SUSTech Southern University of Science and Technology

Optimization on Scanning Ion Conductance Microscopy

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Github: https://github.com/KLDistance

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- Fundamental Principle of SICM
- Fast SICM Model & Applied Techniques*
- Ultra-high Resolution on HSQ Imaging*
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Introduction

SICM System Sketch

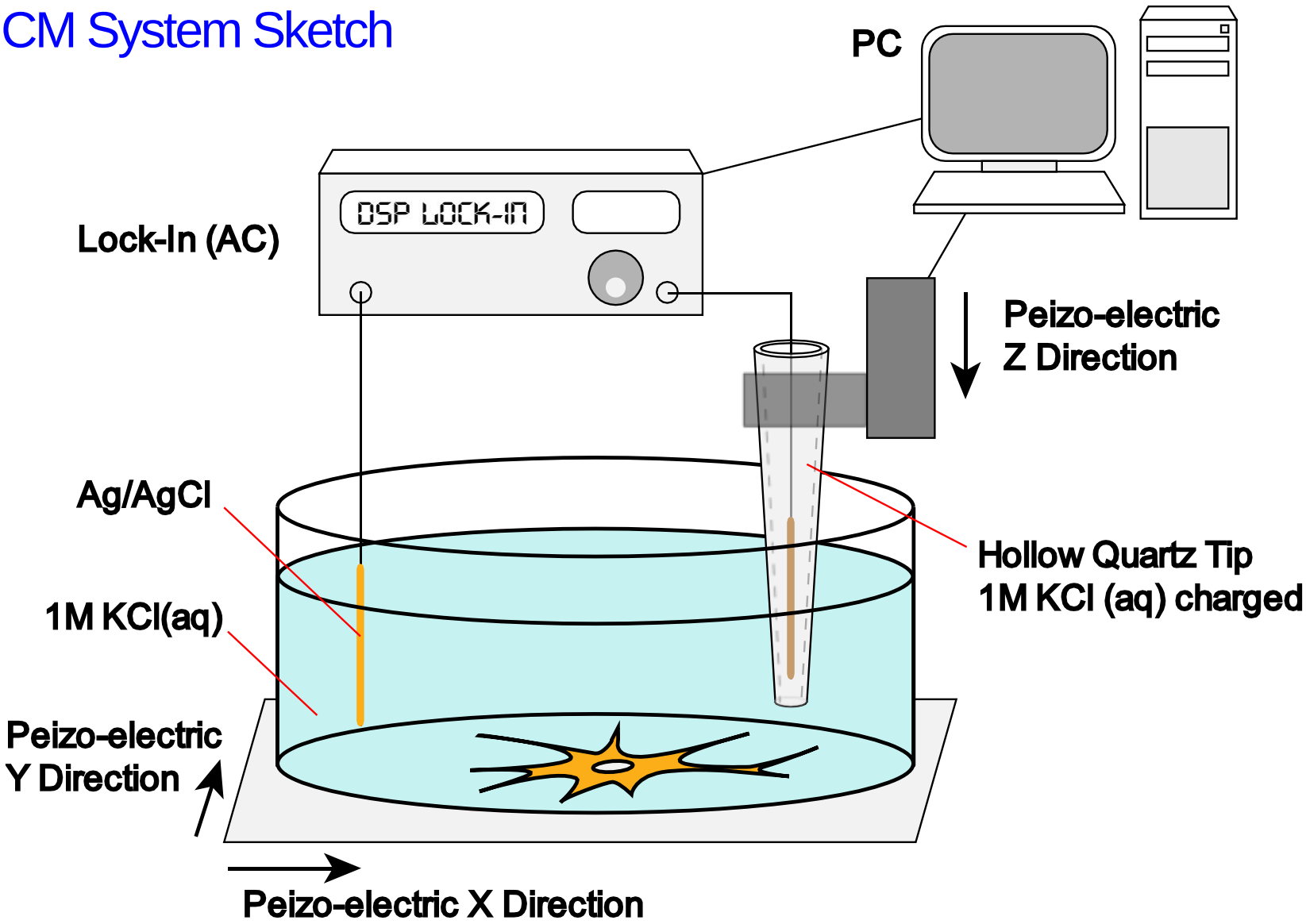


Fig. 1-1. SICM Simple Sketch (Digital device not shown)

Introduction

SICM Principle

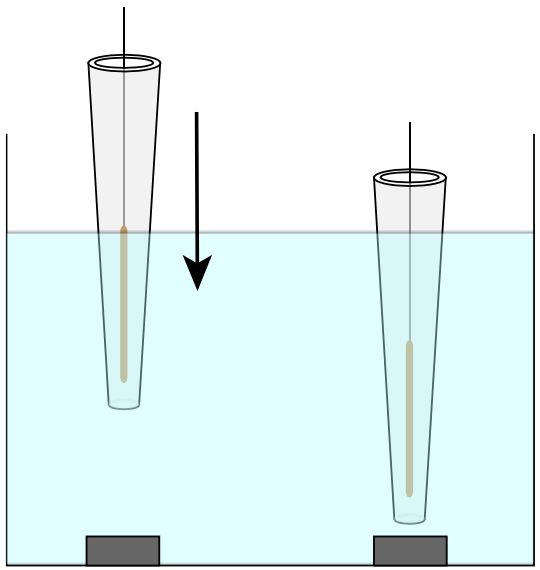


Fig. 1-2. Downward Motion

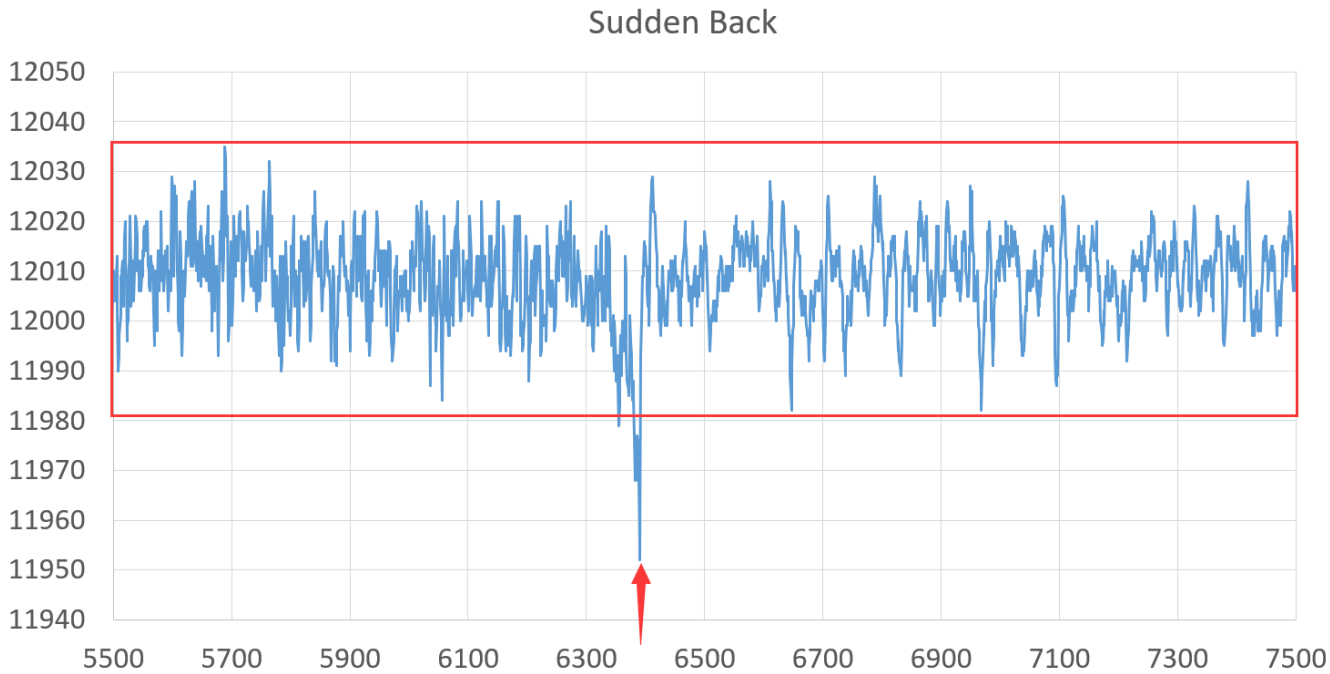


Fig. 1-3. Current Decline Feedback

General displacement current decline expression:

$$I(d) = \frac{V_0}{R_p + R_a^{\frac{r_o}{r_i}}(d)} = \frac{R_p + R_a^{\frac{r_o}{r_i}}(d \to \infty)}{R_p + R_a^{\frac{r_o}{r_i}}(d)} I_0 = \frac{R_p + R_a^{\frac{r_o}{r_i}}(d \to \infty)}{R_p + R_a^{\frac{r_o}{r_i}}(d)} \times \frac{\sigma V_0 r_i}{\frac{1}{\pi \, tan\, \alpha} + \frac{1}{4}}$$

Where, R_p is the resistance at inner side of probe, and R_a is the outside resistance, r_o is the outer radius of tip, r_i is the inner radius, α is the angle of pipet tip.

Johannes Rheinlaender, Tilman E. Shaffer. ***Anal. Chem***. **2017**. 89. 11875-11880

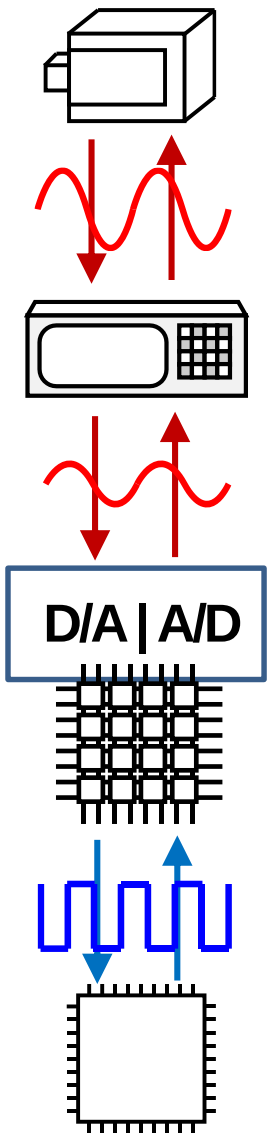
Introduction

SICM Control Subsystem

Servo Off for analog control, no micro-adjustment occurs to raise accuracy and speed.

FPGA is real-time and can generate a voltage -10V ~ 10V interval with 65536 amplitude resolution range.

CPU is a preemptive processor, which can be interrupted by multitasking traps.
Not appropriate for real-time control.



Piezo-Actuator

Analog Pulse (Amplified, Rasterized)

Piezo Controller (Amplifier)

Analog I/O (Rasterized)

Analog-Digital Convertor

FPGA

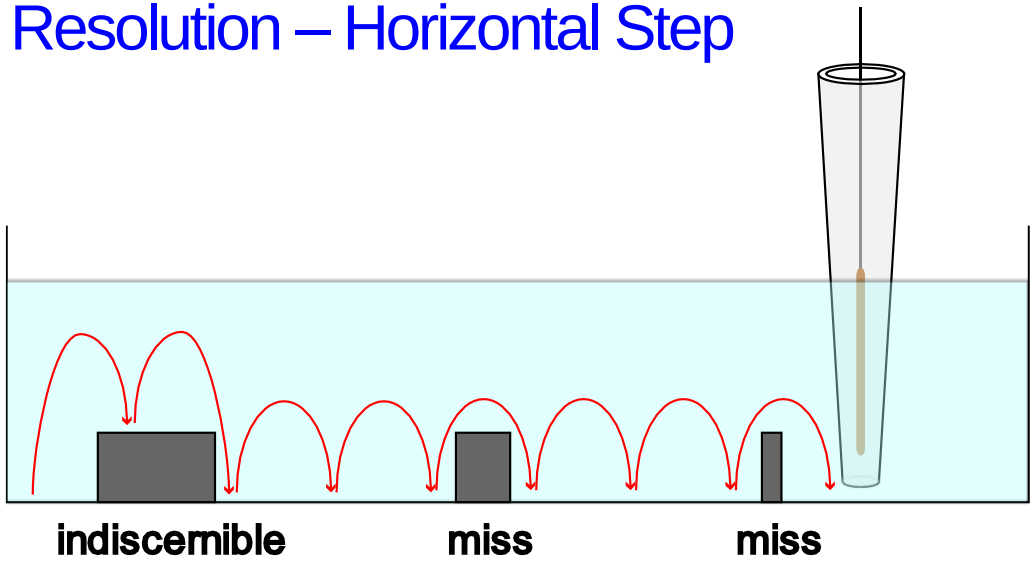
Digital I/O (DMA transfer)

General Processor (PC)

Fig. 1-4. Control Subsystem

Introduction

Resolution – Horizontal Step



1 indiscernible and 2 missed.
Poor x-y resolution

Fig. 1-5. Hopping Model with Large x-y Step

2 discernible and 1 indiscernible.
Relative good x-y resolution

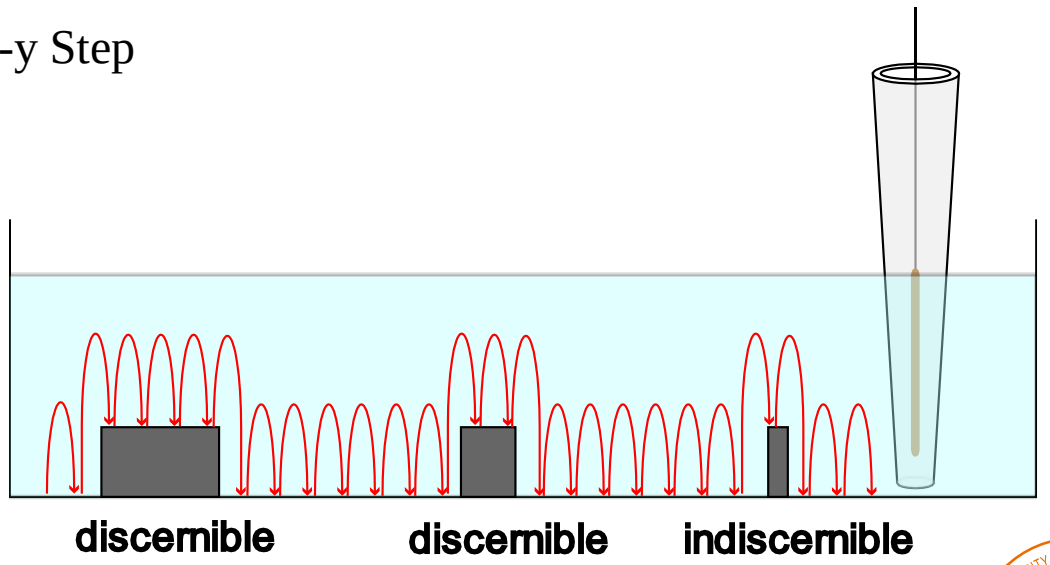


Fig. 1-6. Hopping Model with Small x-y Step

Introduction

Resolution – Tip Aperture

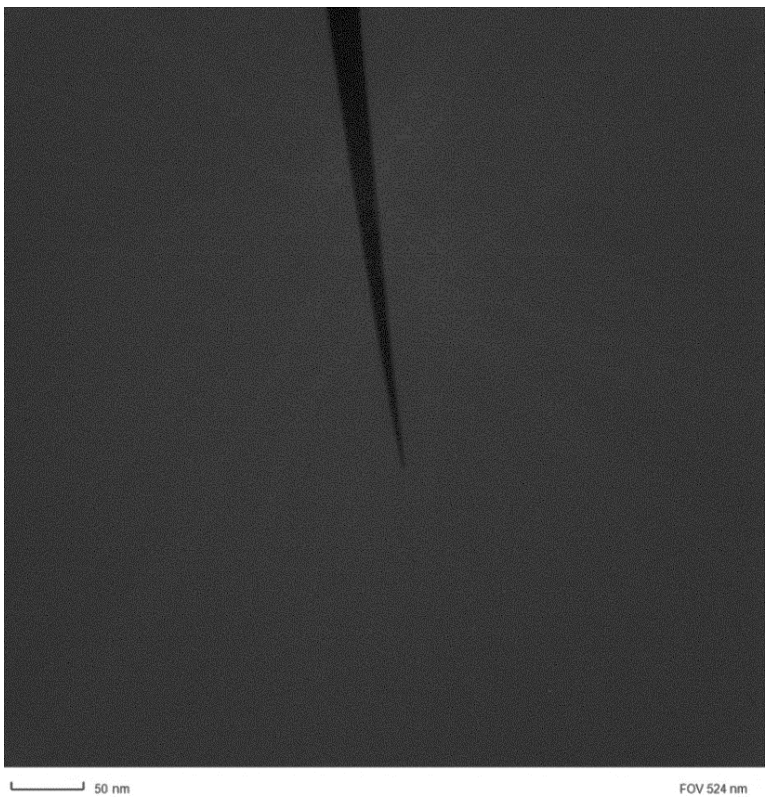


Fig. 1-7. $r_i \leq 5\,nm$ Tip under TEM

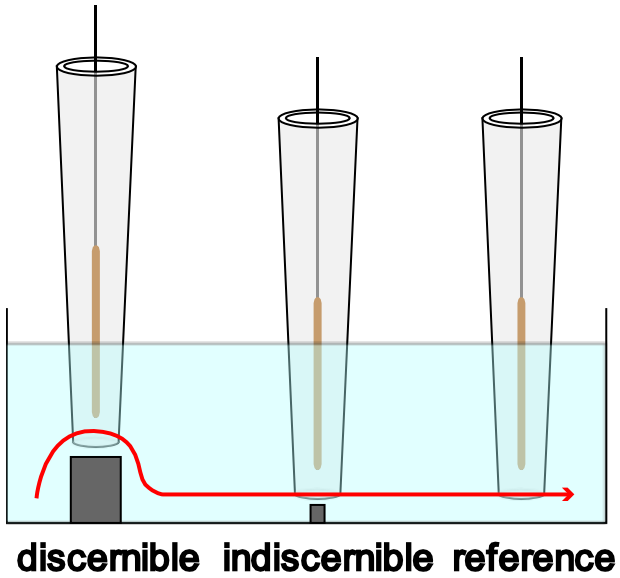


Fig. 1-8. Tip with Large Aperture

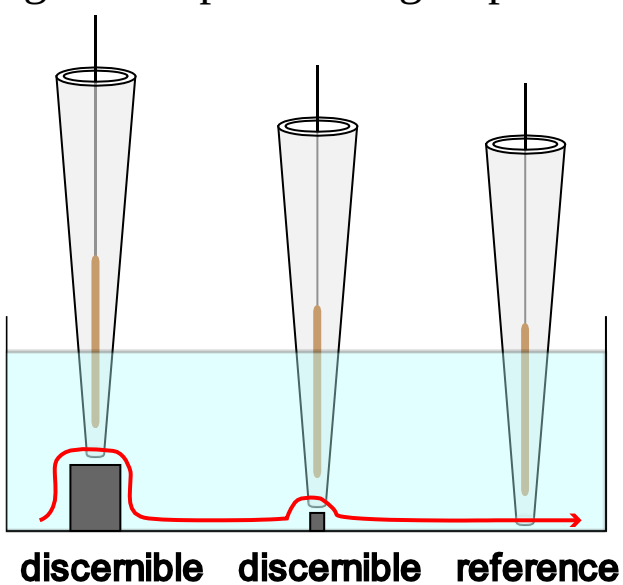


Fig. 1-9. Tip with Small Aperture

Fast Hopping Model

Result

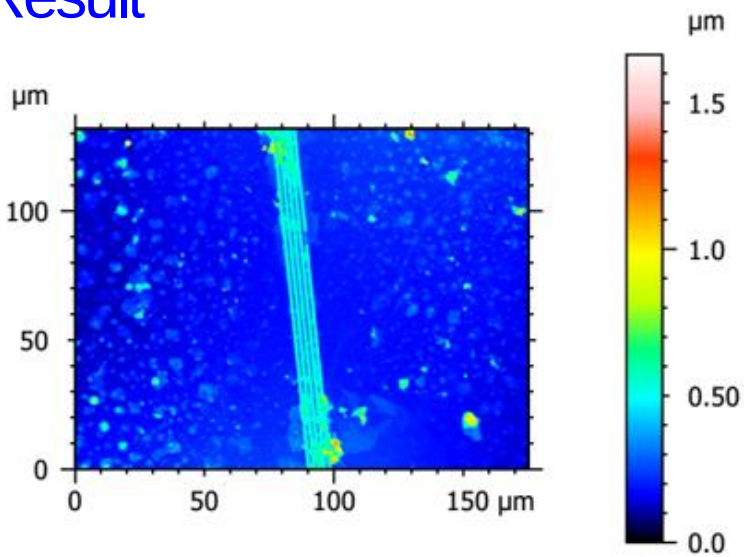


Fig. 2-1. ITO Confocal Microscopy Imaging

Fig. 2-2. Quartz Tip TEM Size Scaling

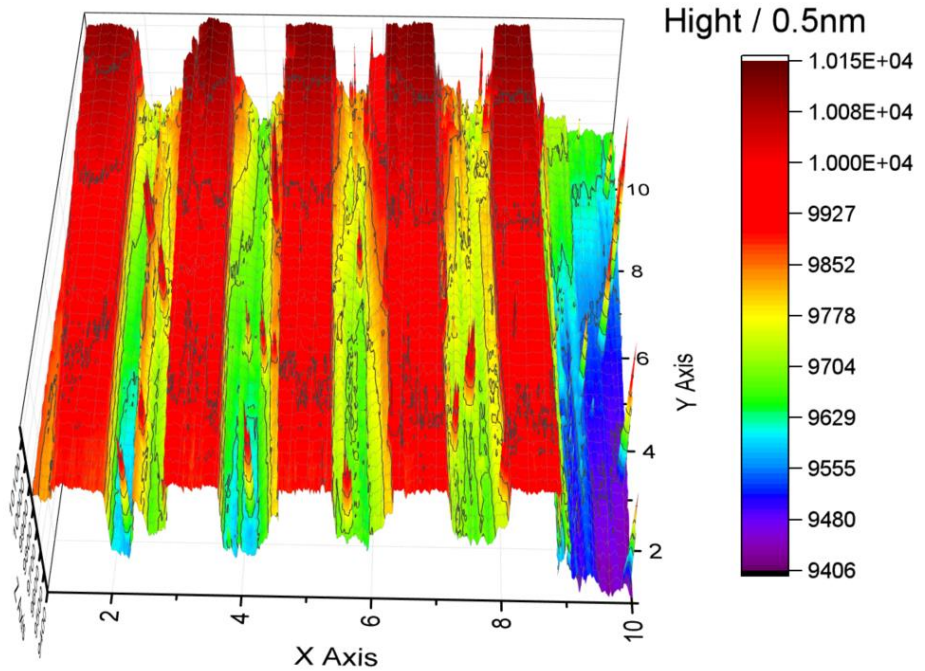


Fig. 2-3. SICM Imaging

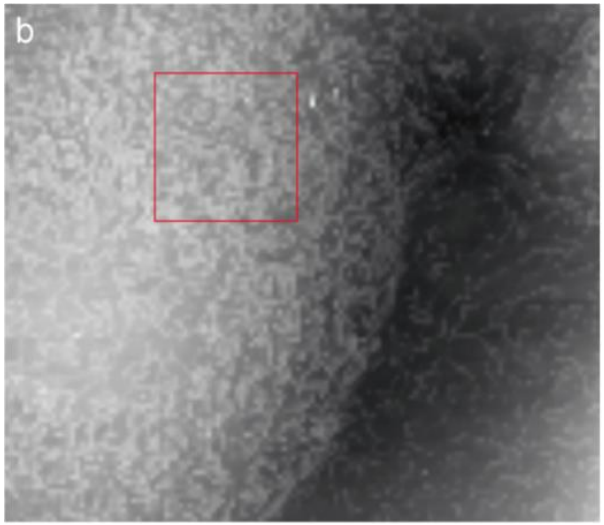
Area: **10µm × 10µm region, 500 × 500 steps**

Time Elapsed: **124 min = 2.07 hr (29.8 ms / point)**

Probe Aperture: **15 nm**

Fast Hopping Model

Comparison



Area: **40μm×40μm region, 128 × 128 steps**

Time Elapsed: **25 min (91.6 ms / point)**

Probe Aperture: **80 nm**

Fig. 2-4. A6 Kidney Epithelial Cell SICM Hopping.

hopping mode and fast SICM. Due to the huge number of points being scanned it is possible to resolve features in fast SICM that are not possible to resolve in the hopping mode in a reasonable time scale for a dynamic, live cell surface. A hopping mode image obtained to the highest resolution possible with the hopping mode software, 512 × 512 pixels would take around 5 h to complete compared to around 10 min for the 1024 × 600 pixel image in fast SICM.

David Klenerman, Yuri Korchev. ***Ultramicroscopy***. **2012**. 10. 1016-1023

Fast Hopping Model

Strategy – Nonlinear Scanning

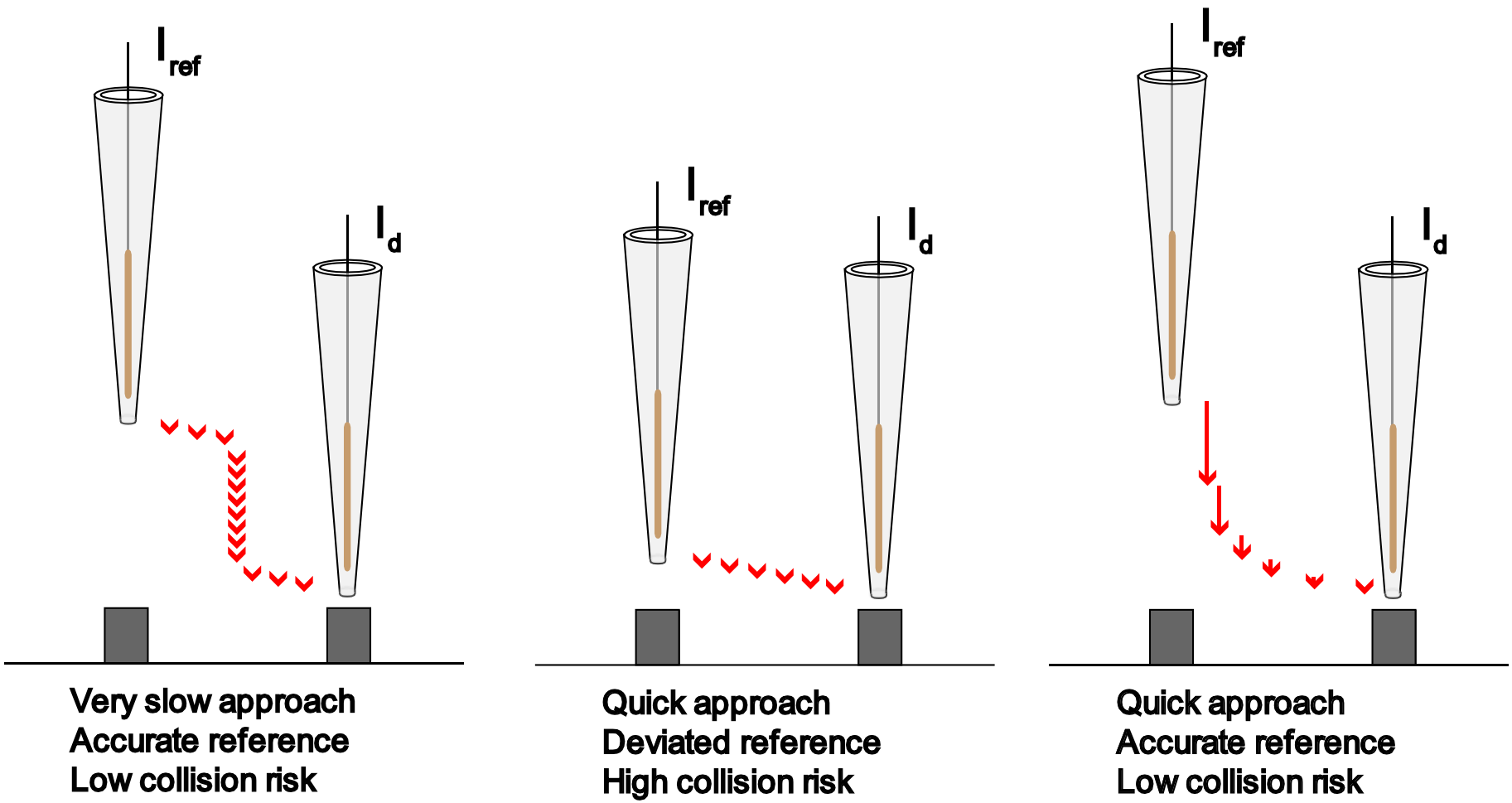


Fig. 2-5. Three Strategies of Single Point Scanning

Fast Hopping Model

Strategy – Region Classification

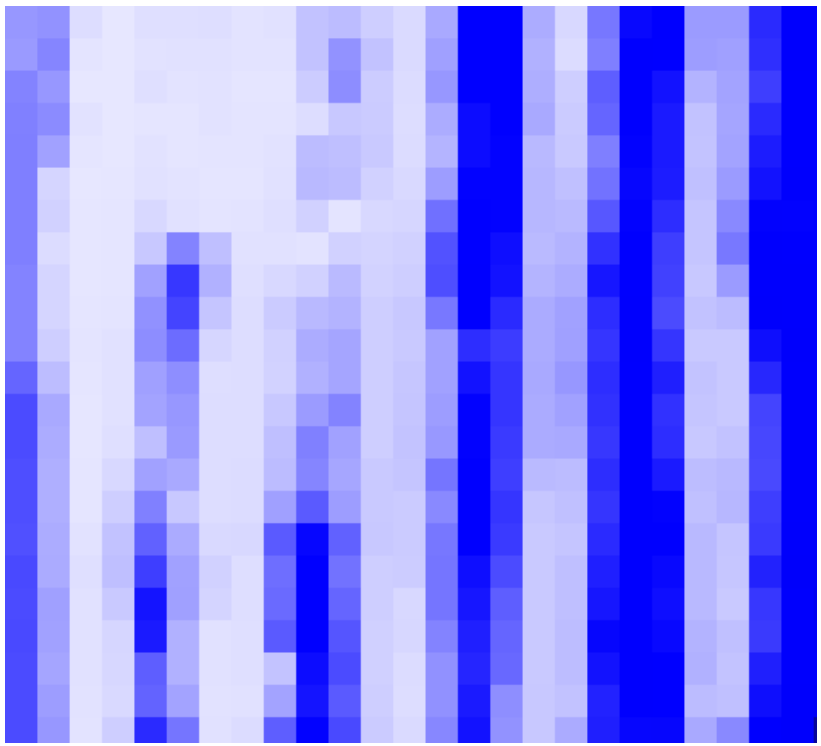


Fig. 2-6. Rough ITO Scanning

25×25 steps in 12×12μm square
Mask Matrix

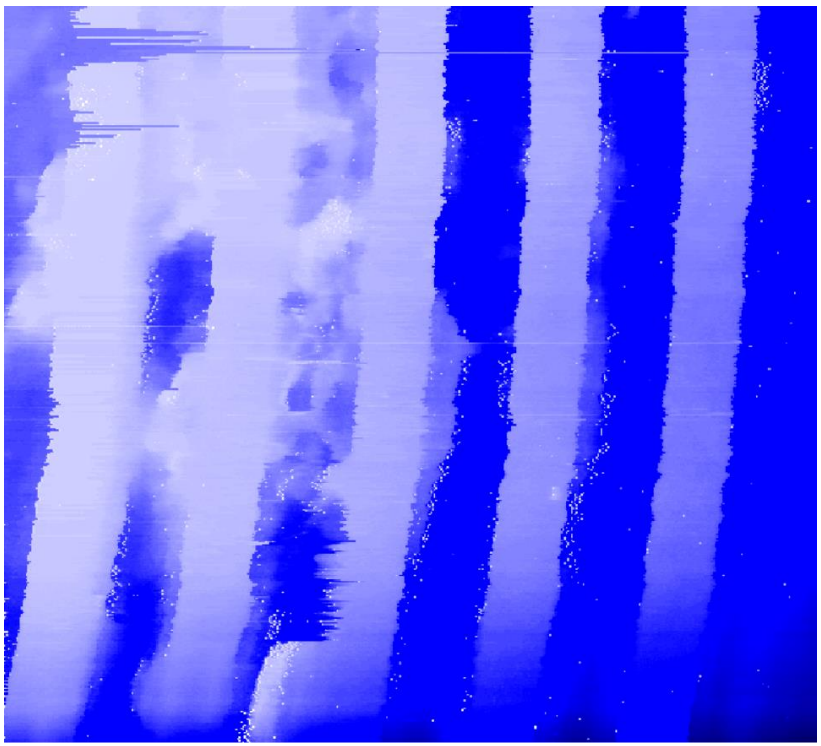


Fig. 2-7. Precise ITO Scanning

500×500 steps in 12×12μm square

Fast Hopping Model

Strategy – Dynamic DMA FIFO

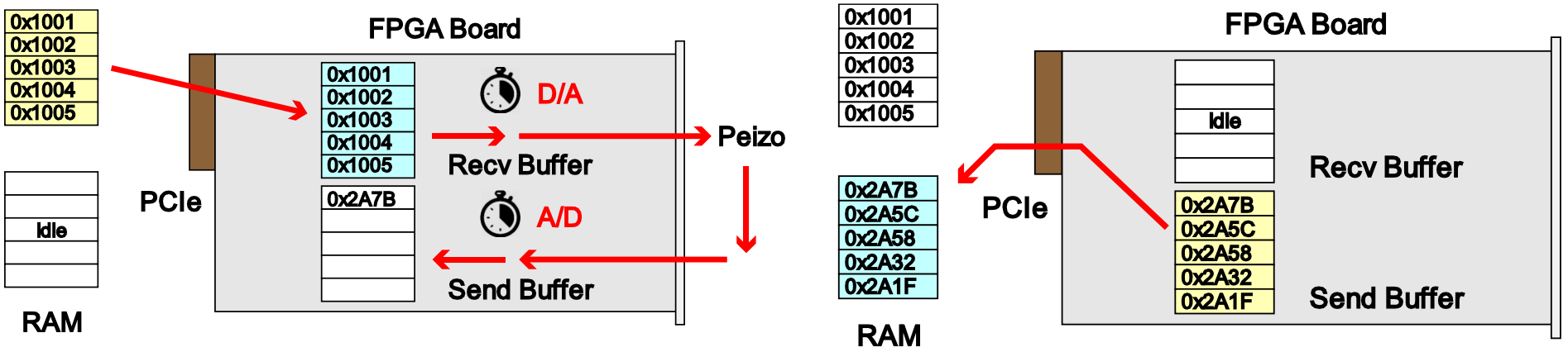


Fig. 2-8. Data Batch Processing and Transmission (Low Efficiency)

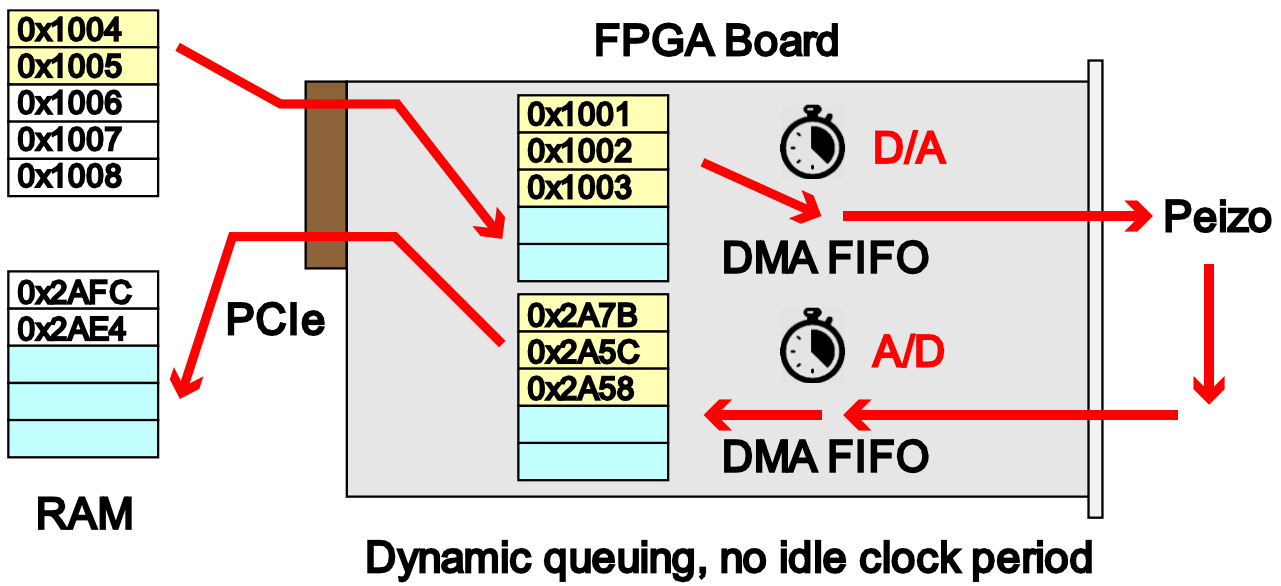


Fig. 2-9. Dynamic DMA FIFO (High Resources Occupying Efficiency)

Ultra-high Resolution Imaging

Result

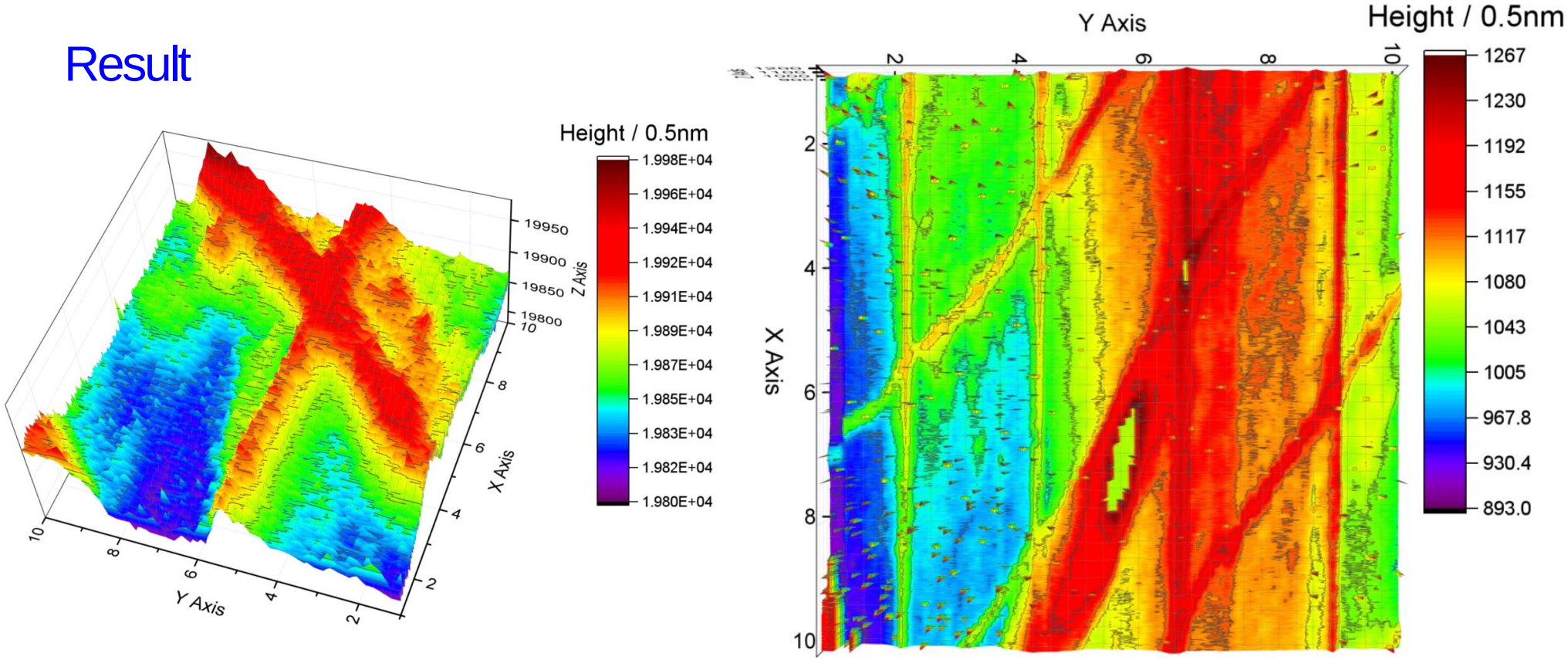


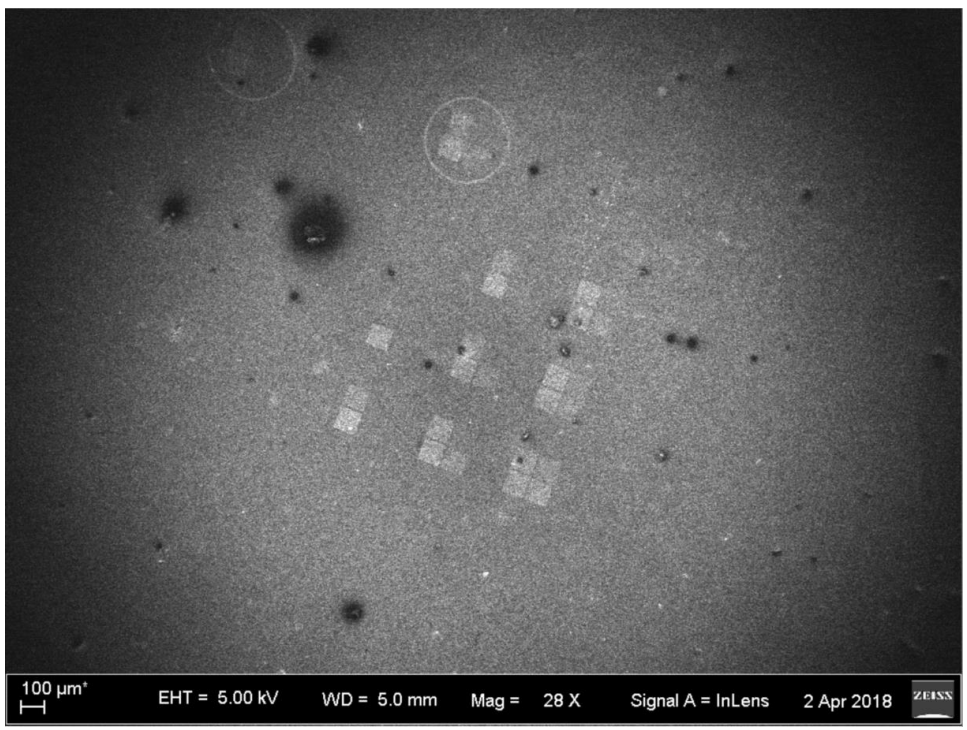
Fig. 3-1 and 3-2. Inclined-crossed HSQ Nanobeam

3-1.
Area: **300nm×90nm region, 600×45 steps**
Time Elapsed: **30.15min (67 ms / point)**
Discernibility: **20nm width, 14nm height** beam.
Probe Resolution: **Below 10nm**.

3-2.
Area: **1.65μm×1.5μm region, 1100×100 steps**
Time Elapsed: **2.75 hr (90 ms / point)**

Ultra-high Resolution Imaging

Result



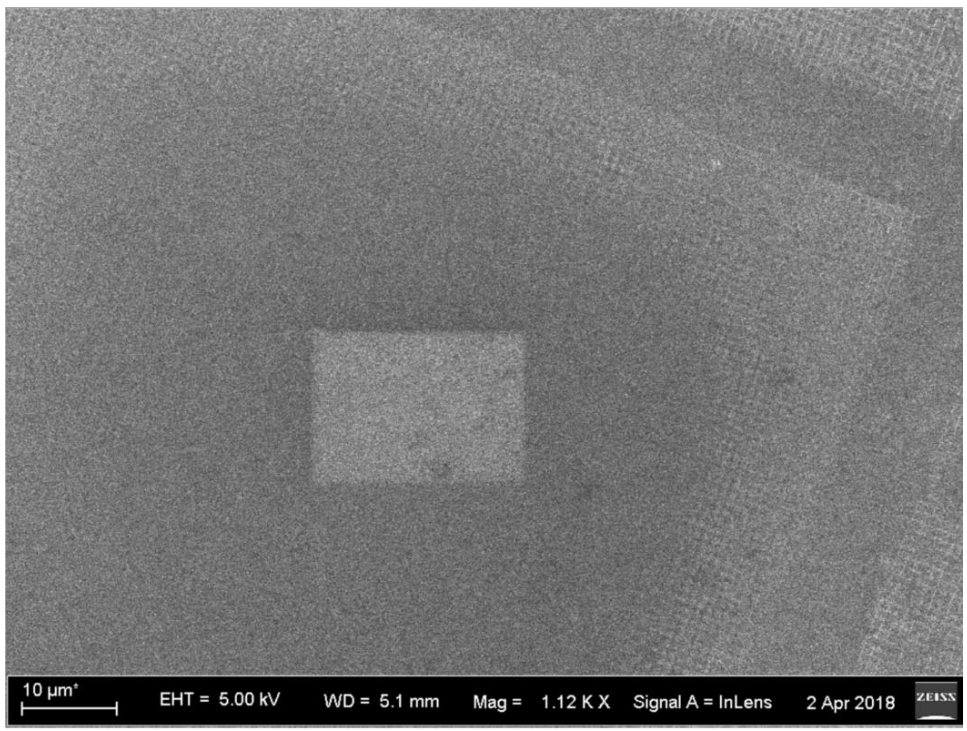


Fig. 3-3 and 3-4. SEM Images of HSQ Beams

It is a pity that this became a pending case till now!

Future Work

Ion Channel Scanning

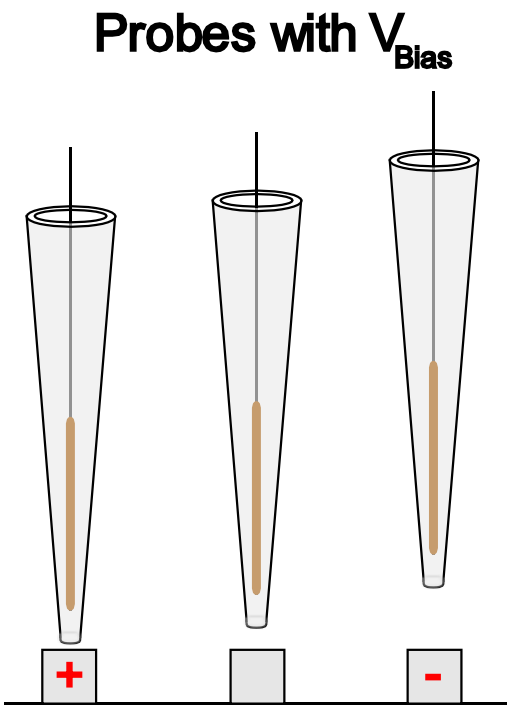


Fig. 4-1. Ion Current Rectification of SICM Scanning Charged Sample

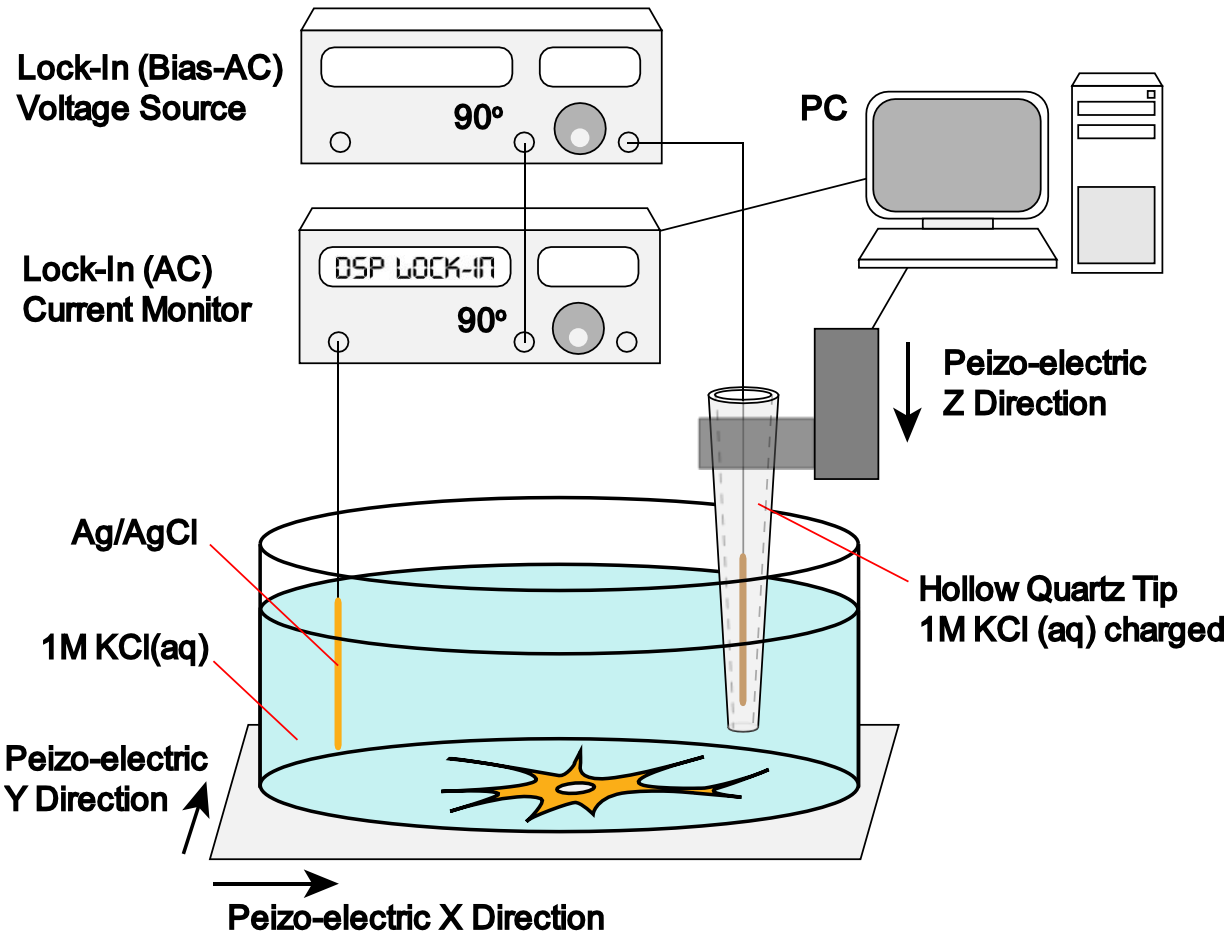
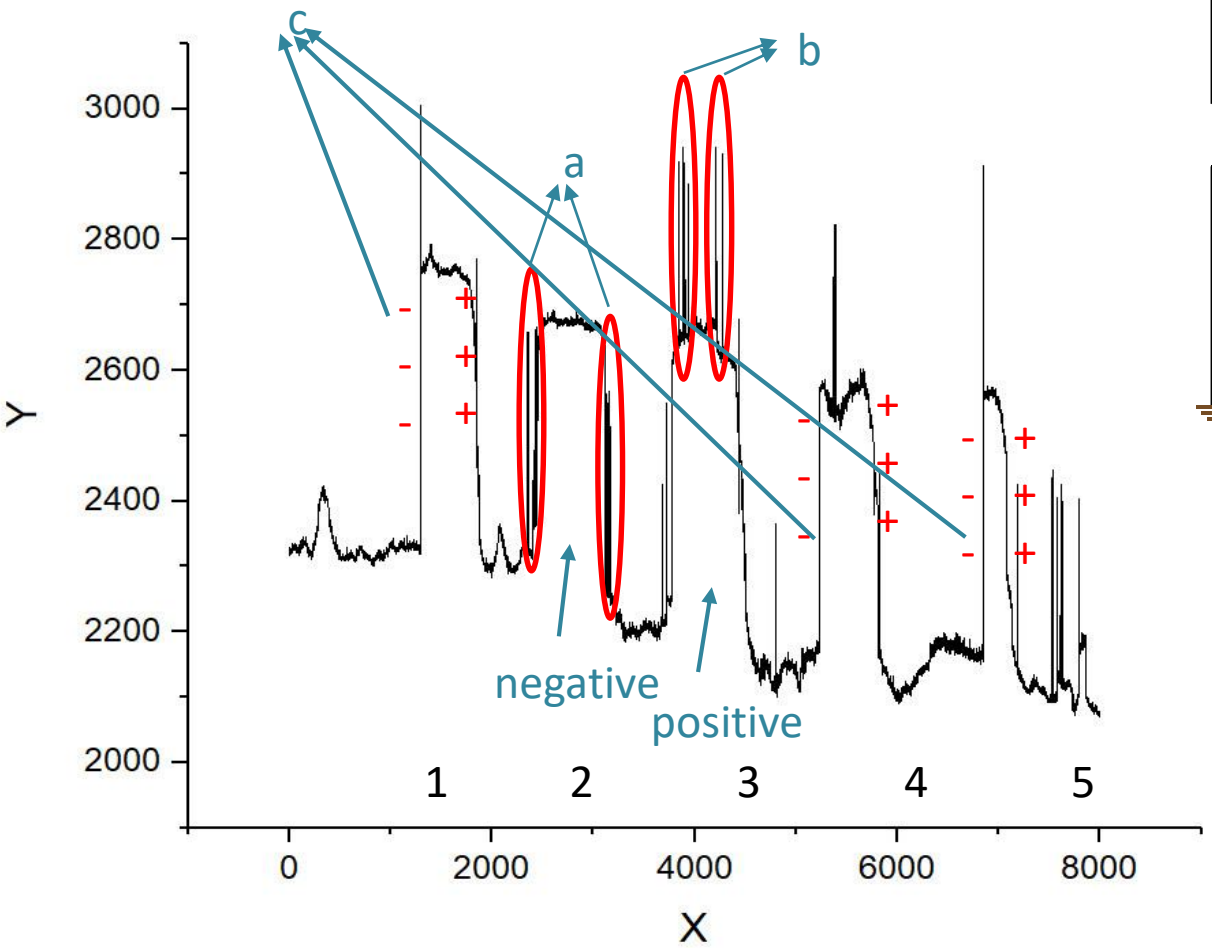


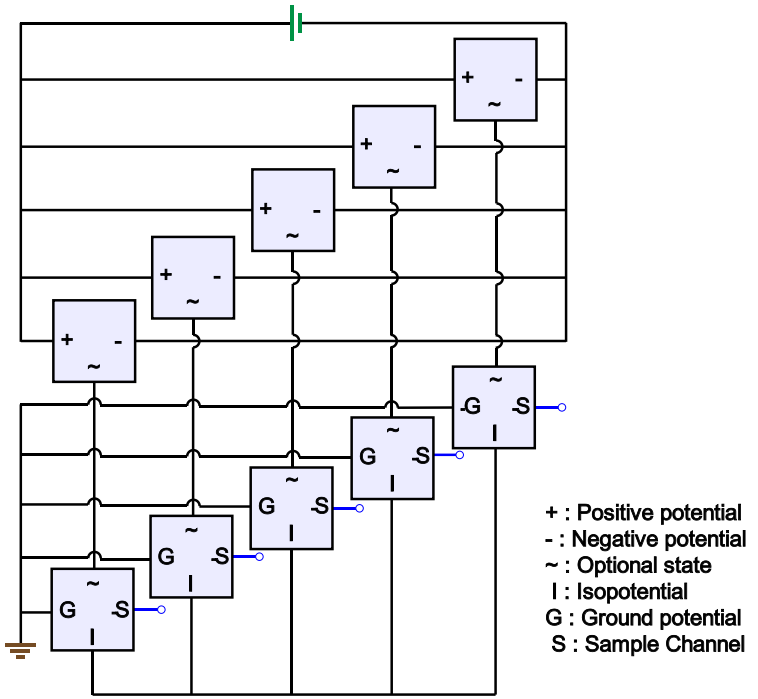
Fig. 4-2. Double Lock-In System Making a Sensitive Bias Tip

David Perry, Rehab AI Botros, Dmitry Momotenko, Sophie L. Kinnear, and Patrick R. Unwin. ***ACS. Nano***. **2015**. 10. 1021-1032.

Future Work

Ion Channel Scanning





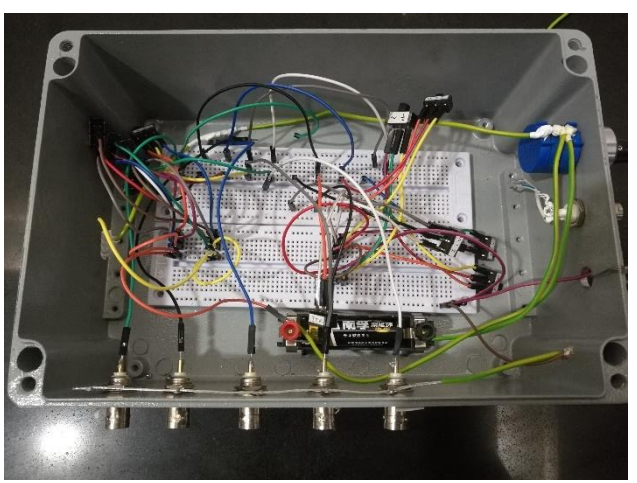
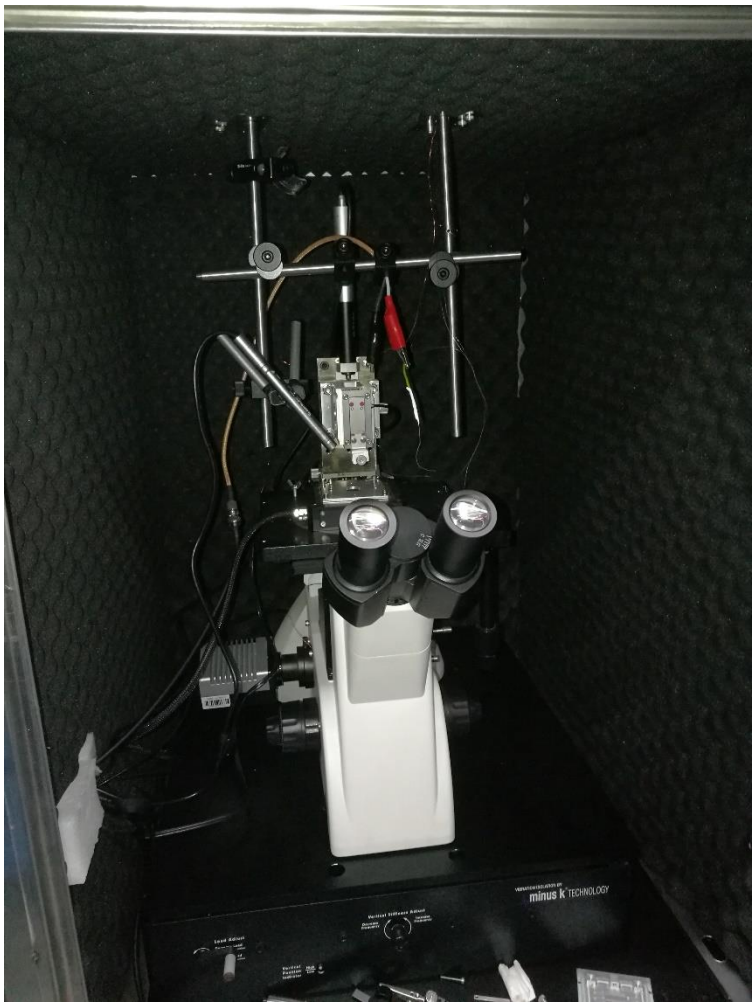


Fig. 4-3. Impact of Charged Sample on SICM Tip

Future Work

Ion Channel Scanning



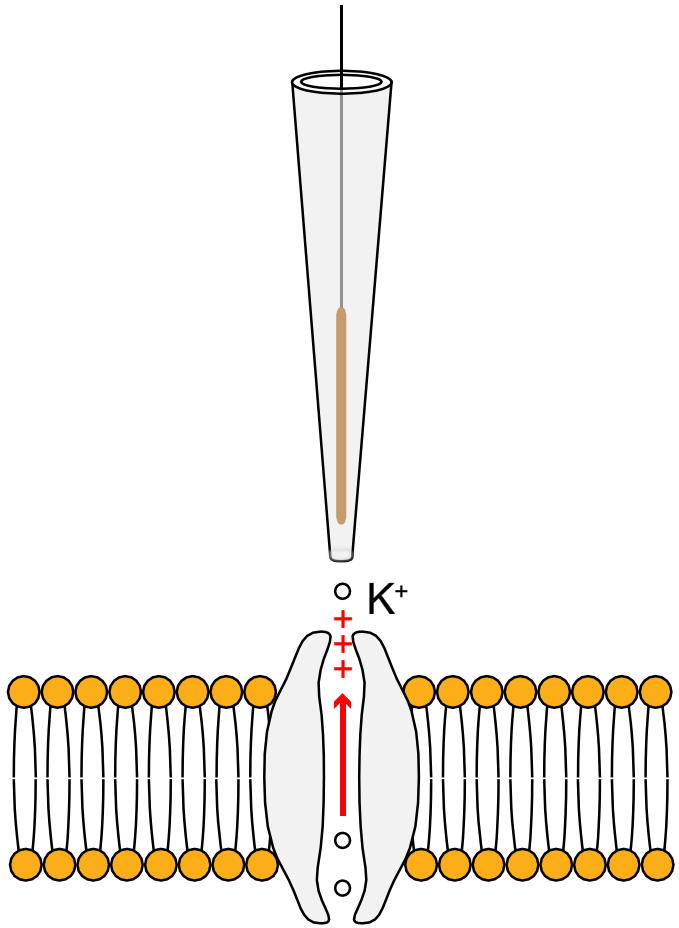


Fig. 4-4. SICM for Cell Imaging

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Acknowledgement

A Group Makes it Work!

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THANKS FOR LISTENING!