- The purpose of this experiment is to get familiar with the STM by attempting to take atomic resolution images of Graphite and Gold

Sun. Feb 5th

- Preliminary Reading: Manual for Burleigh STM
  ~~p~~ Chapters 1, 2, 4

- <u>Notes on Chapter 1: History of microscopy</u>

<u>Optical Microscopy</u>
- Magnifying lens w/ resolution given by
  $\frac{\lambda}{2n}$ λ ← wavelength of light, n ← index of refraction of lens
  ↳ ~ 0.1 microns

<u>Electron Microscopy</u>
- De Broglie wavelength of electron
  $$\lambda = \frac{h}{p}$$ h ← plank's constant, p ← electron momentum
- Electron can be accelerated to momentum
  $$p = \sqrt{2mV}$$
  through potential difference V
- For $V \sim 10^3$ volts, $\lambda < 1 Å = 0.1$ nm

- Shorter wavelengths of light encounter problems?
  I don't really understand this part (p. 13)
- Transmission electron microscope
- Useful for study of regular lattices
- TEM requires a vacuum to avoid electron scattering from air
- TEM analagous to optical microscope

Sun. Feb 5th

- Scanning Electron Microscope (SEM) images surfaces by analyzing intensity of reflected electron beam and secondary electrons produced by incident beam
- An electron beam is scanned across surface
- Resolution 50-100 Å
- Non-conducting materials must be coated in gold
- Also requires vacuum

Acoustic Microscopy
- Can be used to image the inner structures of opaque materials

Scanning Probe Microscopy
- Prior are examples of wave microscopy
- Wave interaction w/ medium which affects index of refraction (wave speed)
- There is also probe microscopy. A point source interacts w/ sample to gather information
- Probe microscopy images 3D surface instead of inner structure of sample
- Different kind of probe tip interactions for different kind of microscopes

- The first was a scanning profolometer which ~~was~~ measured deviations of a stylus as it scanned the surface

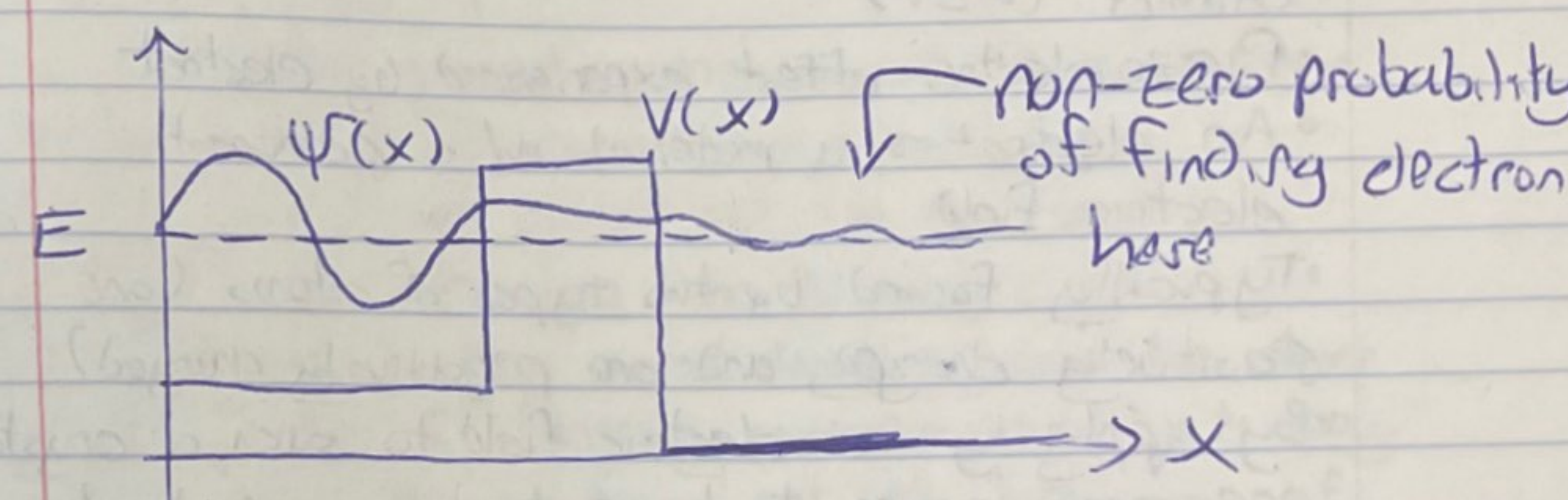
Sun. Feb 5th

Notes on Chapter 2: Operating Principles of STM

- 5 key concepts:
  1) Quantum Tunnelling
  2) Controlled motion over small distances using ~~pz.~~ piezolectrics
  3) Negative feedback
  4) Vibration Isolation
  5) Electronic Data collection

Quantum Tunnelling
- An electron may be found across a potential barrier it does not have the energy to overcome

~~Fig~~ Fig 1:



- The probability of transmission across a potential barrier of height U_0 and length L is
  $$T(E) = \frac{(4k\delta)^2}{(1+(k\delta)^2)^2} e^{2L/\delta} \propto \exp\left(-L\sqrt{2m\varphi/\hbar^2}\right)$$
  w/ $k^2 = \frac{2mE}{\hbar^2}$ $\quad (k\delta)^2 = \frac{E}{U_0 - E} = \frac{E}{\varphi}$
- For typical values, $\hbar = 1.05 \cdot 10^{-34}$ Js, $m = 9 \cdot 10^{-31}$ kg, $\varphi = 5 \cdot 10^{-19}$ J, $T(E) = e^{-2L}$, L in angstroms

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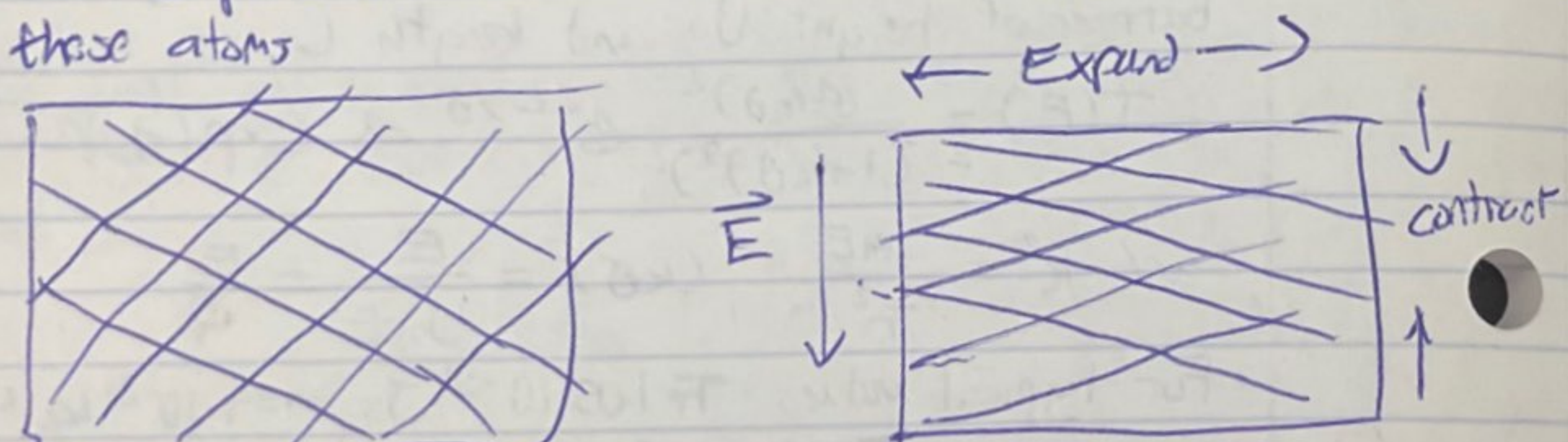
- For each angstrom change in seperation, tunnelling probability decreases by an order of magnitude
  $\Rightarrow$ Tunnelling current sensitively measures distance between tip and sample
- In ~~STP~~ STM, atoms tunnel between sample and probe. Tip of probe is one atom
- Atoms are ~3 Å apart. So the probability of an electron tunneling from the second layer of atoms (not the closest ones) is $e^{-2(3)} \approx 0.002$. i.e. The tip will mostly get electrons from outer surface!

<u>Piezoelectrics</u>

- Tip and sample seperated by 10 Å
- To move tip this close, must uses piezo electric ceramics (PZT)
- Piezoelectric effect experienced by electret
- An electret is a material w/ a permanent electric field
- Typically formed by two types of atoms (one positively charged, and one negatively charged)
- By applying an electric field to such a crystal, one can cause it to contract in one direction and expand in the other due to realignment of those atoms



Sun Feb 5th

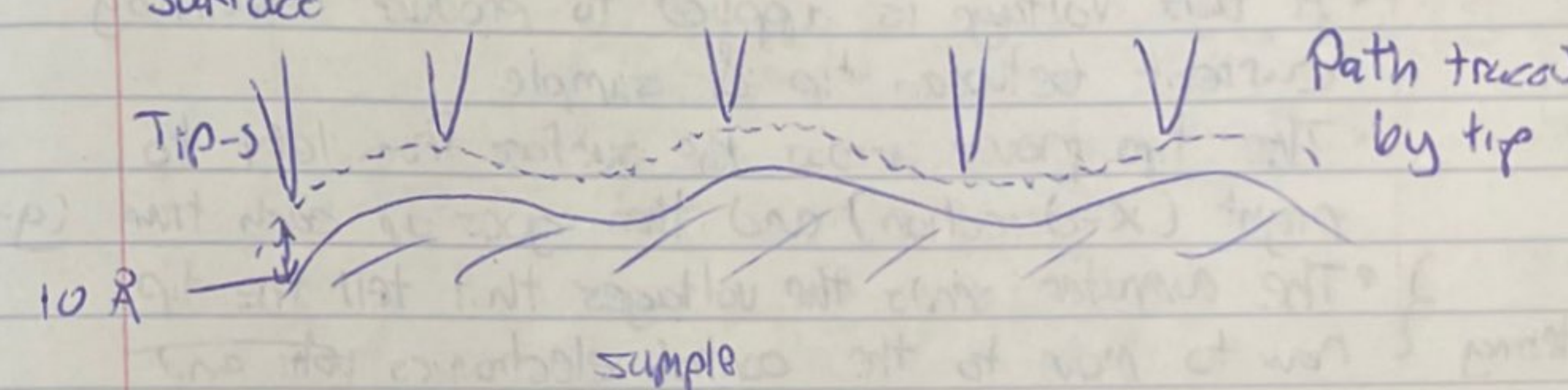
*

- Intersections and spaces in previous figure represent each kind of atom, one positive, one negative
- The piezoelectrics in the STM have a sensitivity of ~150 angstroms/volt
- The computer can control the voltage to mV accuracy $\Rightarrow$ precision of less than an angstrom

- The motion of the STM tip is achieved using a piezo electric cylinders using two electrodes
- ~~By indepen~~
- By changing the voltage of each electrode, one can extend, retract, and bend the tip

<u>Negative Feedback</u>

- Tunnelling current as measure of sample distance
  No current $\Rightarrow$ tip too far
  Some current $\Rightarrow$ tip near sample
- Electronics of obey the following rule:
  "If the tunnelling current decreases, move tip closer to sample. If tunnelling increases, move tip * away."
- This way the tip traces out the topography of surface



Sun Feb 5th

Vibration Isolation
- Everything is vibrating
- Walking around room causes vibrations in tables of ~1 μm = 10^4 Å
- We need to hold tip 10Å from sample, so the STM must be isolated from vibrations. 3 methods

a) Super-Conducting levitation: A magnet above a super-conductor will float above it's surface

b) Spring Damping: If the microscope is hung from a fixed surface, ~~the~~ by springs, the springs will deform in response to vibrations of the fixed surface

c) Stacked plates w/ elastomer spacers: Place microscope on a series of metal plates seperated by elastometer 'O-rings'
- The O-rings act like springs to dampen vibrations
- Each plate vibrates w/ ~1/5 the amplitude of the plate below

Electronic Data Collection
- STM image is built one data point at a time
- A bias voltage is applied to produce tunnelling current between tip & sample
- The tip moves across the surface from left to right (x-direction) and then goes up each time (y-direction)

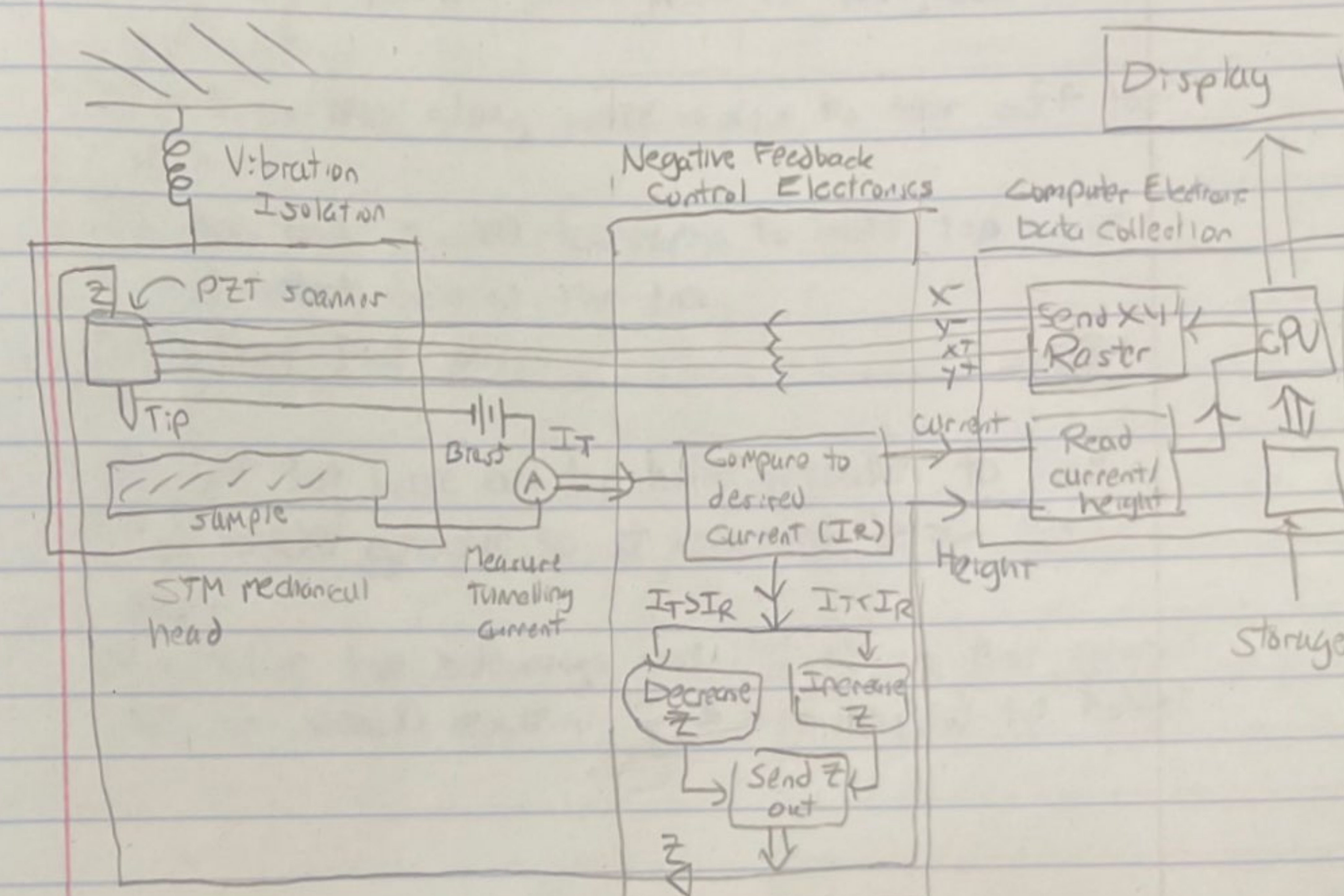
XY rastering
- The computer sends the voltages that tell the tip how to move to the control electronics, ~~which and sends that~~ info which then uses negative feedback to move the ~~sample~~ tip towards and away from sample (Z direction)

Sun Feb 5th

~~The negative feedback~~

Using the PZT scanner
- The voltage required to maintain a constant tunnelling current (Z-voltage) is sent back to the computer

- Computer's POV:
  - a set of X and Y voltages corresponding to the tip's position are sent out
  - a Z voltage corresponding to ~~its the tips height~~ the sample height is returned
- On the display, the (X,Y) position are the cartesian coords of image
- The image is in grayscale. The gray value of each point is proportional to the returned Z voltage



Tues, Feb 7th

- Showed up to lab and identified tools

- Here I will write a description of the microscope and available tools. Nano STM ~~A~~

- Note: Previous STM student, Christian, came in and mentioned that the samples are mislabelled
- One sample is just sitting on table w/ no box?

Tues, Feb 7th

Preparing for Measurement procedure (from NanoSTM manual)

Initializing system
1) Connect power, & USB to computer
2) Turn on STM power
3) Start Nano control software on computer

Preparing and installing STM Tip

1) Clean wire cutters, Flat nose pliers, and pointed tweezers w/ ethanol. Only touch Pt/IR wire w/ these
2) Remove old tip from STM using pointed tweezers
3) Hold end of wire firmly w/ Flat nose pliers
4) move cutters at 4mm as obliquely as possible
5) ~~Pull~~ Close cutters until wire is felt, but do not cut
6) Pull cutters along wire axis to tear off the tip
7) Use the pointed tweezers to hold tip wire just ~~behind~~ behind the tip
8) Release Flat pliers

9) Put tip wire on tip holder, parallel to the tip holder groove so it crosses below tip clamp
10) Move tip sideways until it is in the groove The tip should extend 2-3 mm beyond tip holder

Tues, Feb 7th

* ~~Ha~~ Different samples require different preperation
The required preperation will be noted later

~~A~~
~~A~~

Mounting the sample

1) Unpack sample holder, from plastic storage vial, touching only black plastic handle
2) Put prepared sample on magnetic end of sample holder using tweezers
3) ~~to~~ Lower front end of sample holder onto sample holder guide spheres, then gently settle back end onto approach motor support

Place sample holder into scan head in such a way that it does not touch the tip and so the sample is not pulled by the magnet that pulls the sample holder down onto the approach motor

Tues, Feb 7th

- 10:03 AM, office prof. Tahir arrived. office 915B
We discussed the experiment
- I must image these different surfaces and ~~and~~ use physics to interpret my results, measure size of atoms etc.
- Print images and stick them in lab book

Preparing
~~Mounting~~ Gold Sample

- Sample No. 3T00628. Labelled Graphite but it is gold
- Requires no special preperation

Preparing Graphite (HOPG) Sample

1) Put sample on table w/ tweezers
2) Stick adhesive tape gently to top of HOPG and pull it off to remove top layer
3) Remove any loose flakes w/ tweezers

Tues, Feb 7th

First Measurements w/ Graphite

- Sample No. BT06351
- Got Ethanol and scotch tape from lab tech
- Initialized system (p. 9), blue ~~LD~~ ~~LD~~ ~~L~~ LED actuated at 10:28 AM
- Message saying 'No controller detected'?
- Unplug and replug USB, and restarting system fixed this
- Attempted to cut a wire but I dropped it
- Having steady hands is really hard
- Second attempt was successful, but I dropped the tip on the paper at some point so ~~I ks~~ it's possible the end facing the sample holder ~~+~~ is the dull end
- I picked the sharper looking end for the tip
  - I used a STAEDLER triangle to get ~~a~~ 4mm
  - I accidentally used rounded tweezers instead of pliers to do this
- Prepared ~~HOPT~~ HOPG as per p. 11
- Mounted sample as per p. 10
- Load default parameters from File >> Parameters >> Load parameter settings and load C:\Program Files (x86)\Nanosurf Nano\Config \Default_STM.par

Tues, Feb 7th

Manual Course Approach

1) Push sample holder to ~1mm of tip
2) Rotate sample so tip points to a flat area
3) Place magnifying cover over scan ~~head~~ head so you can see reflection of tip in sample

- Did this as instructed. Mirror image hard to see in Graphite due to distortions and lack of light. The tip looks sharp!

Fine approach motor

1) Watch distance between tip & sample w/ help from magnifier
2) Click Advance button in approach group of acquisition tab until gap between tip & reflection is barely visible
~~3) If motor not~~

- Motor moved as expected, but reflection of tip is hard to see
- I moved it as close as I could

Scanned with CamScanner

Tues, Feb 7th

Automatic Final Approach
1) Preparation Group: Wizards >> Imaging
2) Give expected feature size & height to the best of your ability. Set scan quality

Next: Name measurement series
3) Activate Gallery panel in info pane
4) Check history tab
5) Enter name in top entry box

Approaching:
6) Click Approach on Approach Group & in Acquisition tab

- For approaching HOPG, left default vals.
- Feature size 50nm
- Feature height 5nm
- Medium speed / good quality
- Followed instructions
- Approach did not end after 20 seconds. Go back to ~~manual~~ manual approach

- ~~Rotated~~ -Removed sample & rotated microscope so that reflection was more visible
- Remounted, and approached sample
- Automatic approach still not working
- Opened SPM parameters >> Approach
- Set move speed from 70% -> 100%
- Still taking way too long

Tues, Feb 7th

- Decreased gap using fine approach even more
- I repeated this process until the motor stopped moving in fine adjustment
- Tip may have crashed
- I may need to clean the motors next time

- Unmounted and packaged sample
- Turned off software & power
- Before Friday, figure out ~~surfa~~ required feature size & height for graphite
- I left the tip in the clamp for next time

Fri, Feb 10th

- Tip is still positioned & sharp!
- Turned on STM as on pg. 4
- Prepared HOPG (sample ~~BTO 631~~ BTO 6351)
as on 11
- Mounted sample as on 10
- Reflection visible!
- Fine approach as on 13
- Loaded default parameters but set approach speed to 200%
- System does not let me do that, set to 100%

- Automatic final approach at 9:36 AM
- Let that run while reading about sol^ns for approach too long in ~~lab manual~~ operating ~~instructions~~ instructions
- I think I can get a closer fine approach
- Put my eye right to magnefying lens and got a much closer fine approach
- Retry at 9:37 AM
- Quit at 9:44 AM
- Maintanence: Clean surfaces w/ acetone + cotton swap
sample support
- Turned off microscopes & repackaged sample
- Sample fell on table

Fri, Feb 10th

Claning:
~~Moisten tissue (KIM (KIMTECH Science Wipes) and clean interior surface of scan head~~
- Moisten cotton swap w/ acetone and clean sample holder support surfaces

- Moisten KIMTECH wipes and move along sample holder in axial direction. Put sample holder back in container
- Allow all parts to dry

- Reprepared sample BTO 6351 and remounted as before
- Redid page 13
- Still not working. I forgot to set appropriate parameters
- Loaded STM parameters file
- Set approach speed 100%
- Left default feature size ~~a~~ & height

- It still is not working :C
- Automatic approach just goes on and on

- Prof Tahir walked in at 10:15 AM
- Tip was too close and not sharp enough
- Also tungsten tip that I am working with is okay, Pt/Ir not necessary

Fri, Feb 10th

• Repeated the process on p. 9. This time I made sure to hold the wire w/ pliers instead of tweezers, and tugged on the cutters ~~a~~ in the wire's axial ~~direct~~ direction for a much sharper tip

• Remounted sample and reapproached
• Set ~~values back to~~ params to default STM w/ 70% speed
• Attempt at final approach, 10:36 AM
• Still nothing
• Replayed w/ manual approach until reflection and tip were almost indiscernible
- Approach done INSTANTLY

• Image ~~π~~ is $(250nm)^2$
• I want to ~~dec~~ decrease this range
• I am just getting a flat colour map, even at 50nm x 50nm

• TA walked in. Said to play w/ different params
• Something was wrong w/ software. Probe light was red
• Restarted software and changed move speed to 100%
• Told me to start w/ big image and try to zoom later
• Mess w/ setpoint voltage and PID gain to get approach
• Set point 1nA, P-Gain 1000, I-gain 200, D-gain 0, scanning worked

Fri, Feb 10th

But ~~image~~ stopped imaging properly after a few lines
• Increased tip voltage from 50 mV -> 250 mV
• No change
• Inclined surface possibly
• ~~Tip is crashing~~ Tip could be crashing or getting too far
• Line graph of Z-axis varying wildly

• Also, watch probe light on computer. Red = too close
• System froze as I played w/ values
• Restarted everything. Replug USB
• Fine approach not moving at all!
• Restarted software!
• ~~Reprepared~~ Reprepared sample and a fresh new tip
• After setting speed 100% and tip voltage 250mV, this worked
• TA explained that tip voltage is meant to decrease the potential barrier of air so higher tip voltage means more tunnelling

<u>Params</u>:

Image size: 200 nm — Set point: 1nA — Tip Voltage: 250mV
Time / line: 0.2 s — P-Gain: 1000
Points / line: 128 — I-Gain: 2000
Rotation: 0° — D-Gain: 0

• Produced ~~image~~ Image00044
~~Time/line~~ Very sharp change
• Time / line -> 0.4s produced Image00045

Fri, Feb 10th

~~• Probe status orange~~
• Probe status orange. Imgs corrupted. Reapproach
• System crashed
• Restarted & tried again. Image corrupted again

• Probably surface imperfections. I will cleave w/ tape again
• The surface of this sample is extremely flakey and messy
• Last time I mentioned there was a sample w/ no box
• Looks like graphite. It has a much smoothe surface so I'll use that

• During scan, red light. Tip crashed
• Played w/ params trying to get approach to work
• Tip seems to keep crashing
• Decreased move speed to 55% (other params default)
• That worked well enough to see details but image suddenly became white
hypothesis • Increased set point to 2nA
• Probe light flashing orange-green
• ~~Set Tip voltage~~
• Tip keeps losing contact w/ sample after a few lines
• Cleaved sample w/ tape to remove bumpy outer layer and reapproached (Tip voltage 250mV, set point 1nA)

Fri, Feb 10th

• Params:
• The tip voltage lowers the potential barrier created by air. Higher voltage ⟹ more tunnelling
• Setpoint: the desired tunnelling current. Higher current ⟹ closer tip required
• PID ⟹ related to negative feedback cycle. Learn more about this

Fri, Feb 10th

9PM

<u>What is PID</u>: From wikipedia

- Define the error function

$$\varepsilon(t) = J_{set}(t) - J_{true}(t)$$

where J_{set} is the current set point and J_{true} is the ~~actual~~ actual current

- PID defines a control function

$$u(t) = K_p \varepsilon(t) + K_i \int_0^t \varepsilon(\tau)\, d\tau + K_d \frac{de(t)}{dt}$$

- The PID values in the system must refer to K_p, K_i, K_d 20

<u>P-Term</u>: related to the error right now
<u>I-Term</u>: ~~The~~ accounts for the history of errors
<u>D-Term</u>: Accounts for future trend of errors

- In my case, the control variable should be the ~~height~~ distance between the tip and the sample?

In Nano STM operating Manual:

- ~~D~~ Increasing P-Gain decreases error signal
- Increasing I gain decreases error signal over time
- ~~D~~ Increasing D-gain decreases fast changes in error signal, but amplifies high frequency noise

Tues. Feb 14th

- Tip from last time ~~is~~ is still in STM

- Prepared graphite sample
- Manual approach. Tip may have crashed
- Attempt approach w/ pg 14 params

- But we move speed 55% ~~and~~ 0.5 on pg 20
- Approach didn't go through. Time to replace tip
- Accidentally crashed tip while approaching sample
- I will cut the end off the same wire bit again
- It is too short now
- Success. Now try final ~~approach~~ approach w/ move speed ~~X~~ 60%
- It worked! ☺
- Produced images 46 and 47
- Still fairly choppy images
- I will increase resolution. 256 points per line
- And time to 0.5 s per line
- About halfway through image, probe light ~~K~~ turned orange. Too far. Must reapproach
- Probe light flashing orange/green ~~brief~~ during scan
- ~~About~~ About halfway through scan, reapproach
- Each slice of the image doesn't quite line up. Some sort of drift of the tip perhaps?
- Product was ~~im~~ image 0048

- Perhaps the tip is still too far for a good image. I will try turning ~~voltage~~ tip voltage to 150mV so it needs to be closer

Tues
~~Fri~~ Feb 14th

• Stopped during image to reapproach, w/ ~60 lines left
• ~~Image~~ 0044 a bit better
• Reapproach, try at 50.1mV now
• It is taking way too long to approach
• Go back to 150mV
• Experiment w/ PID
• What is the effect of keeping PID ratios but decreasing the ~~total~~ amplitude?
PID from (1000, 2000, 0)
to (100, 200, 0)
• Probe light turned red? No crash apparent. Still red after retracting tip. Restart software

these were pretty clear

• ~~Res~~ Reset params and ~~x~~ try again
• Probe light turns red ~~at~~ as soon as I hit ~~approach~~ approach
• I changed PID back to (1000, 2000, 0)
• It worked again. Image00050
• Image00051 is the downscan of same region!
• Okay I'm going to zoom in to a flat area. ~~Pick a flat~~ Flat area is an area w/ a ~~constant col~~ uniform colour on image
• Zoomed into $(664\ nm)^2$ area
• Zoom again into ~~(6~~ $(5.97\ nm)^2$ region
• Product is image 00052. Very grainy.
• I will try decreasing PID gain, Perhaps probe is reacting too fast
• PID → (400, 800, 0)
• No difference. ~~Left~~ Left setup for 20 mins for

Tues
~~Fri~~ Feb 14th

• ~~Try PID (100, 200, 0)~~
interview w/ prof Marjoribanks
• Try PID (100, 200, 0)
• Image0053, less grainy, but drift is still apparent
• Image0054 is down scan, looks very different
• ~~Maybe I~~

• Try PID (100, 50, 0)
• Probe light red. ~~Do no~~ ~~I~~ PID too low causes this to happen? Why?
• Perhaps too slow of a response to changing terrain causes crash

• Discussion w/ TA:
- Change set point & time per line. Worry about PID later. Explore how these affect quality
- Try P = 1000. I want P greater than I?
- Start at 200nm. Once a good image is seen, try 50nm. Then 10nm and so on

Fri, Feb 17th

- Cut new tungsten tip
- Prepared HOPG sample and mounted in scan head w/ probe tip pointing to a smooth area

- Set params to those required for ~~Img.~~ Image 50 & Image 51 and approached

That is:

Image size: 200 nm
Time/line: 0.5 s
points/line: 256
Move speed: 60%

Setpoint: 1 nA
PID: (1000, 2000, 0)
Tip voltage: 150 mV

- Approach taking too long. I noticed there was still a very ~~br~~ visible gap between sample and it's reflection so I returned to manual approach

- The approach was successful!
- The resulting Image0055 seems kind of warped
- I will take another one w/ the same settings. Perhaps the system just needs to settle
- ~~At~~ Thermal effects acting on scan head on nm scale. Maybe turn down time/line for this, to scan faster
- Image0056 looks similar to 55
- Turning down time at this scale only made image streakier. I think 0.5 s/line is optimal

- Streaky image still. Perhaps sample must be cleaned and better tip cut.
- Image0057 is the best it'll be at this scale? Time to zoom in
- Find a flat area in downscan
- Try 50nm × 50nm

- Contour plot of current looks like pure white noise. ~~Ply~~ Playing w/ params until this is not the case
- Images 58 and 59 are the best so far at this scale. Currently,

Time/line = 0.2 s,
Setpoint = 504 pA PID = (700, 200, 0)
Tip voltage = 50.1 mV

- The line graph is changing ~~p~~ by quite a bit for each line through. Plenty of room for

- Turning setpoint to ~~305~~ 3.05 pA produced images 0060 and 0061 w/ time/line 0.01 s
- What am I looking at?
- Software crashed
- Restarted and reapproached sample

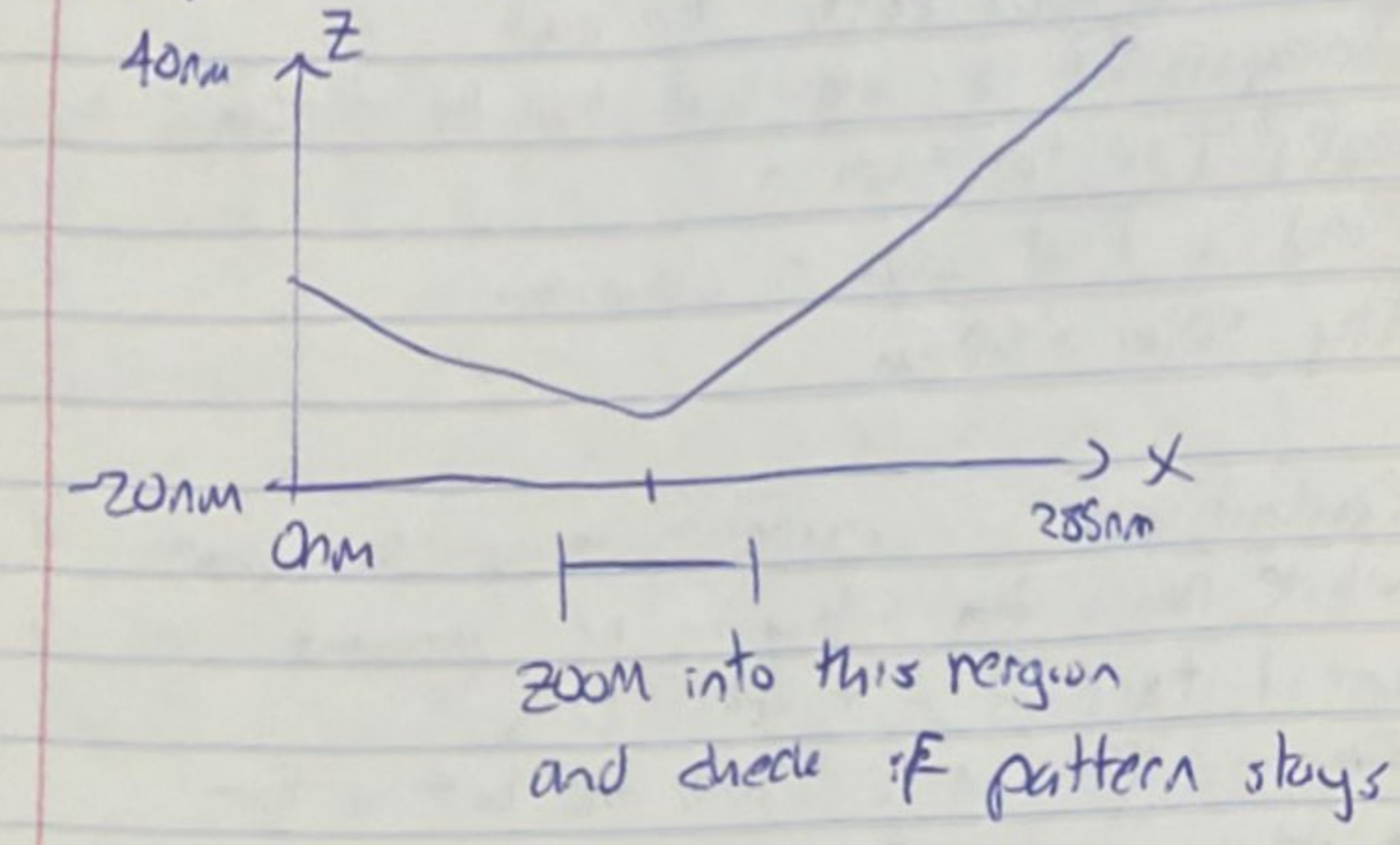
- I believe 60 & 61 are just noise.
- The picoamp scale for current is likely much

78nm

Fr, Feb 17th

more noise sensitive than the nano amp scale

• To check if image is real, use line graph. Currently, for each slice, we have



• I got the same structure on the edge but its hard to trust

• I'm cutting a new probe
• Image 063 w/ new tip and clean sample MUCH better, default settings w/ tip voltage 250mV

• Image 064 w/ setpoint 2nA, voltage 50.1mV PID = (1000, 800, 0)
• Zoom in for image 0065
• Zooming in beyond this point just gives noise
• Perhaps tip has picked up particles. Tried STM cleaning pulse and reapproached

Fr. Feb 17th

• Replaced tip & cleaned sample

• It is possible that tip got too close while zooming in. Try increasing voltage to prevent this.
• Evidence: After zooming back out, image was quite blurry

• My new strategy is to zoom in on well defined surface features and make them look more clear
~~• Image 0072 for example~~
• Such as image 0072
• Setpoint ~~4→6~~ 4nA → 8nA gets image 73
• It is hard to say which image is best
• I will go w/ ~~74~~ 73
• Zoom into flat region to the right of large feature. Image is still suffering from noise due to very small current variations

• Image 075. Noisy atoms?
• Image 076 and Image 077 are upscan and downscan respectively
• Line graph pattern is stable. Still changing a bit too quickly, but I think these are atoms
• Setpoint ~~.5~~ 1nA. Voltage 50.1mV
• Time 0.06s/line. 256 points
• PID (650, 350, 0)
• Zoomed in and features got bigger. These

Fri, Feb 17th

are definitely atoms!! (Image 0078)

• Making tip voltage too big might increase noise
• It lowers the potential barrier due to air and may cause tunnelling from below surface, which causes noise
outer

Tues, Feb 28th

• Turned on STM & software
• Move speed 60%
• On pg 29, tip was replaced & did not crash so I will continue using it
• Cleaved graphite sample w/ tape
• Approached sample
• Tip crashed :C
• Cut a new one
• Tip may have gotten too close on approach
• The images produced are extremely choppy, like image 44
• Increasing time/line to 0.4 from 0.2s seems to improve quality at 200 nm scale
• Zoomed into an area w/ well defined topography and saw nothing. Time to throw away tip
• I trimmed the end of the same tip
• Tip crashed
• I keep trimming the tip, but the line graph is extremely choppy. I might just have to cut a new one entirely
• New tip produced clear image w/ setpoint 2nA and voltage 44.7mV
• Zoom into well defined topography
• Feature in image 74. Continue zooming
• Result is image 81. I threw out image 80 bcs I zoomed into the ~~who~~ wrong area
• Image 81 used setpoint 4nA, voltage 44.7mV PID = (600, 500, 0), and time/line 0.12s
• Zoom in to the left of large peak
• Image 82 time/line 26ms

Tues, Feb 28th

- Looks like atoms
- Probe status went orange & I had to reapproach
- Zoomed back out to ~~500m~~ 500nm
- I have to basically start again
- Nice topography in Images 00083, 00084.
- I am just playing w/ params
- Image 0085 w/ default settings
- Zoom into center
- Image 0086 has a faint atomic lattice
- Again, I lost it
- Get image 87 w/ default params but I-Gain = 800
- Zoom into flat region and set point 5nA
- Result is Image0088 (time/line 52ms)
- I will let the system image for a while to reduce the effects of thermal drift
- Withdrew tip & ran STM cleaning pulse
- Unable to get a good image

Fri, March 3rd

- Today I will spend some time imaging gold
- Time/line 0.3s, setpoint 4nA, PID = (1000, 800, 0)
- Tip voltage ~~500m~~ 500mV
- Resulted in image 106 of gold sample
- Rotate plane by 30°
- Structures reproduced in image 107, not noise
- Very streaky in measurement direction
- Image 108 very streaky
- Prepare new tip
- Beautiful image 109 ☺ w/ new tip
- Image 110 at 50nm scale
- Image 111 at 20nm. Starting to look grainy
- Image 112 at 5nm. Looks too homogeneous?
- What happens if ~~tpe~~ time/line -> 0.06s?
Horrible image 113. Back to 0.~~3~~3s and wait
- Images 114-116 at this setting
- What if I increase time/line? 0.4s for Img 117, ~~118~~
- ~~0.5~~ 0.5s for Img 118
- Gold is conductive => homogeneous electrons
- This may mean I need to spend ~~a~~ a longer time imaging gold to see its features
- But I need to balance this effect w/ thermal ~~dri~~ drift
- Zoomed in to 2nm for Image 119, 120
- Drifted probe too far from sample. Reapproach required
- ~~Mig~~ Run an STM cleaning pulse
- I lost it :C
- Back too 100nm scale w/ Img 121

Fri, March 3rd

- I will trim the tip once more
- Img122 at 500nm
- Img123 at 100nm,
- Img124 at 5nm
- Reduce voltage to ~~0.00nm~~ 400mV
- Withdraw, cleaning pulse, reapproach
- Lost completely. Recut tip

- Could electrical interference be the culprit?
- ~~If~~ I don't know how to fix that
- In the ~~meantime,~~ mean time, I will rotate the ~~surface~~ sample and approach a new area

-Time/line 0.35, setpoint 1nA, PID=(1000, 800, 0), voltage 500mV for img 126 at 200nm
- 50nm for Img 128
- 20nm for Img 129
- Img 130 w/ setpoint 5nA
- Lost the structure

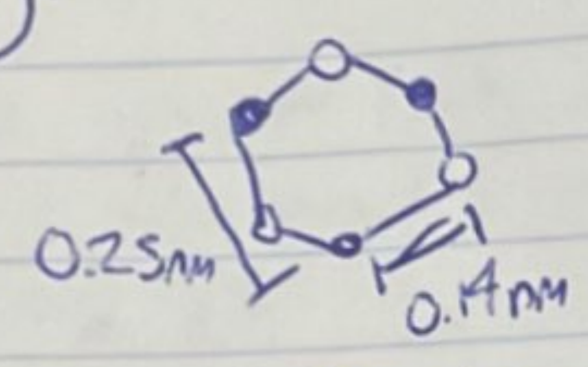
Fri, March 3rd

- Back to imaging graphite
- Cut a new tip
- Cleaved graphite sample and mounted it
- ~~Image flat~~
- Graphite is streaky in image
- Played w/ params and saw nothing
- Rotated surf. STM cleaning pulse
- Image 131 default params, time/line 0.365
- Zoom into ridge in image. setpoint 1.5nA
- Time/line 0.10ms. Image 132
- Not seeing anything :C

Analysis

- Image0077 is my best photo of the graphite lattice
- Throughout the entire image there is a clear triangular lattice of black points; these are low areas / gaps between the atoms
- The actual atoms are a bit harder to make out due to distortion
- The image quality could be improved. There are white/black streaks in the scan direction

- The NanoSTM manual describes a carbon lattice like so



• have neighbours in the plane below
o do not

- Atoms w/o neighbours in the plane below appear higher than the others due to a higher electrical conductivity

- This structure is hard to make out in Image0077. There are clearly white peaks and orange peaks throughout, but the lattice is unclear
- To get the atomic diameter, I will find a clear ~~pathe~~ patch in my image and measure (relatively) the distance between the edges of two black spots

- Picking a clear area to do this results in an atomic diameter of about 113.3pm, for carbon
- The accepted value is 140pm.
- My figure has a relative error of about 20%

- This is an extremely rudimentary analysis based on an image of dubious quality
- The true estimate of the diameter could be improved greatly by making use of a computer ~~alog~~ algorithm to find the average peak radius

- I could improve my imaging by continuing to experiment w/ PID values and/or considering the effects of electrical interference or air currents in the environment

- For the gold sample, I found it much easier to get an image at the 200nm scale than the graphite. Perhaps the conductive properties of gold made it easier to achieve this
- I was not able to get a clear image at the atomic ~~str~~ level. For gold, you need to image for a longer time since electrons are distributed homogeneously through a conductor
- However, the atomic lattice is sensitive and prone to changing due to thermal / environmental effects during this time, which makes getting a clear

- More time is required
- Abstract included in ~~STM summary and~~ STM_Summary_and_Abstract.pdf

• The following pages contain the images I took

• Printing issue caused me to not ~~g~~ get physical copies for many images taken on pg. 34, 35

Image 0044

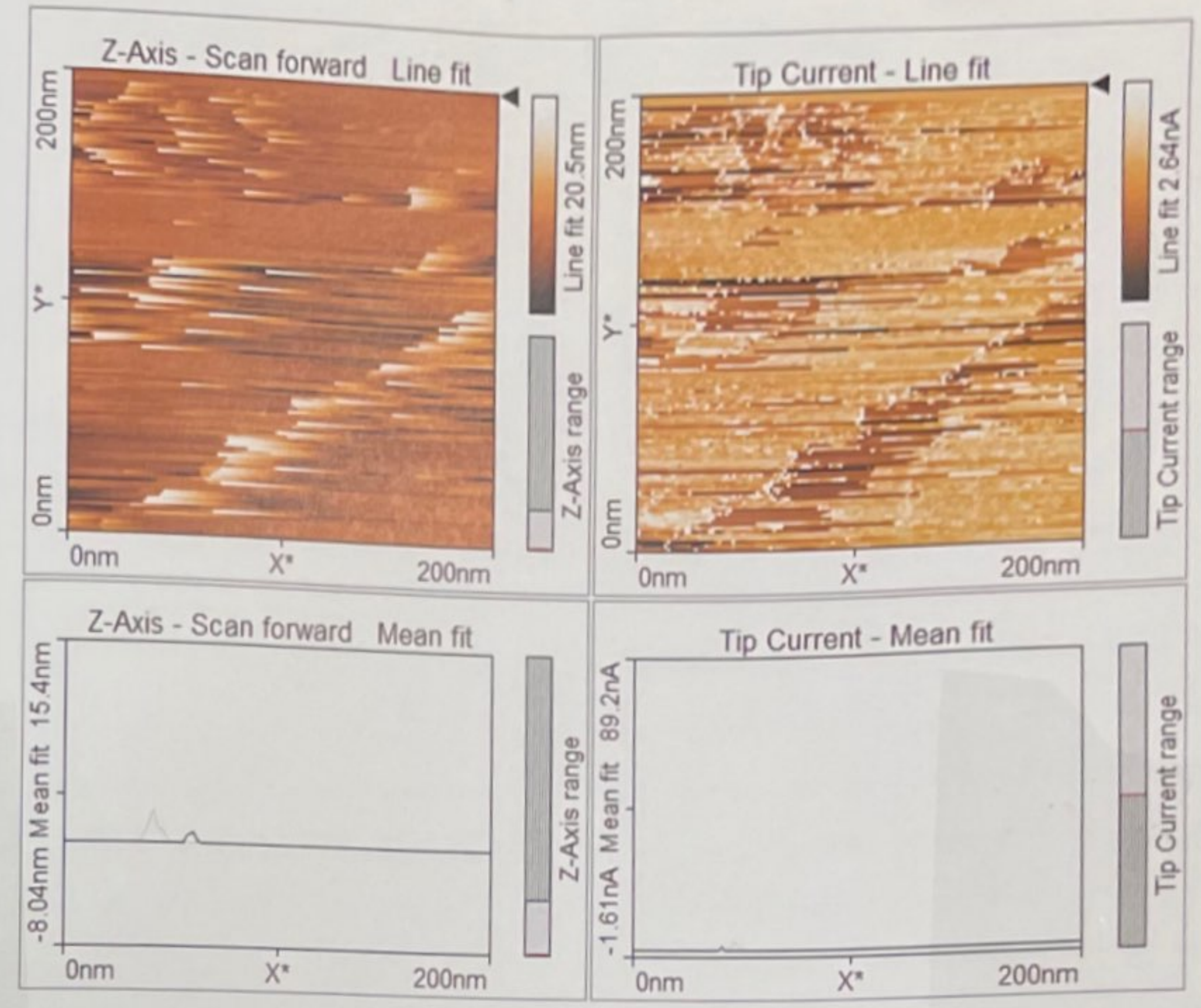


Image 0045

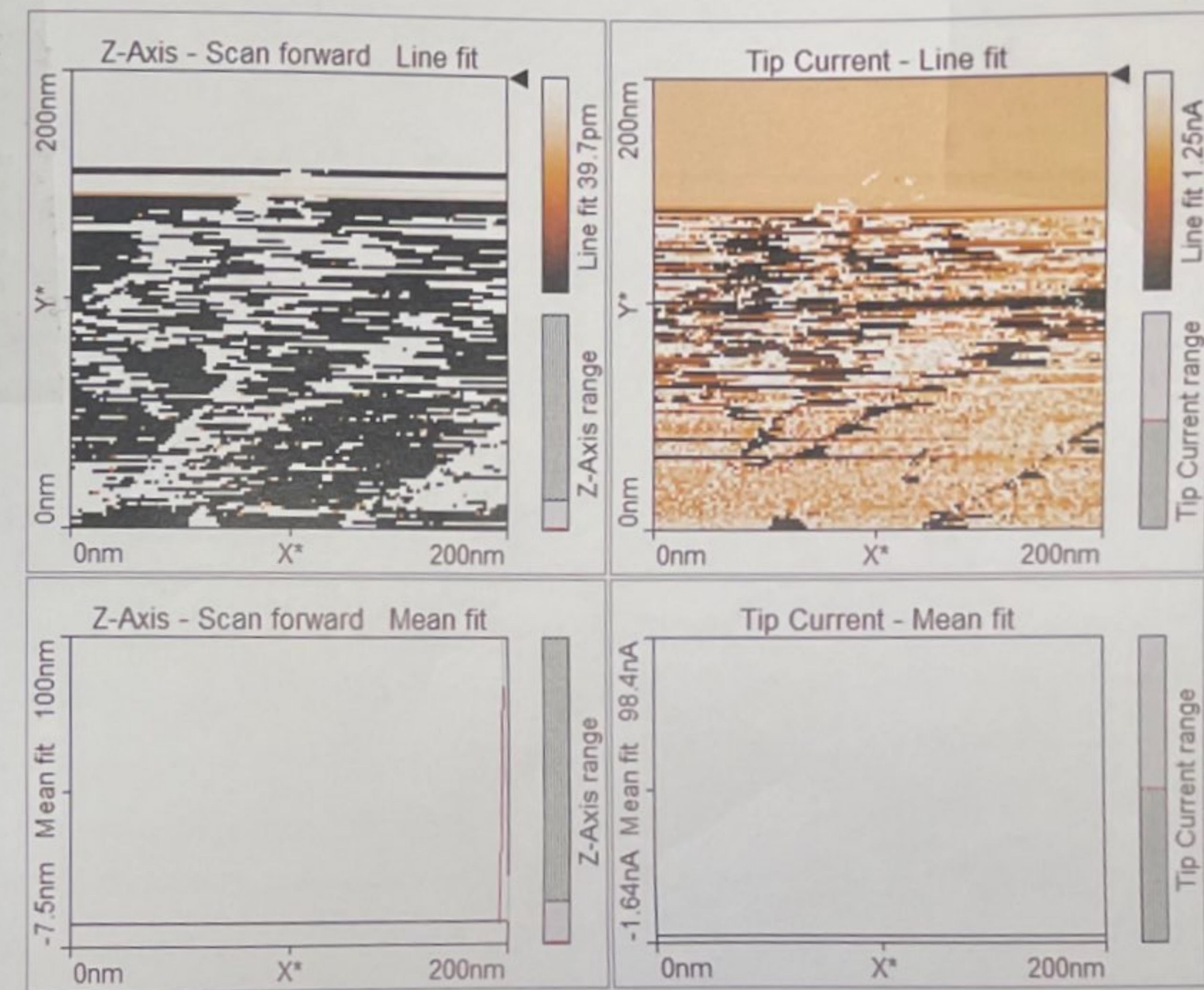


Image0046

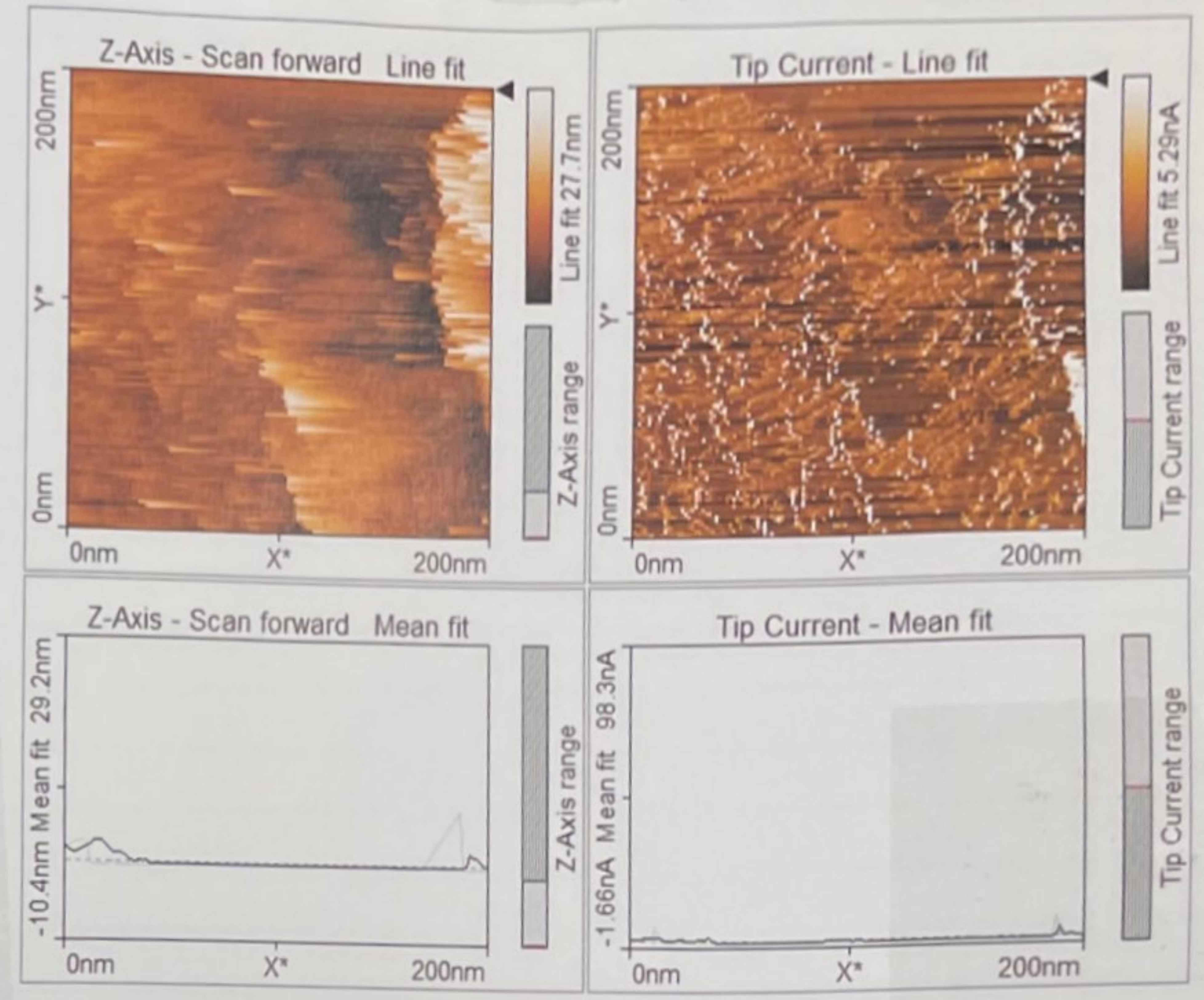


Image0047

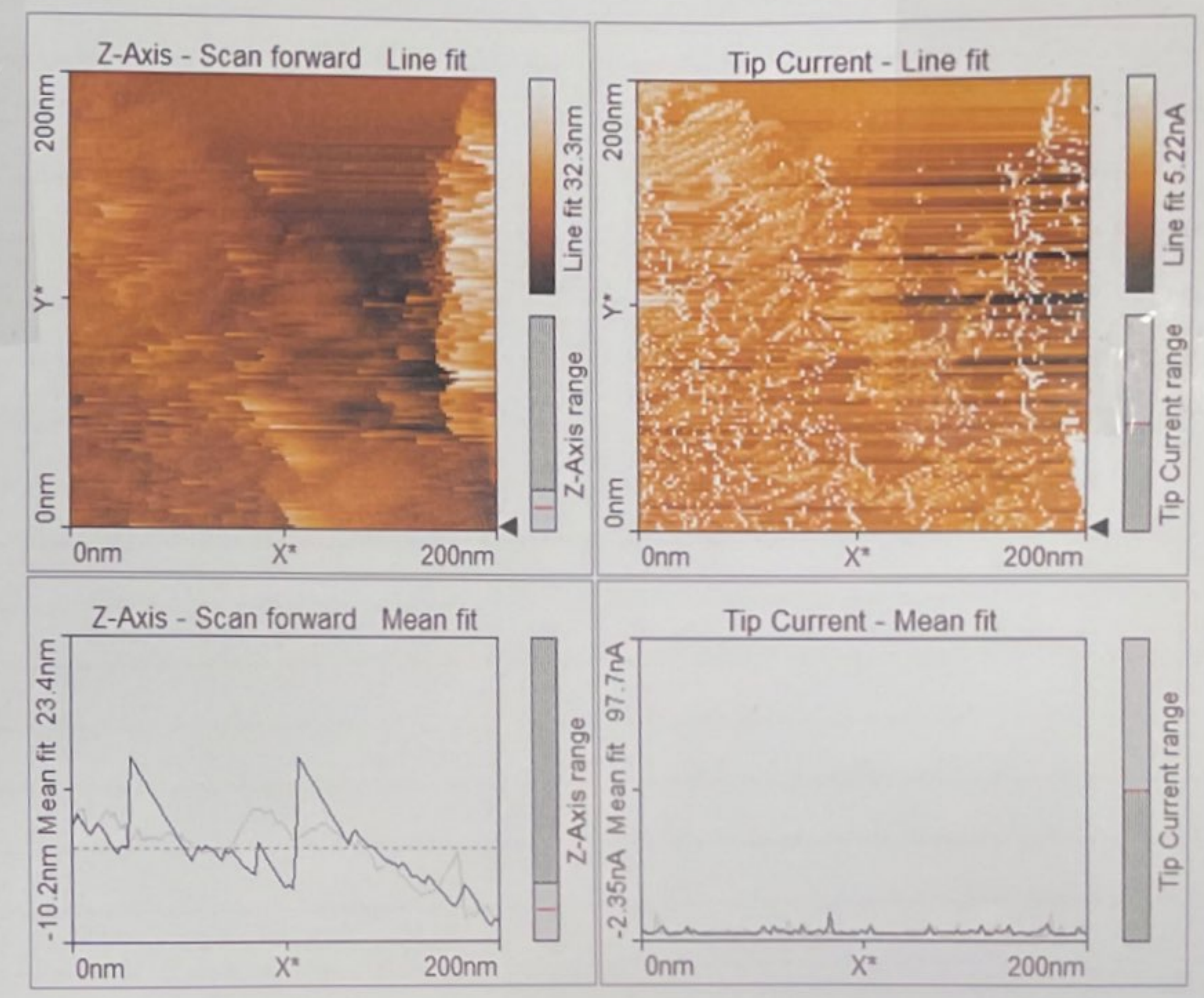


Image 0048

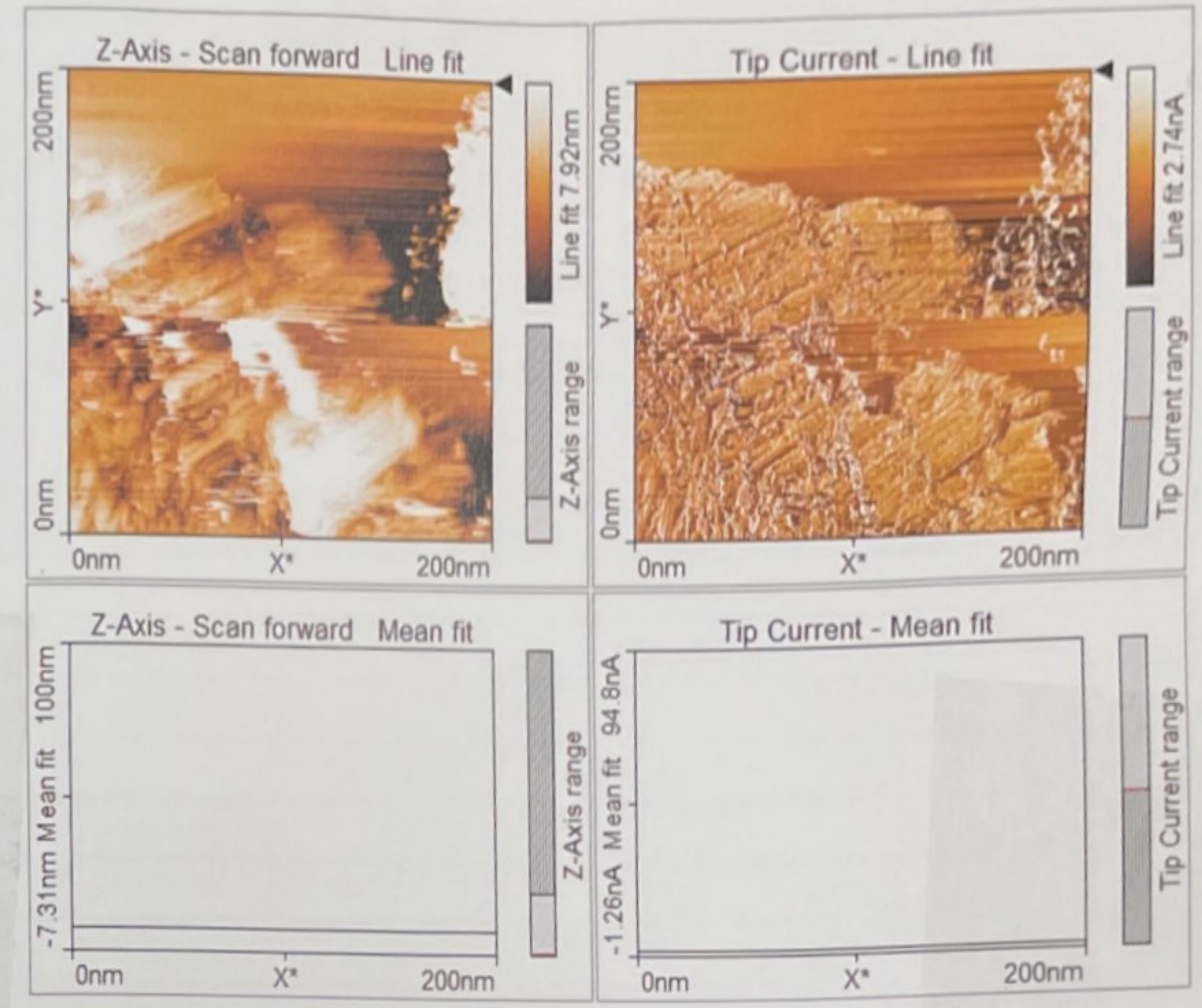


Image 0049

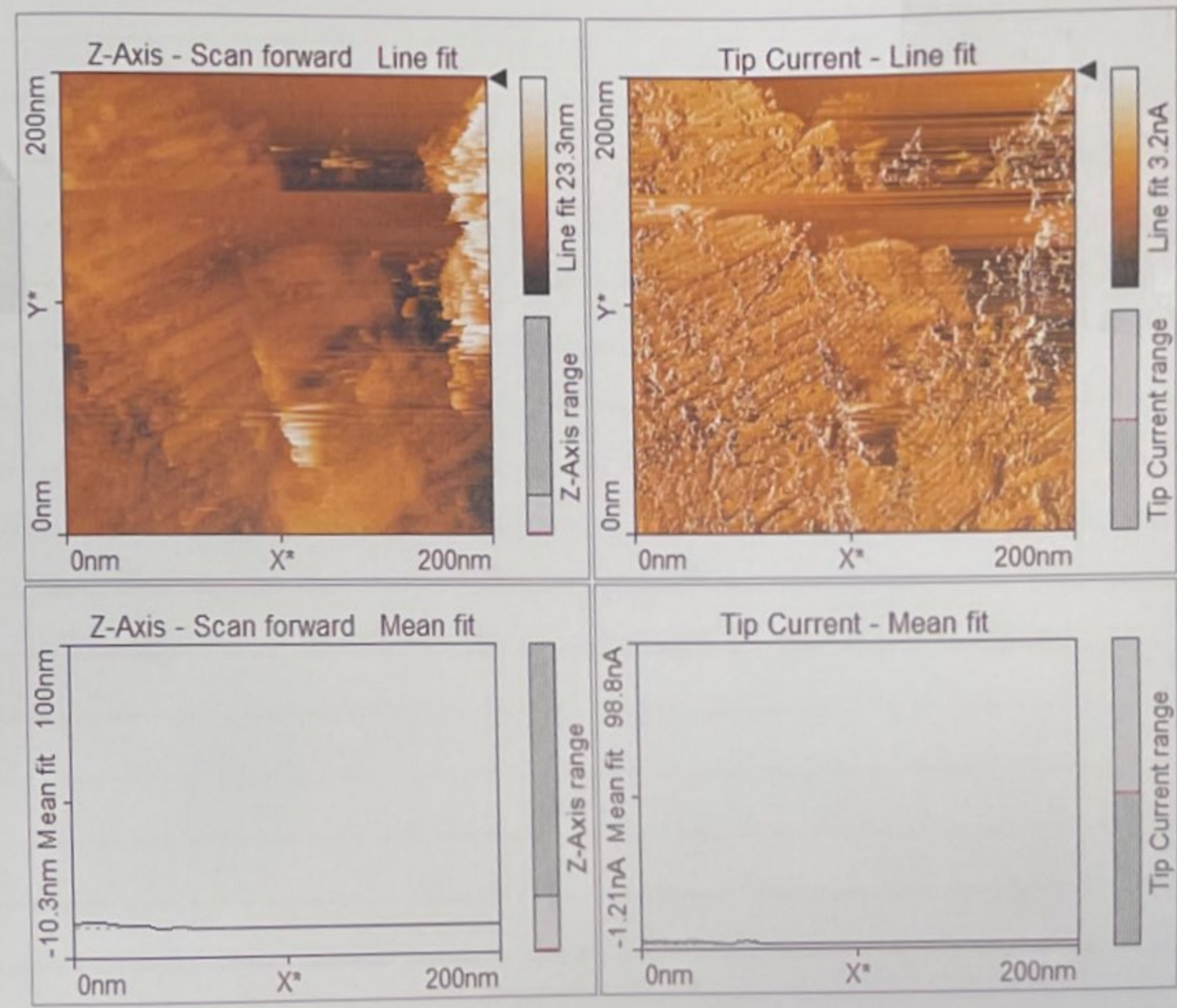


Image 0050

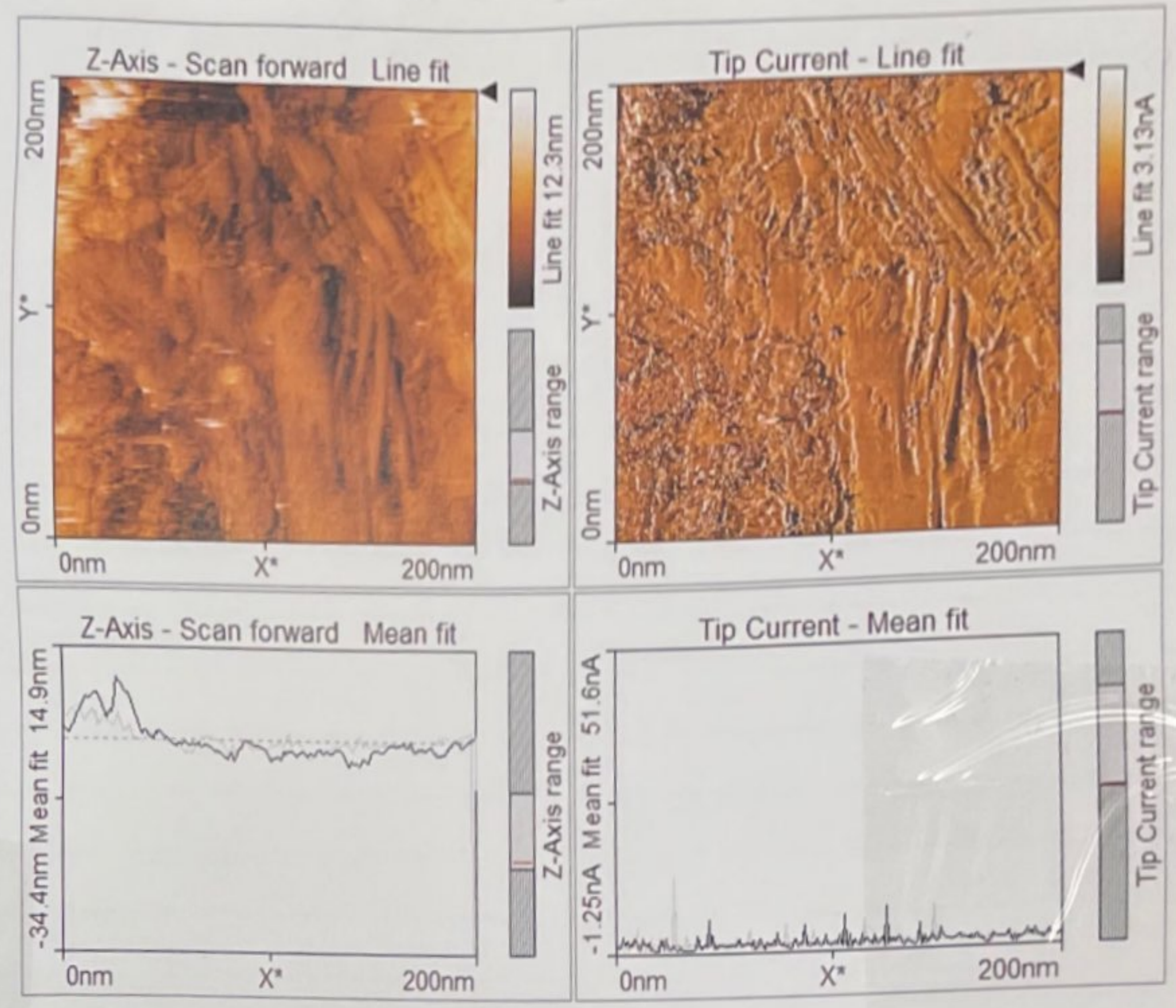


Image 0051

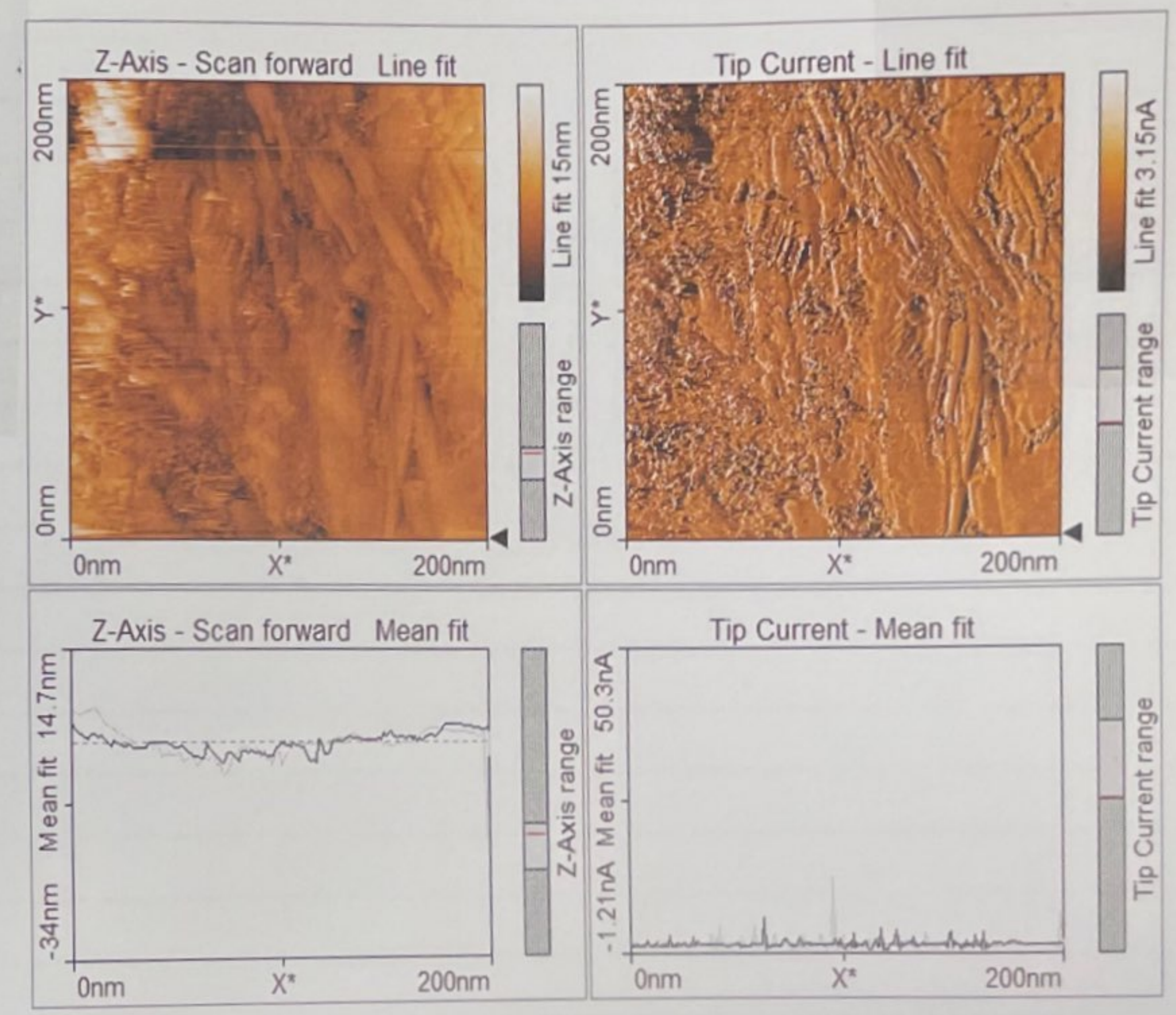


Image 00352

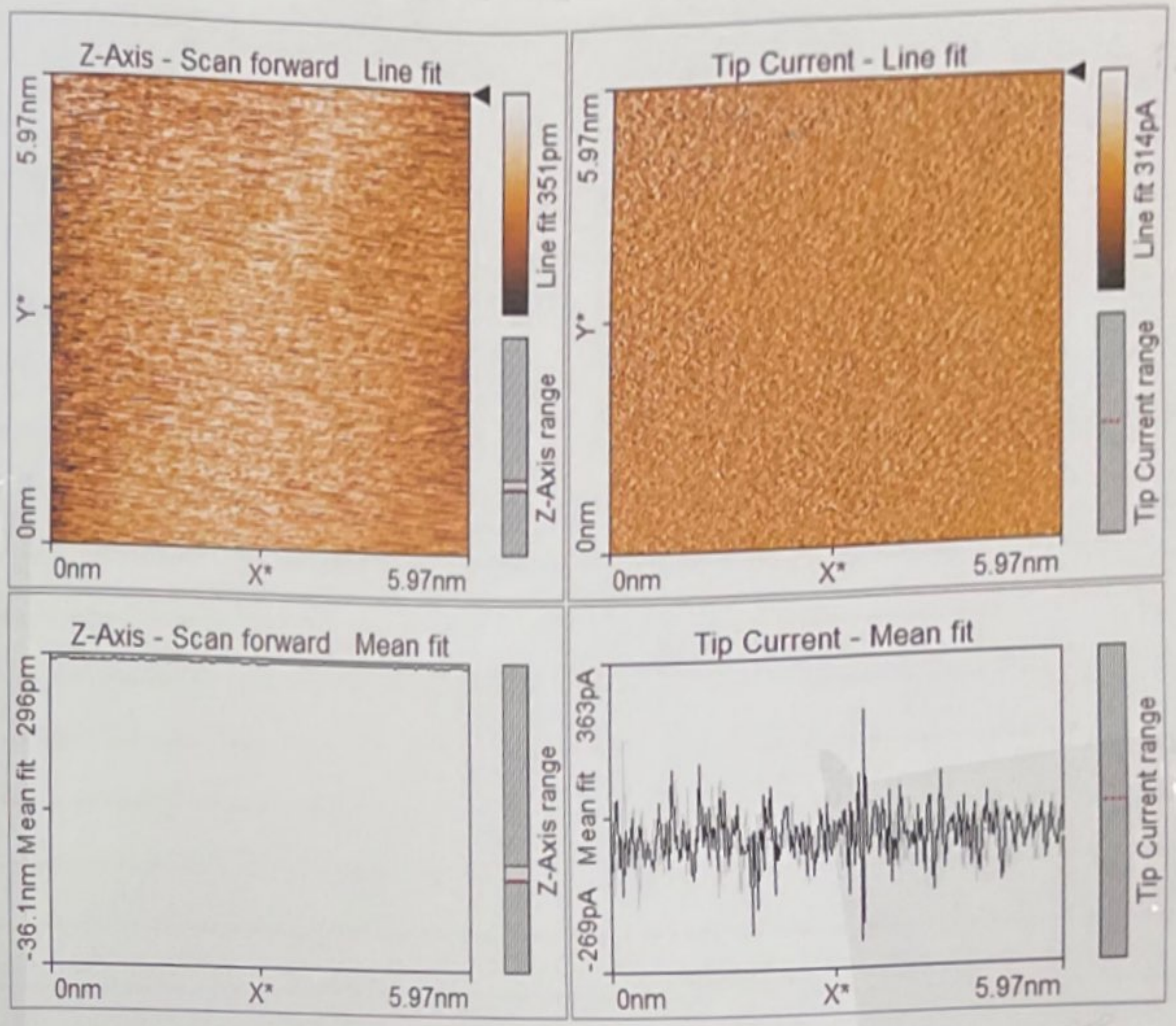


Image 003[illegible]

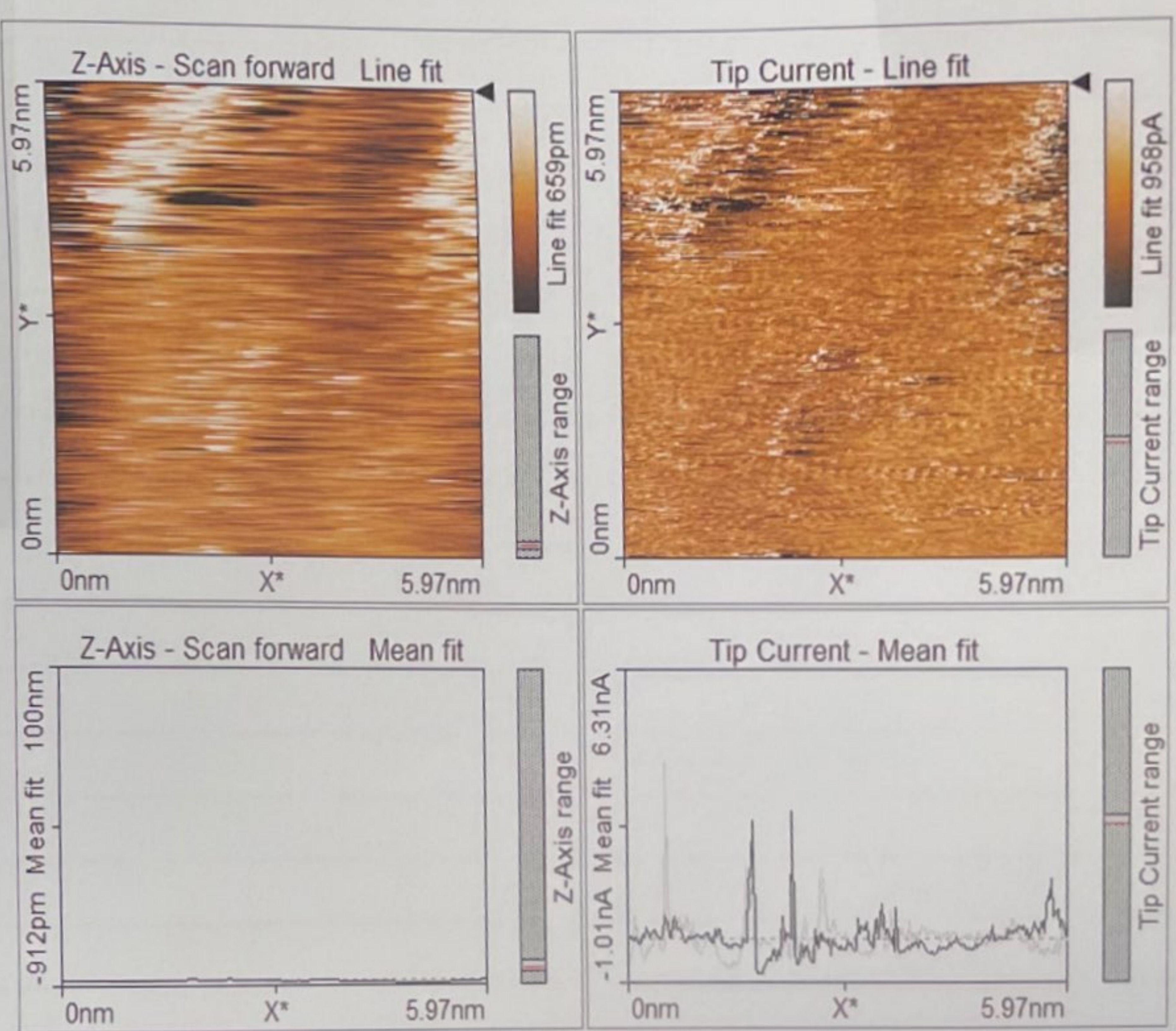


Image0054

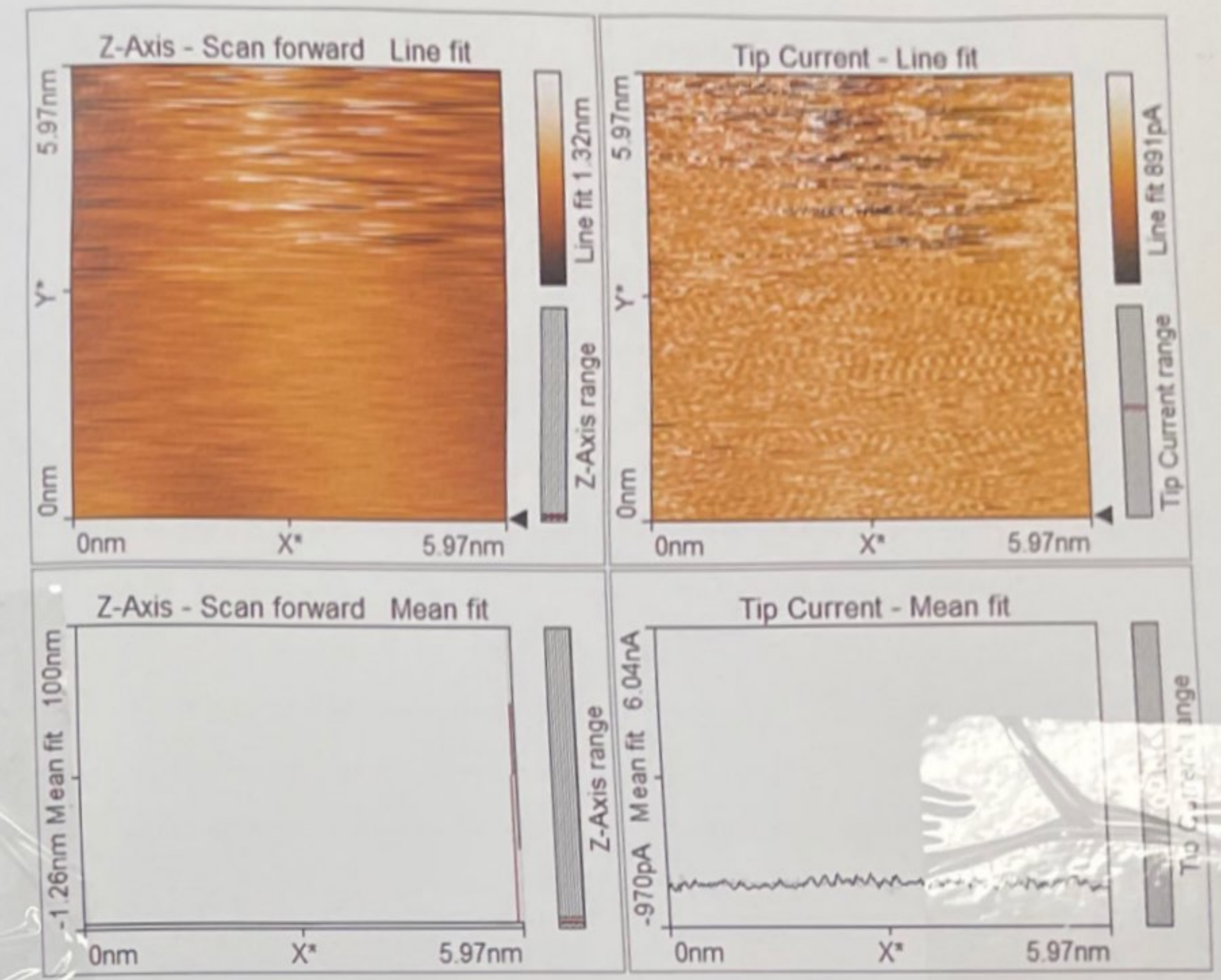


Image0055

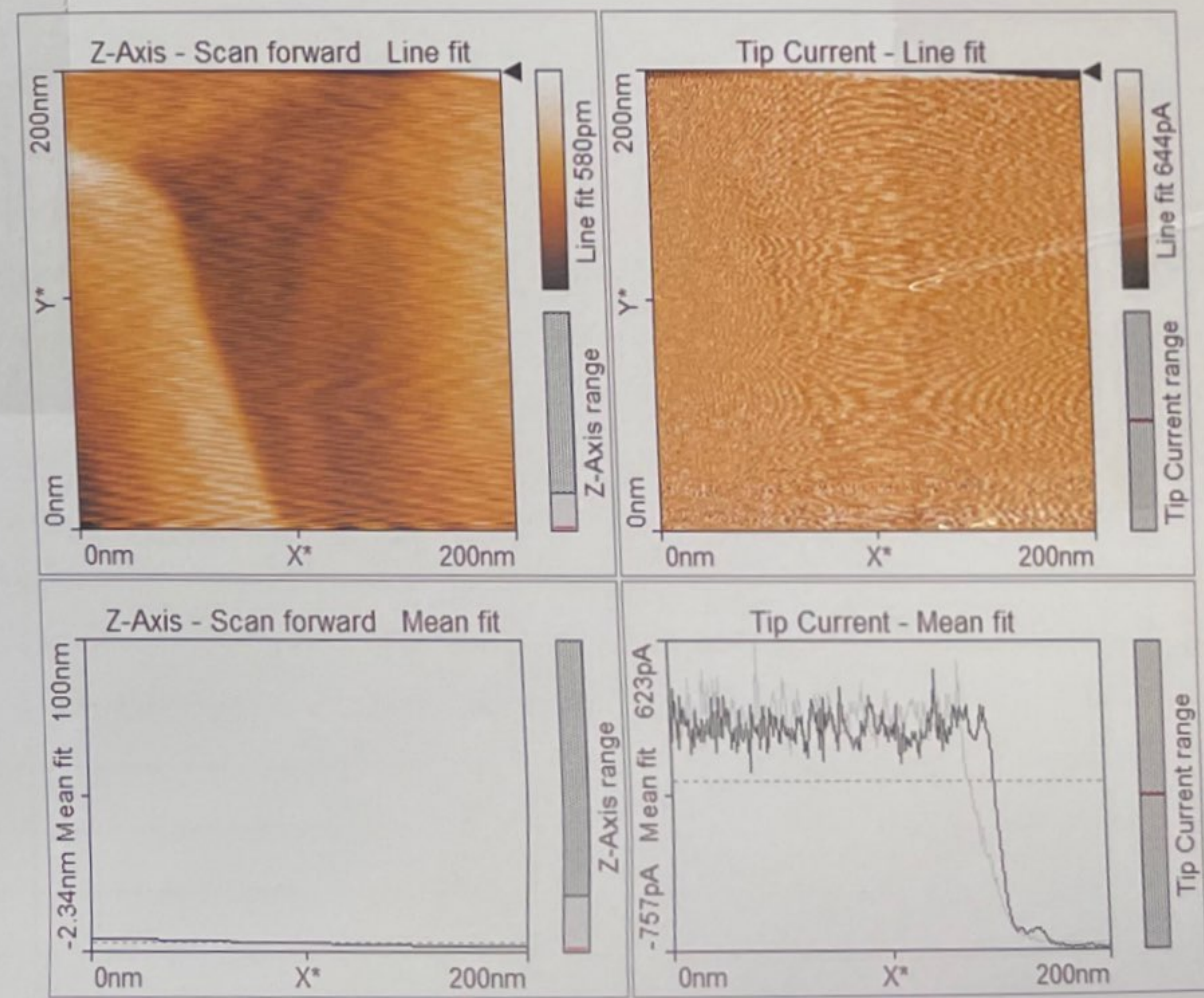


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Image0056

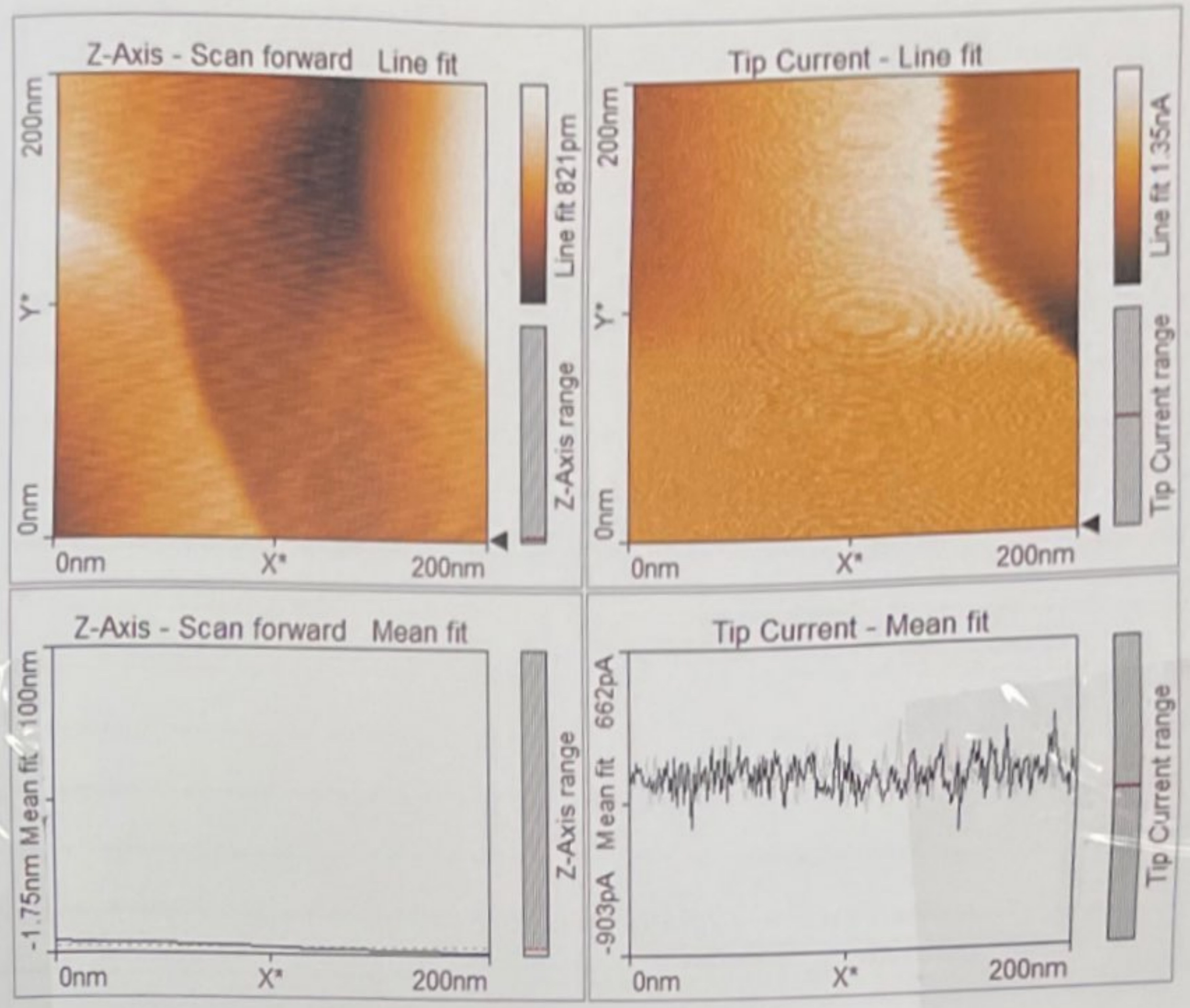

Image0057

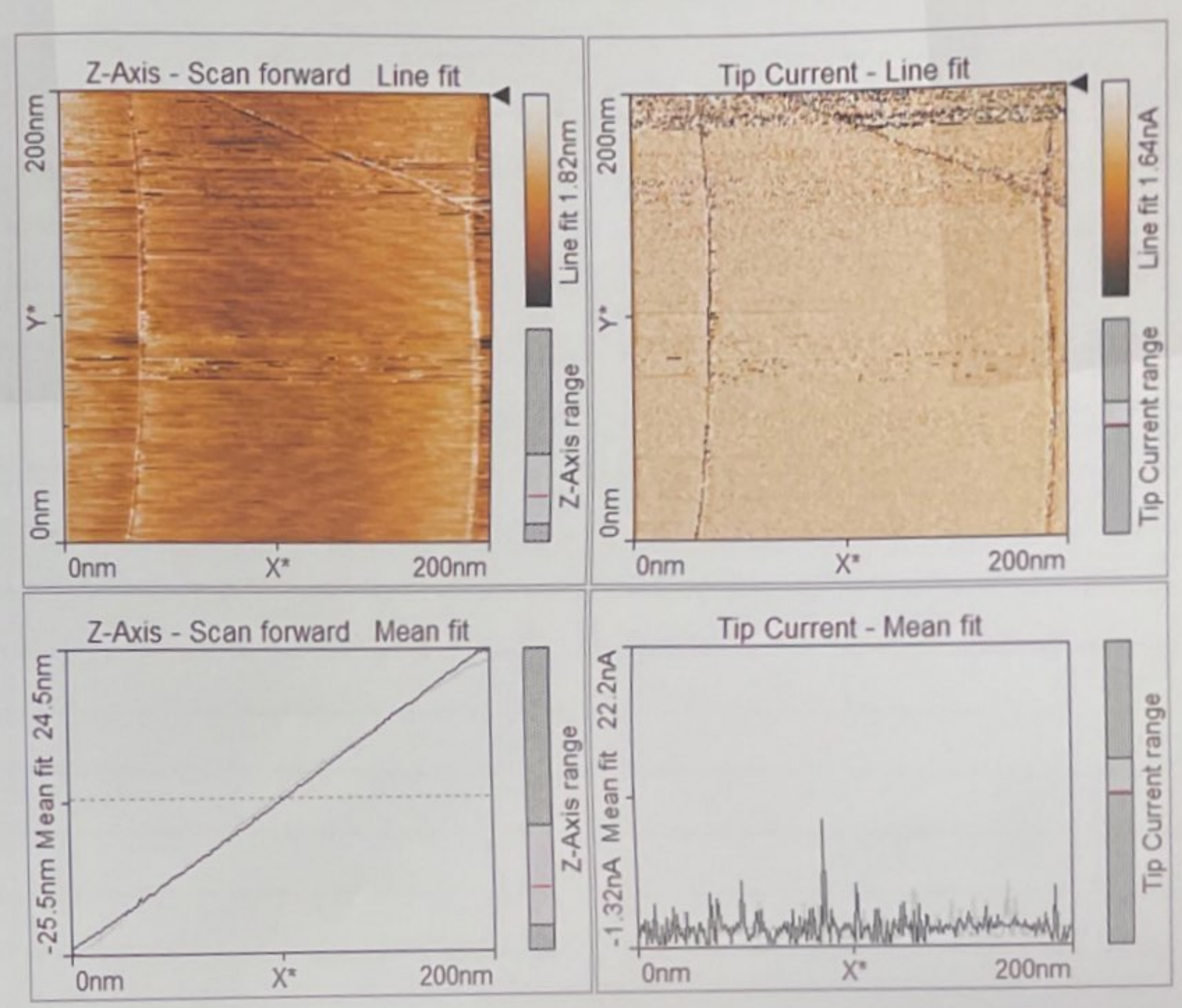

Image 0058

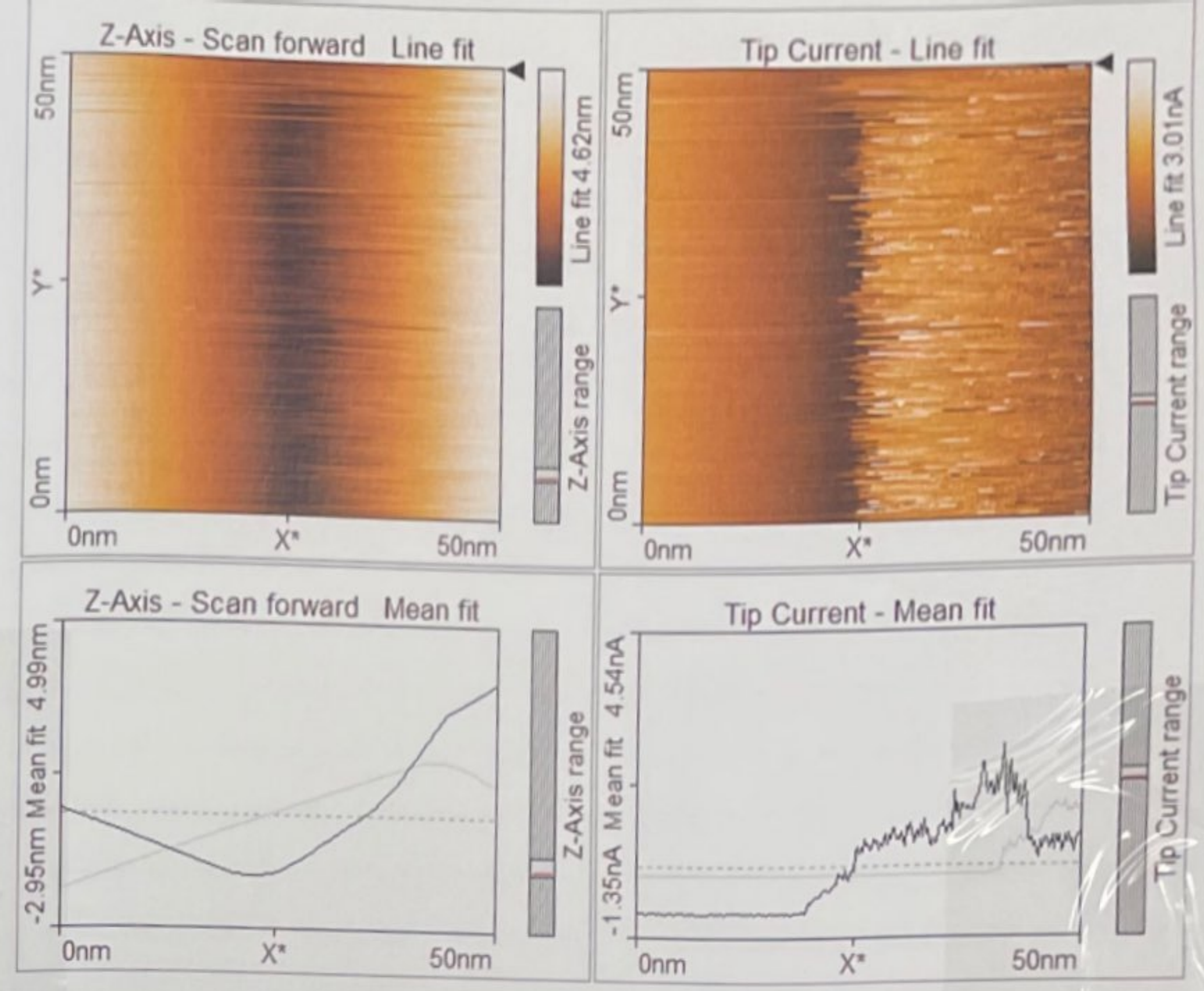

Image 0059

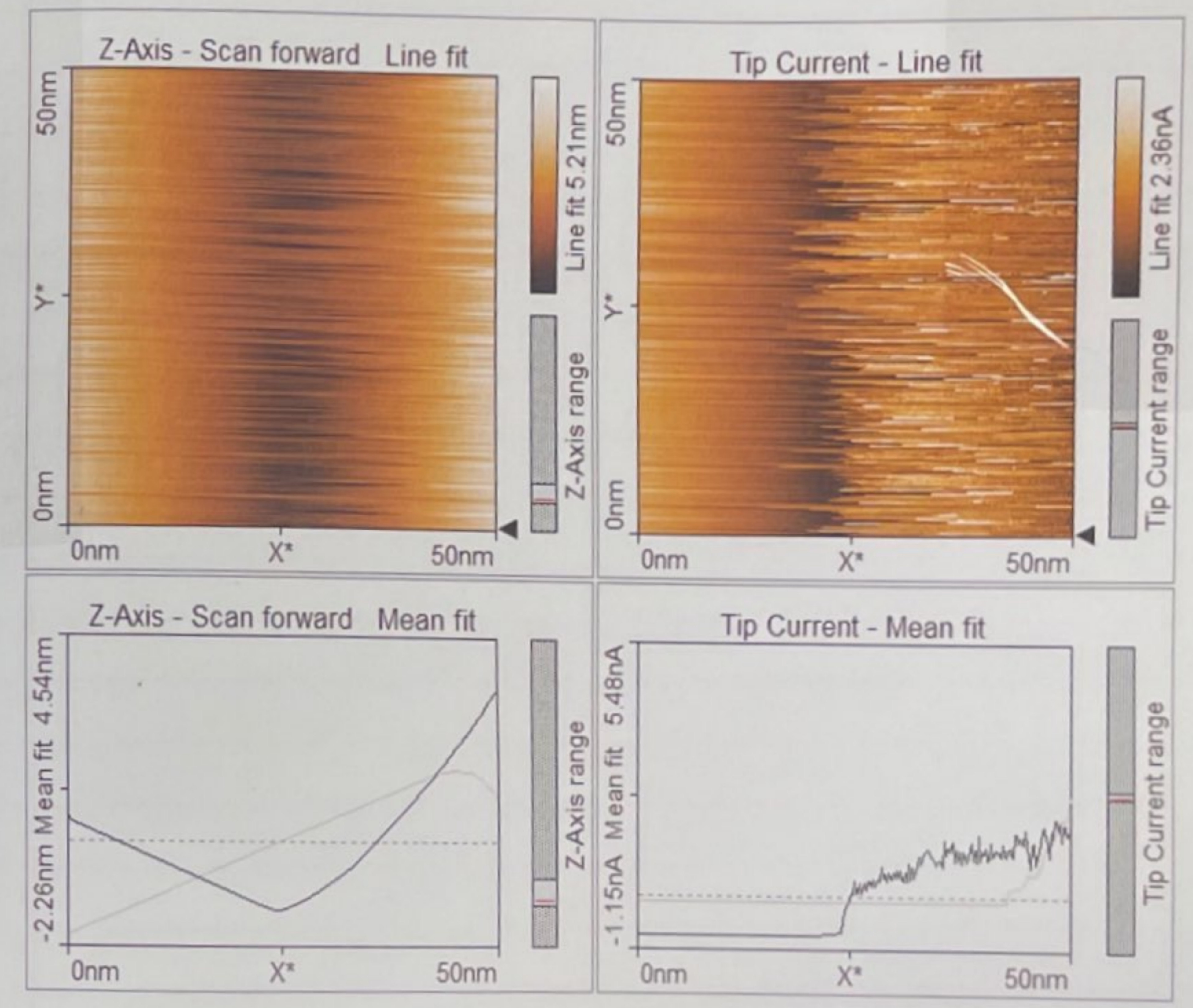

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Image0060

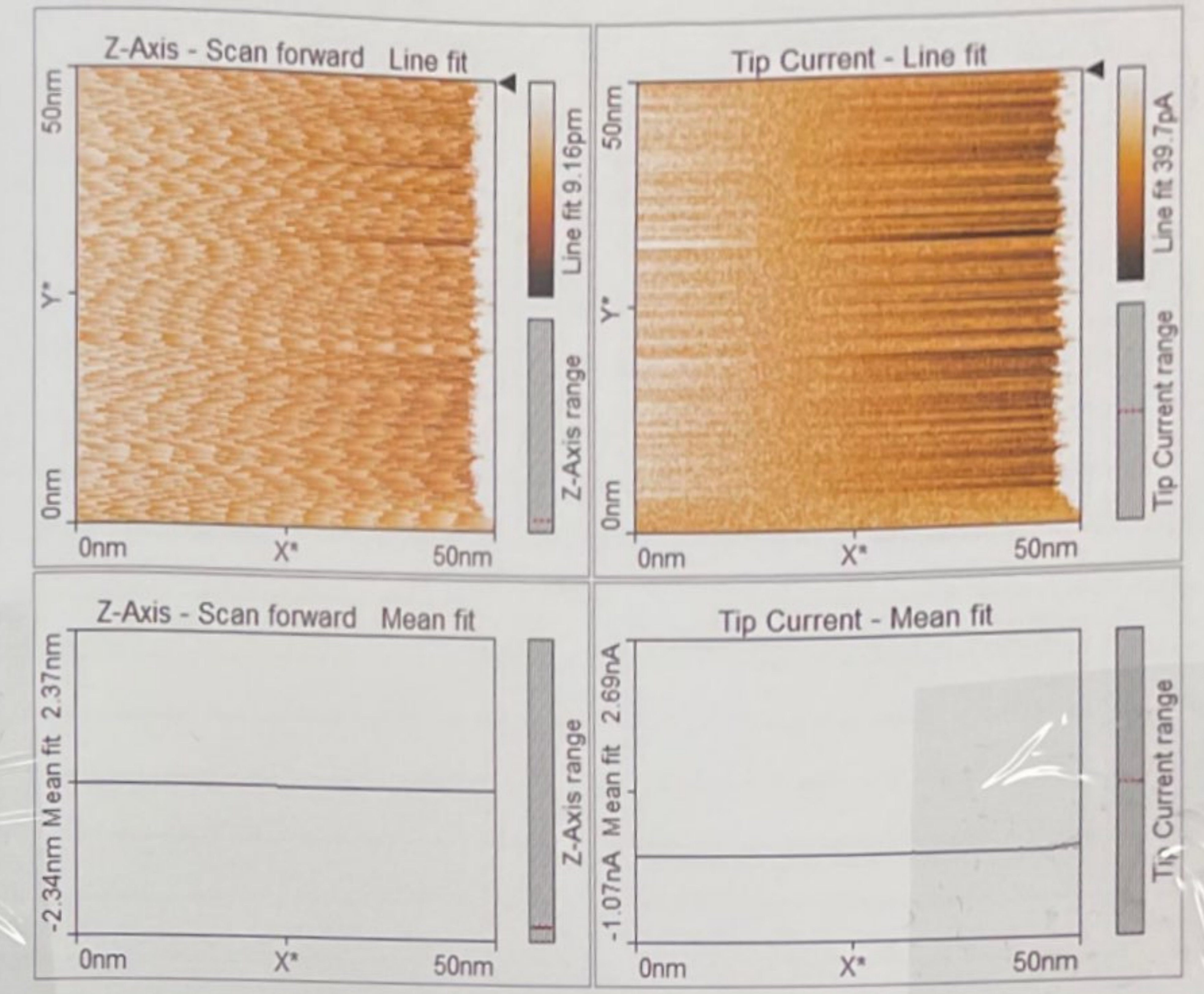


Image0061

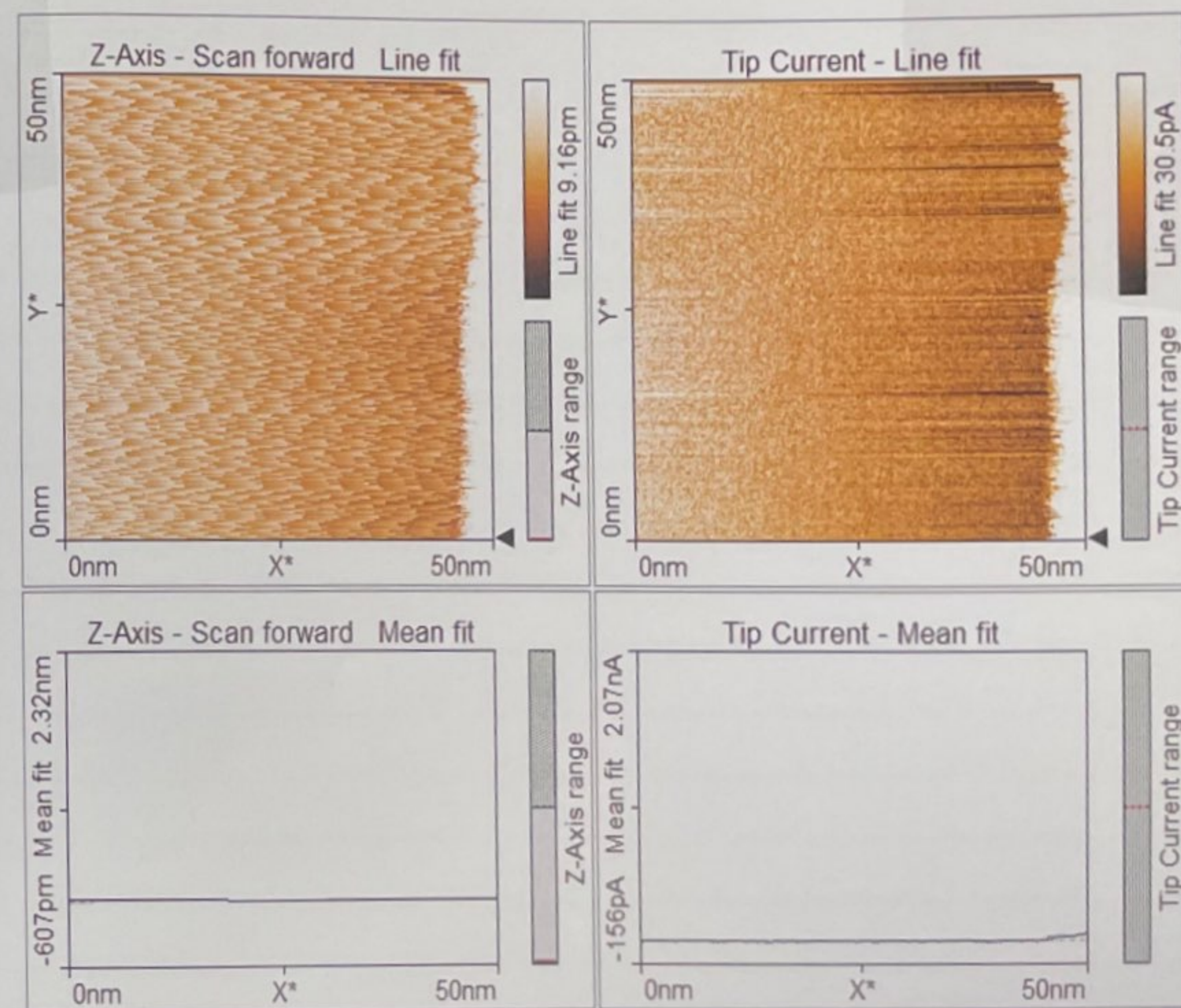
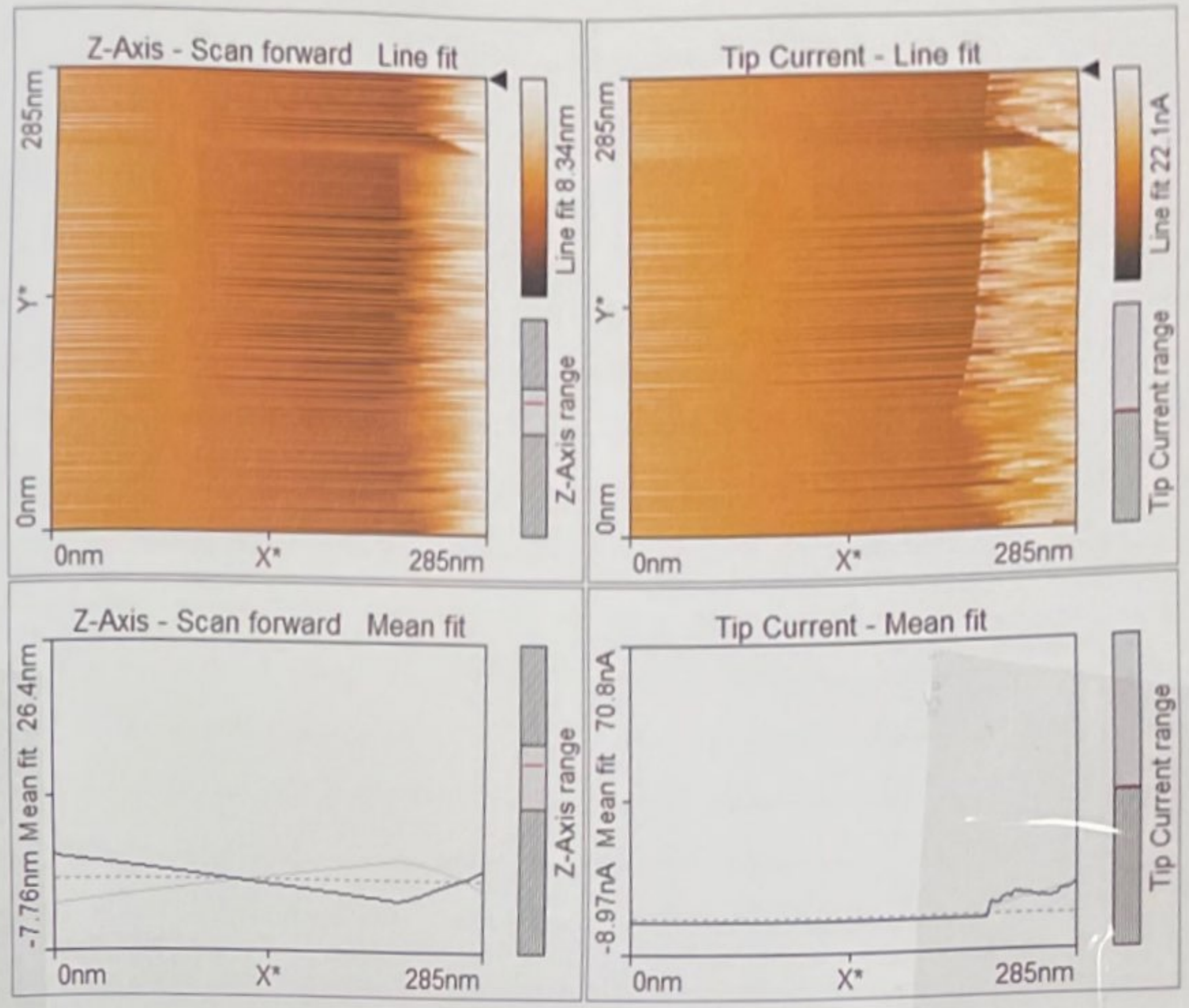


Image0062



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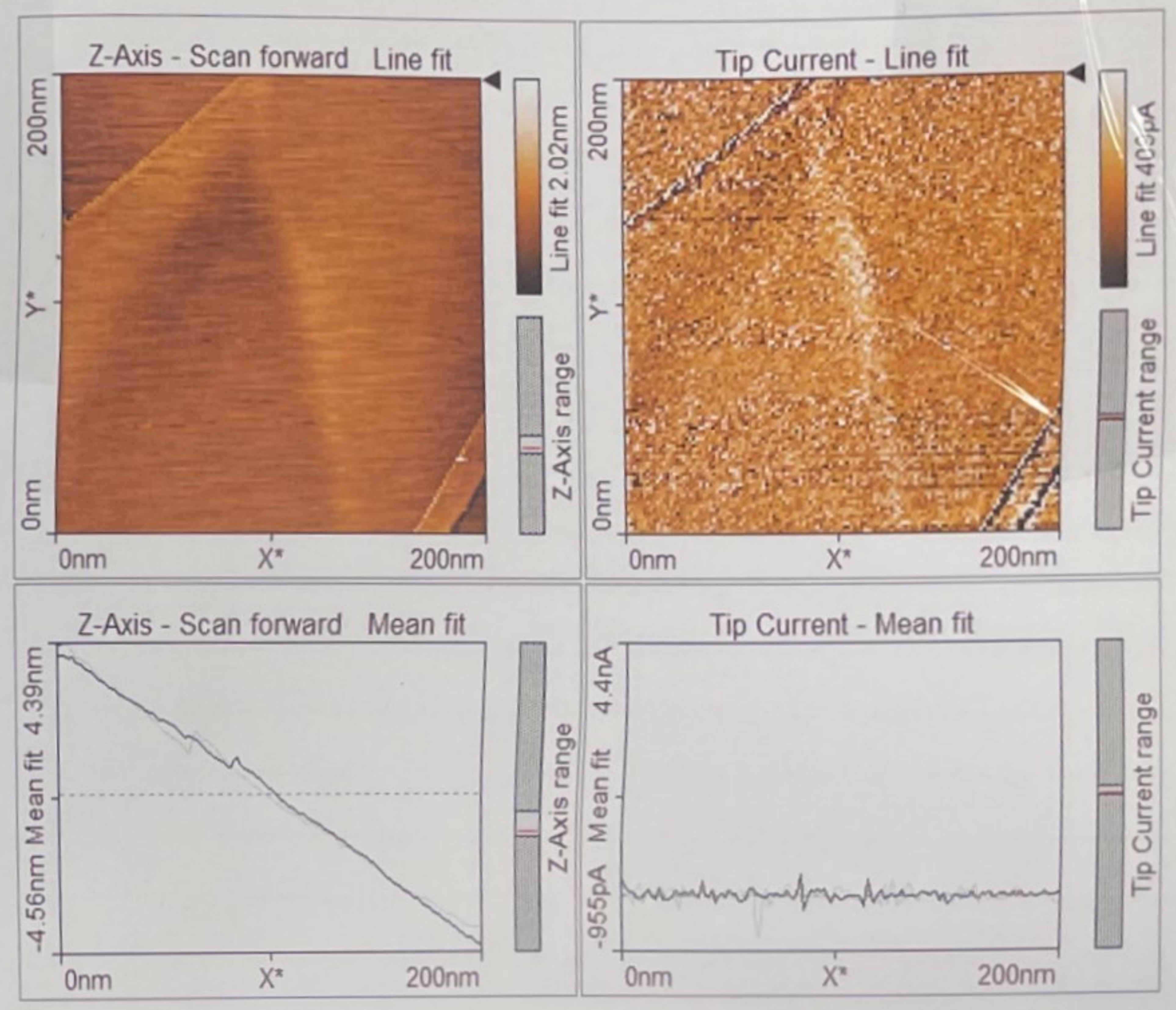

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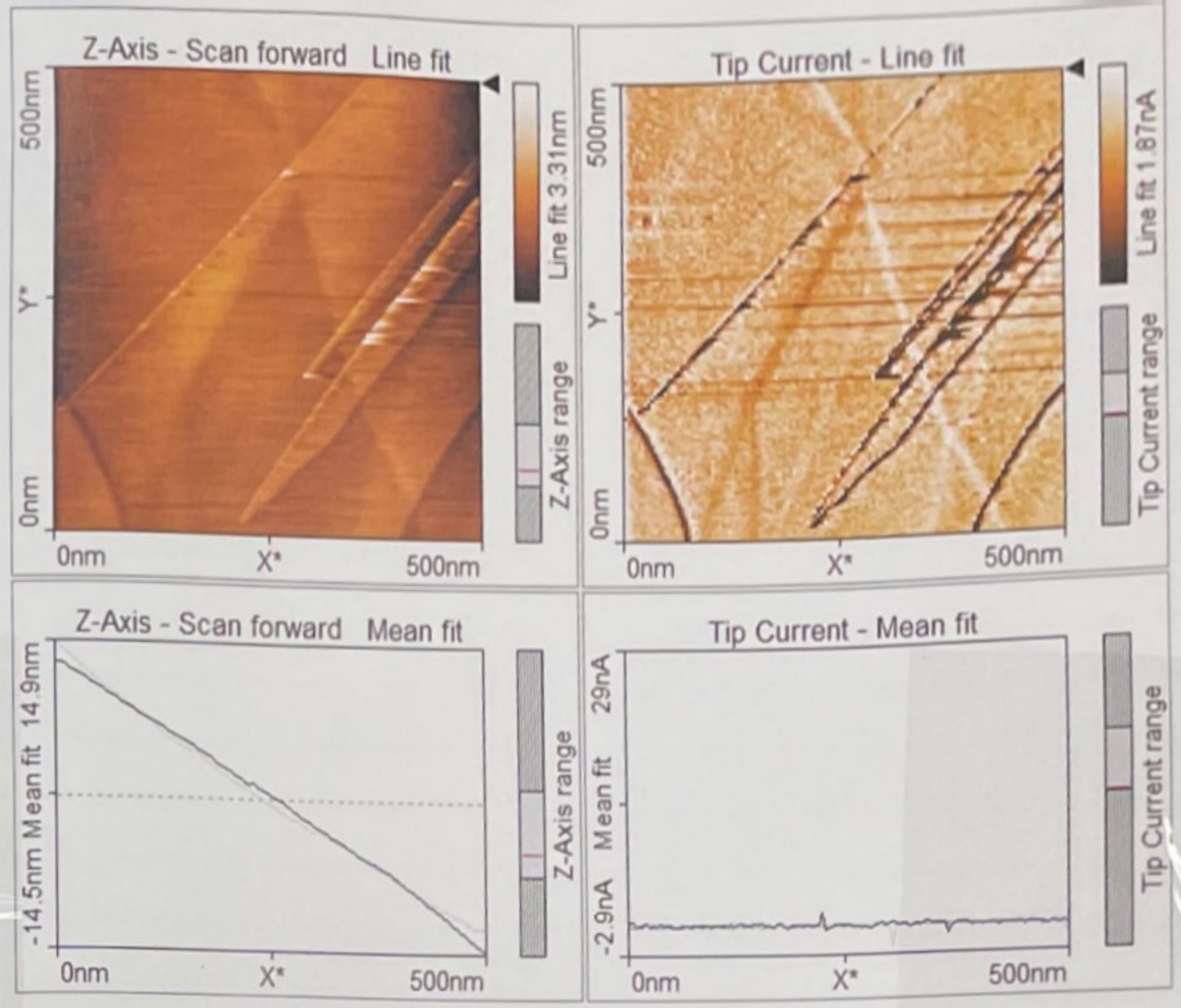

Image0065

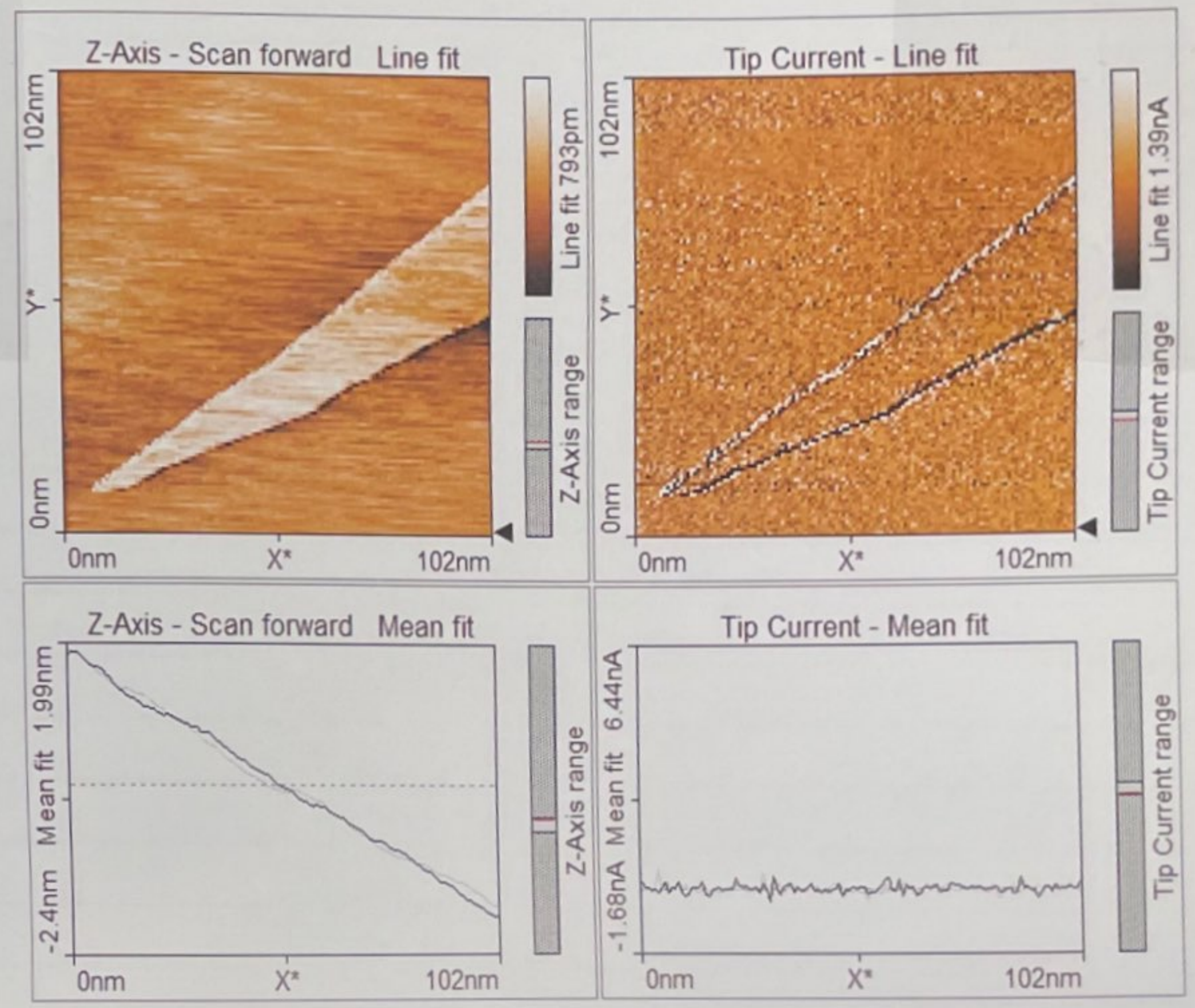

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Image0066

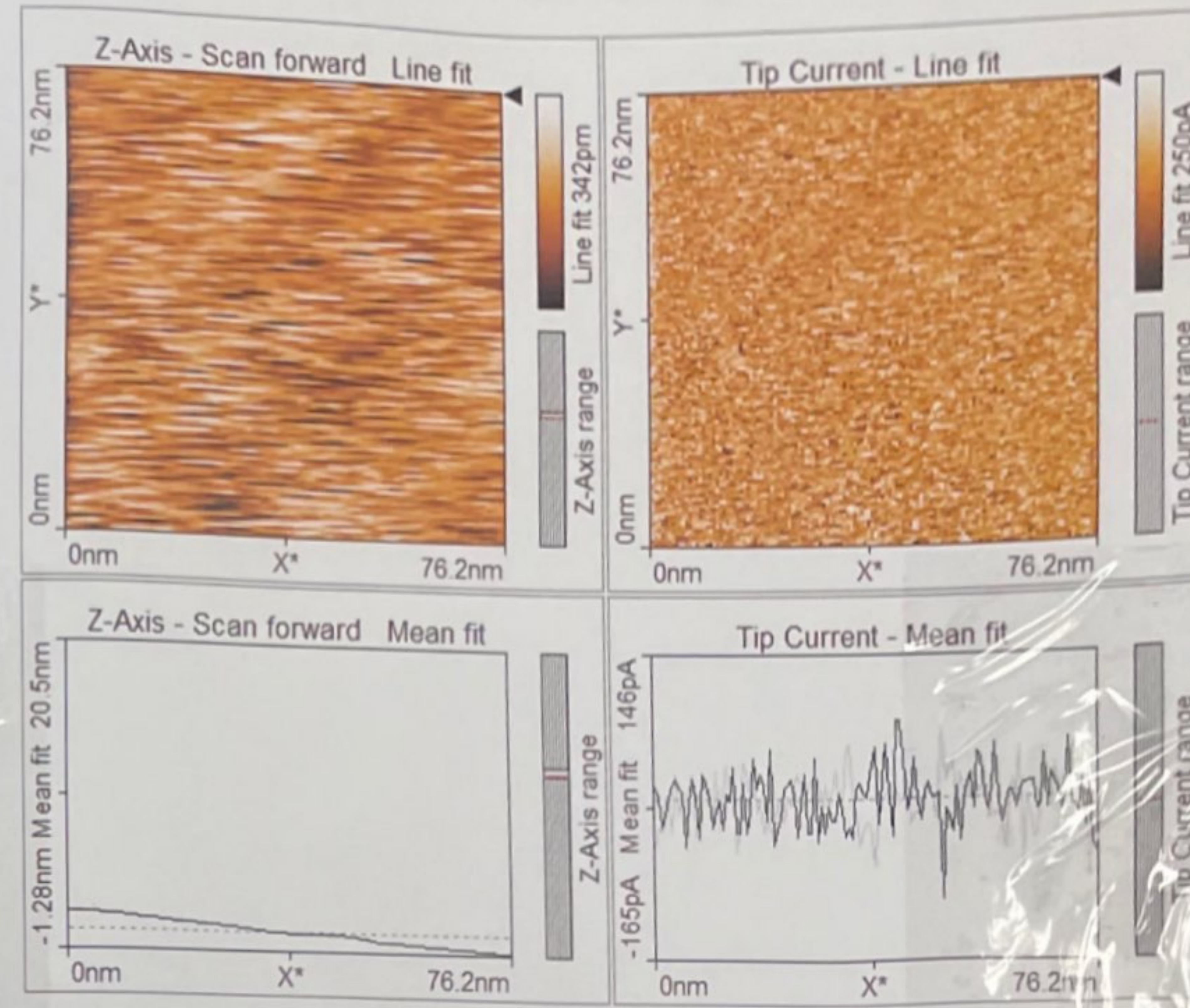
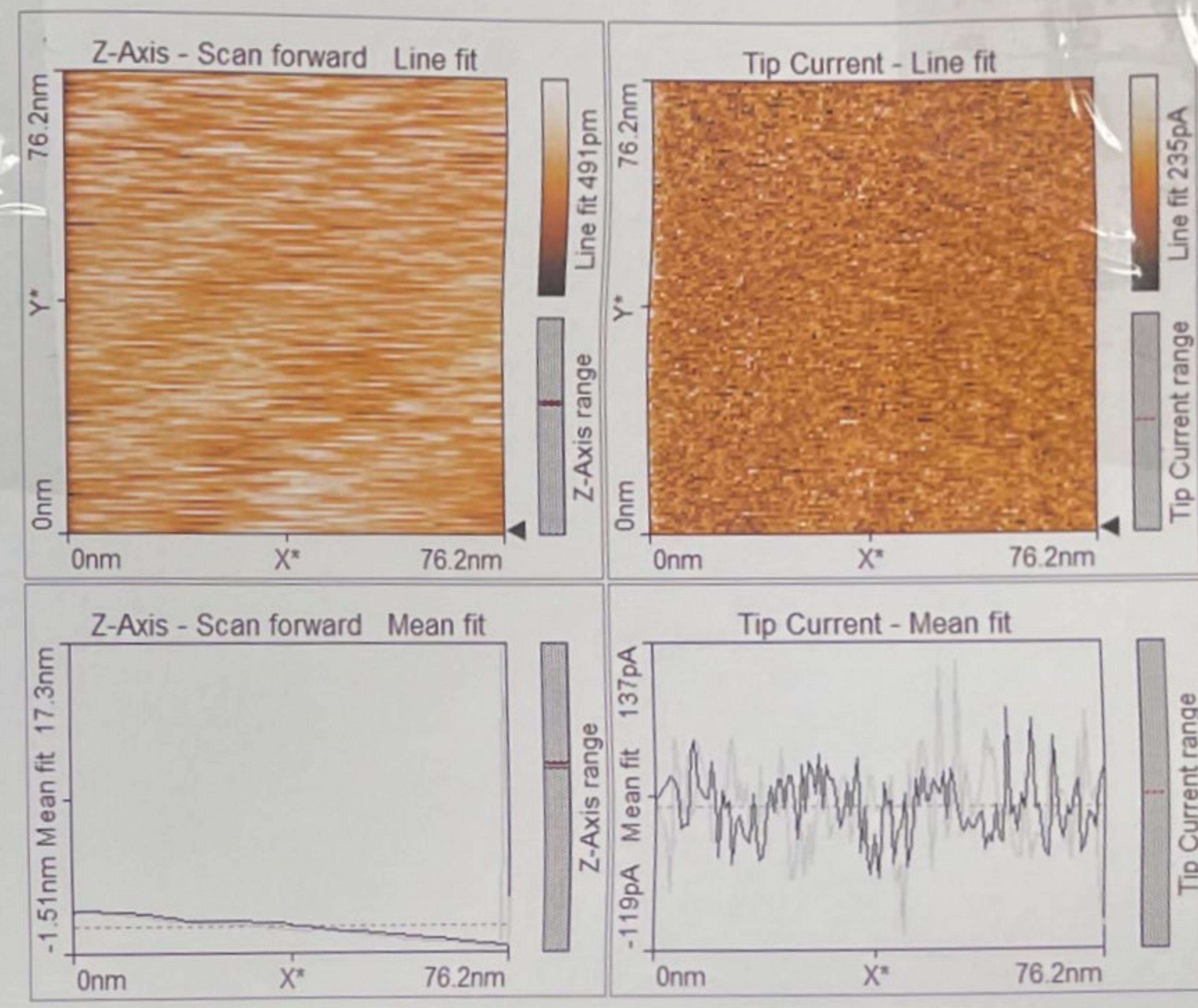
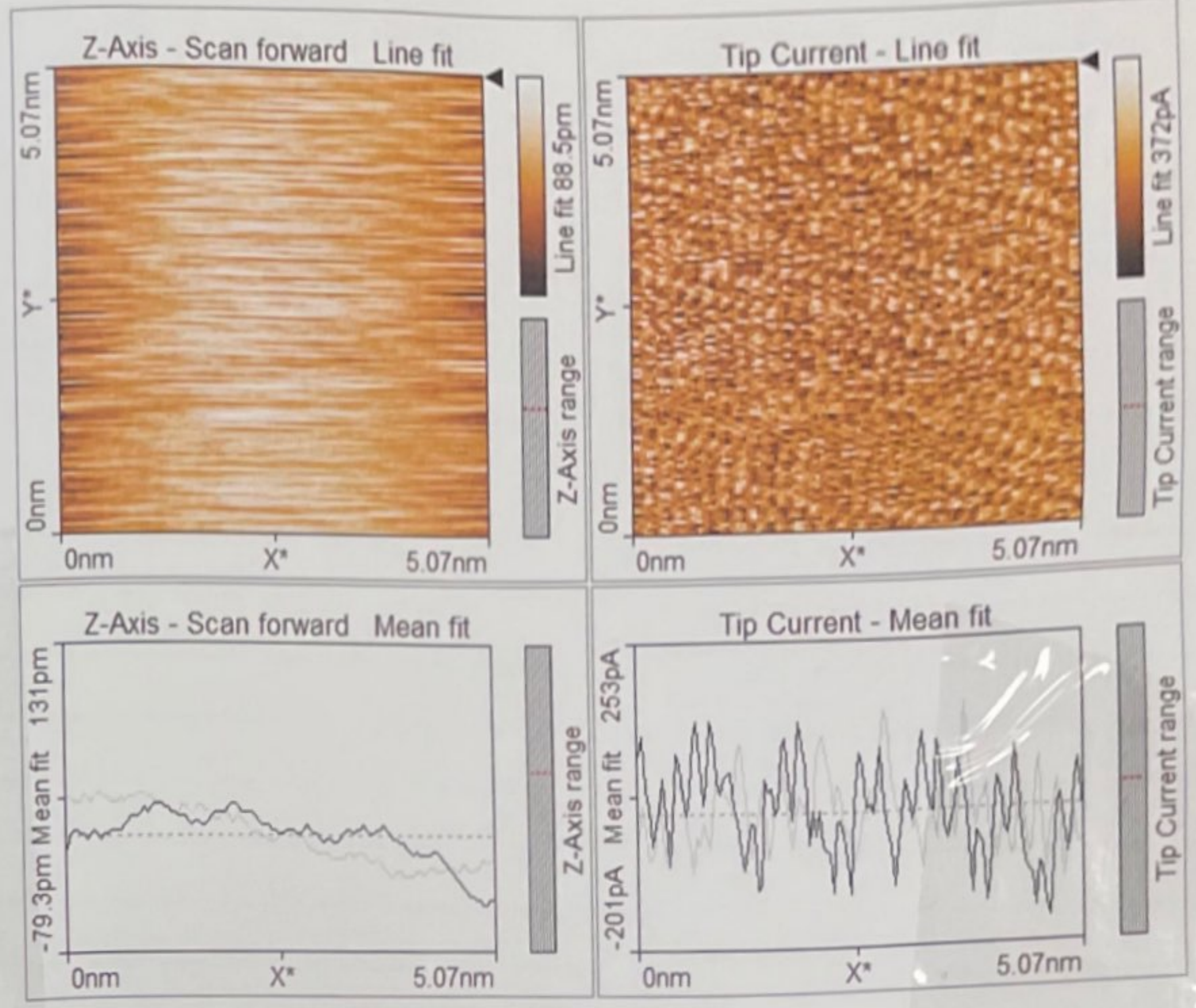


Image0067



I[illegible] 068



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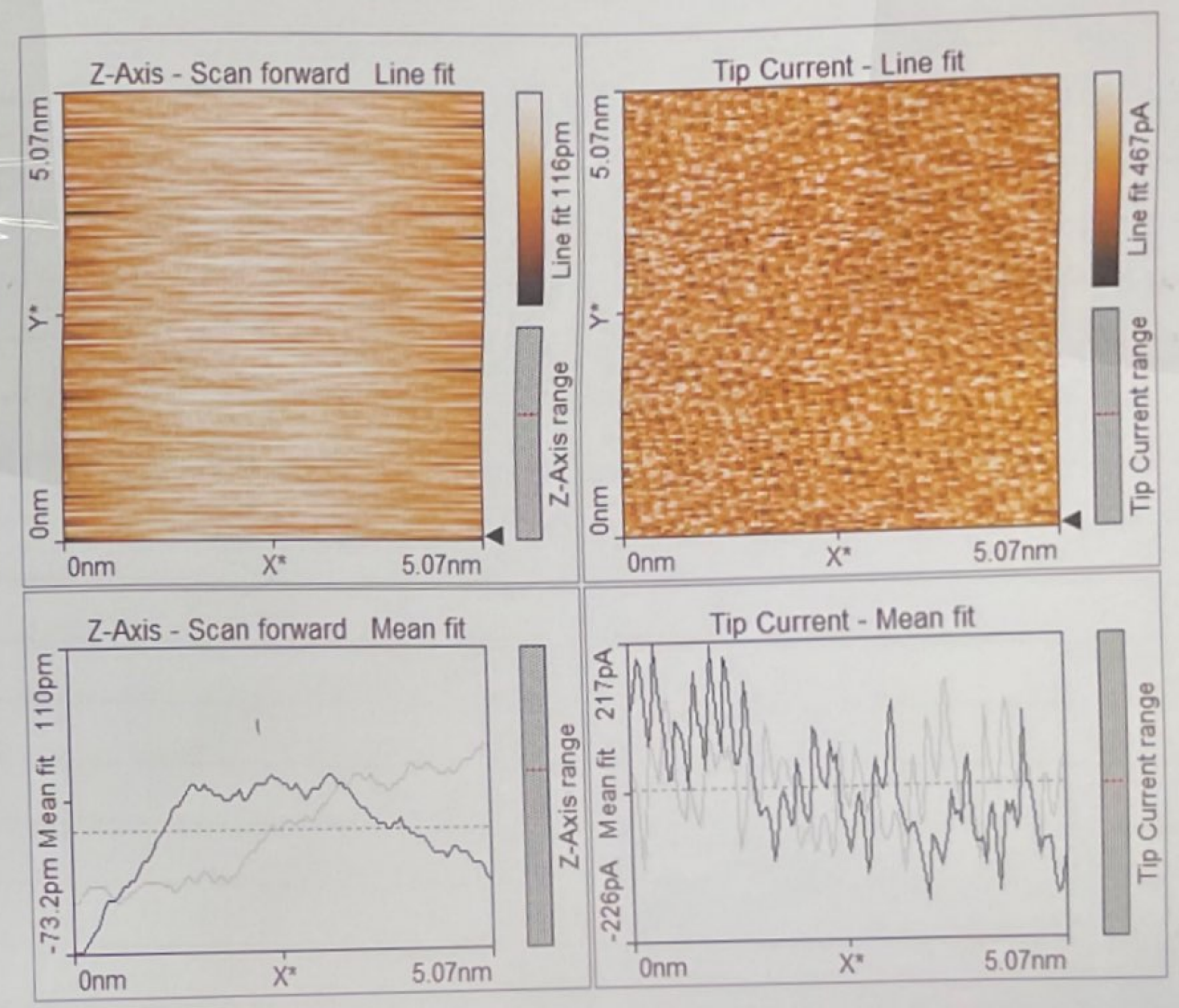

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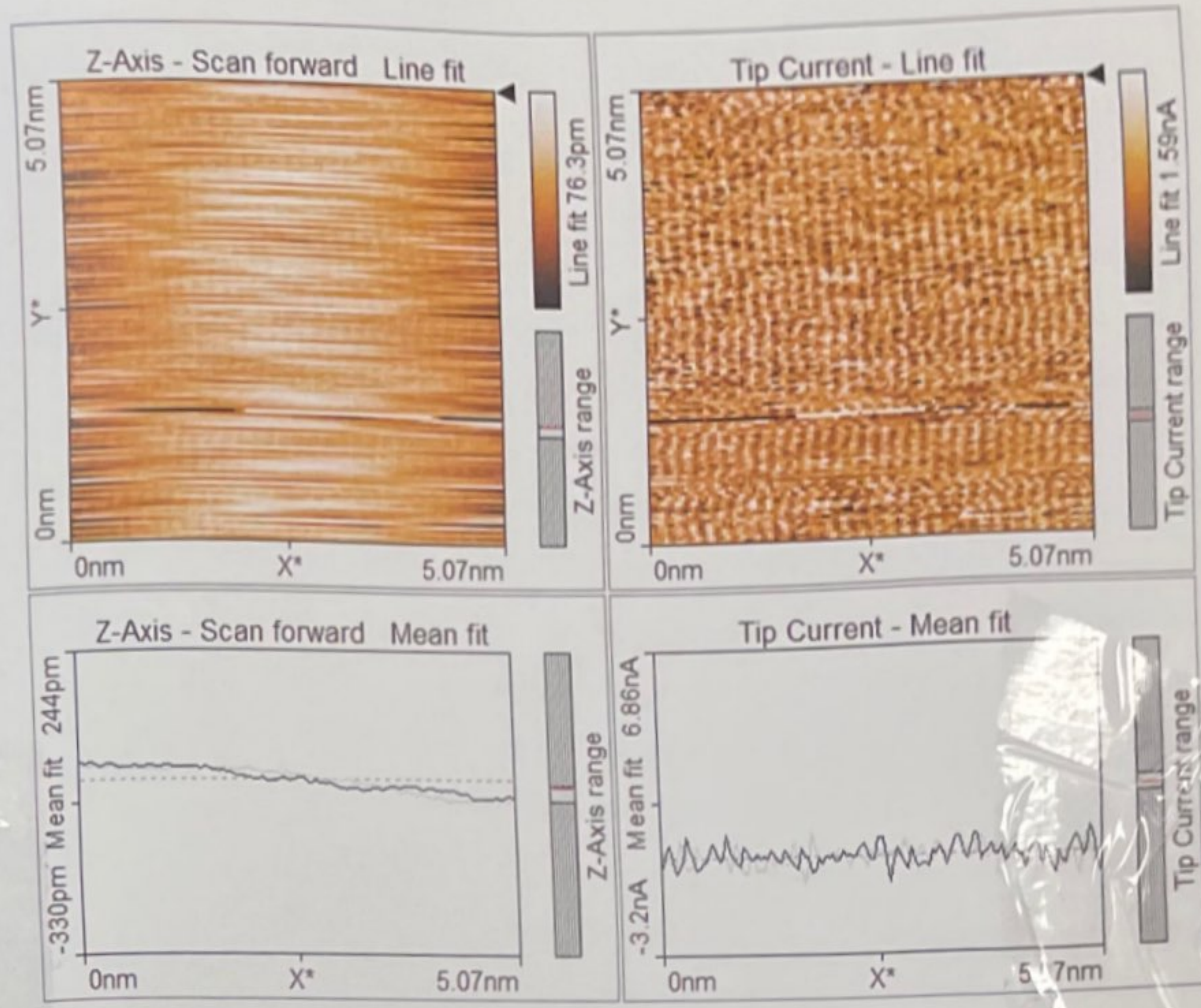

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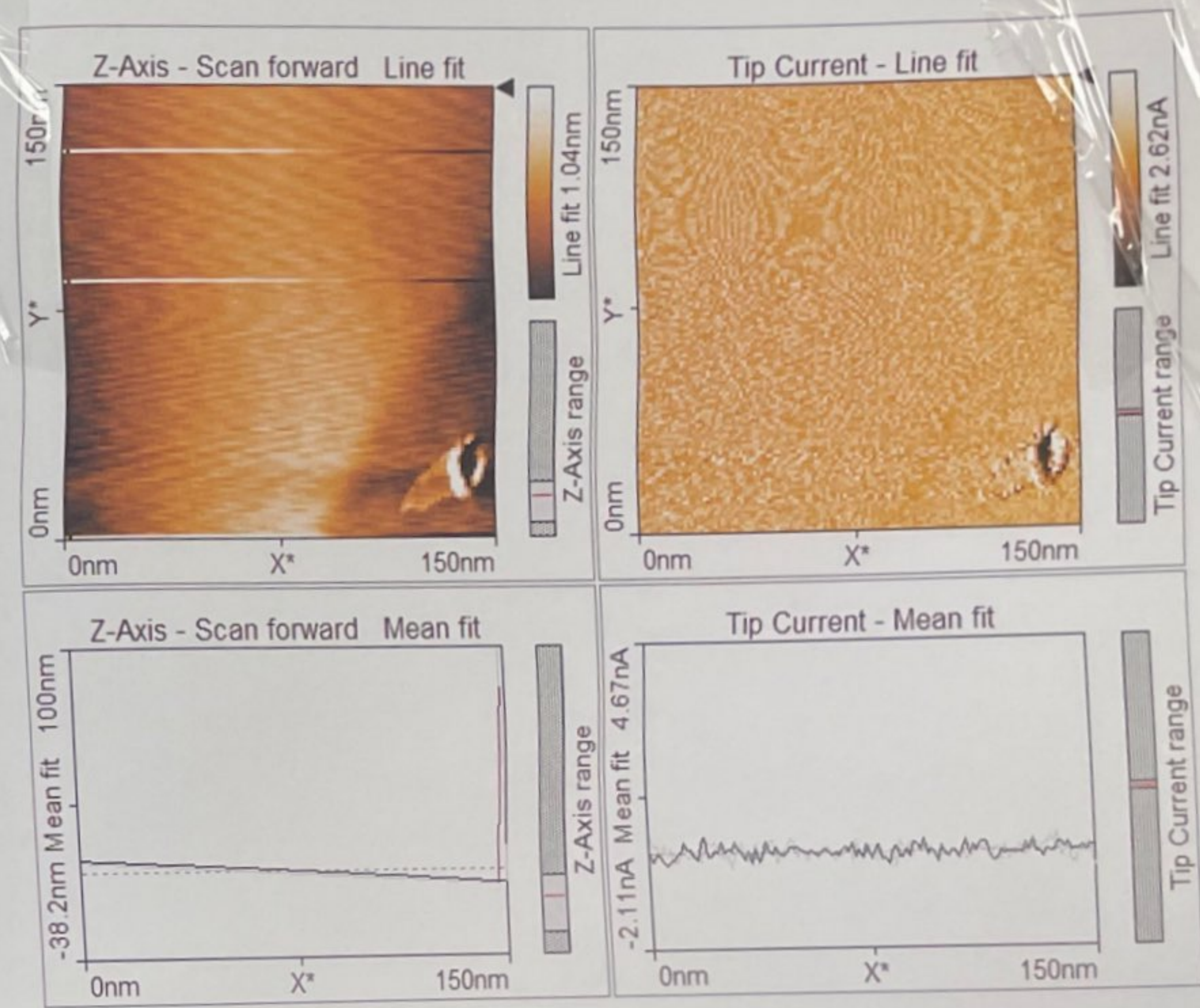


Image0072

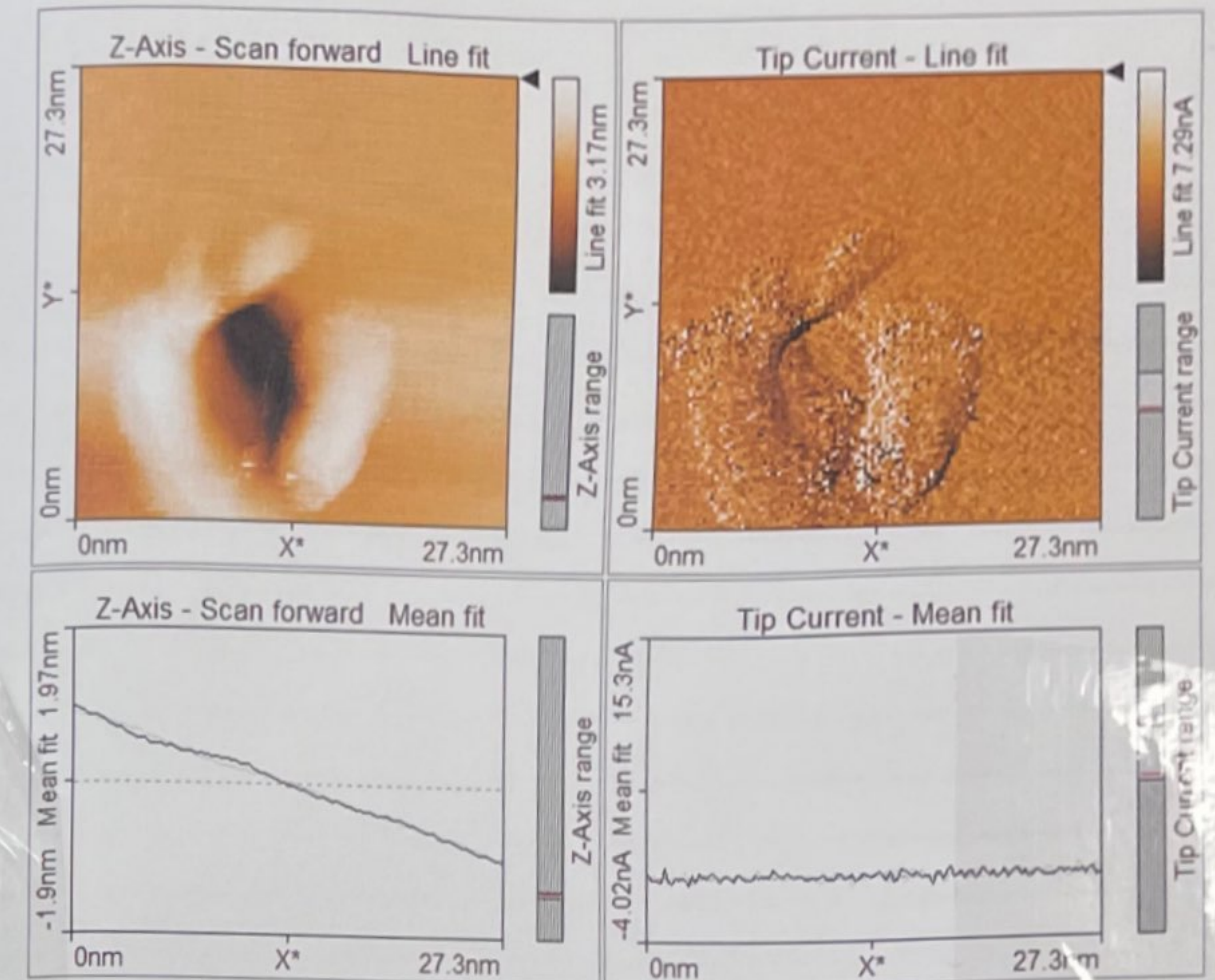
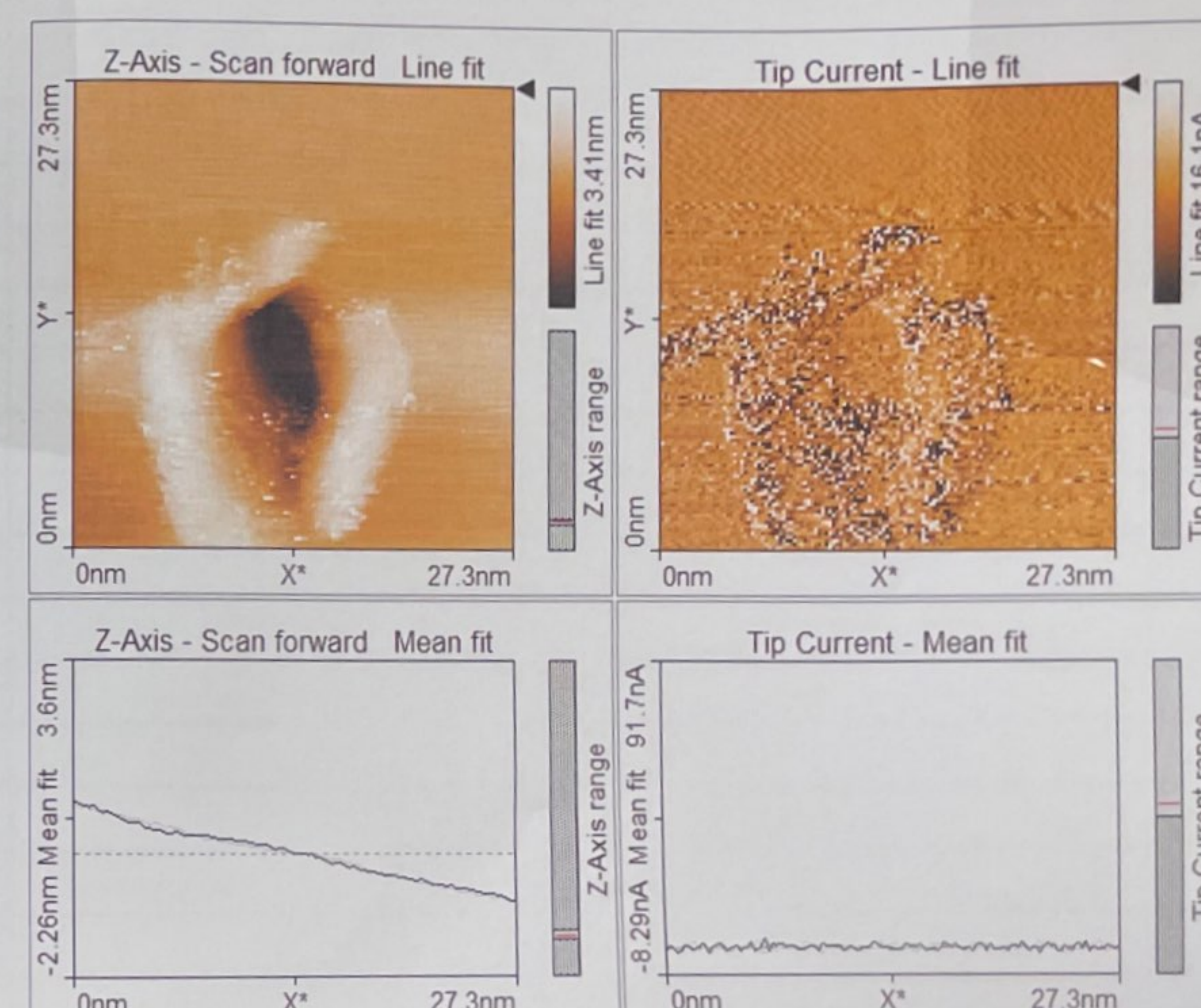


Image0073



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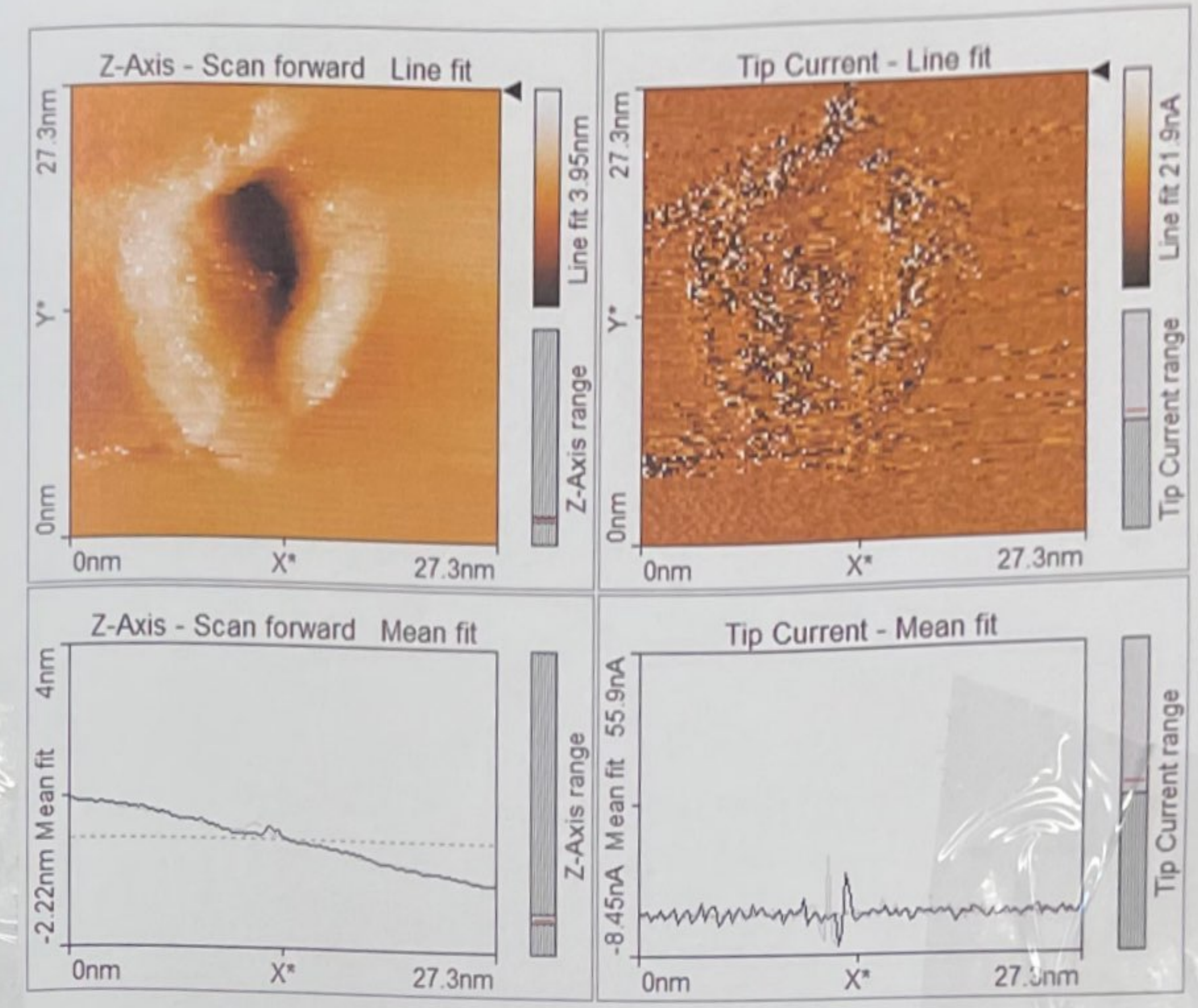
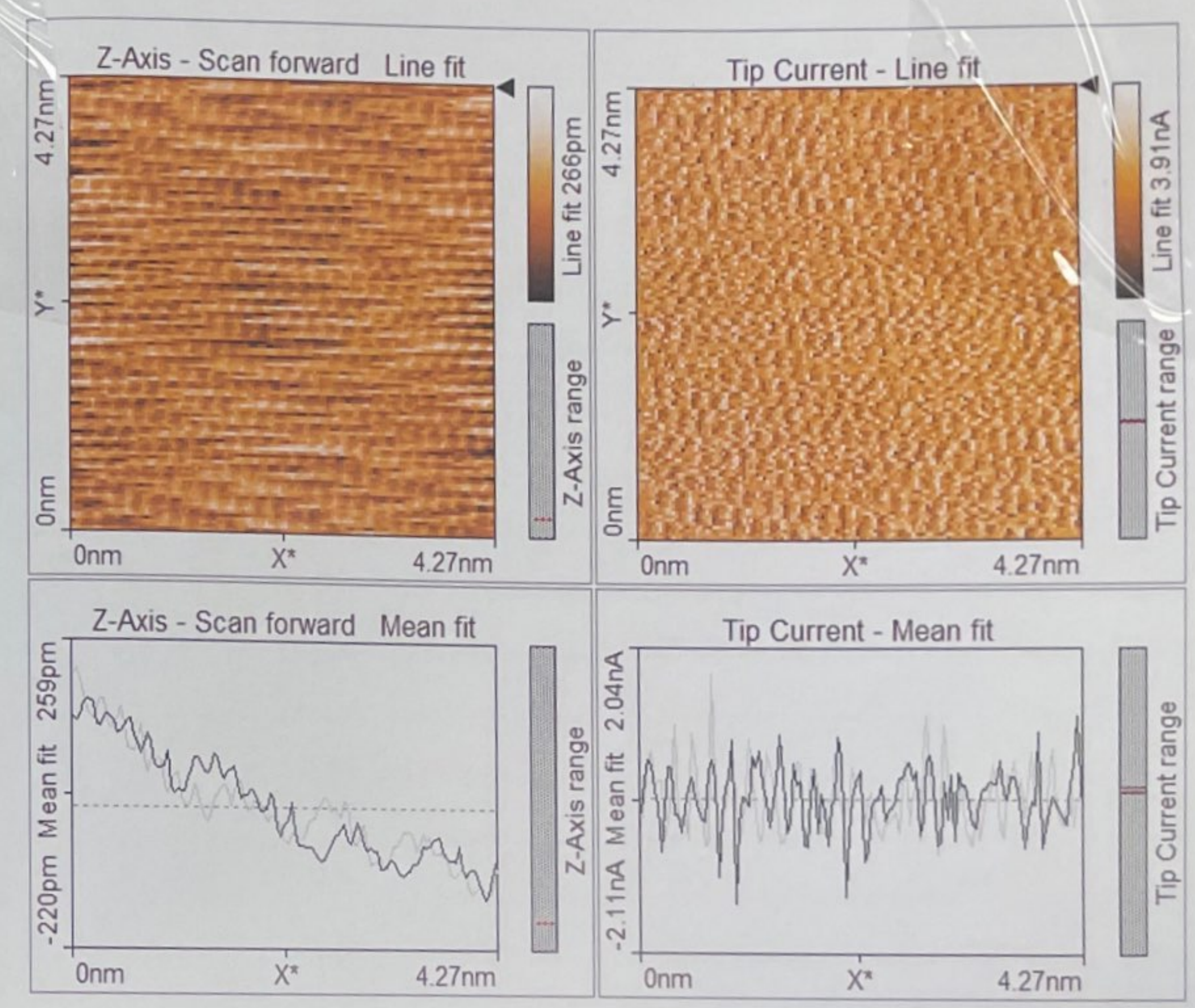


Image0075



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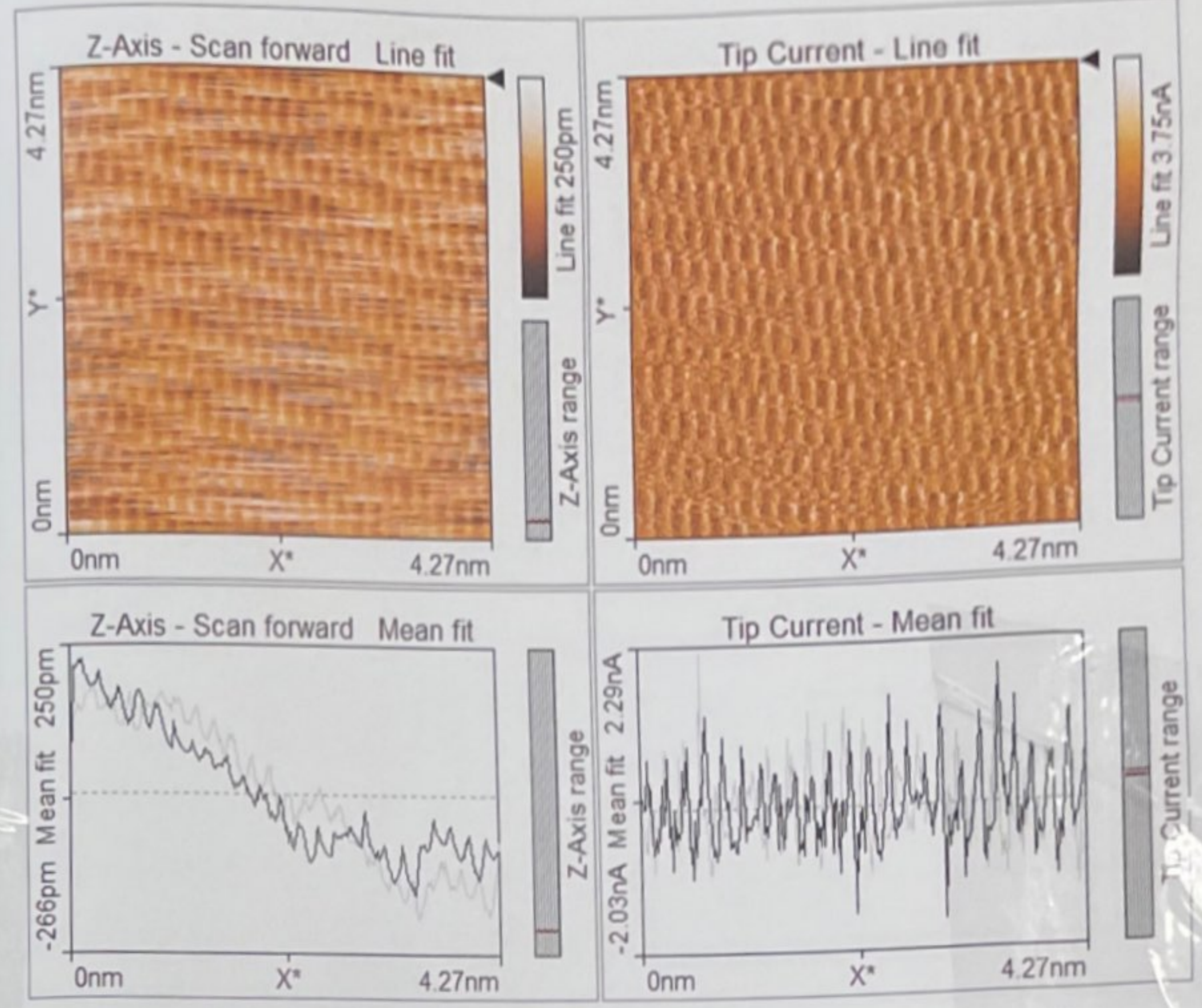

Image0077

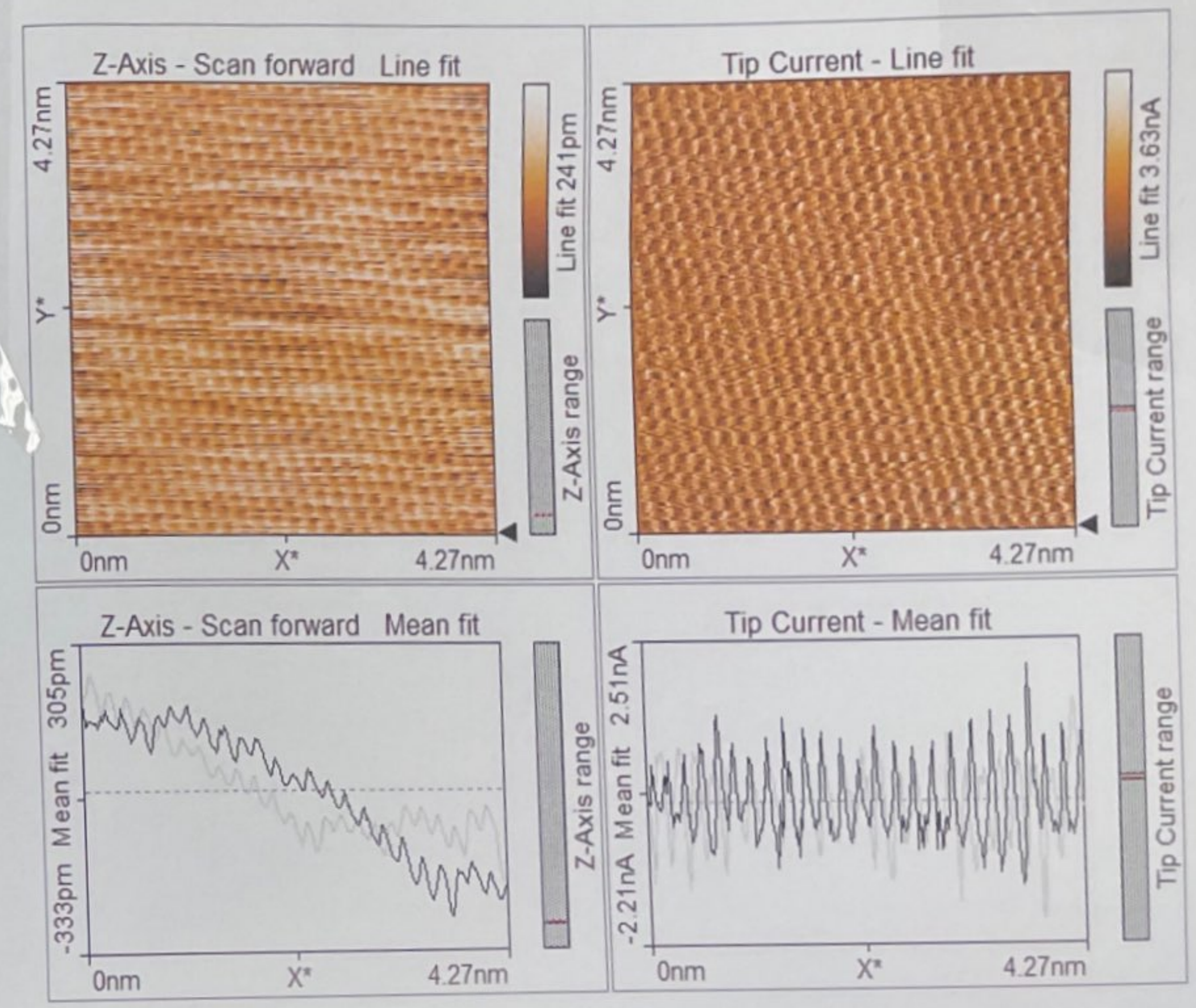

Image0078

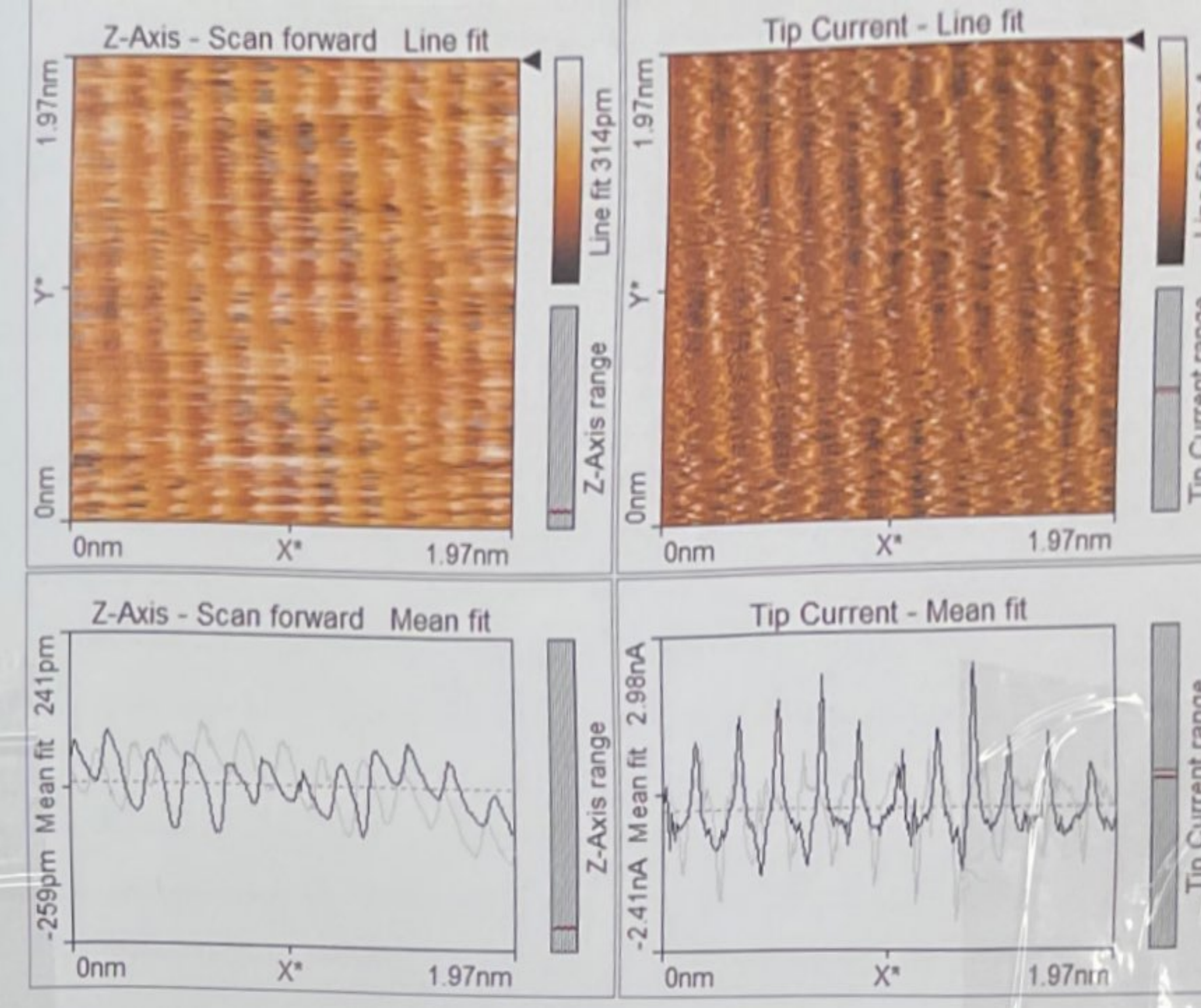
Z-Axis - Scan forward Line fit
1.97nm
Y*
0nm
X*
Line fit 314pm
Z-Axis range
Tip Current - Line fit
Line fit 3.68nA
Tip Current range
Z-Axis - Scan forward Mean fit
-259pm Mean fit 241pm
Tip Current - Mean fit
-2.41nA Mean fit 2.98nA

Image 0074

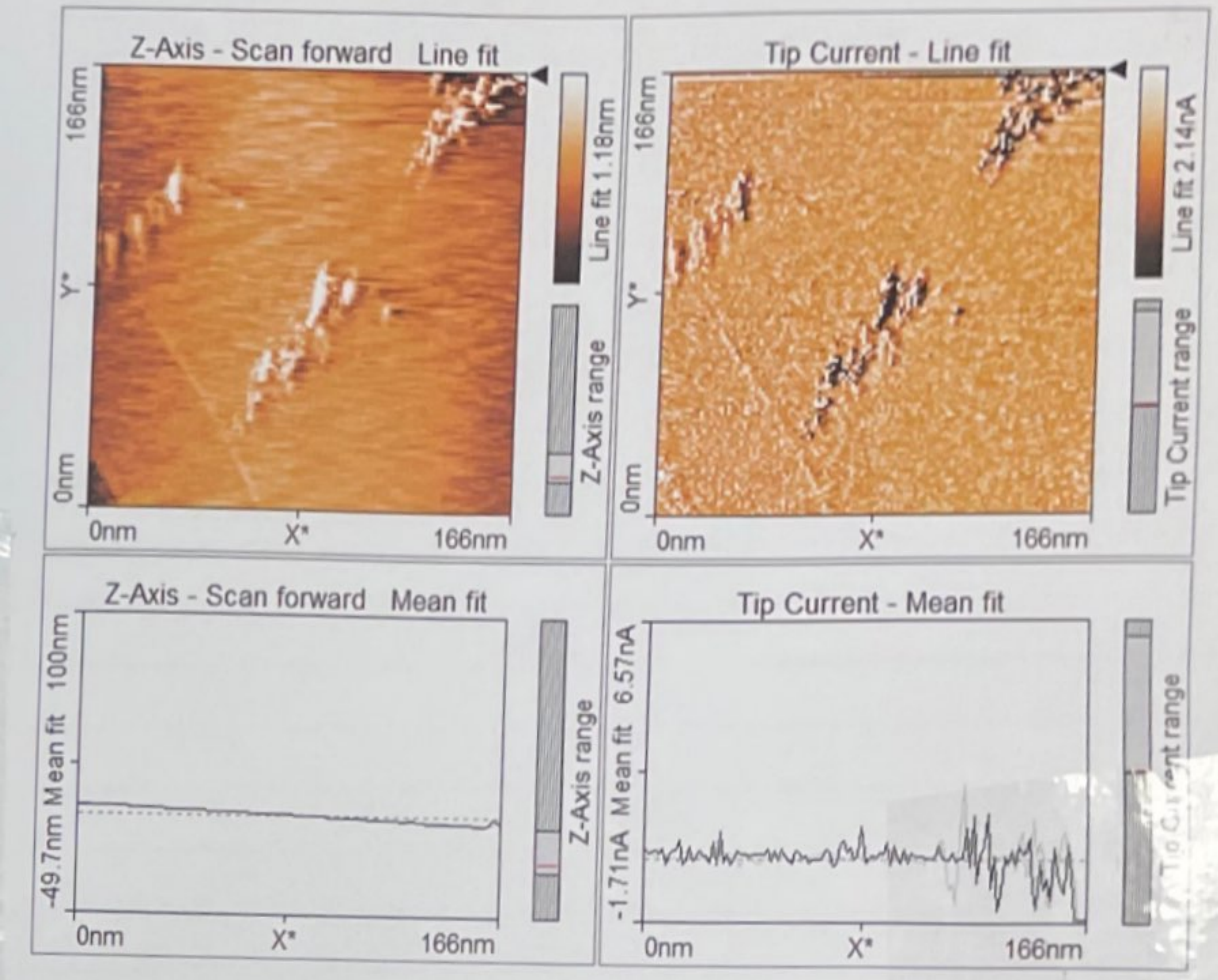

Image 0081

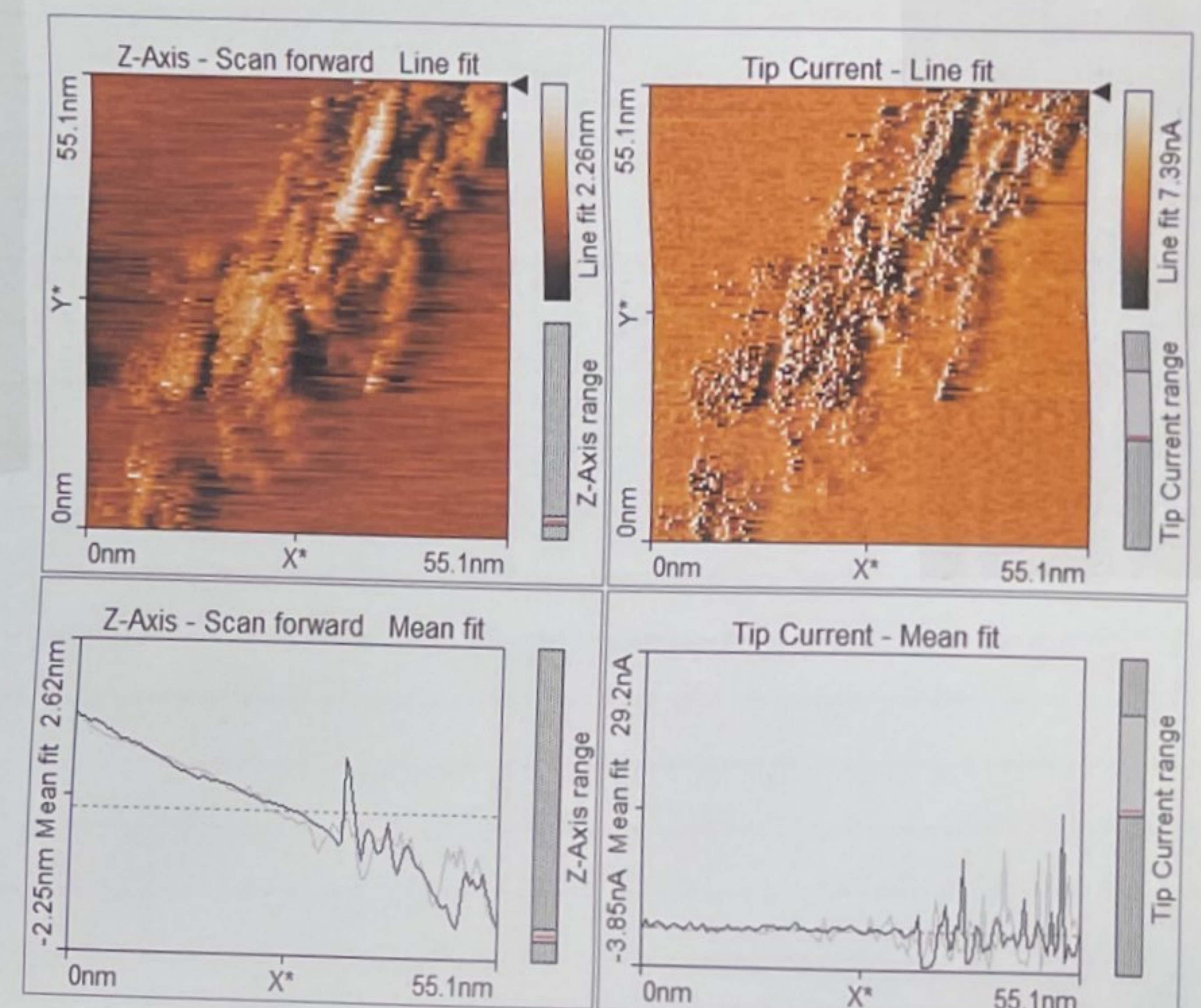

Image 0082

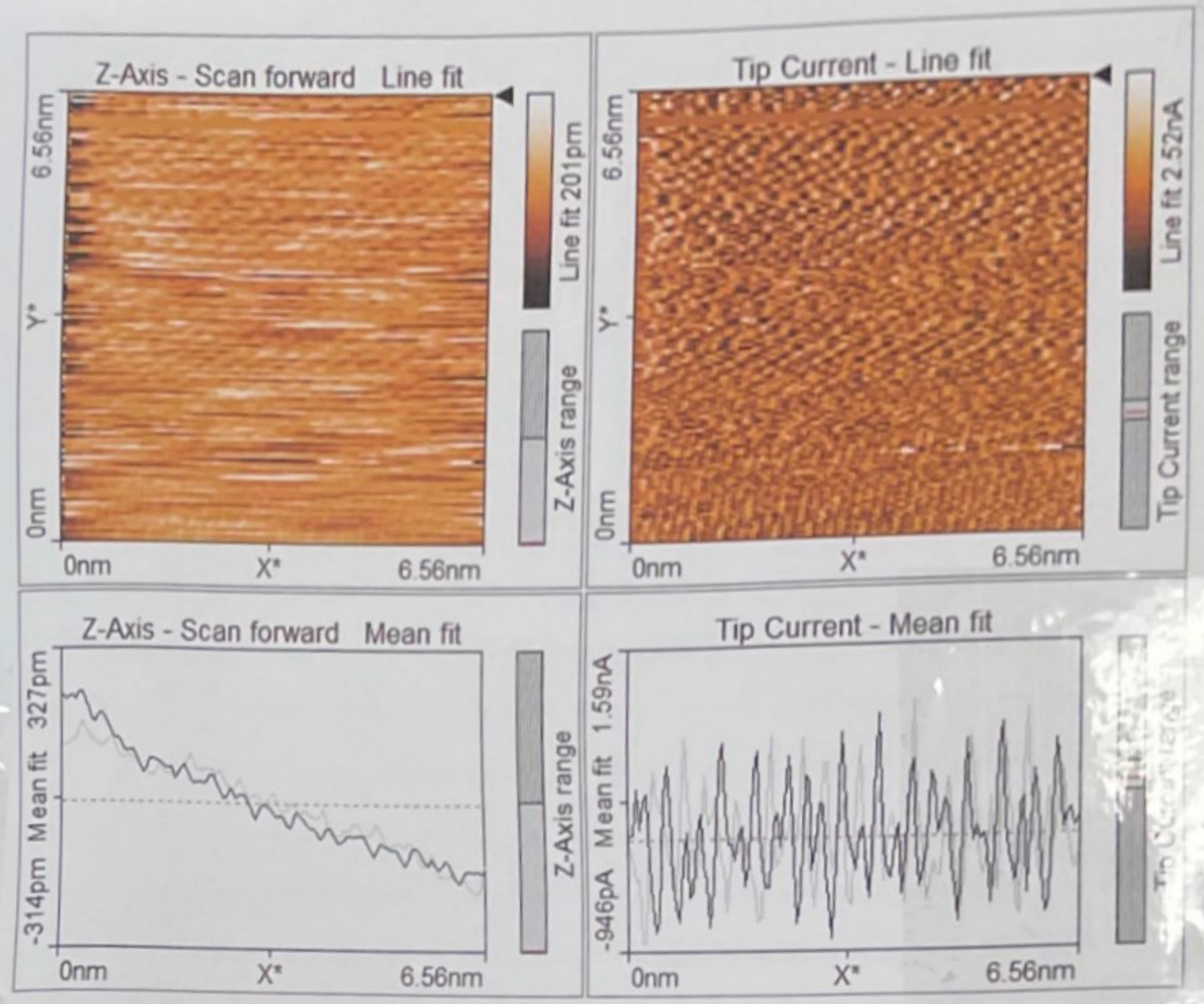

Image 0083

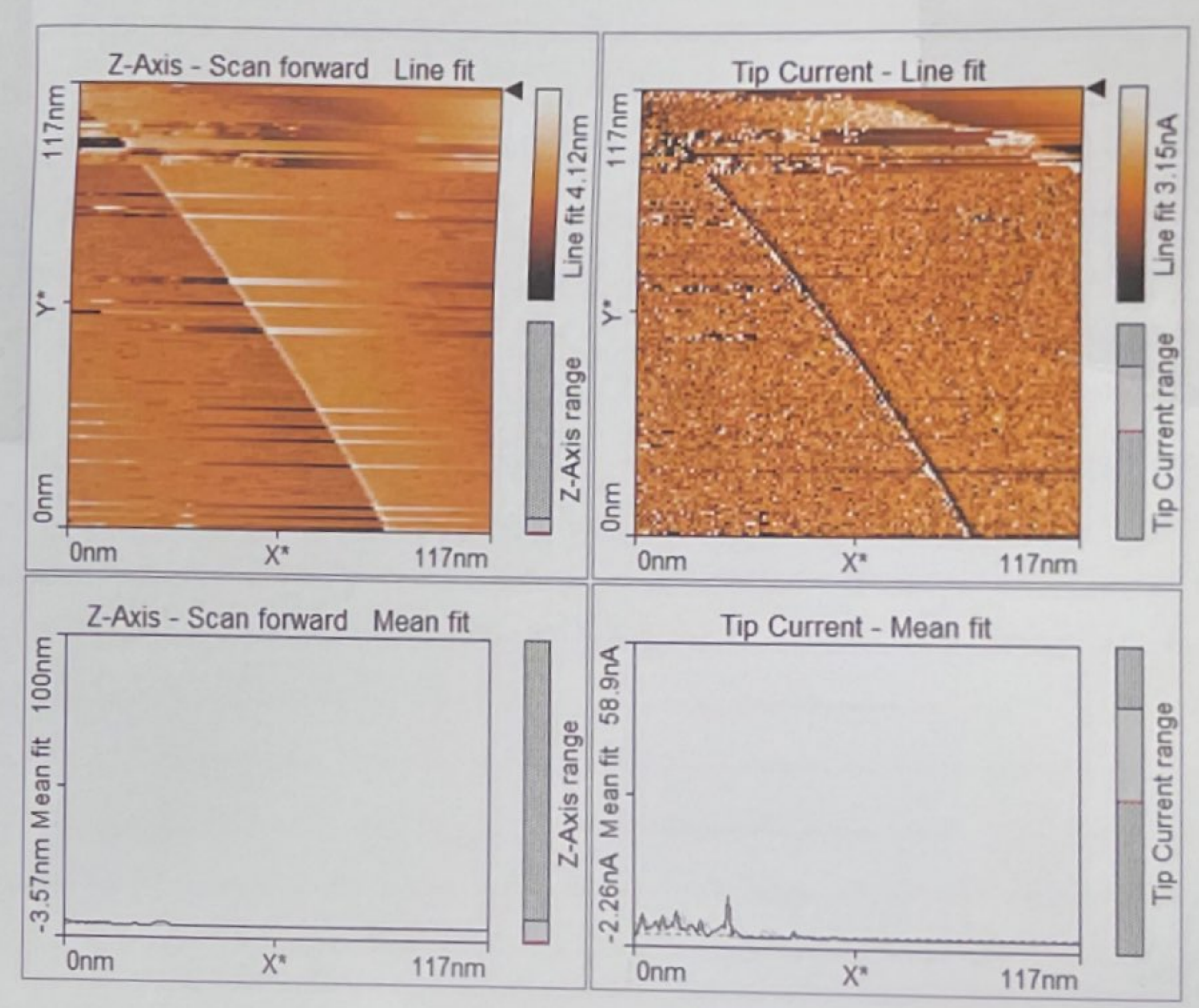

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Image 0084

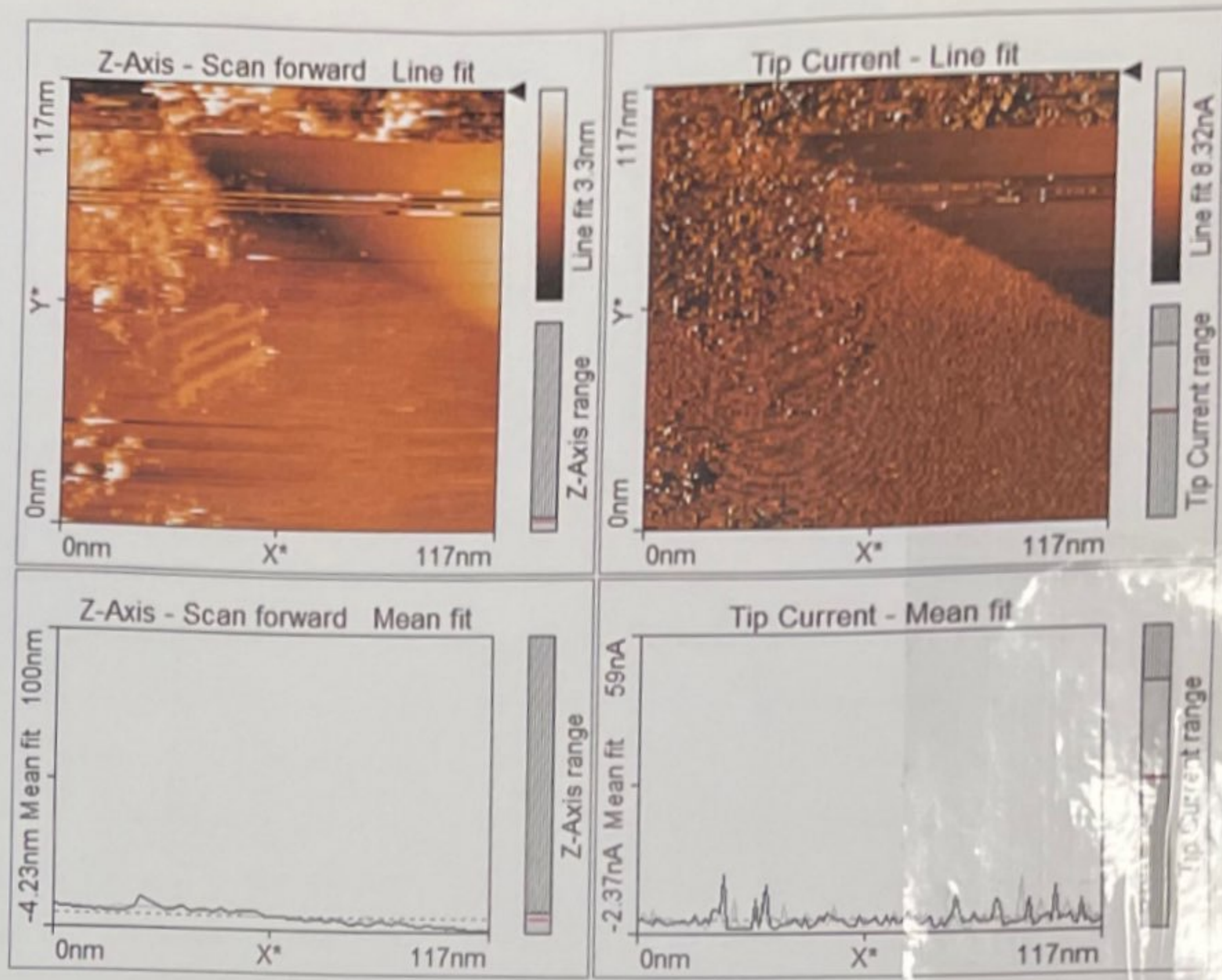
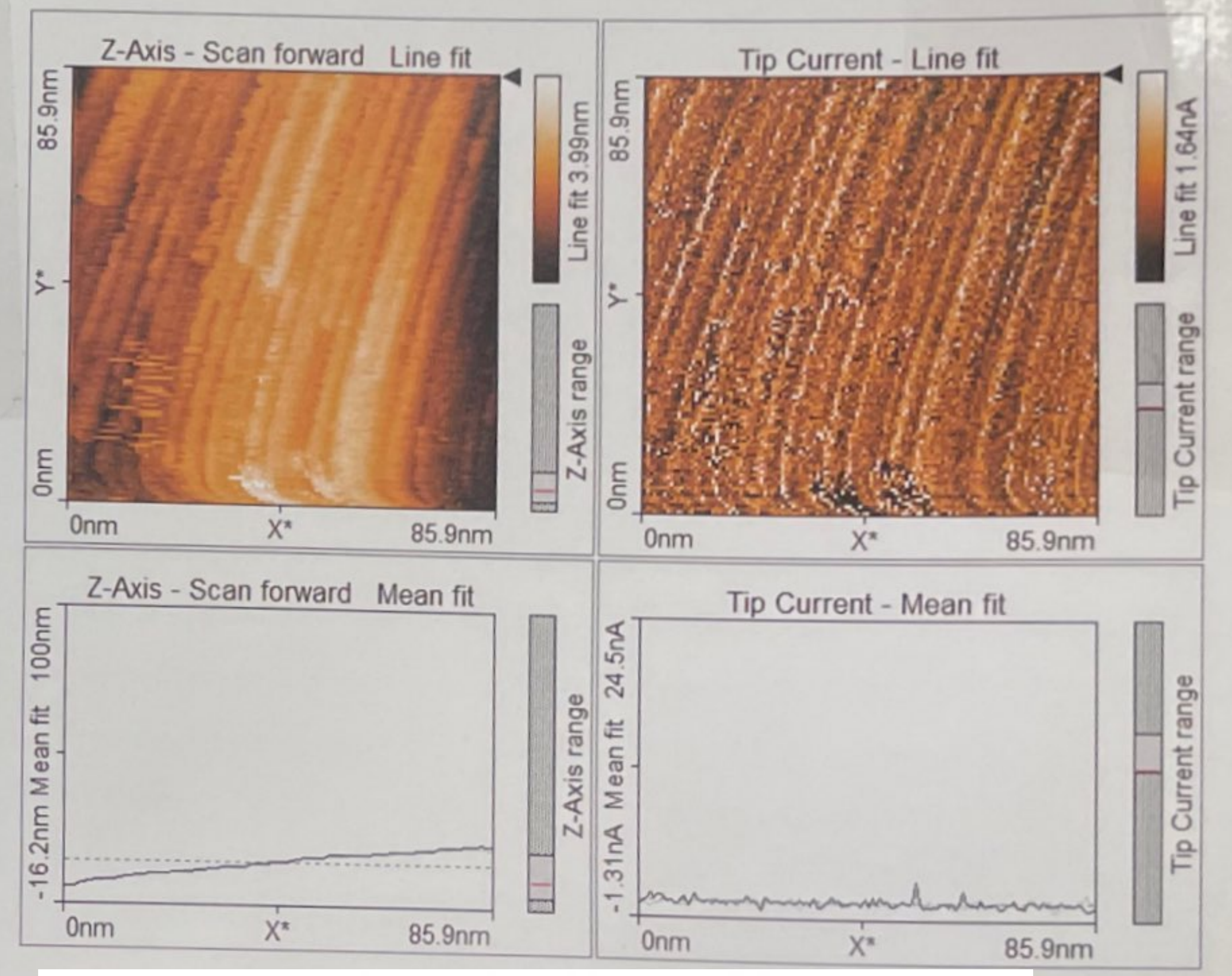


Image 0085



92

Image0086

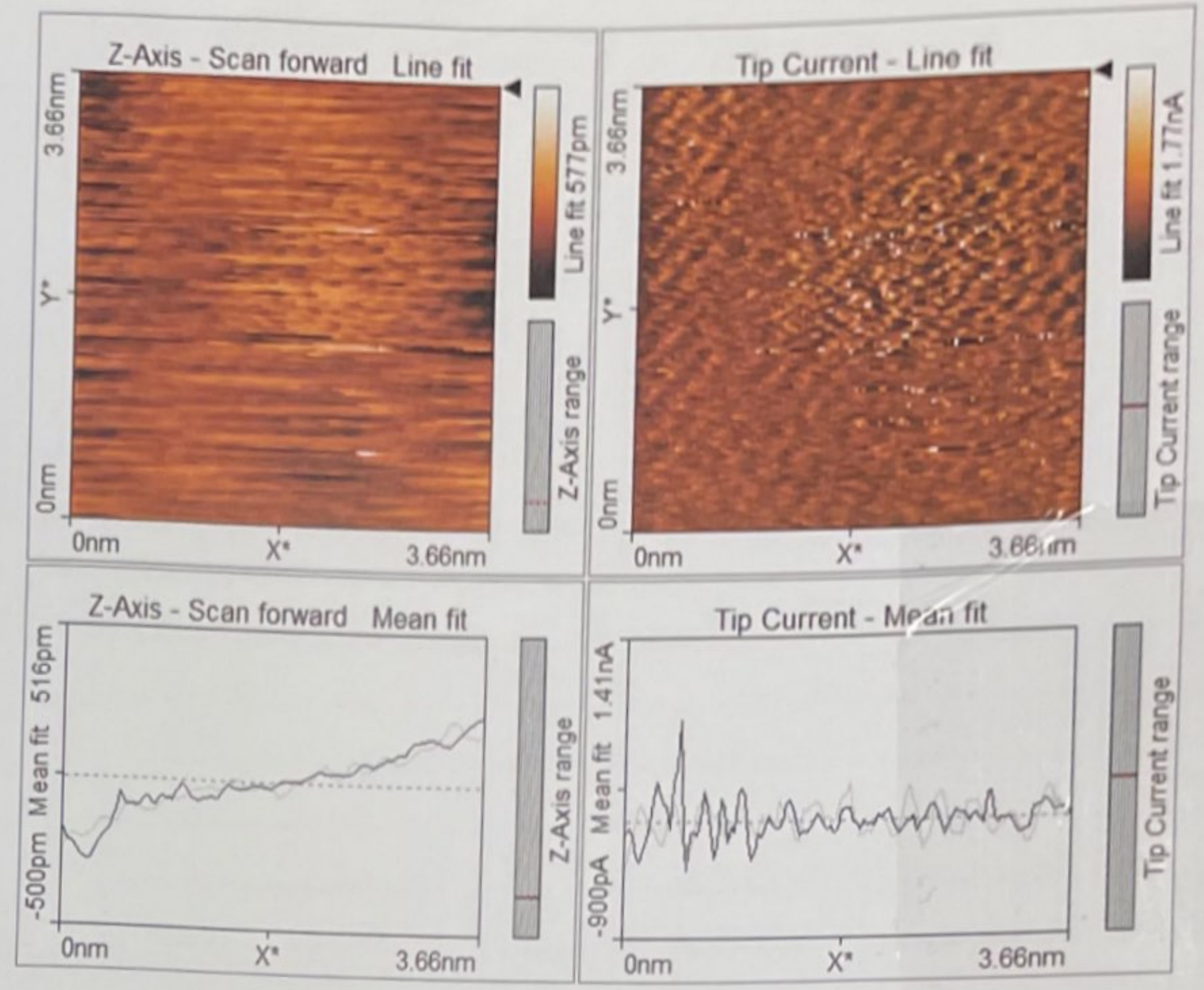
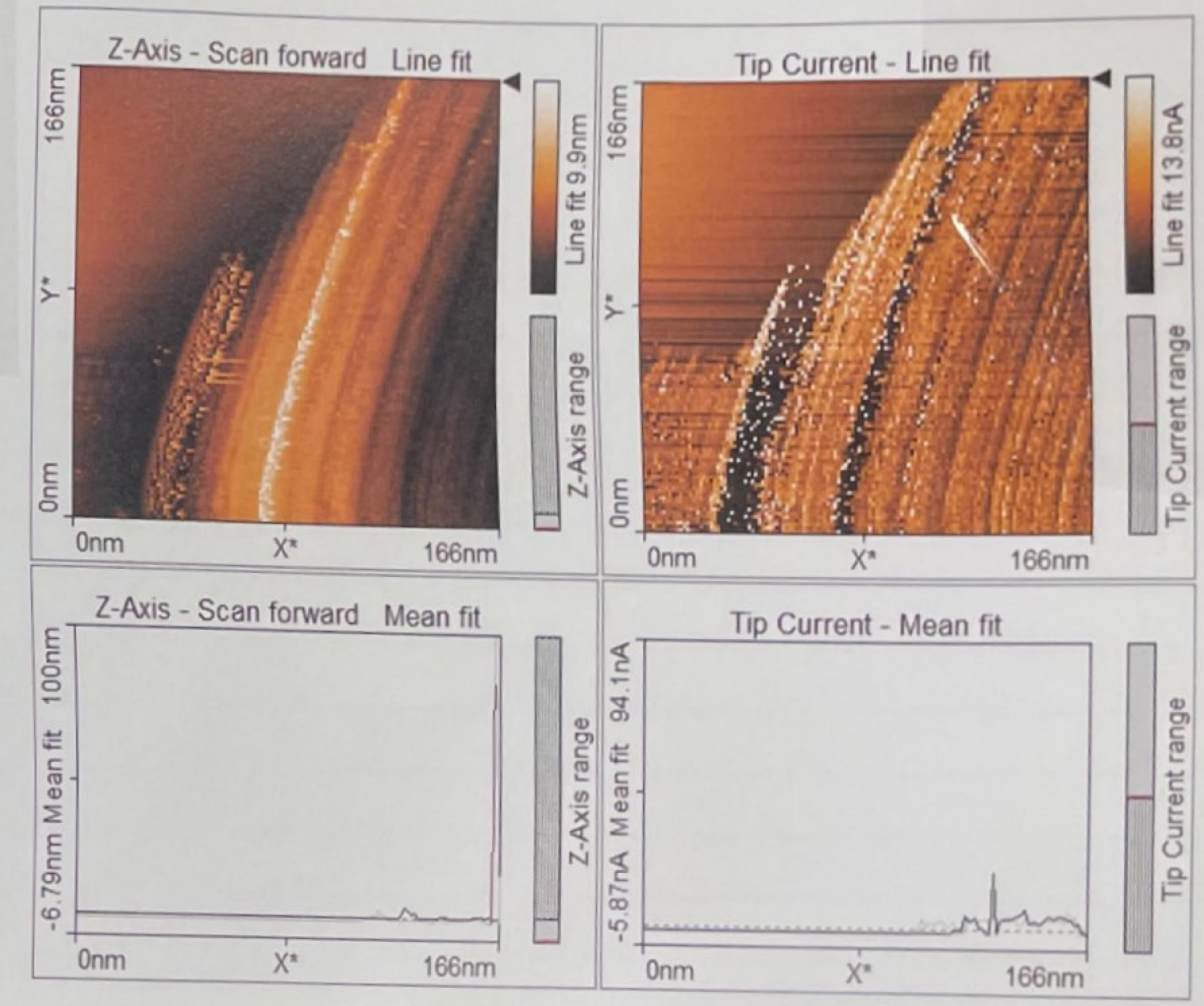


Image0087



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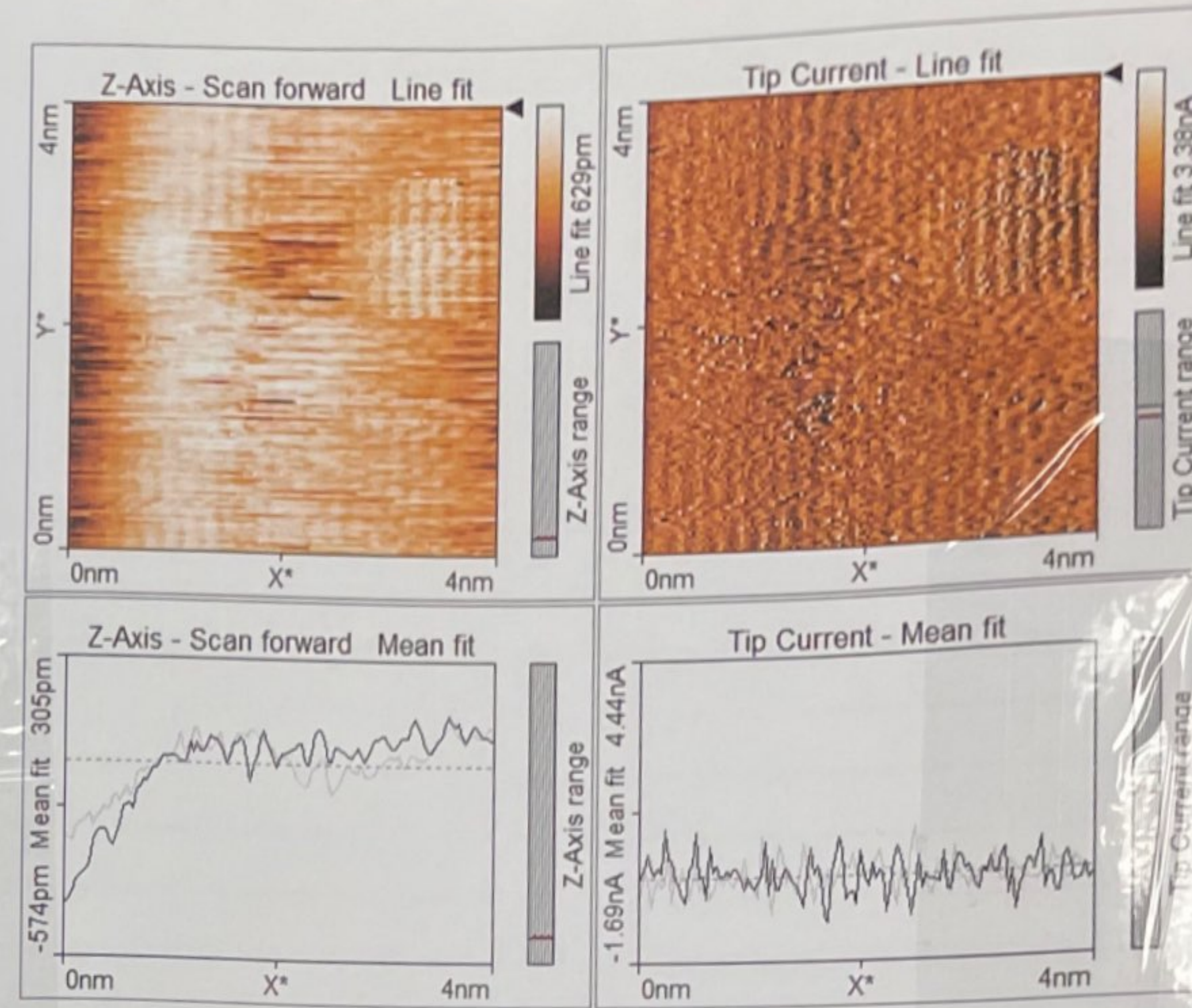


Image0106

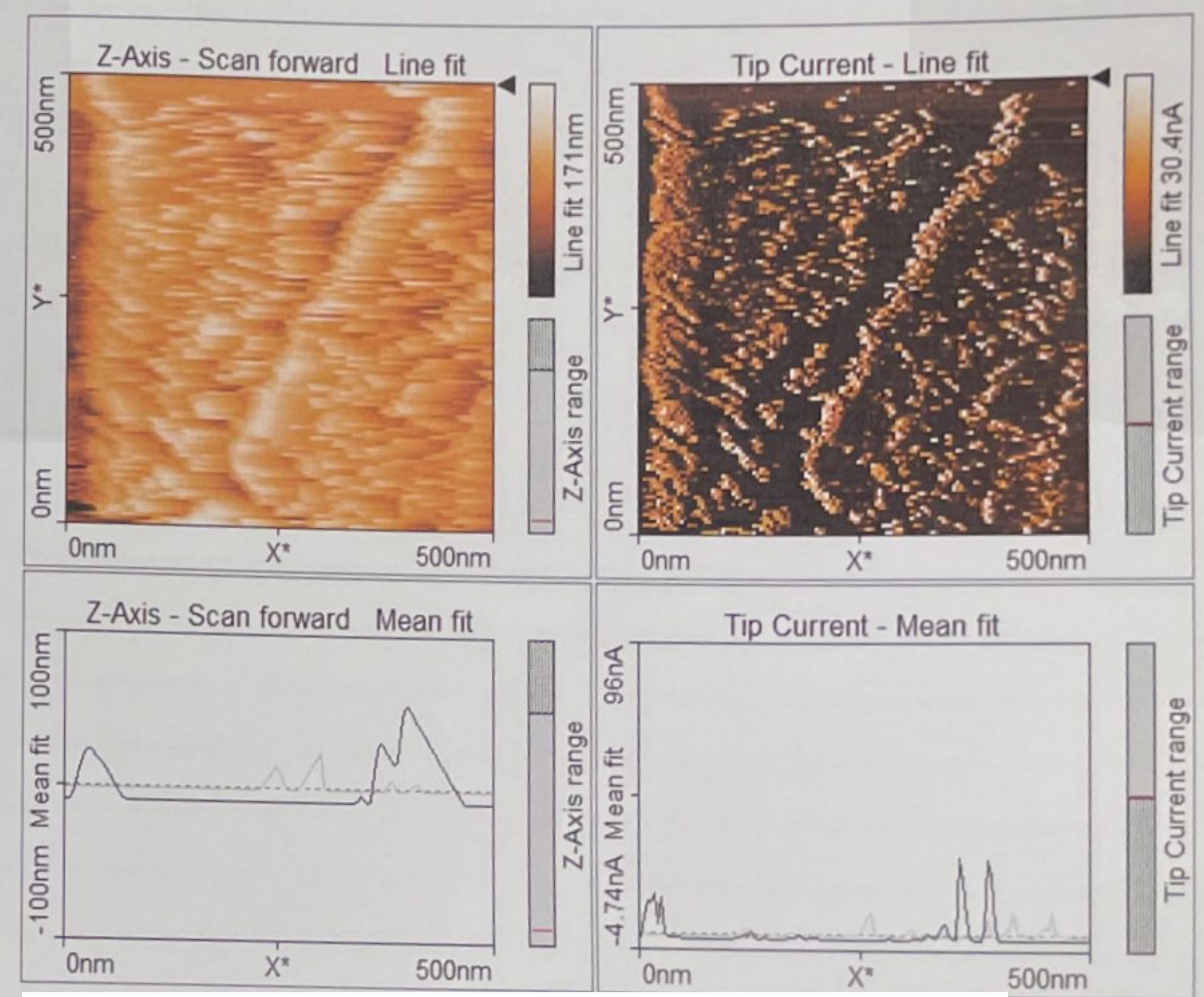


Image 00107

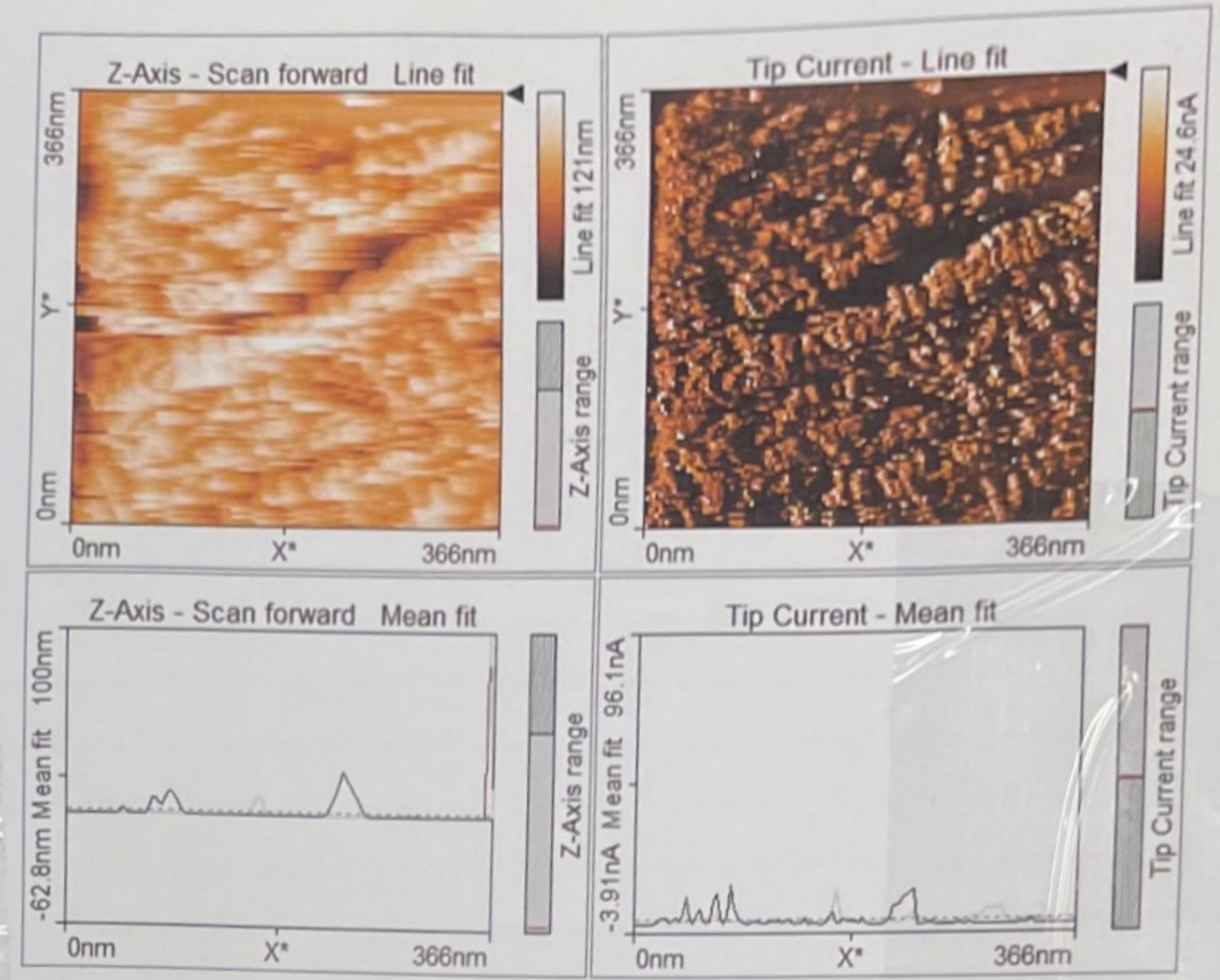
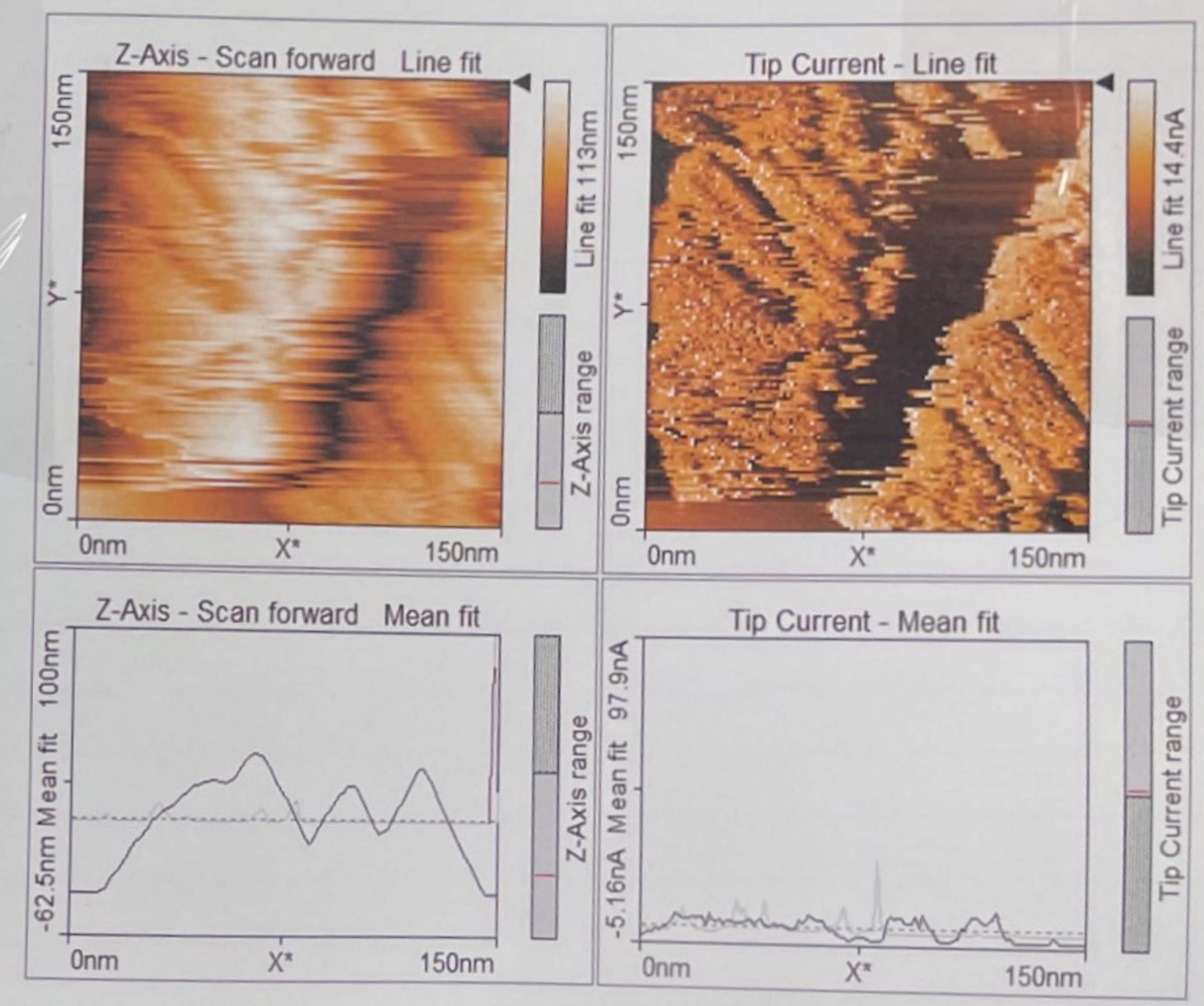


Image 00108



ge 00109

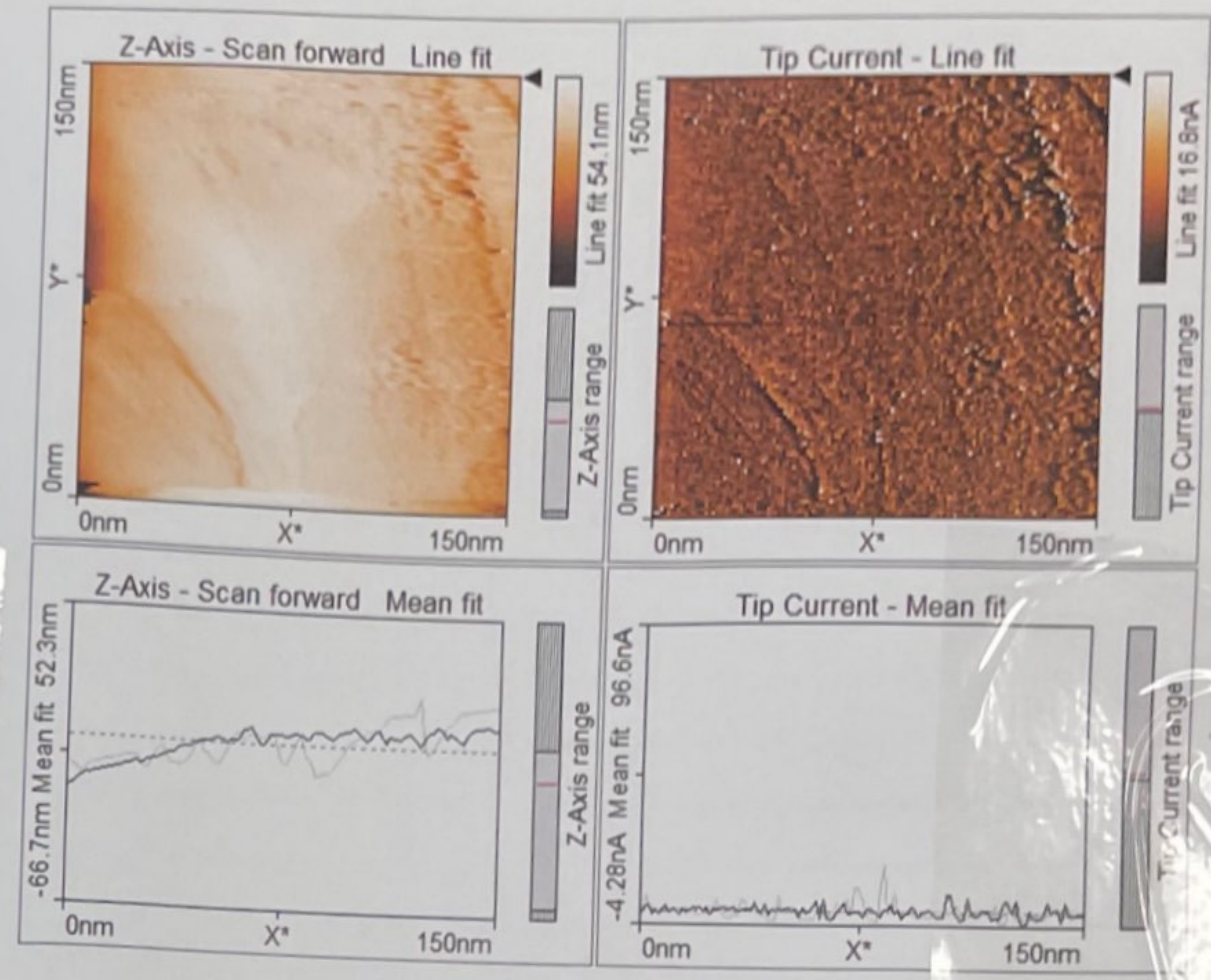


Image 00110

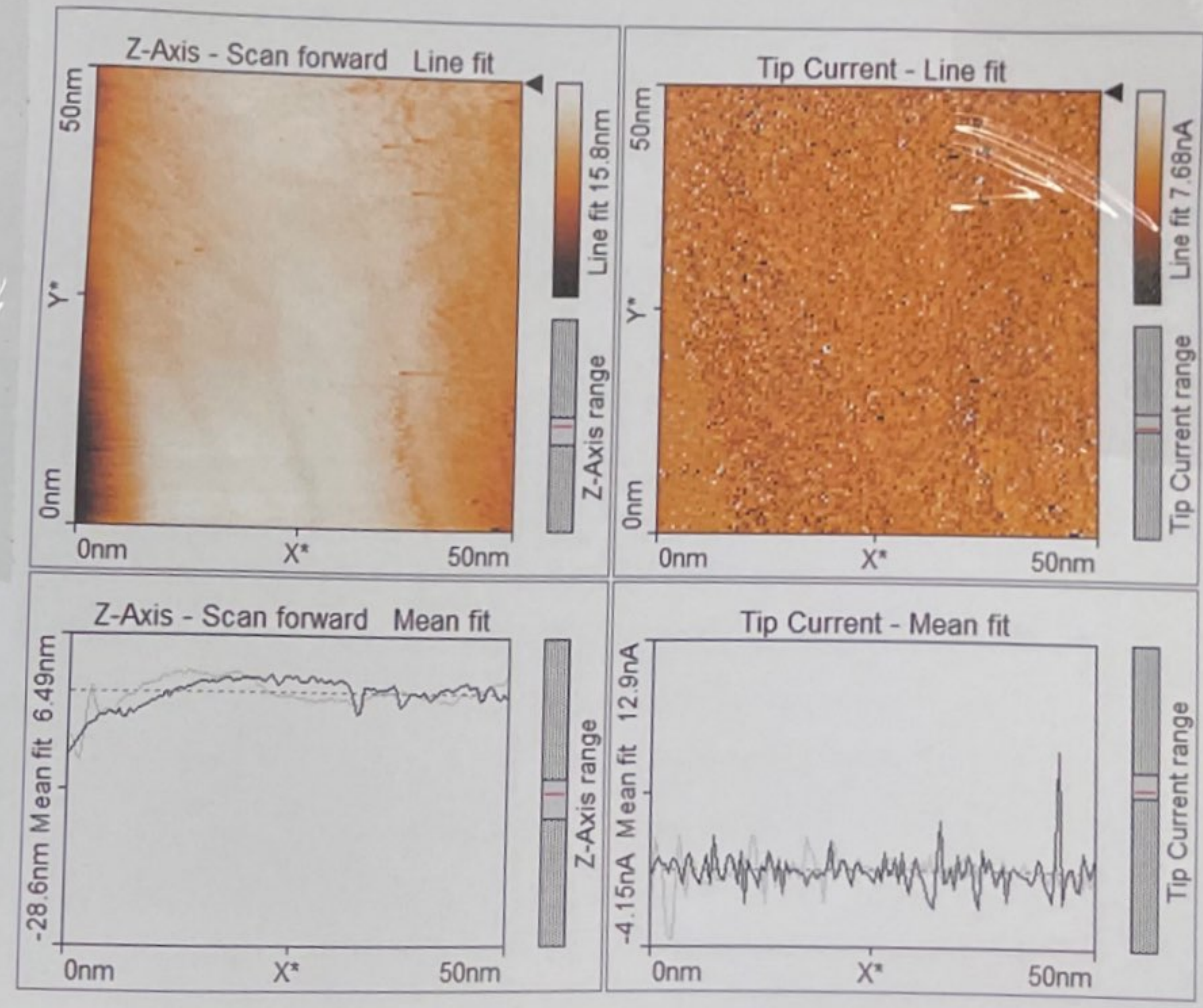


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Image00111

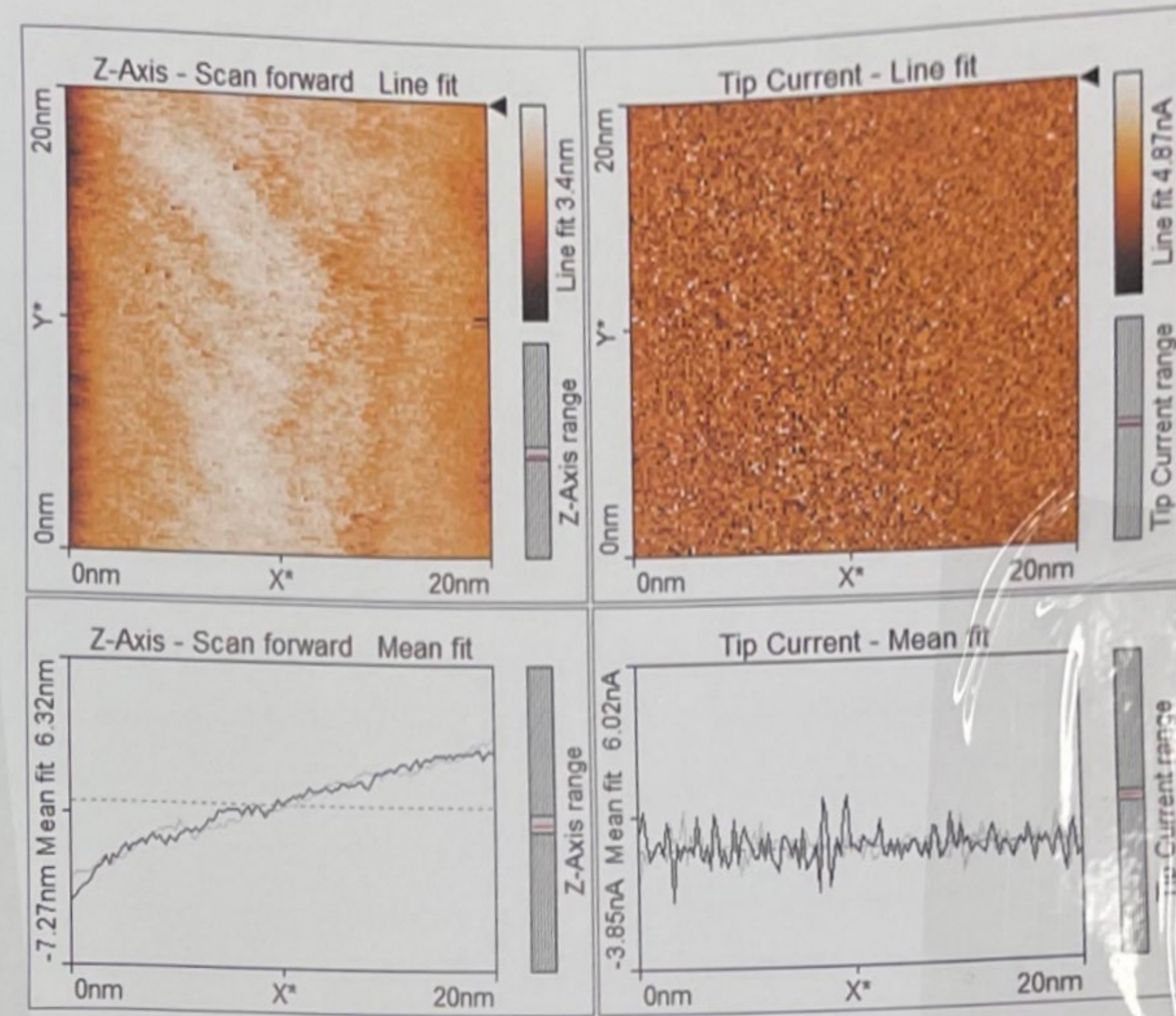

Image00112

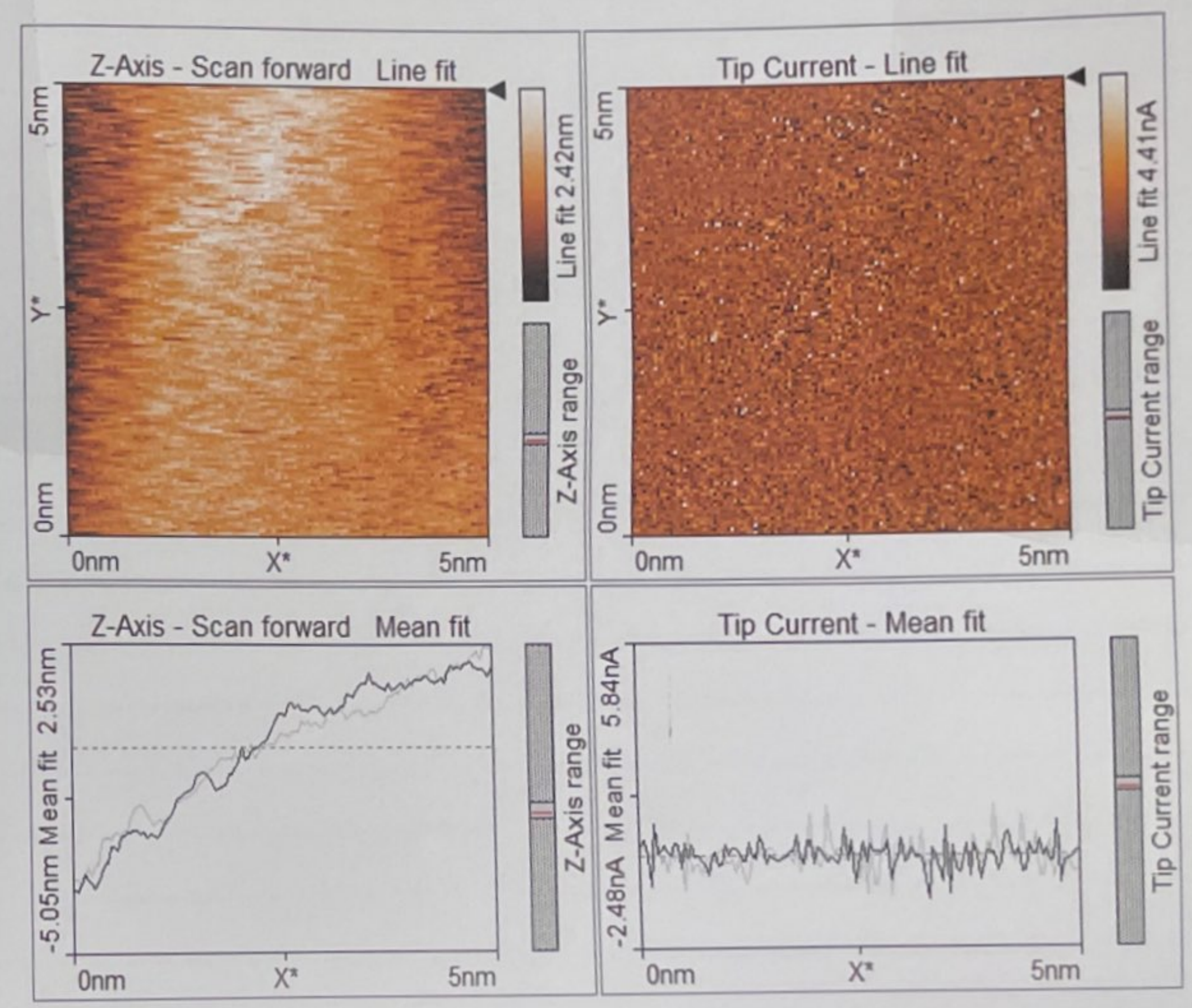

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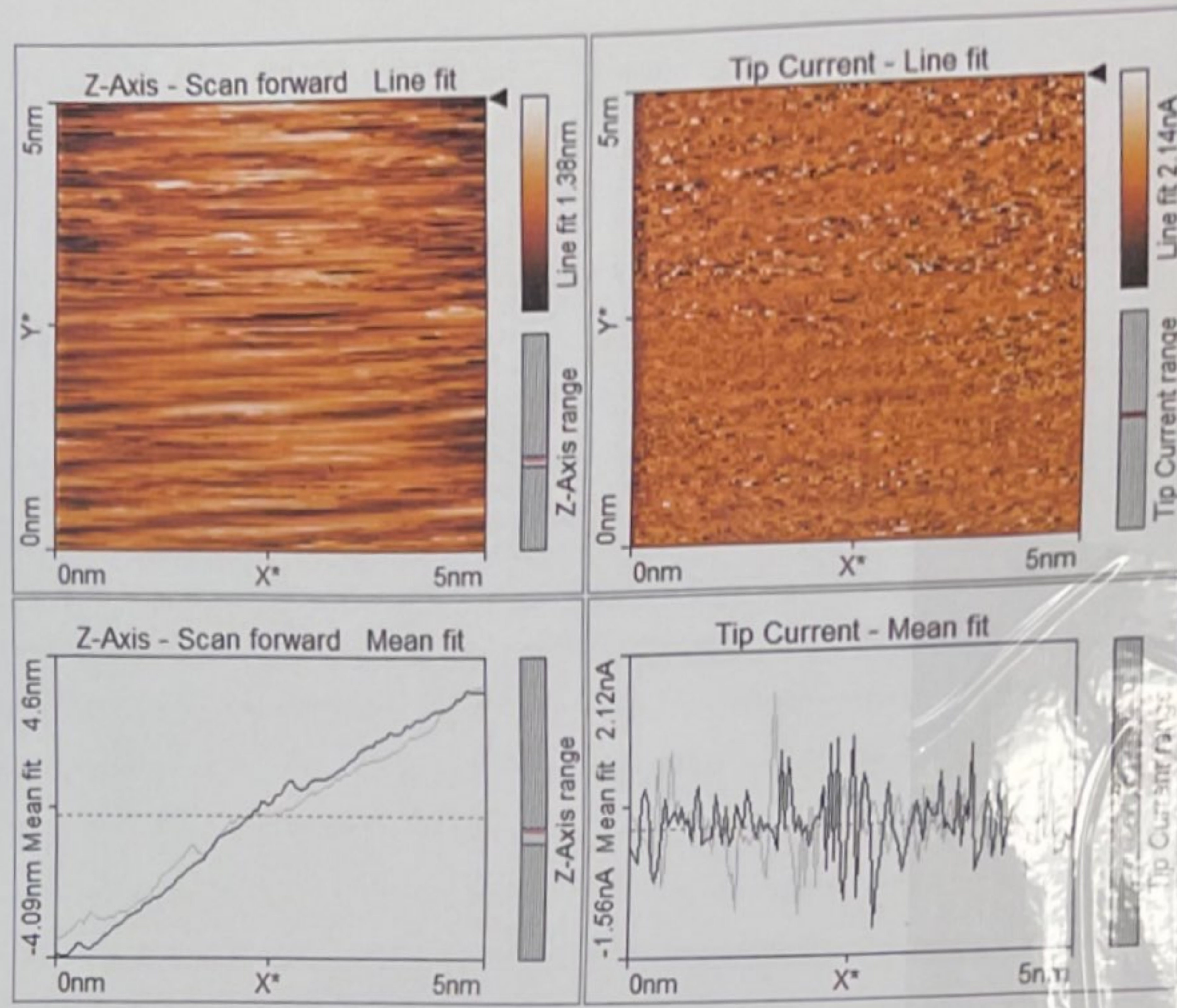
Image00113



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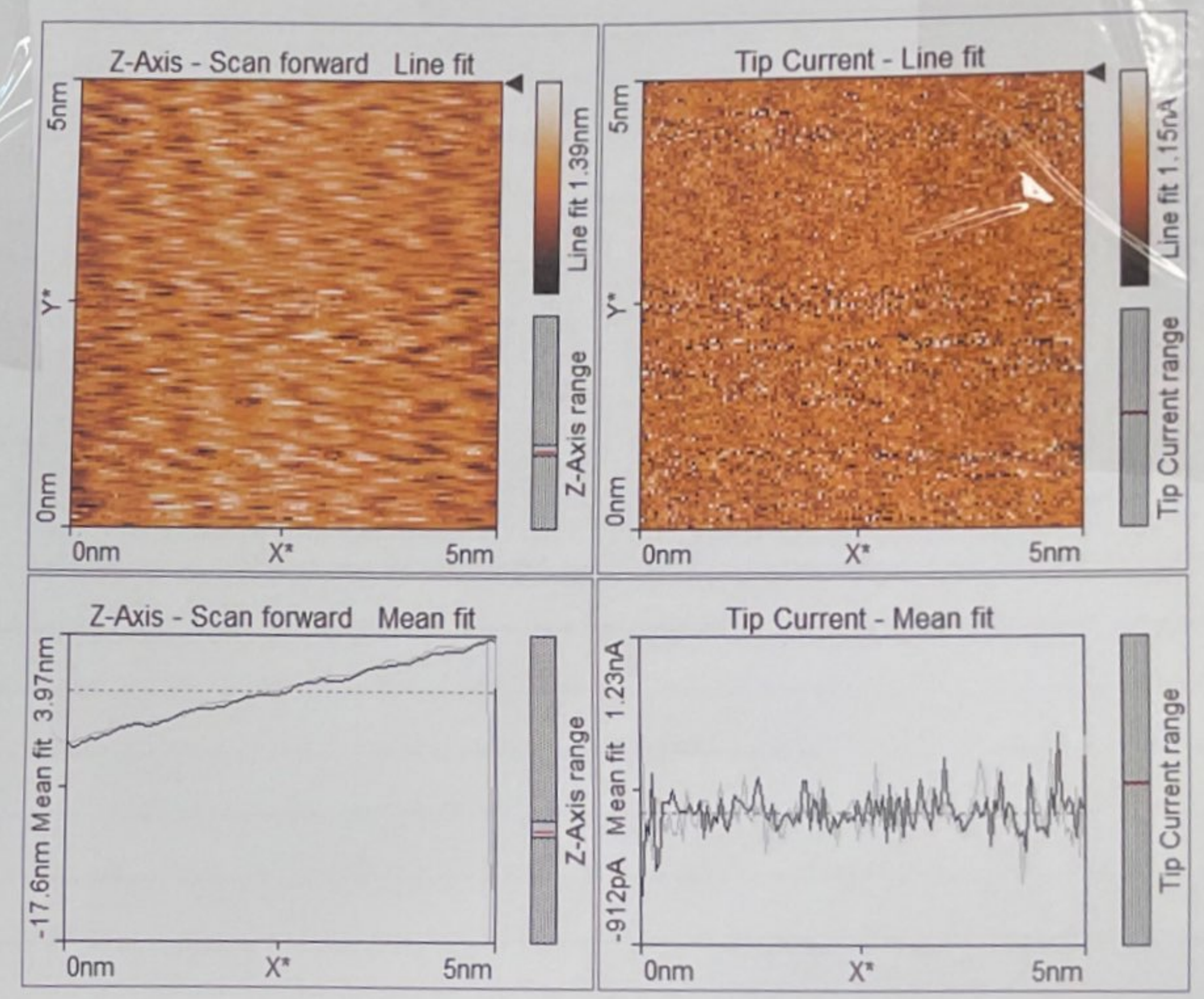

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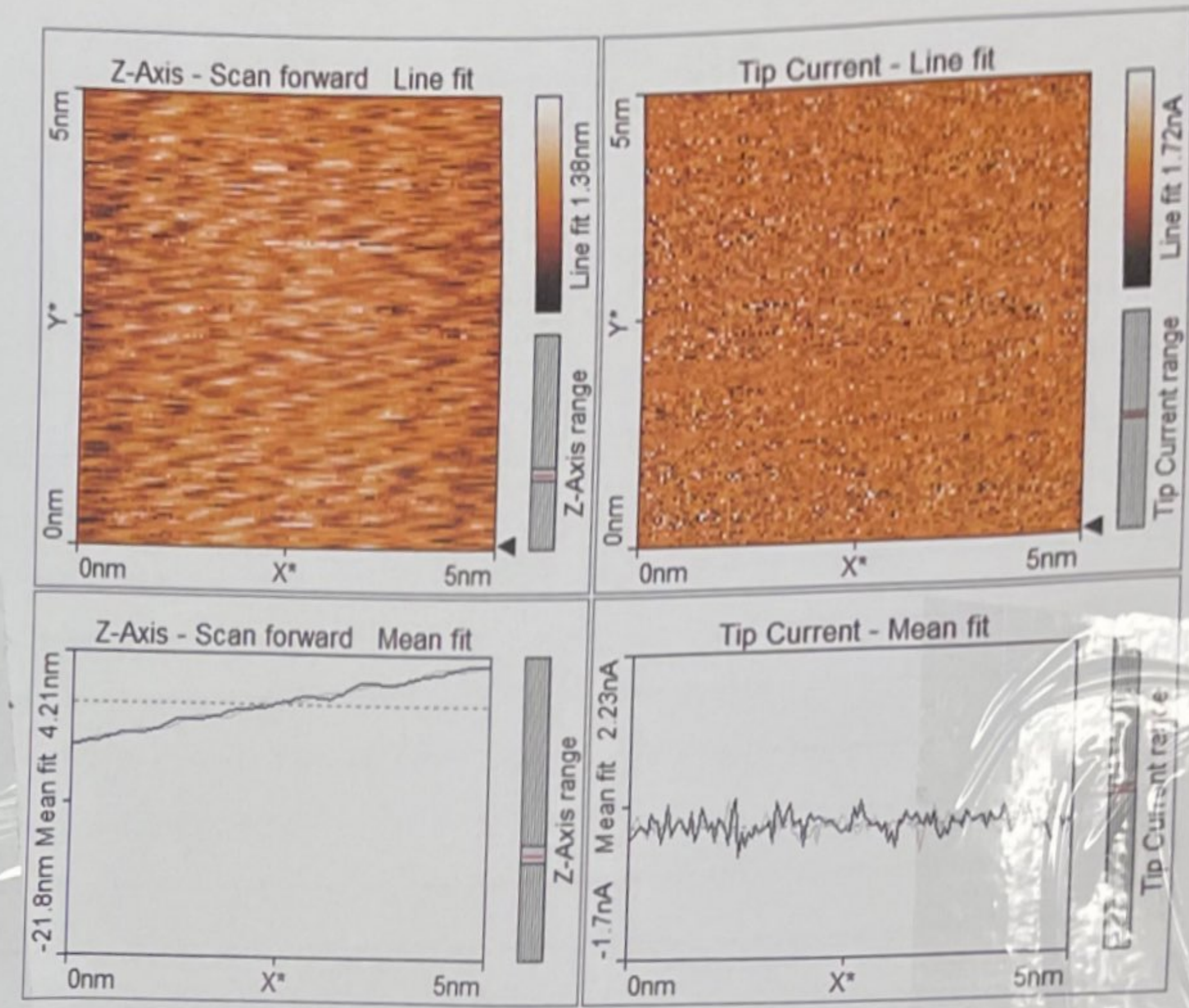

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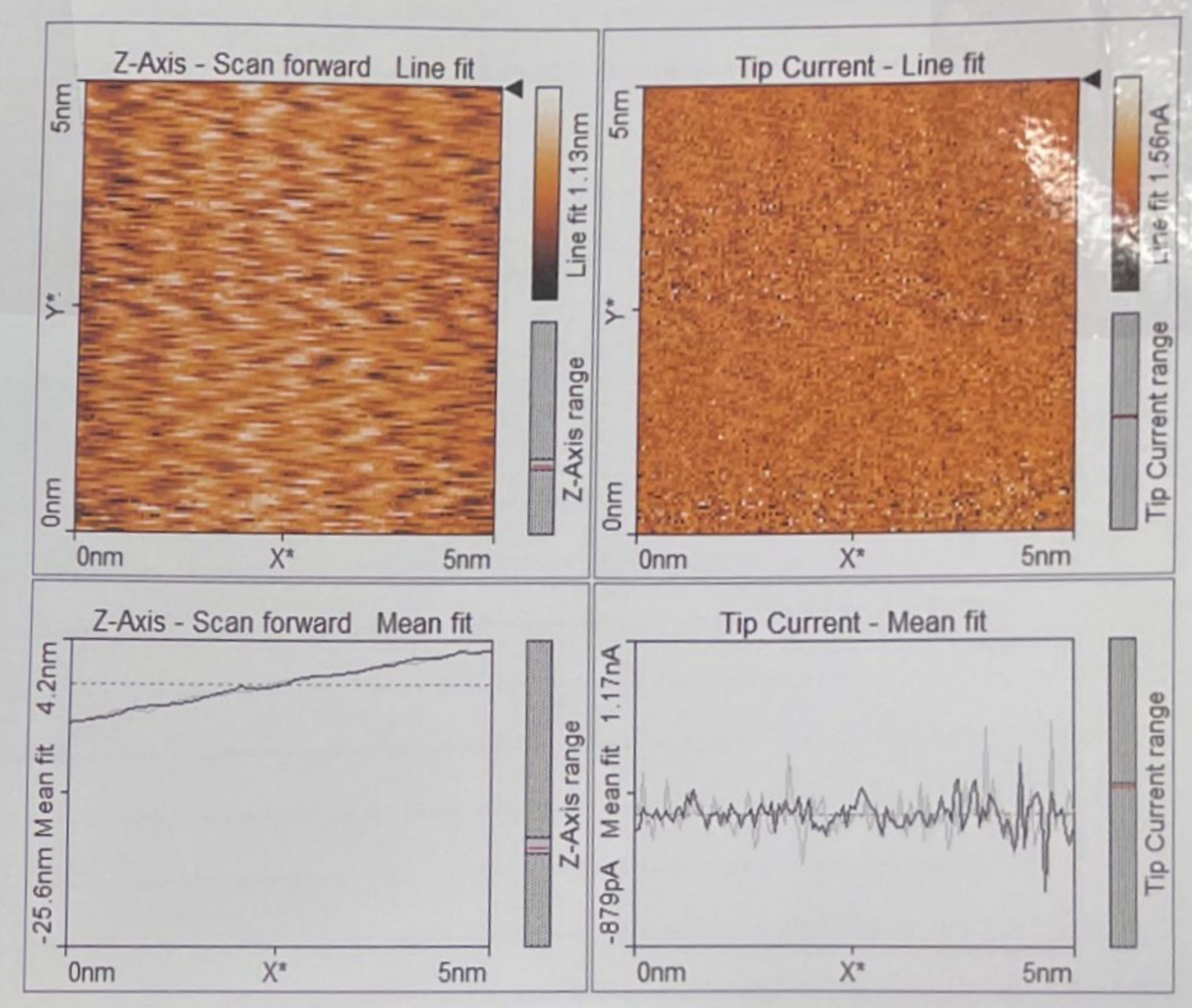

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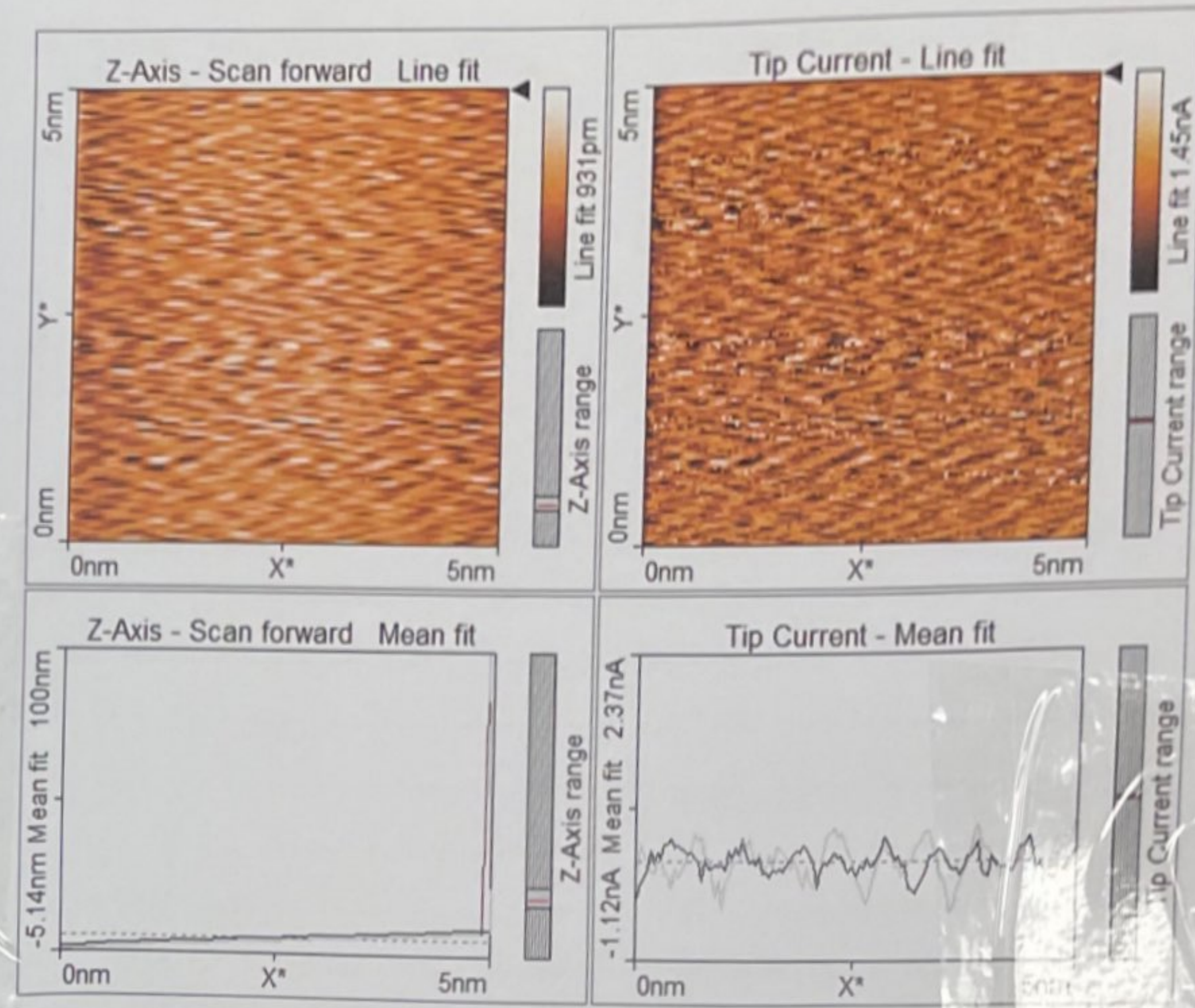

Img0118

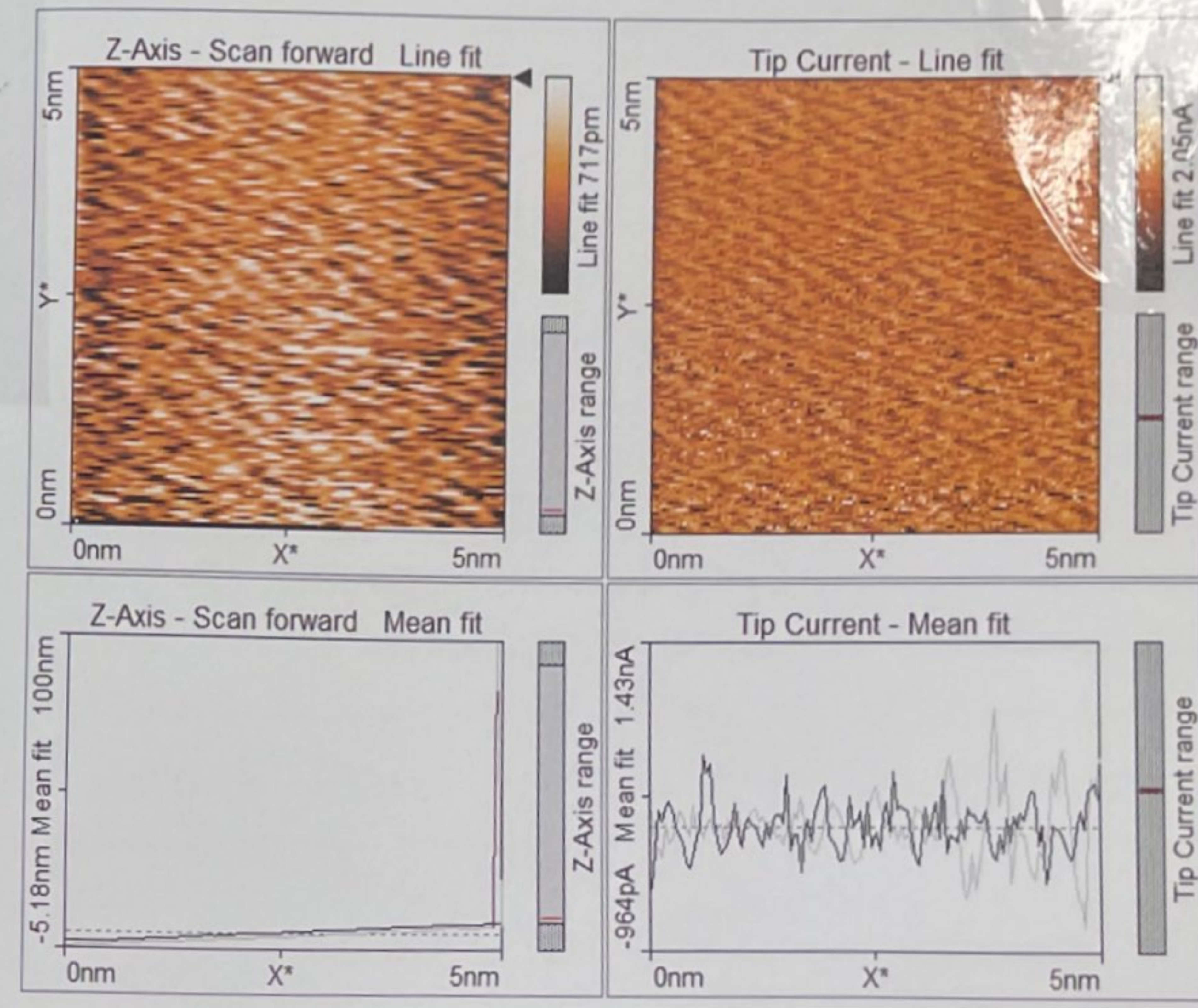

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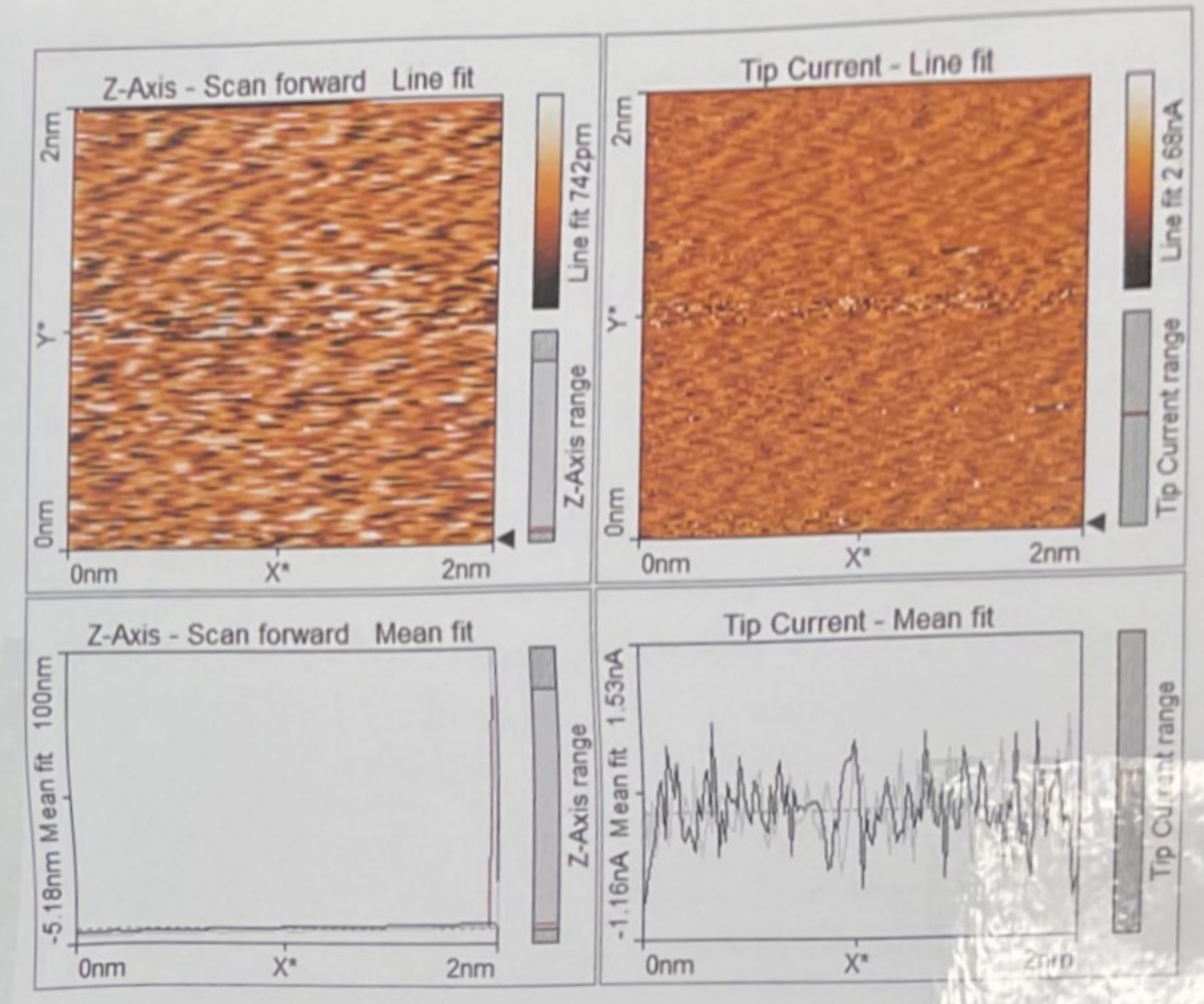
Image 00119



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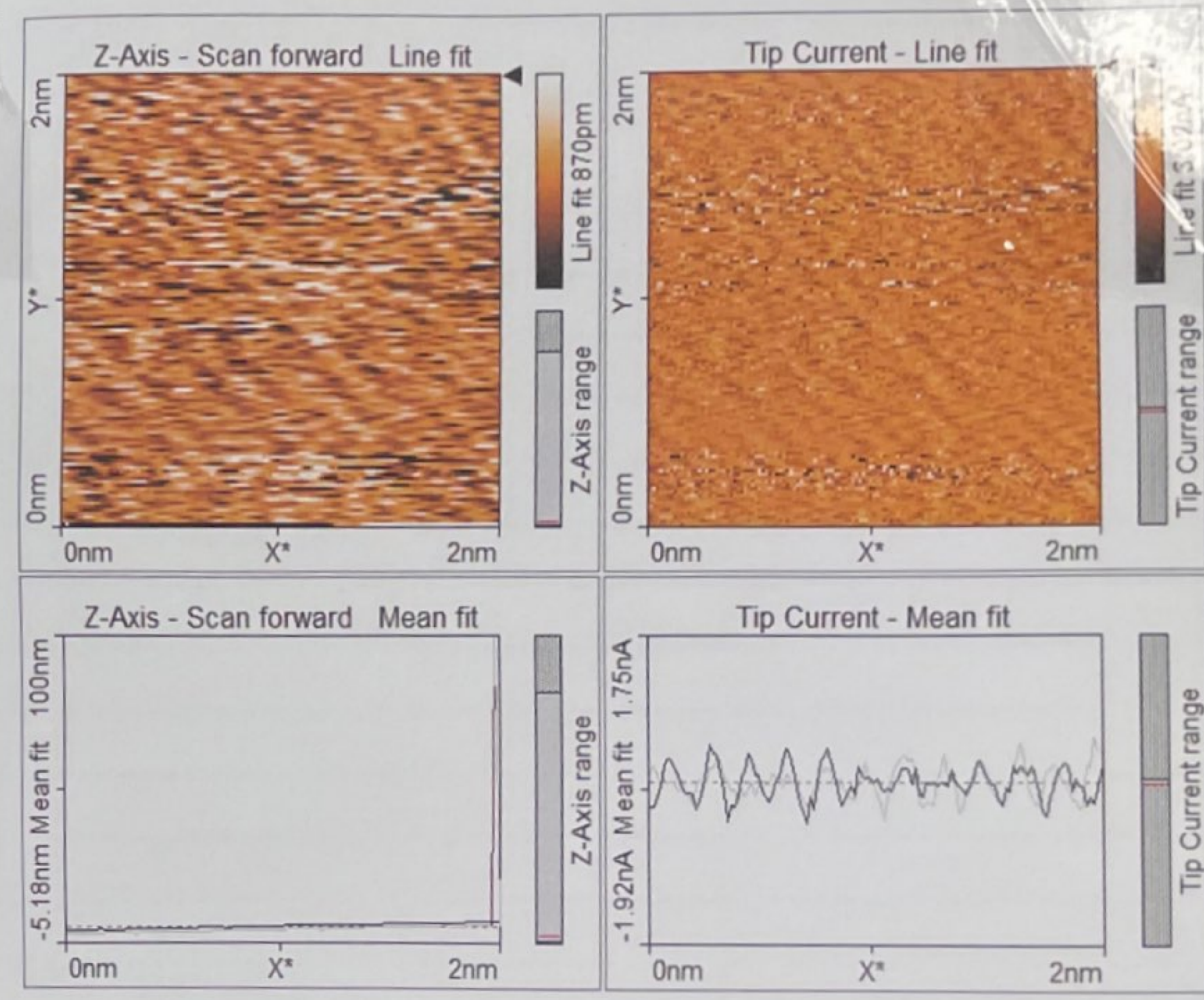

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Image0125

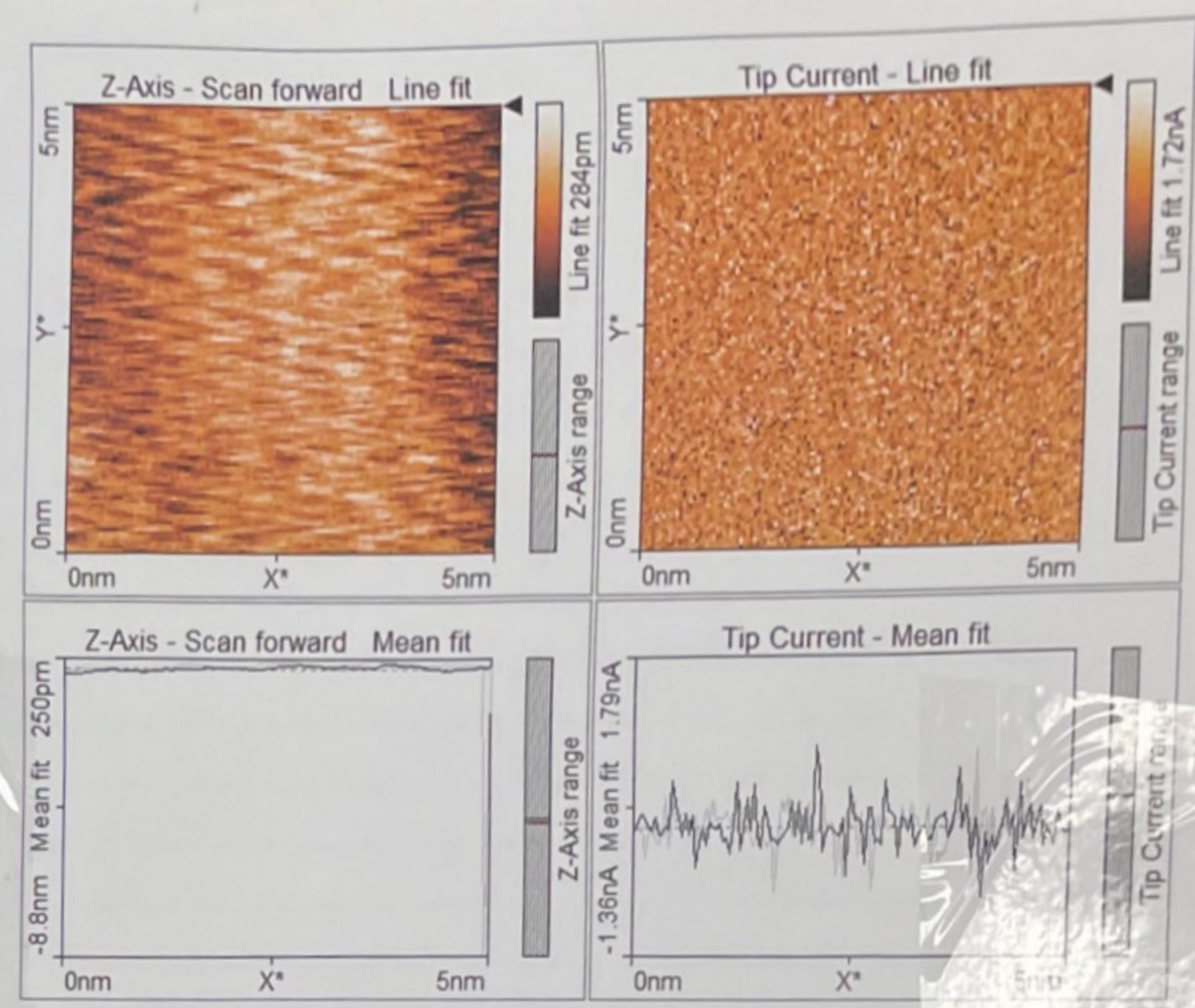

Image0126