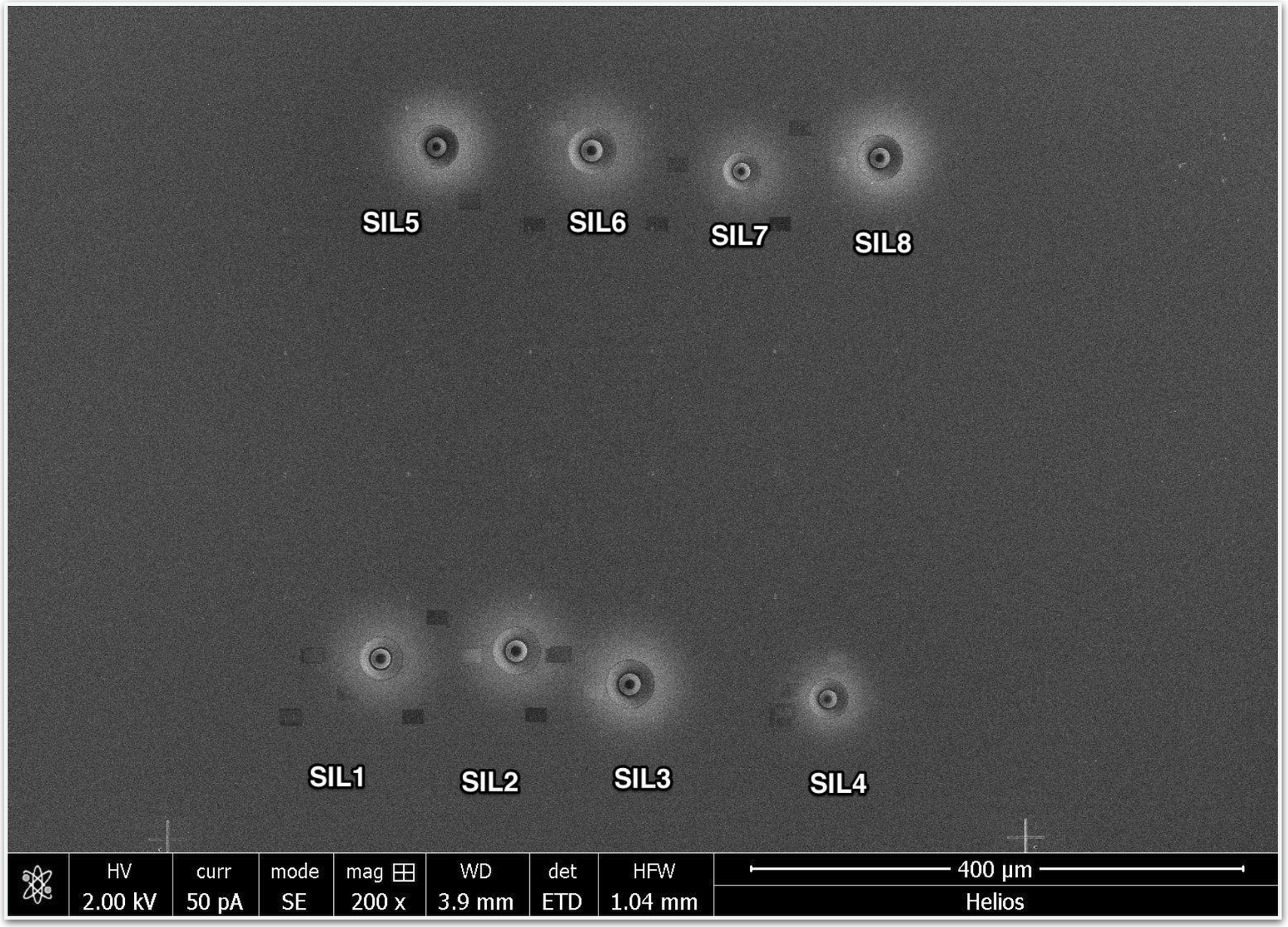
Focused Ion Beam

- Purpose:
    - Generation of makers (for location of NVs) and chip names (for distinguish among different samples and different sides of a sample)
    - Generation of solid immersion lens (SIL)
- Notice:
    - Fix sample to stage by silver colloid before FIB
    - Remove silver colloid and Al after FIB
- Problem:
    - Processing time is long to fabricate a big SIL -> find shallow NVs / increase yield rate
- Link: http://sealzhang.tk/experimental%20physics/2017/03/24/FIB-chipname-marker / http://sealzhang.tk/experimental%20physics/2016/11/23/FIB-SIL

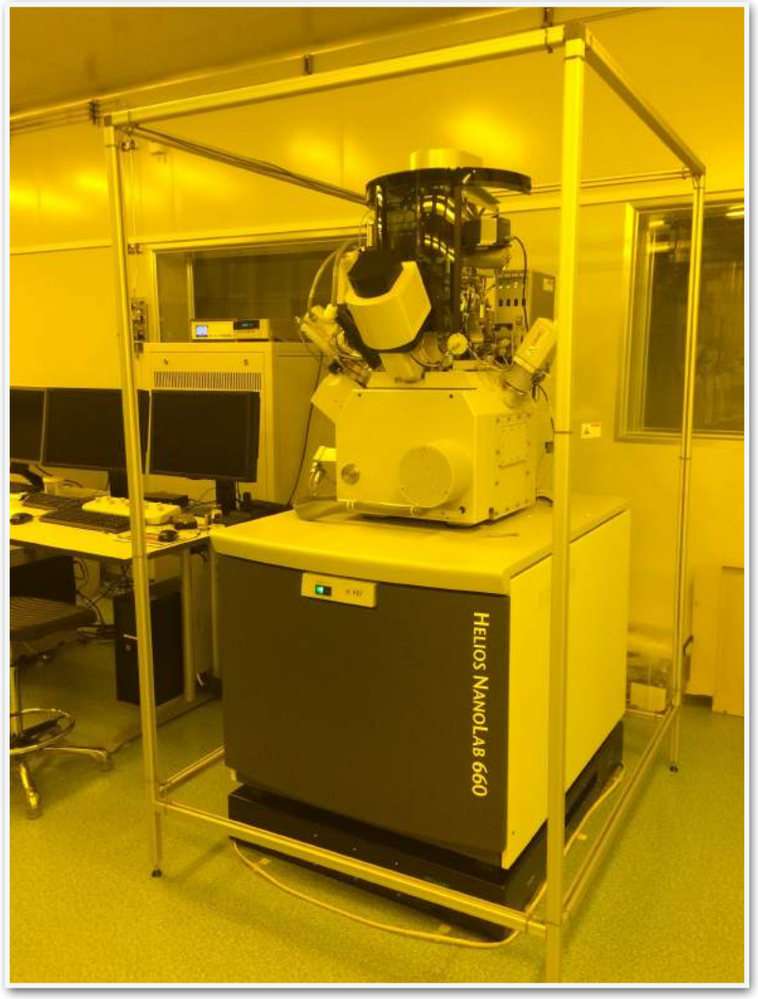
Focused Ion Beam: Markers



Focused Ion Beam: SILs



Focused Ion Beam



- Machine: Helios Nanolab 660
- Datasheet link: https://www.fei.com/documents/helios-nanolab-660-datasheet/

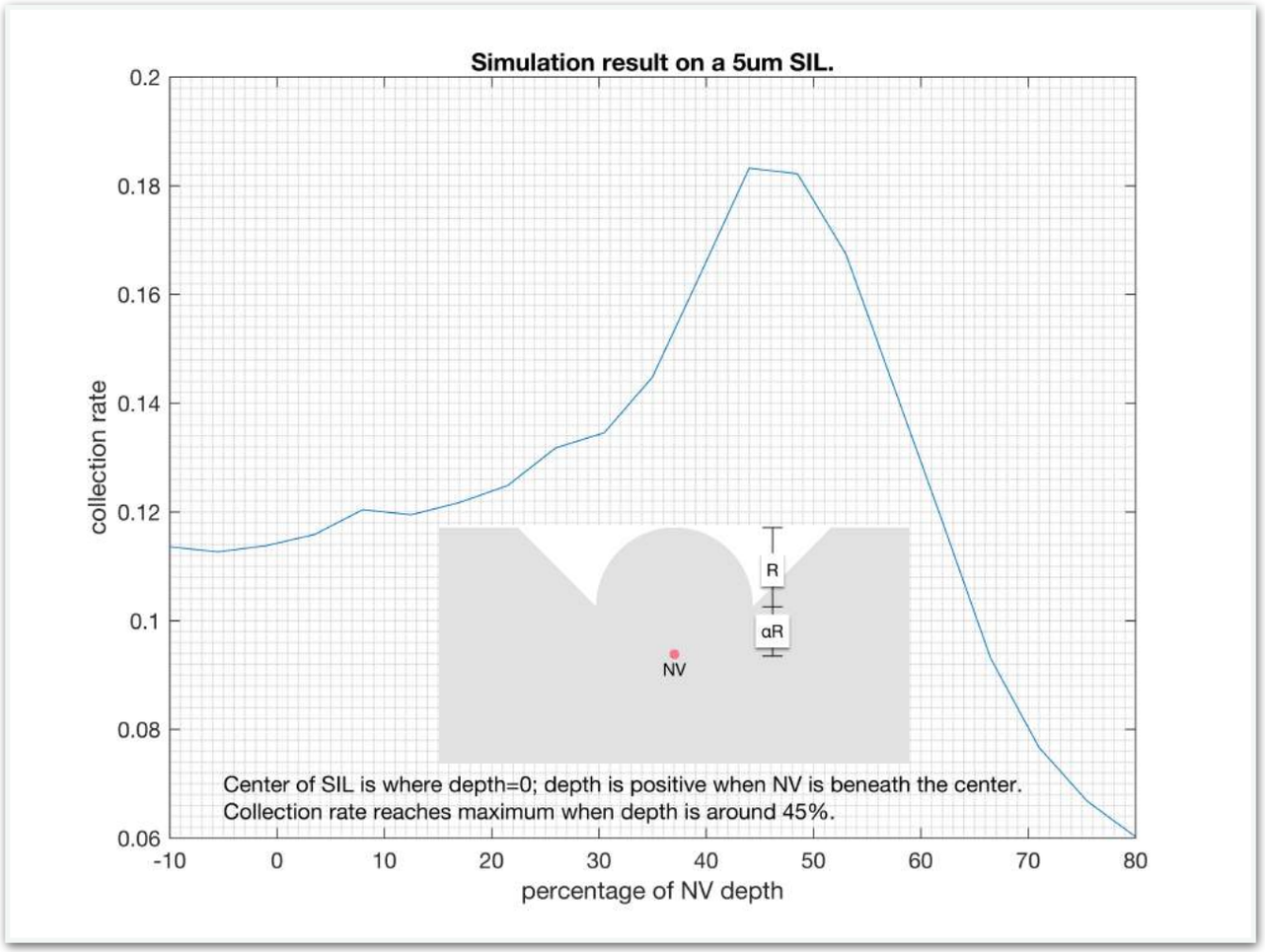
NV Location and SIL Calculation

Prepare	NV Density Estimation > Piranha Clean > ICP Etch
Chipname & Marker	Evaporation of Al > FIB > Clean after FIB
NV Location	NV Location and SIL Calculation
SIL Fabrication	Piranha Clean > Al Evaporate > FIB Fabrication > Clean and Remove Al > Three-acid Clean to Remove Carbon > ICP Etch
Test	Test for Efficiency
Waveguide	Piranha Clean > PMMA Spin-coating and Baking > Evaporate Al 20nm > EBL and Develop > Plasma Clean > Evaporate Ti+Au > Liftoff
Waveguide Thickening	Waveguide Thickening
AR Coating	Antireflection Coating by ALD
Mount	Fix by Cryogenic Colloid > Wire Bonding

NV Location and SIL Calculation

- Purpose:
  - Find relative xy position and depth of NVs (markers as reference)
  - Design the size of SIL based on depth of NV
- Problem:
  - Enhancement of collection efficiency is largely dependent on relative depth of NV w.r.t. SIL center
  - Inaccuracy in location (especially in z direction) leads to low collection efficiency
- Link: https://github.com/zhangchuheng123/NV_program

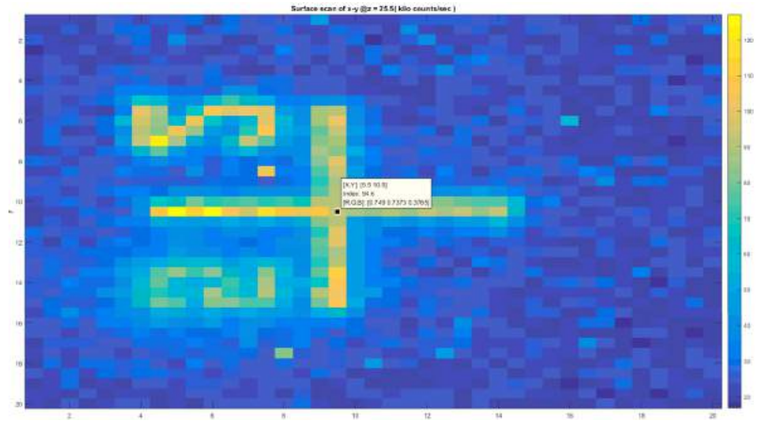
NV Location and SIL Calculation



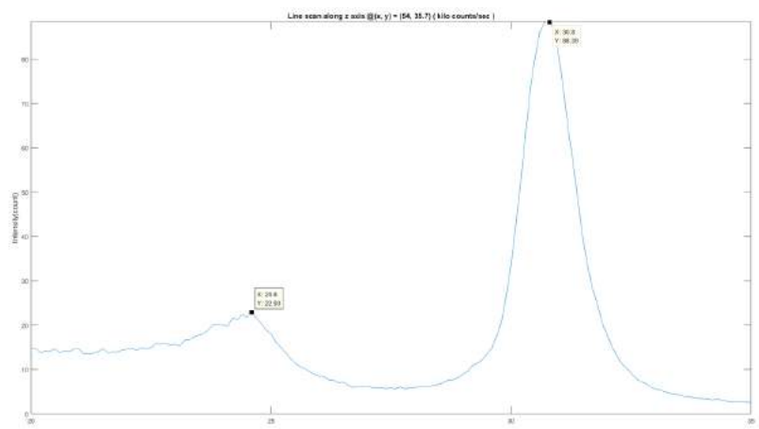
- Simulation -> unimodal with depth, optimal around 45%
- Empirical -> optimal around 30%

NV Location and SIL Calculation

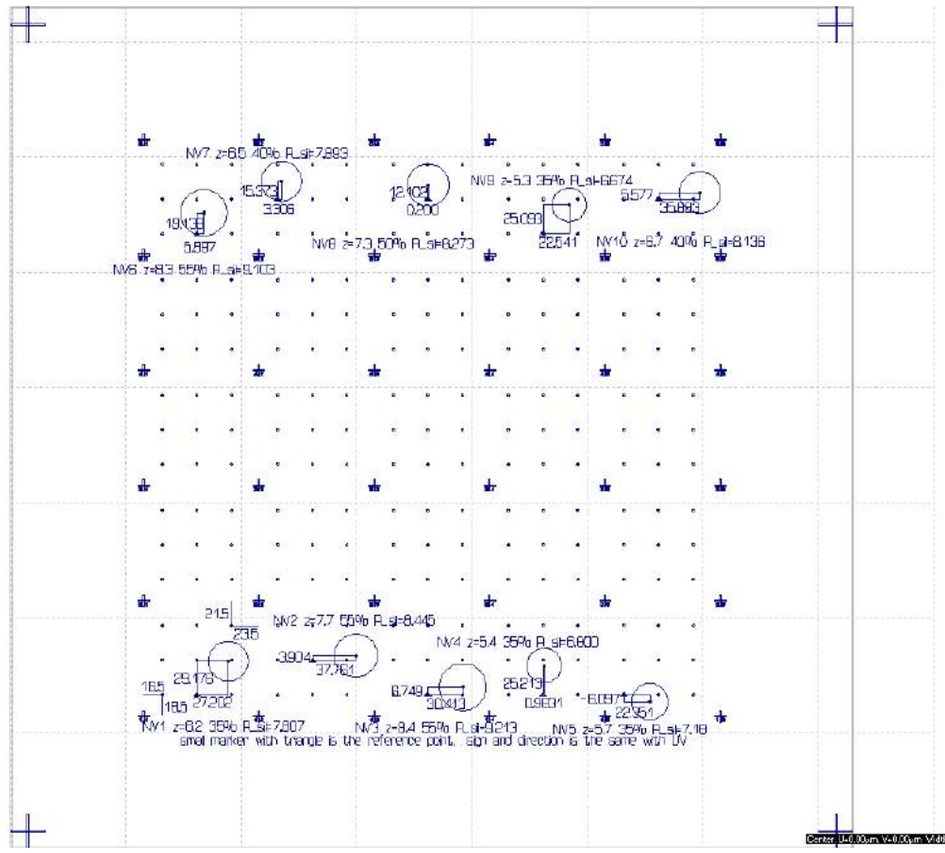
a



b



c



a. marker in confocal system
b. surface peak and NV peak
c. design graph of SIL

Three-acid Clean

Prepare	NV Density Estimation > Piranha Clean > ICP Etch
Chipname & Marker	Evaporation of Al > FIB > Clean after FIB
NV Location	NV Location and SIL Calculation
SIL Fabrication	Piranha Clean > Al Evaporate > FIB Fabrication > Clean and Remove Al > Three-acid Clean to Remove Carbon > ICP Etch
Test	Test for Efficiency
Waveguide	Piranha Clean > PMMA Spin-coating and Baking > Evaporate Al 20nm > EBL and Develop > Plasma Clean > Evaporate Ti+Au > Liftoff
Waveguide Thickening	Waveguide Thickening
AR Coating	Antireflection Coating by ALD
Mount	Fix by Cryogenic Colloid > Wire Bonding

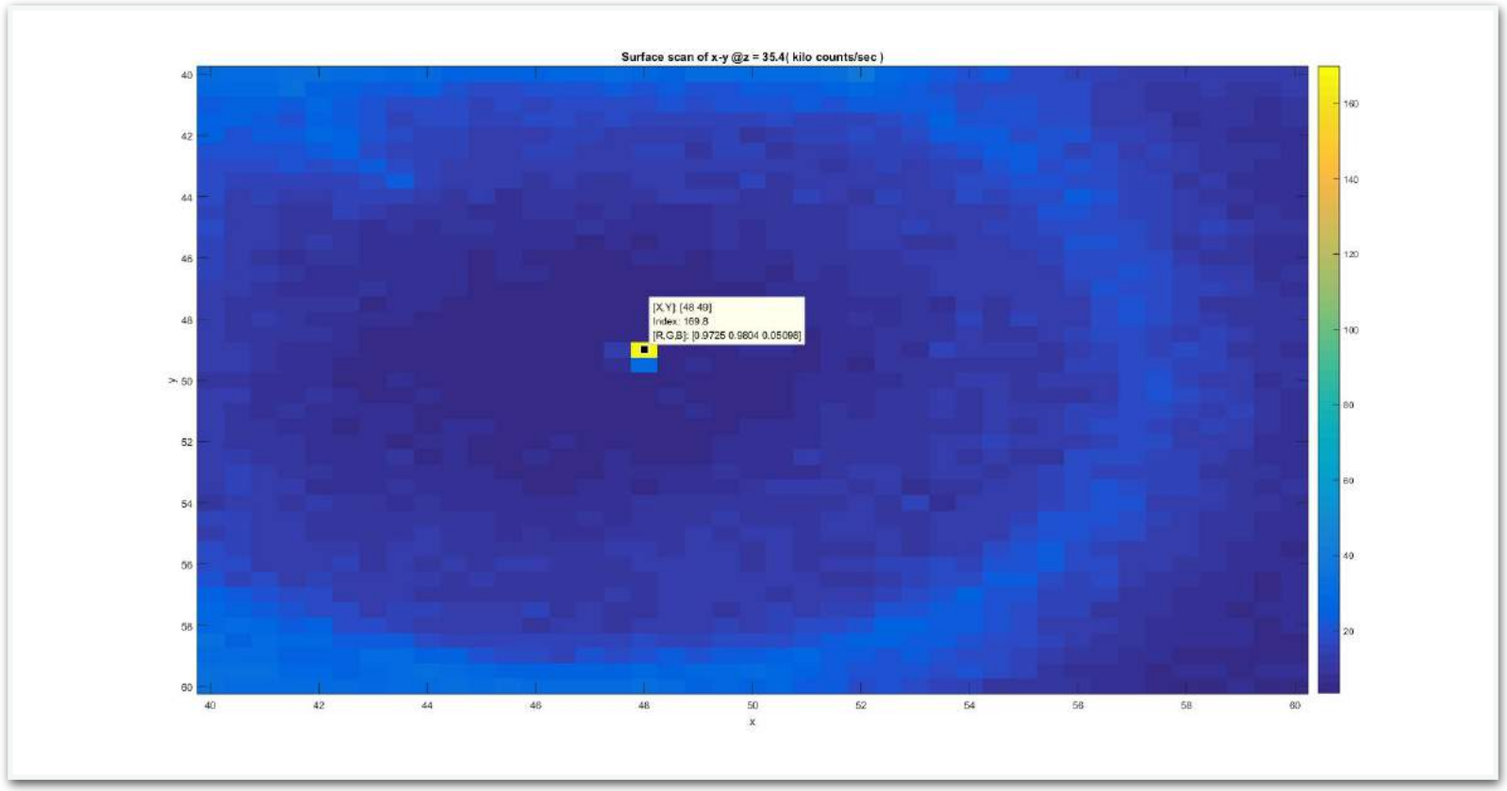
Three-acid Clean

- Purpose:
  - Remove carbon residual induced by FIB etch
- Notice:
  - more or less similar to piranha clean
- Link: http://sealzhang.tk/experimental%20physics/2016/11/23/three-acid-clean

SIL Efficiency Test

Prepare	NV Density Estimation > Piranha Clean > ICP Etch
Chipname & Marker	Evaporation of Al > FIB > Clean after FIB
NV Location	NV Location and SIL Calculation
SIL Fabrication	Piranha Clean > Al Evaporate > FIB Fabrication > Clean and Remove Al > Three-acid Clean to Remove Carbon > ICP Etch
Test	Test for Efficiency
Waveguide	Piranha Clean > PMMA Spin-coating and Baking > Evaporate Al 20nm > EBL and Develop > Plasma Clean > Evaporate Ti+Au > Liftoff
Waveguide Thickening	Waveguide Thickening
AR Coating	Antireflection Coating by ALD
Mount	Fix by Cryogenic Colloid > Wire Bonding

SIL Efficiency Test



- Purpose:
  - Test NV count after SIL fabrication - generally 5~10 times enhancement after SIL
  - Accumulate data: NV count vs. NV depth

Depth Related Formulas

- $R_{SIL} = \eta d_{measure}/(1+\alpha)$ before SIL
- $R_{SIL} = d_{measure}/(1+\eta\alpha)$ after SIL

- Relation between real and measured depth

$$d_{real} = \sqrt{\frac{n_o n_d - NA^2}{n_o^2 - NA^2}}\, d_{measure} = \eta d_{measure}$$

oil 1.518 diamond 2.408 NA 1.49

- empirically, $\eta \approx 1.7$

EBL and Relevant

Prepare	NV Density Estimation > Piranha Clean > ICP Etch
Chipname & Marker	Evaporation of Al > FIB > Clean after FIB
NV Location	NV Location and SIL Calculation
SIL Fabrication	Piranha Clean > Al Evaporate > FIB Fabrication > Clean and Remove Al > Three-acid Clean to Remove Carbon > ICP Etch
Test	Test for Efficiency
Waveguide	Piranha Clean > PMMA Spin-coating and Baking > Evaporate Al 20nm > EBL and Develop > Plasma Clean > Evaporate Ti+Au > Liftoff
Waveguide Thickening	Waveguide Thickening
AR Coating	Antireflection Coating by ALD
Mount	Fix by Cryogenic Colloid > Wire Bonding

EBL and Relevant: Process

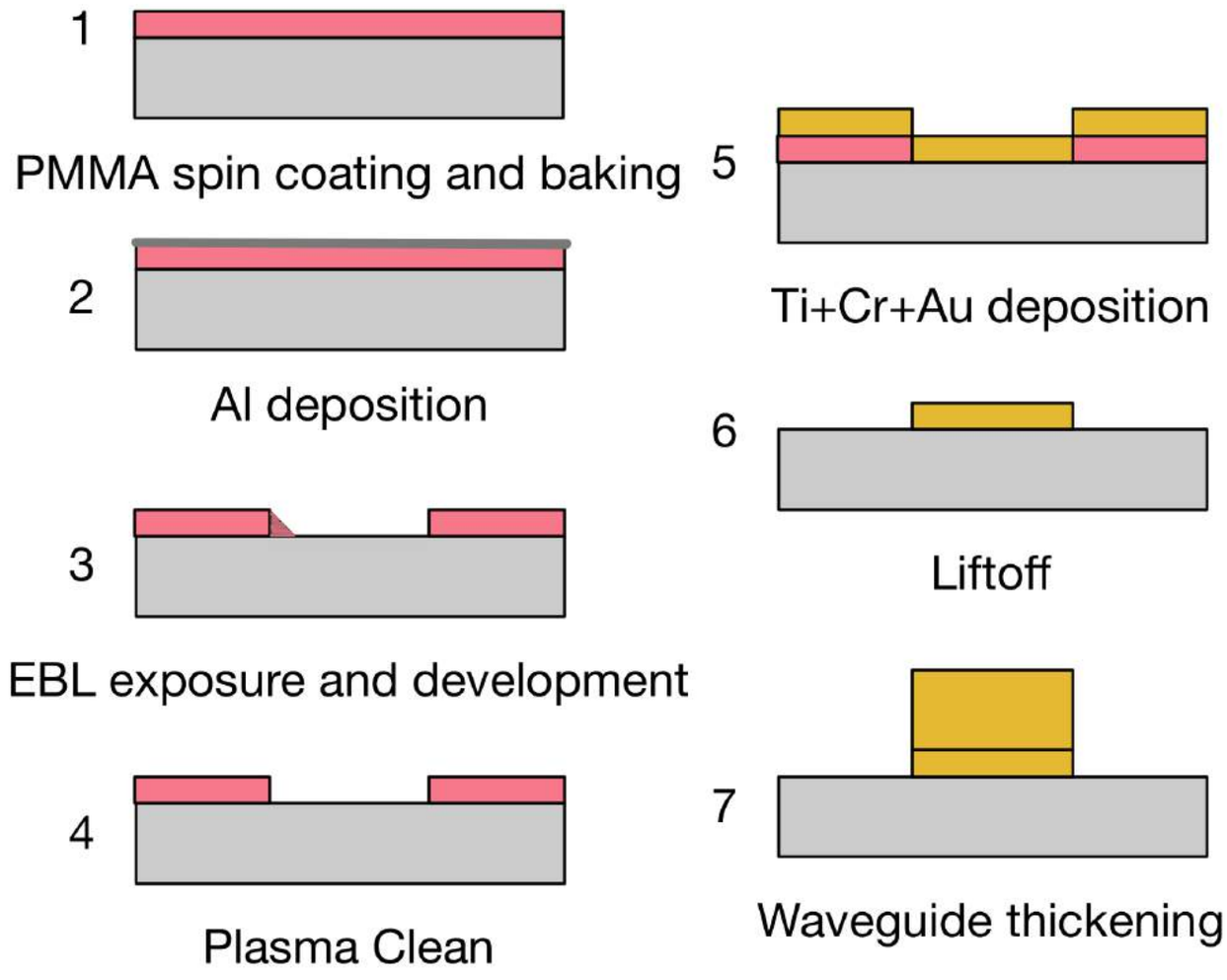


Figure. waveguide fabrication process

EBL and Relevant: Result

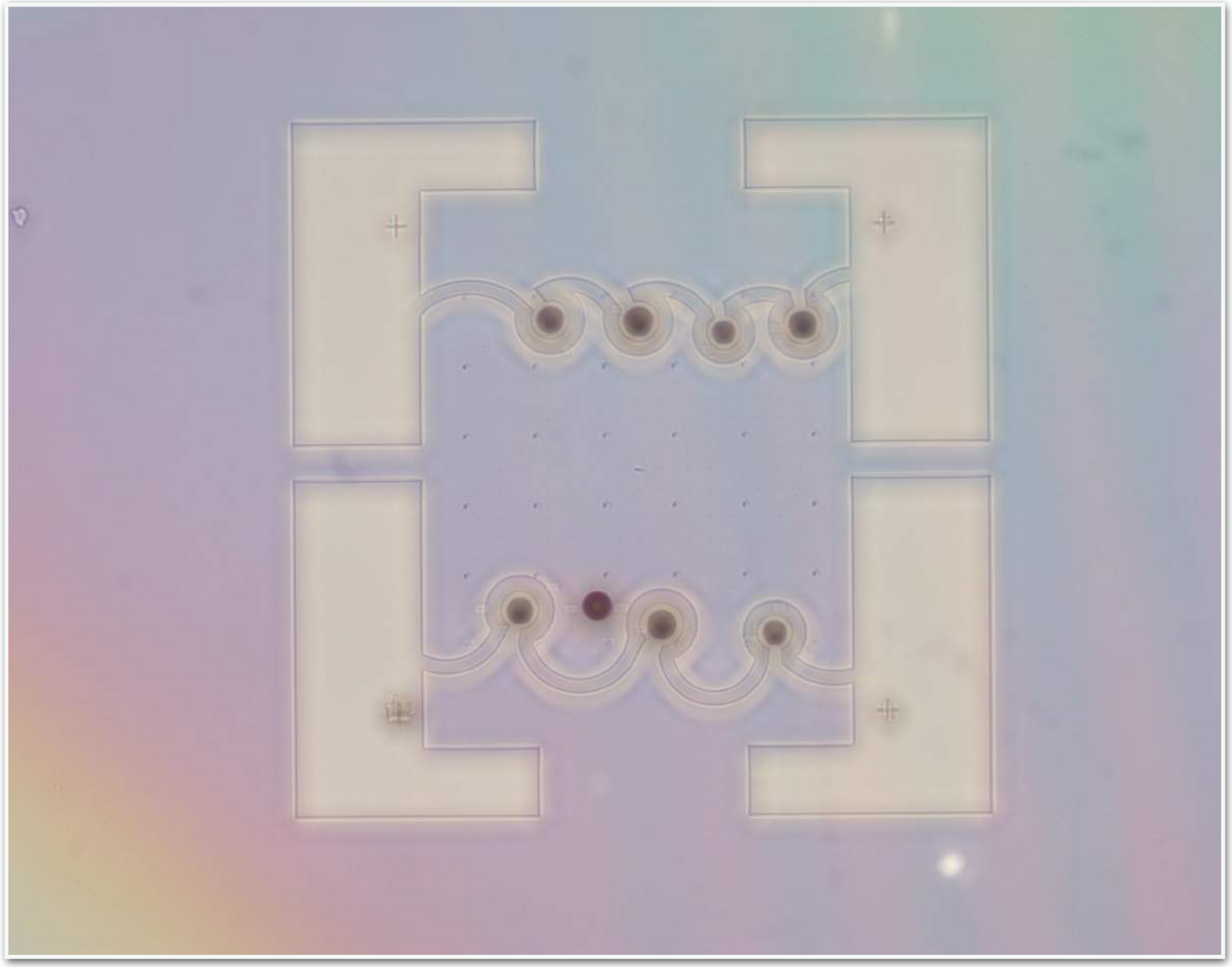
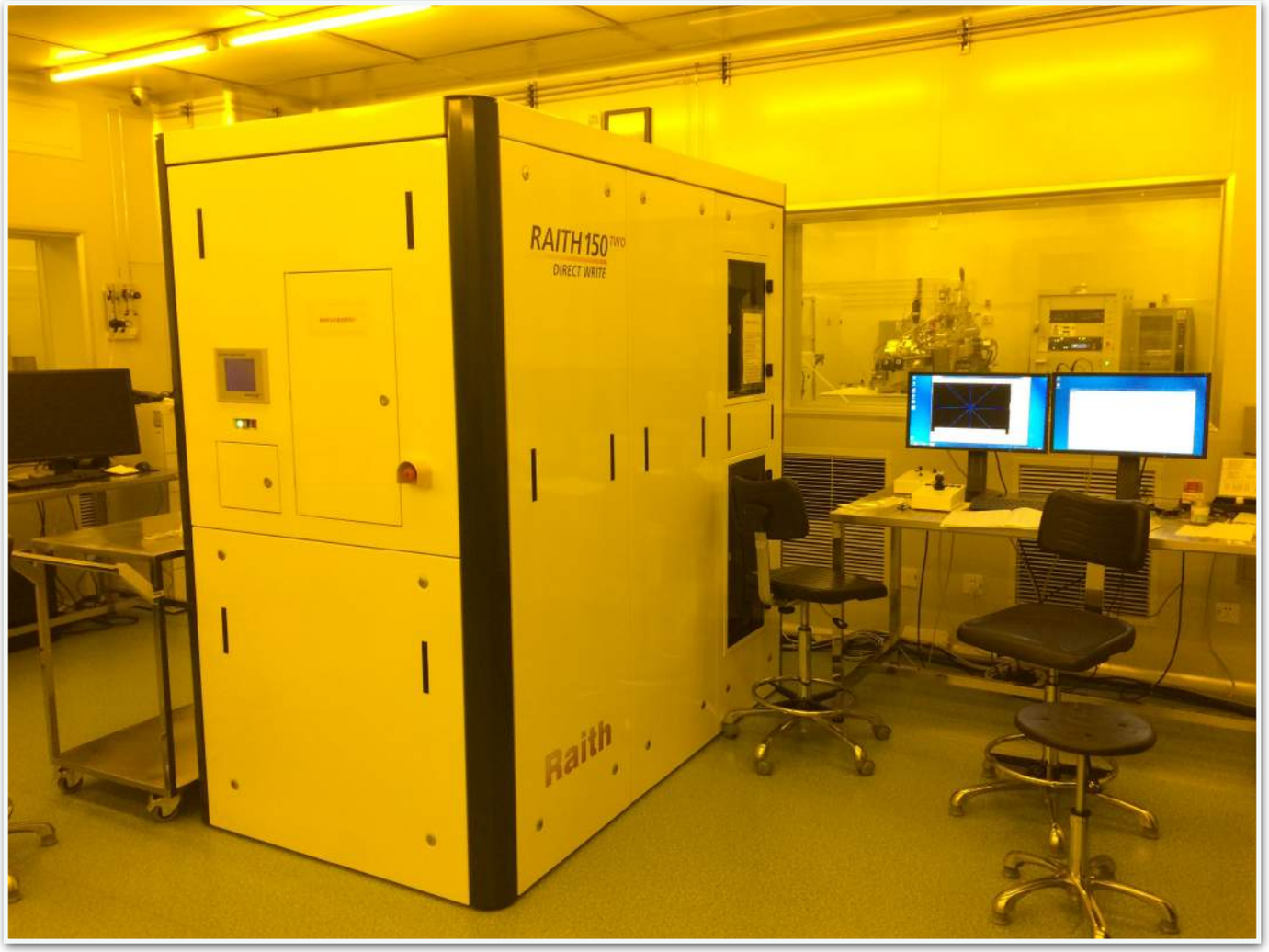


Figure. microscopy image of waveguide after liftoff

EBL and Relevant

- Purpose:
  - Waveguide fabrication
- Notice:
  - Check EBL design file before start processing
  - Metal layer on SIL is hard to remove - do liftoff carefully
- Problem:
  - NV disappearance after NV thickening
- Link:
  http://sealzhang.tk/experimental%20physics/2016/11/23/PMMA-Spin-coating
  http://sealzhang.tk/experimental%20physics/2016/11/23/EBL
  http://sealzhang.tk/experimental%20physics/2017/03/24/liftoff

EBL and Relevant: EBL



- Machine: Raith 150 Two https://www.raith.com/products/raith150-two.html
- Line width: ~10nm
- Stitching / Overlay accuracy: ~ 35nm

AR Coating

Prepare	NV Density Estimation > Piranha Clean > ICP Etch
Chipname & Marker	Evaporation of Al > FIB > Clean after FIB
NV Location	NV Location and SIL Calculation
SIL Fabrication	Piranha Clean > Al Evaporate > FIB Fabrication > Clean and Remove Al > Three-acid Clean to Remove Carbon > ICP Etch
Test	Test for Efficiency
Waveguide	Piranha Clean > PMMA Spin-coating and Baking > Evaporate Al 20nm > EBL and Develop > Plasma Clean > Evaporate Ti+Au > Liftoff
Waveguide Thickening	Waveguide Thickening
AR Coating	Antireflection Coating by ALD
Mount	Fix by Cryogenic Colloid > Wire Bonding

AR Coating: ALD

- Purpose:
  - Avoid NV fluorescence reflection on the surface
- Problem:
  - Thickness of dielectric layer vs. NV count > optimal found theoretically and experimentally (by Huili)

AR Coating: ALD

- Machine: Oxford Instruments - FlexAL
- Link: http://www.oxford-instruments.cn/products/etching-deposition-and-growth/tools/ald-systems/flexal

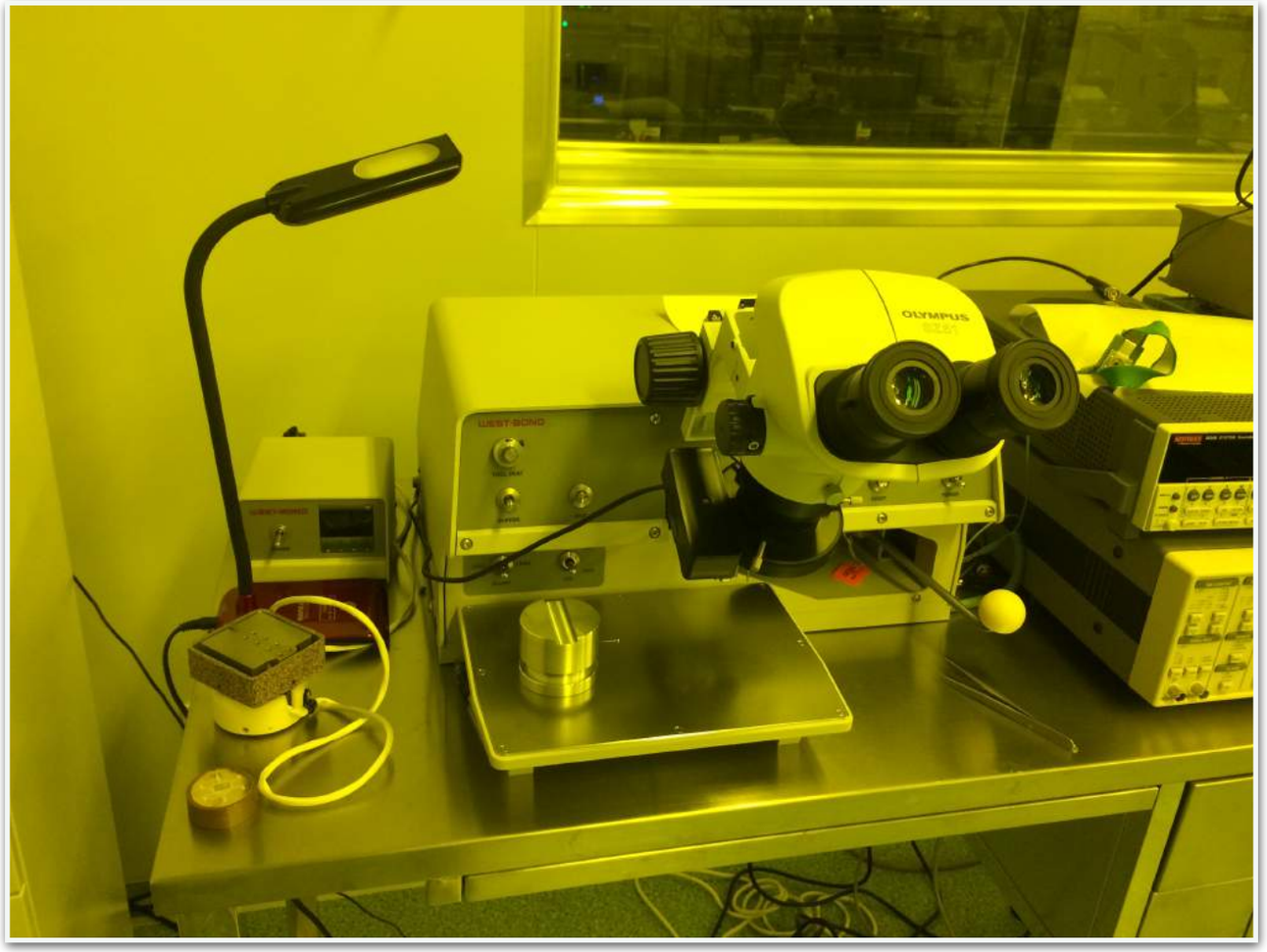
Wire Bonding

Prepare	NV Density Estimation > Piranha Clean > ICP Etch
Chipname & Marker	Evaporation of Al > FIB > Clean after FIB
NV Location	NV Location and SIL Calculation
SIL Fabrication	Piranha Clean > Al Evaporate > FIB Fabrication > Clean and Remove Al > Three-acid Clean to Remove Carbon > ICP Etch
Test	Test for Efficiency
Waveguide	Piranha Clean > PMMA Spin-coating and Baking > Evaporate Al 20nm > EBL and Develop > Plasma Clean > Evaporate Ti+Au > Liftoff
Waveguide Thickening	Waveguide Thickening
AR Coating	Antireflection Coating by ALD
Mount	Fix by Cryogenic Colloid > Wire Bonding

Wire Bonding

- Purpose:
  - Connect waveguide with microwave electrodes
- Notice:
  - Bonding voltage is dependent on wire material and substrate material - better follow empirical solution

Wire Bonder



- Machine: West-bond
- Link: http://www.westbond.com/machines_manual_wire_bonders.htm

Main Problem

- Unsatisfactory yield rate:
  - NV missing
    - Mechanism of missing after galvanization
  - Strange NV spectrum
    - Check NV spectrum before SIL fabrication
    - Etch several microns near surface / annealing
- Unstable NV count promotion
  - More precise NV location
  - 111 face sample
  - AR coating

THX

… up to date fabrication scheme @ http://sealzhang.tk