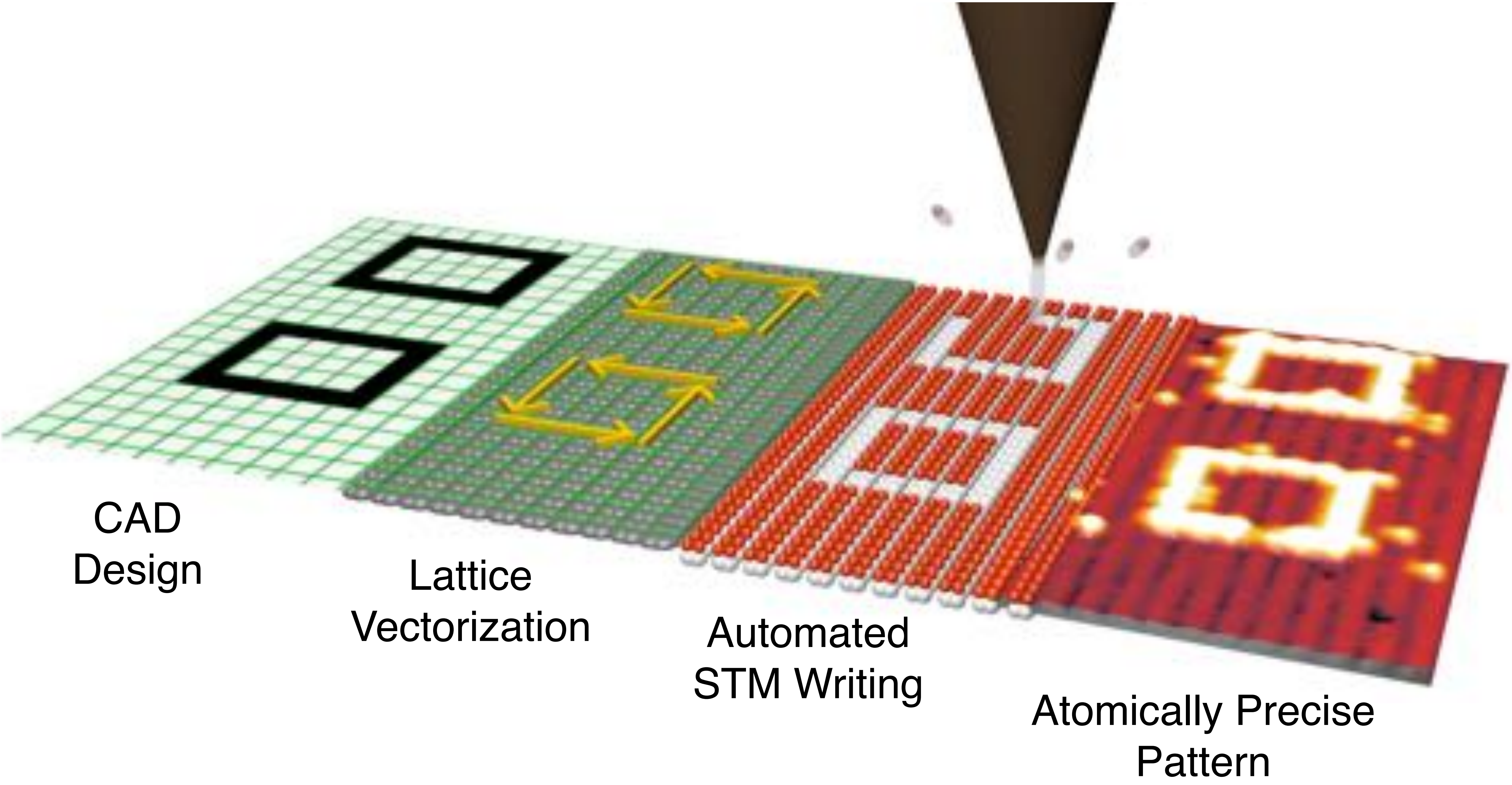
ZyVector™: controlling STM Lithography



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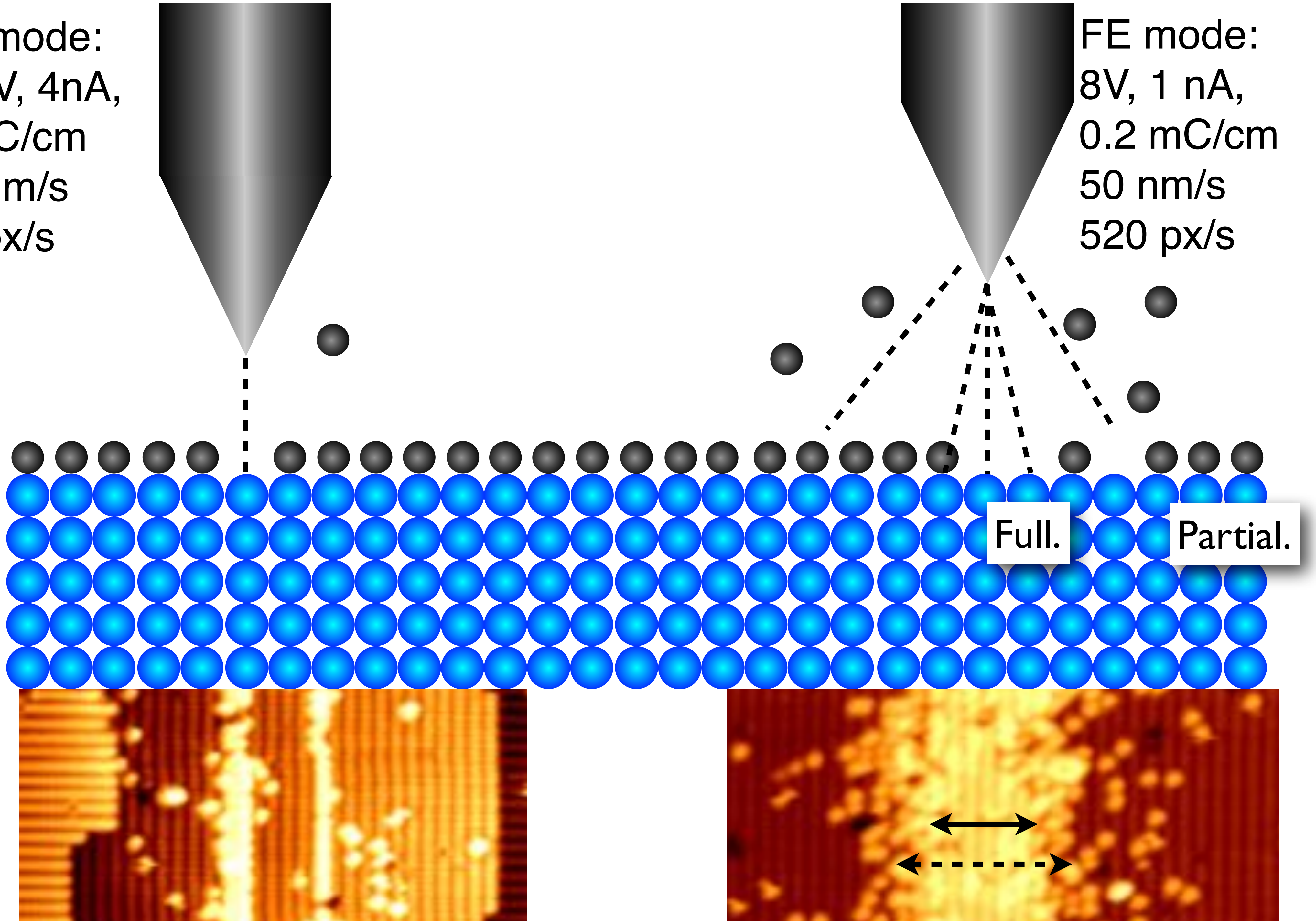
What is STM Lithography?

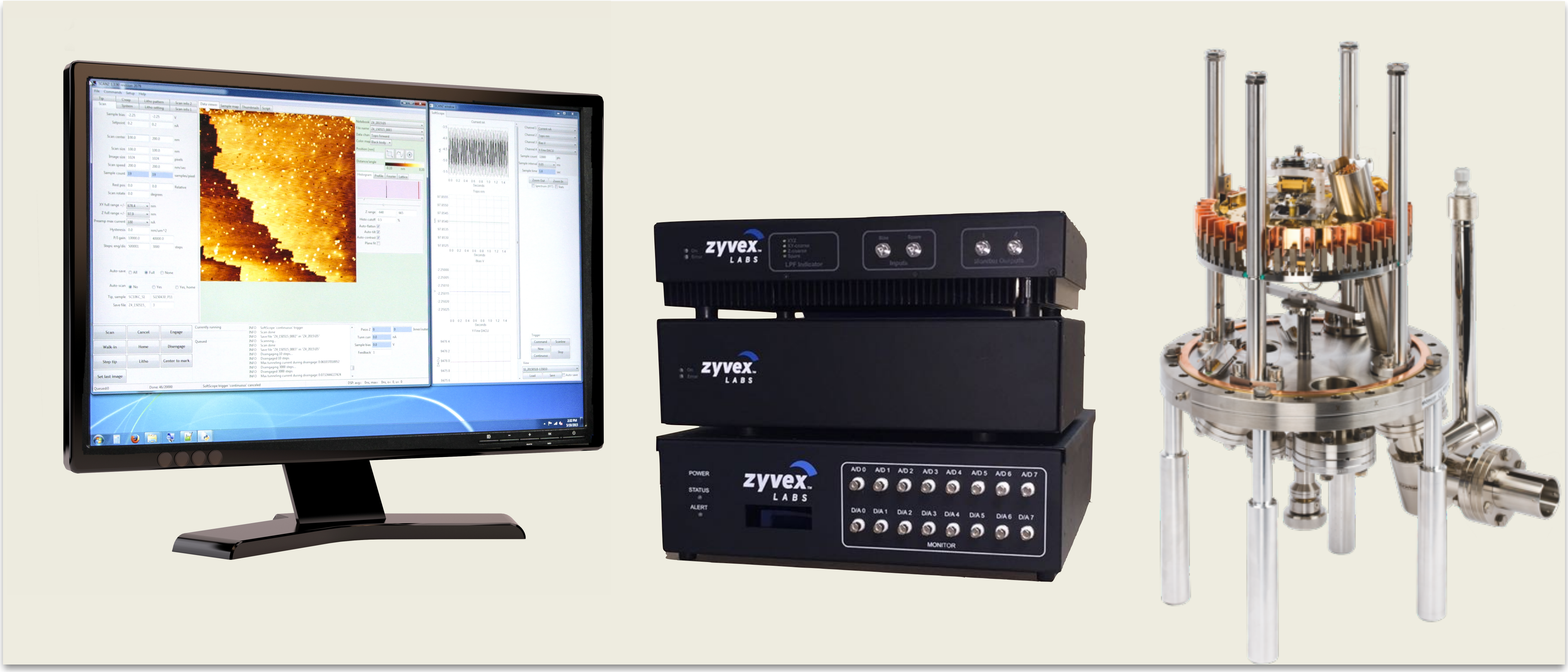


AP mode:
4.5 V, 4nA,
2 mC/cm
20 nm/s
26 px/s

FE mode:
8V, 1 nA,
0.2 mC/cm
50 nm/s
520 px/s

An STM creates patterns by removing H atoms from a Si(001) surface.

The ZyVector System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POWER
STATUS
ALERT
zyvex LABS
A/D 0 A/D 1 A/D 2 A/D 3 A/D 4 A/D 5 A/D 6 A/D 7
D/A 0 D/A 1 D/A 2 D/A 3 D/A 4 D/A 5 D/A 6 D/A 7
MONITOR

- The ZyVector system hardware comprises:
  - 20-bit Digital Controller for STM feedback loop control, and real-time creep and hysteresis correction for sub-nm tip position precision.
  - high-voltage amplifier piezo drivers, with connections to a ScientaOmicron STM.
- The ZyVector software, Scanz, is optimized for automated STM lithography.

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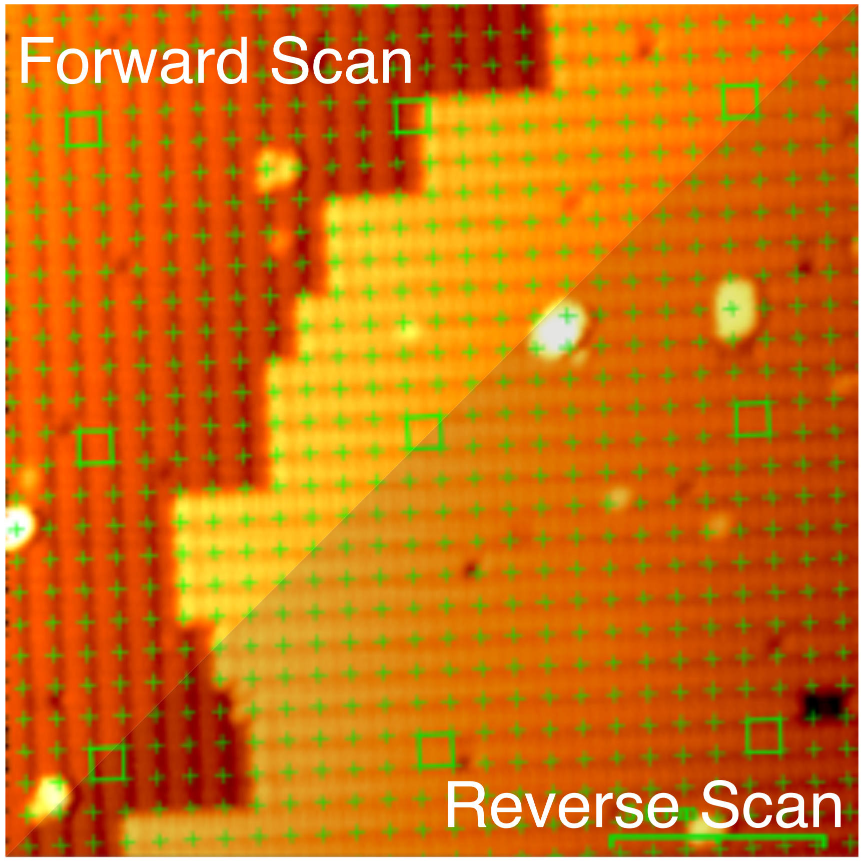
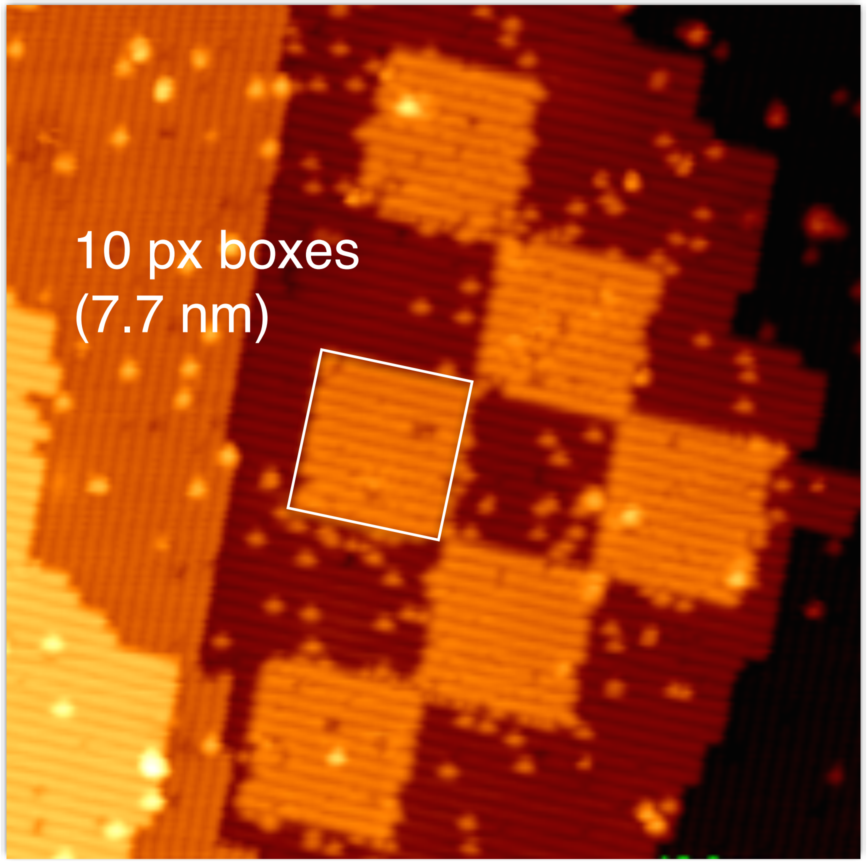
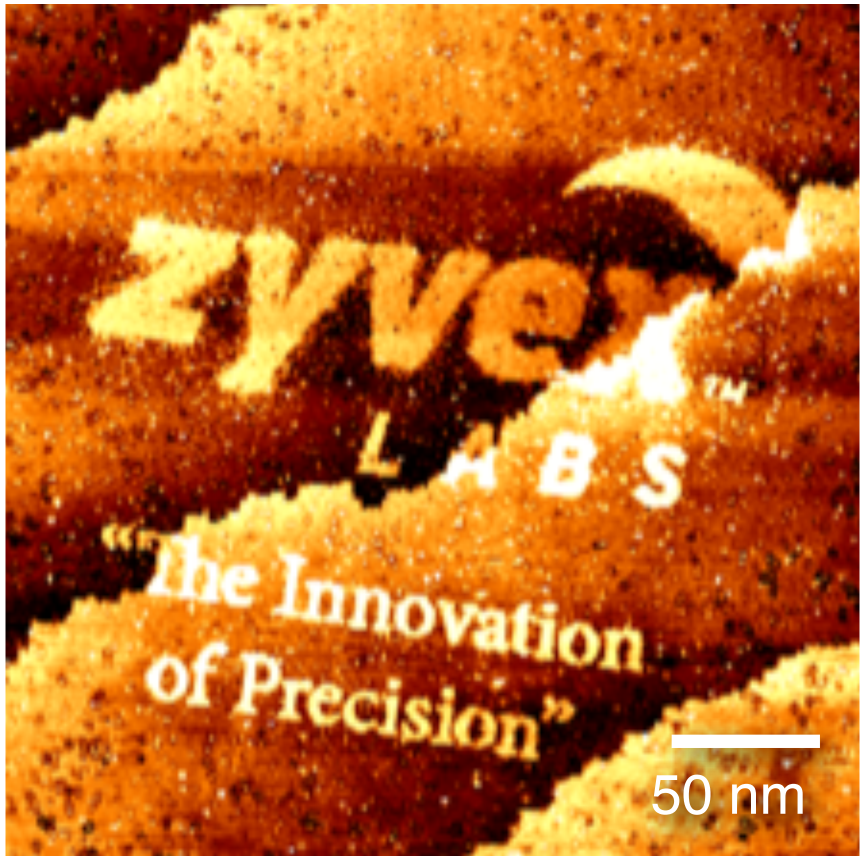
ZyVector Features







Distortion-free Imaging

Precise Tip Motion

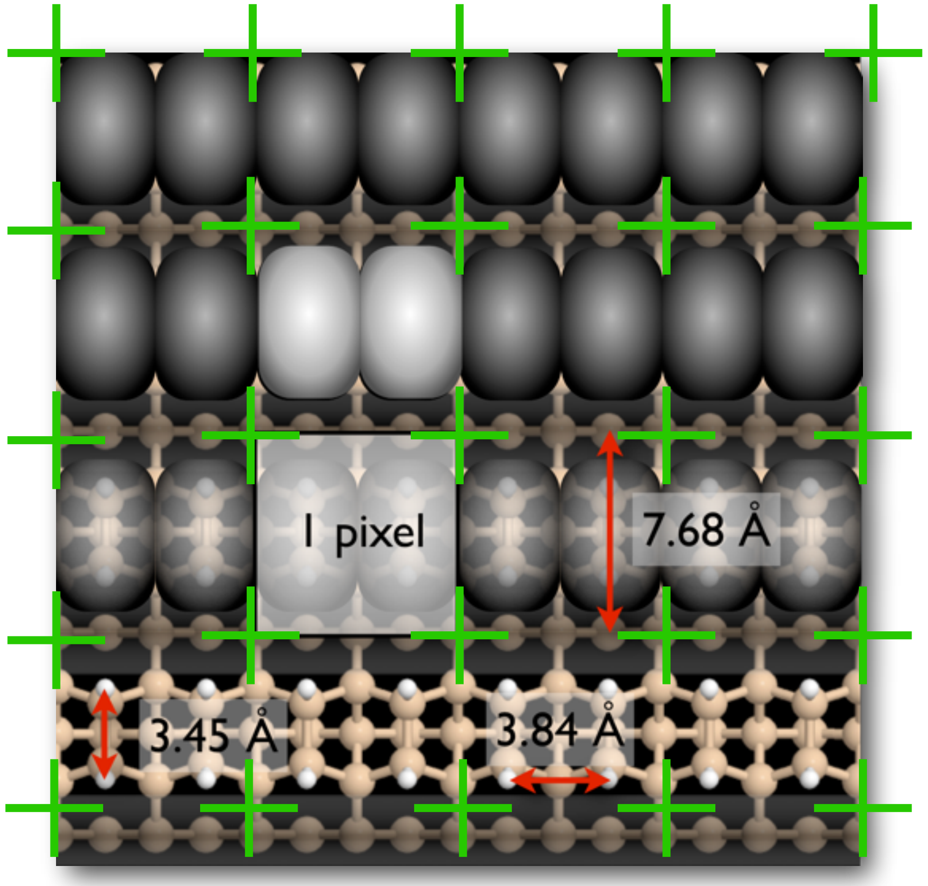
Patterning from CAD files

Automatic pattern alignment to atomic lattice

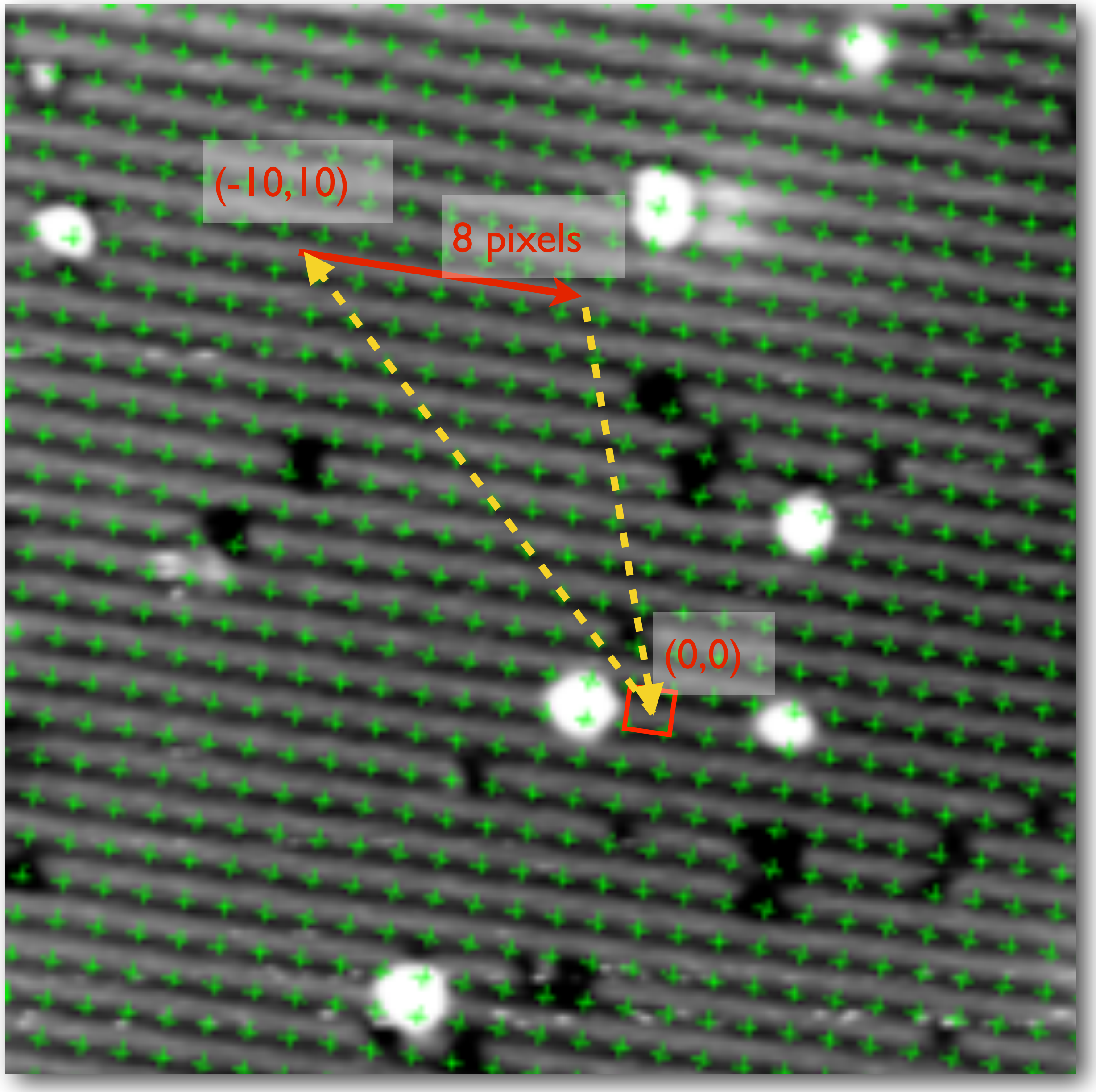
Atomic Resolution Patterns Made Easy

Automation of complex tasks through Scripting

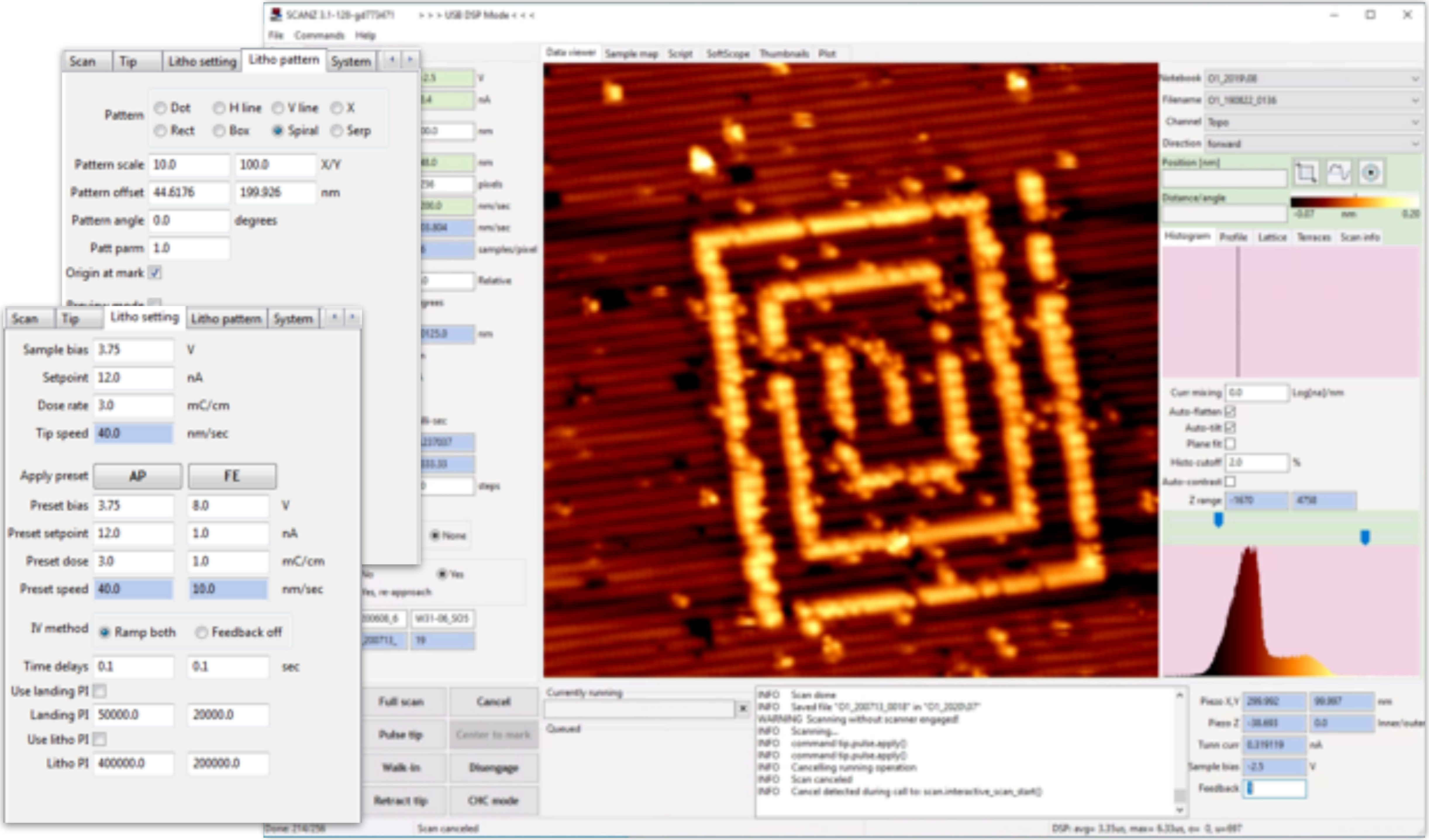
Digital Vector Patterning



The lithography pixel; 2 dimers on a dimer row, 0.768 nm wide.



Writing Simple Patterns



Litho pattern

Pattern	○ Dot	○ H line	○ V line	○ X
	○ Rect	○ Box	● Spiral	○ Serp

Pattern scale	10.0	100.0	X/Y
Pattern offset	44.6176	199.926	nm
Pattern angle	0.0	degrees	
Patt parm	1.0		
Origin at mark	☑		

Litho setting

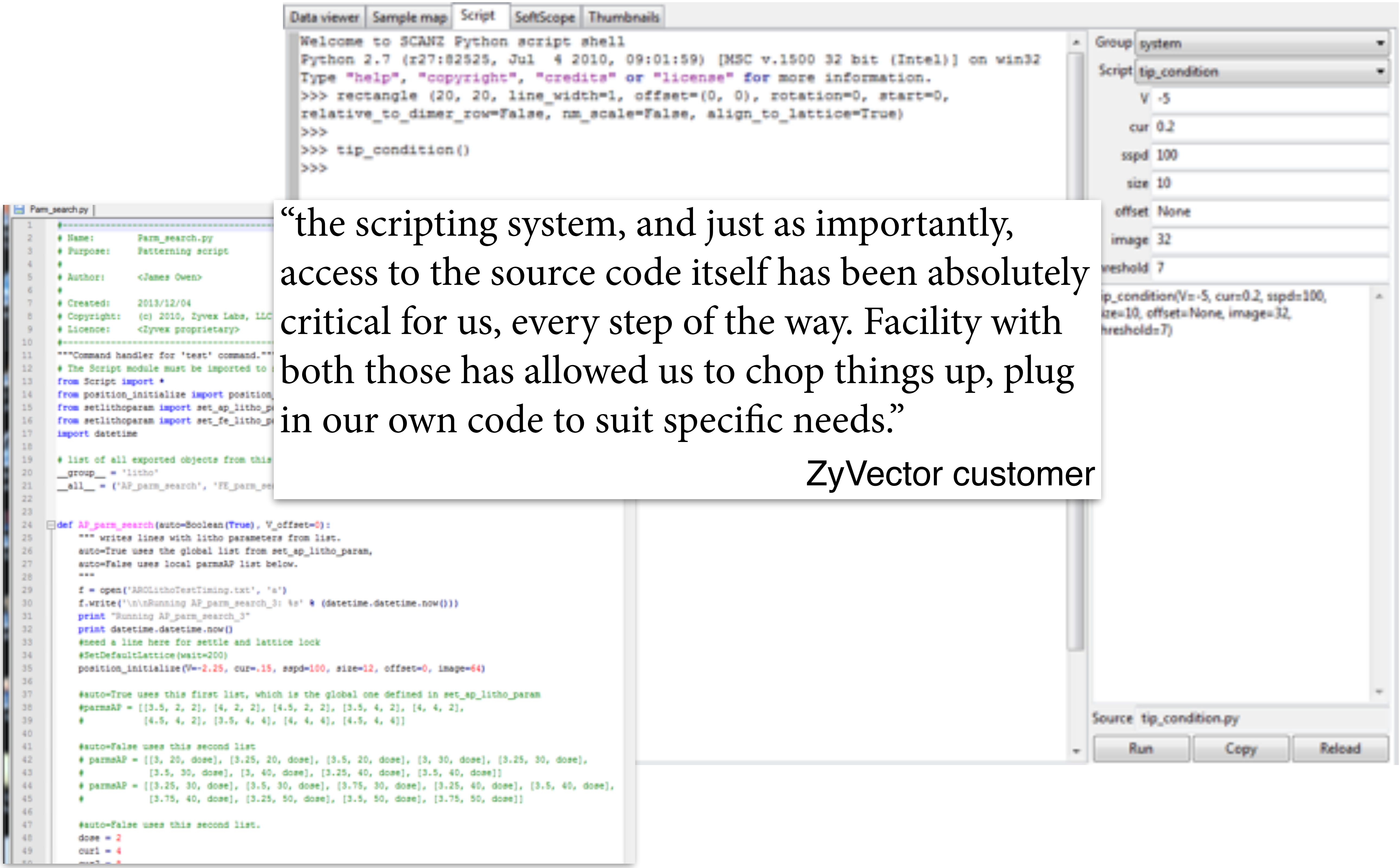
Sample bias	3.75		V
Setpoint	12.0		nA
Dose rate	3.0		mC/cm
Tip speed	40.0		nm/sec
Apply preset	AP	FE	
Preset bias	3.75	8.0	V
Preset setpoint	12.0	1.0	nA
Preset dose	3.0	1.0	mC/cm
Preset speed	40.0	10.0	nm/sec
IV method	● Ramp both	○ Feedback off	
Time delays	0.1	0.1	sec
Use landing PI	□		
Landing PI	50000.0	20000.0	
Use litho PI	□		
Litho PI	400000.0	200000.0	

```
INFO     Scan done
INFO     Saved file "D1_200713_0018" in "D1_2020.07"
WARNING  Scanning without scanner engaged!
INFO     Scanning...
INFO     command tip.pulse.apply()
INFO     command tip.pulse.apply()
INFO     Cancelling running operation
INFO     Scan canceled
INFO     Cancel detected during call to: scan.interactive_scan_start()
```

Scan canceled

Simple shapes can be selected in the GUI and drawn with one click.

Automation through Scripting



```
Welcome to SCANZ Python script shell
Python 2.7 (r27:82525, Jul  4 2010, 09:01:59) [MSC v.1500 32 bit (Intel)] on win32
Type "help", "copyright", "credits" or "license" for more information.
>>> rectangle (20, 20, line_width=1, offset=(0, 0), rotation=0, start=0,
relative_to_dimer_row=False, nm_scale=False, align_to_lattice=True)
>>>
>>> tip_condition()
>>>
```

Group: system
Script: tip_condition
V: -5
cur: 0.2
sspd: 100
size: 10
offset: None
image: 32
reshold: 7

```
ip_condition(V=-5, cur=0.2, sspd=100,
ize=10, offset=None, image=32,
hreshold=7)
```

Source: tip_condition.py

```
#-------------------------------------------
# Name:        Parm_search.py
# Purpose:     Patterning script
#
# Author:      <James Owen>
#
# Created:     2013/12/04
# Copyright:   (c) 2010, Zyvex Labs, LLC
# Licence:     <Zyvex proprietary>
#-------------------------------------------
"""Command handler for 'test' command."""
# The Script module must be imported to
from Script import *
from position_initialize import position_
from setlithoparam import set_ap_litho_p
from setlithoparam import set_fe_litho_p
import datetime

# list of all exported objects from this
__group__ = 'litho'
__all__ = ('AP_parm_search', 'FE_parm_se


def AP_parm_search(auto=Boolean(True), V_offset=0):
    """ writes lines with litho parameters from list.
    auto=True uses the global list from set_ap_litho_param,
    auto=False uses local parmaAP list below.
    """
    f = open('AROLithoTestTiming.txt', 'a')
    f.write('\n\nRunning AP_parm_search_3: %s' % (datetime.datetime.now()))
    print "Running AP_parm_search_3"
    print datetime.datetime.now()
    #need a line here for settle and lattice lock
    #SetDefaultLattice(wait=200)
    position_initialize(V=-2.25, cur=.15, sspd=100, size=12, offset=0, image=64)

    #auto=True uses this first list, which is the global one defined in set_ap_litho_param
    #parmsAP = [[3.5, 2, 2], [4, 2, 2], [4.5, 2, 2], [3.5, 4, 2], [4, 4, 2],
    #           [4.5, 4, 2], [3.5, 4, 4], [4, 4, 4], [4.5, 4, 4]]

    #auto=False uses this second list
    # parmsAP = [[3, 20, dose], [3.25, 20, dose], [3.5, 20, dose], [3, 30, dose], [3.25, 30, dose],
    #            [3.5, 30, dose], [3, 40, dose], [3.25, 40, dose], [3.5, 40, dose]]
    # parmsAP = [[3.25, 30, dose], [3.5, 30, dose], [3.75, 30, dose], [3.25, 40, dose], [3.5, 40, dose],
    #            [3.75, 40, dose], [3.25, 50, dose], [3.5, 50, dose], [3.75, 50, dose]]

    #auto=False uses this second list.
    dose = 2
    cur1 = 4
```

> “the scripting system, and just as importantly, access to the source code itself has been absolutely critical for us, every step of the way. Facility with both those has allowed us to chop things up, plug in our own code to suit specific needs.”
>
> ZyVector customer

Writing complex patterns

1.

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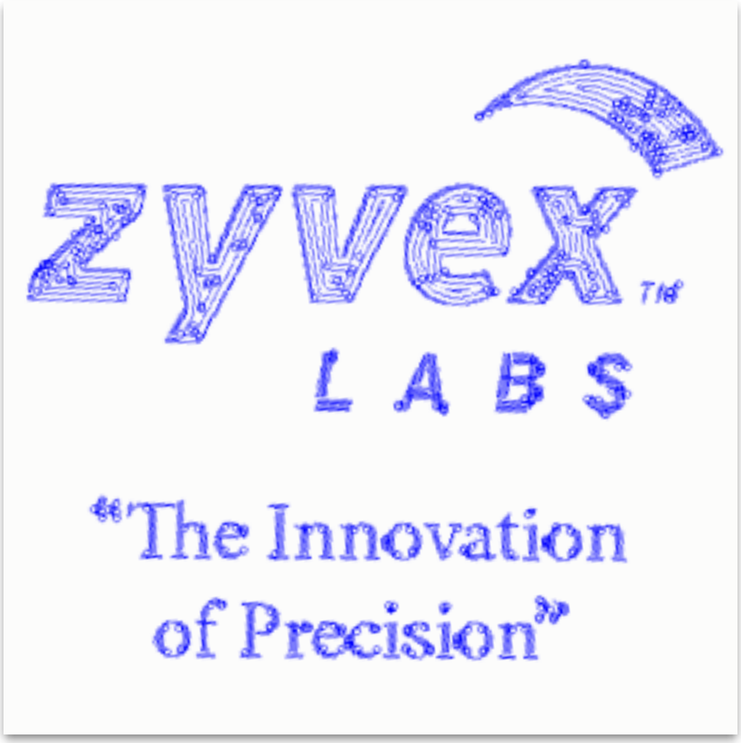
of Precision"

Pattern File comprises black-and-white bitmap input file.

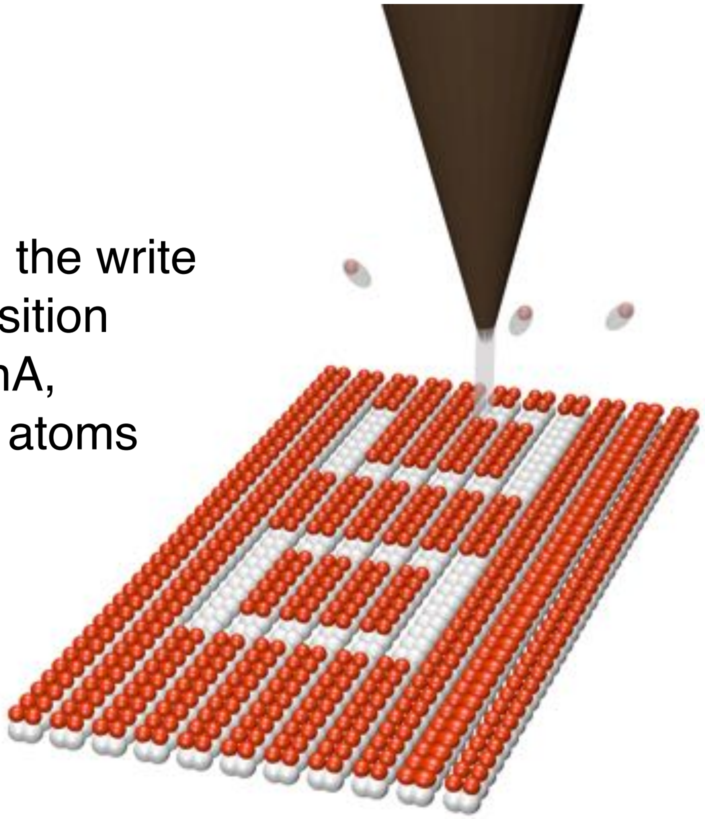
2.



ZyVector converts the pattern file into write vectors, following the Si(001) lattice.

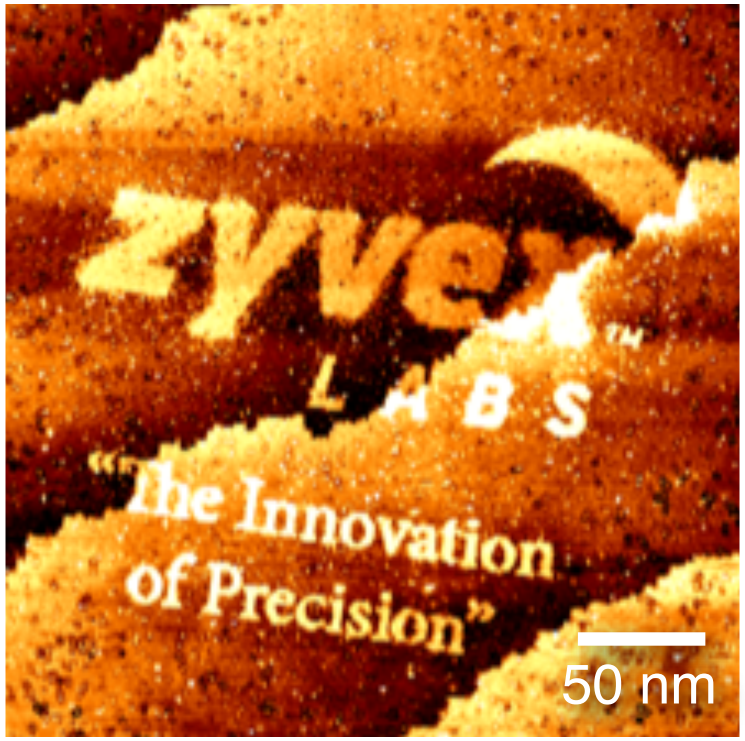
3.

STM tip moves along the write vectors with 1.5 Å position precision at 4.5 V, 4 nA, 20 nm/s, removing H atoms

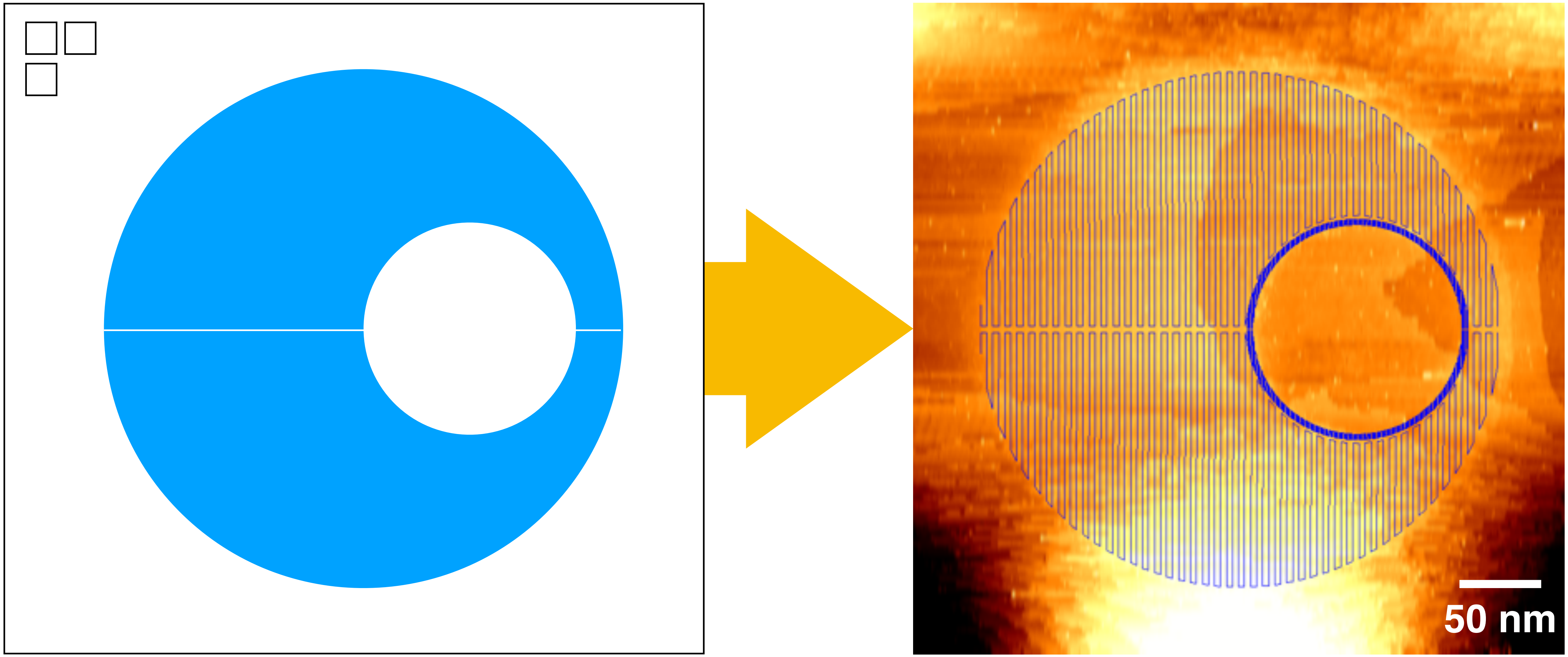


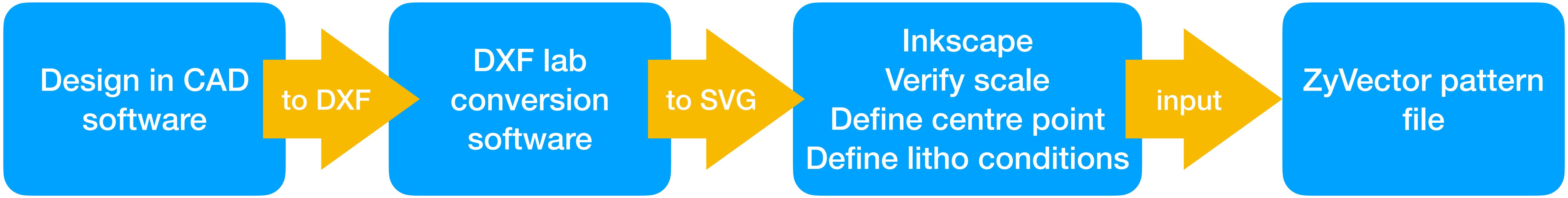
4.

The final atomic-resolution pattern of exposed Si dangling bonds



Complex patterns from a CAD file.




Design in CAD software

to DXF

DXF lab conversion software

to SVG

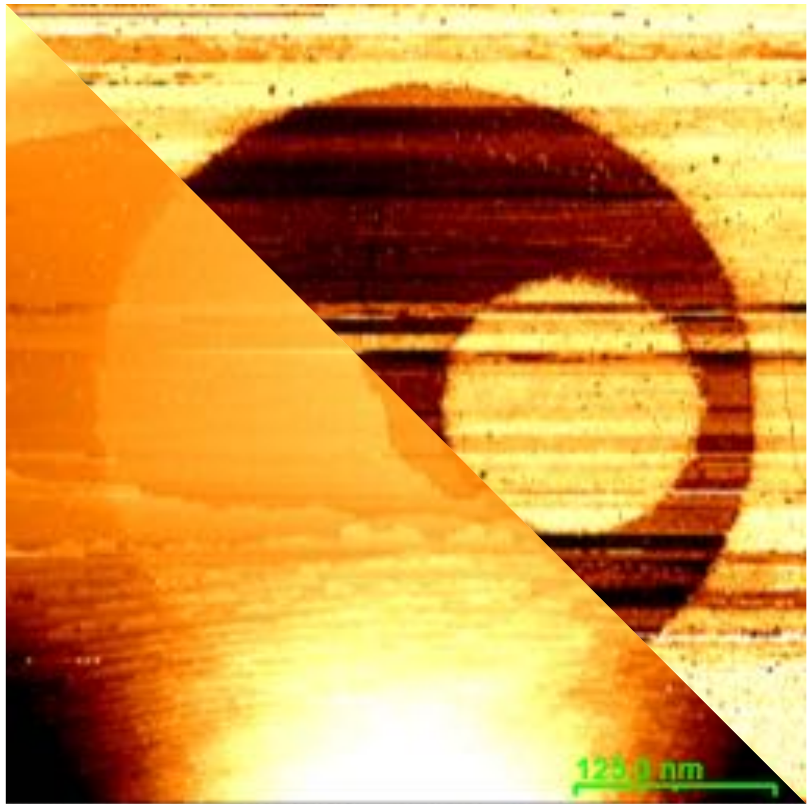
Inkscape
Verify scale
Define centre point
Define litho conditions

input

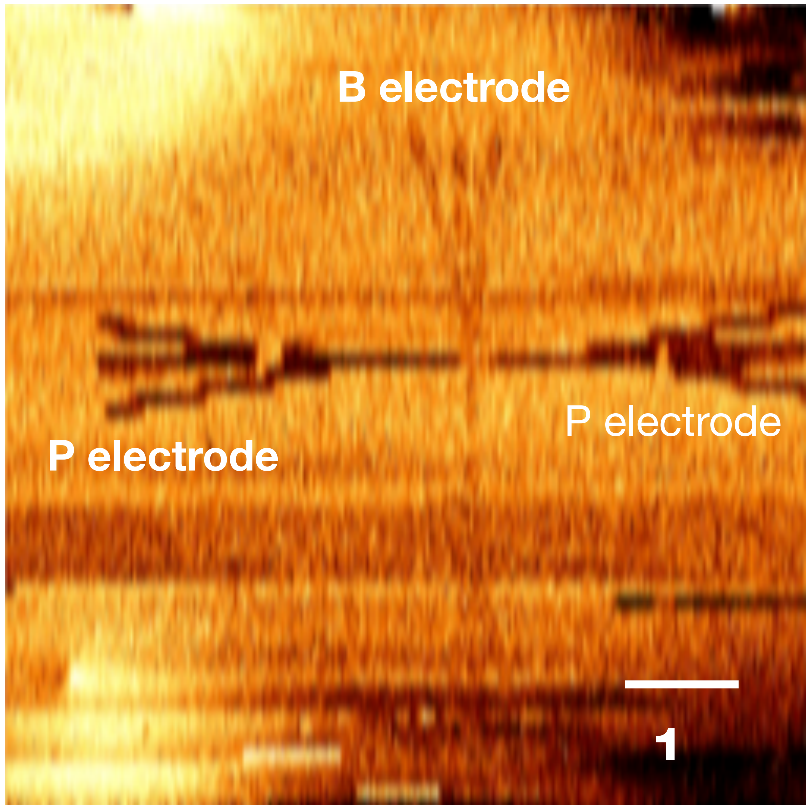
ZyVector pattern file

A CAD file can also be used as a pattern input file via an SVG file.

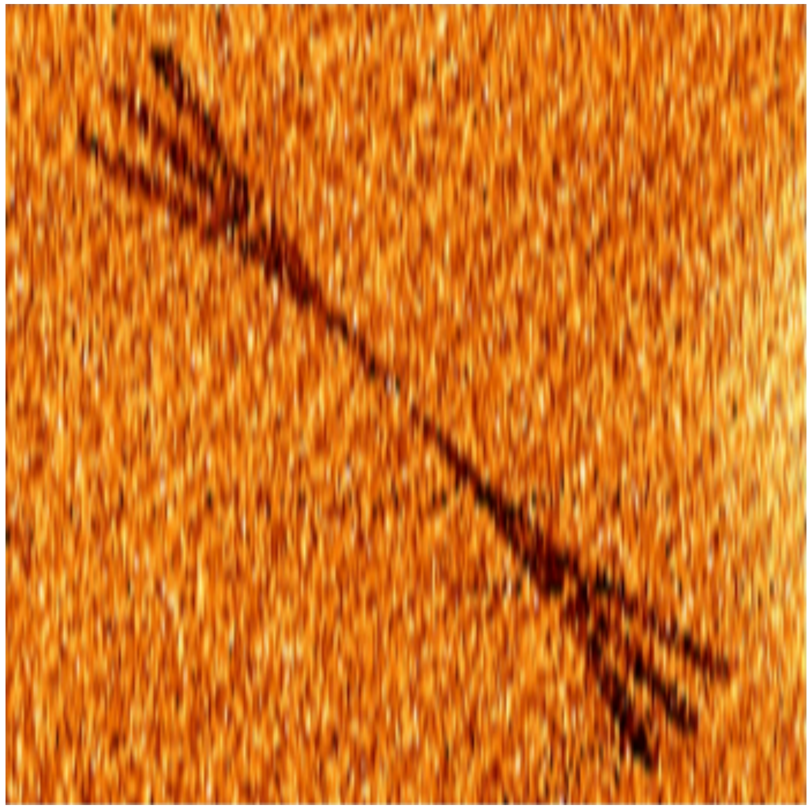
Image modes for pattern detection



As dI/dZ is a measure of the surface electronic properties, it shows surface features such as lithography patches with good contrast, even on rough surfaces, where topography is lost.



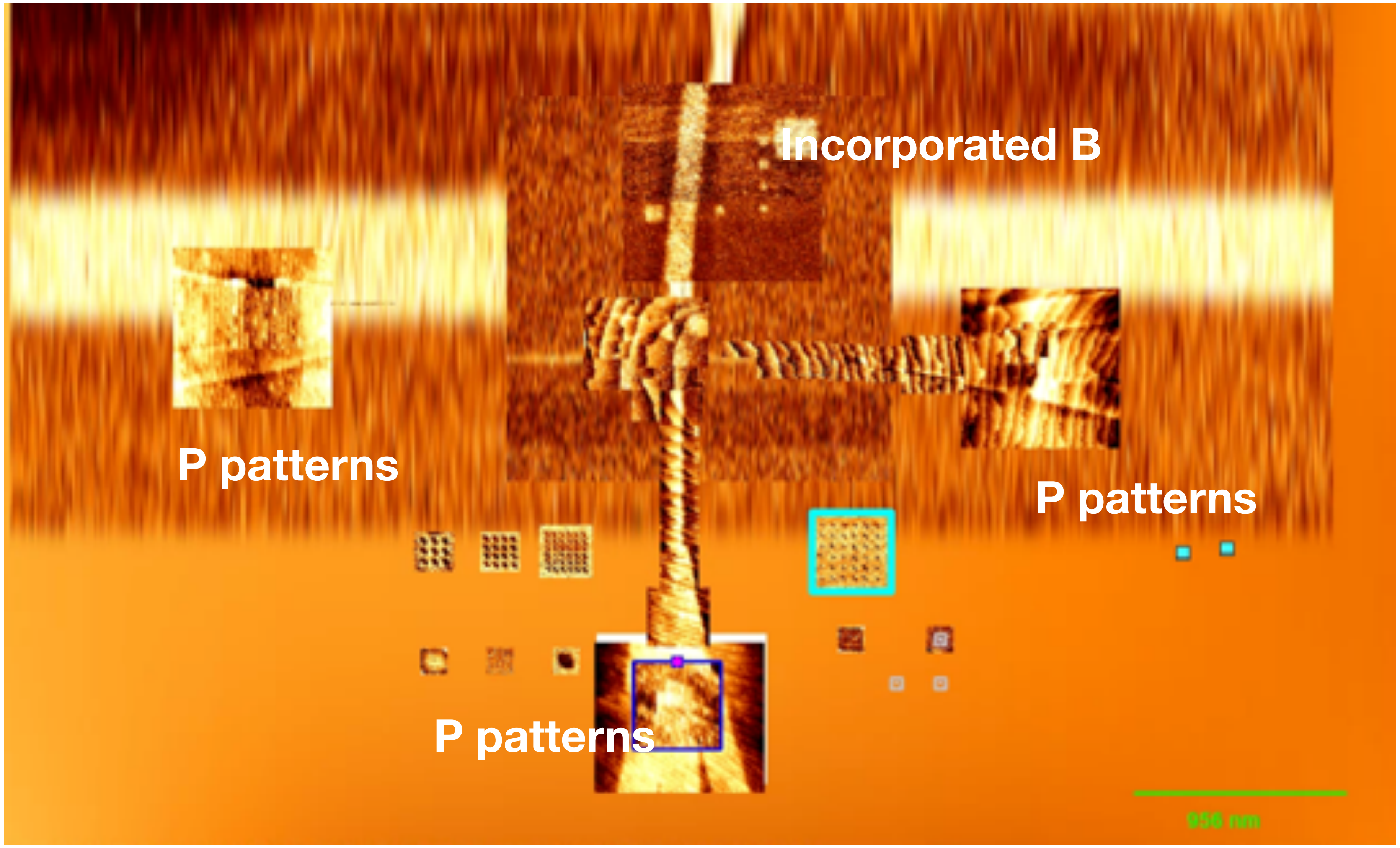
After incorporation



20 nm overgrowth

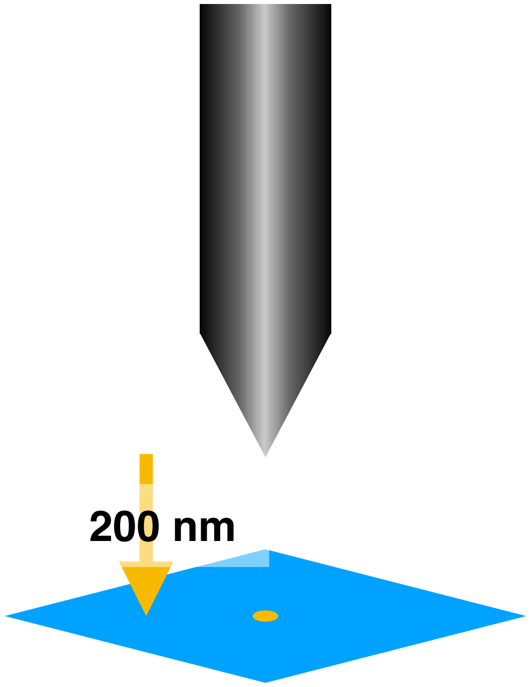
For observing buried structures, we use dI/dV imaging to give contrast of the P-doped and B-doped regions, even under 20 nm of overgrown Si.

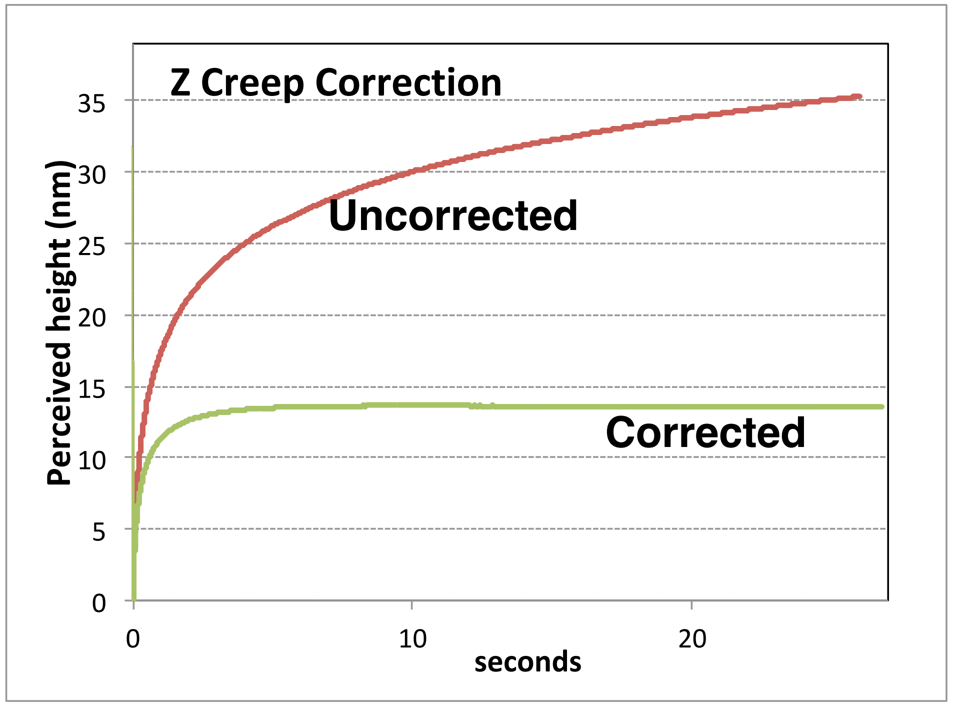
Powerful GUI for complex patterning

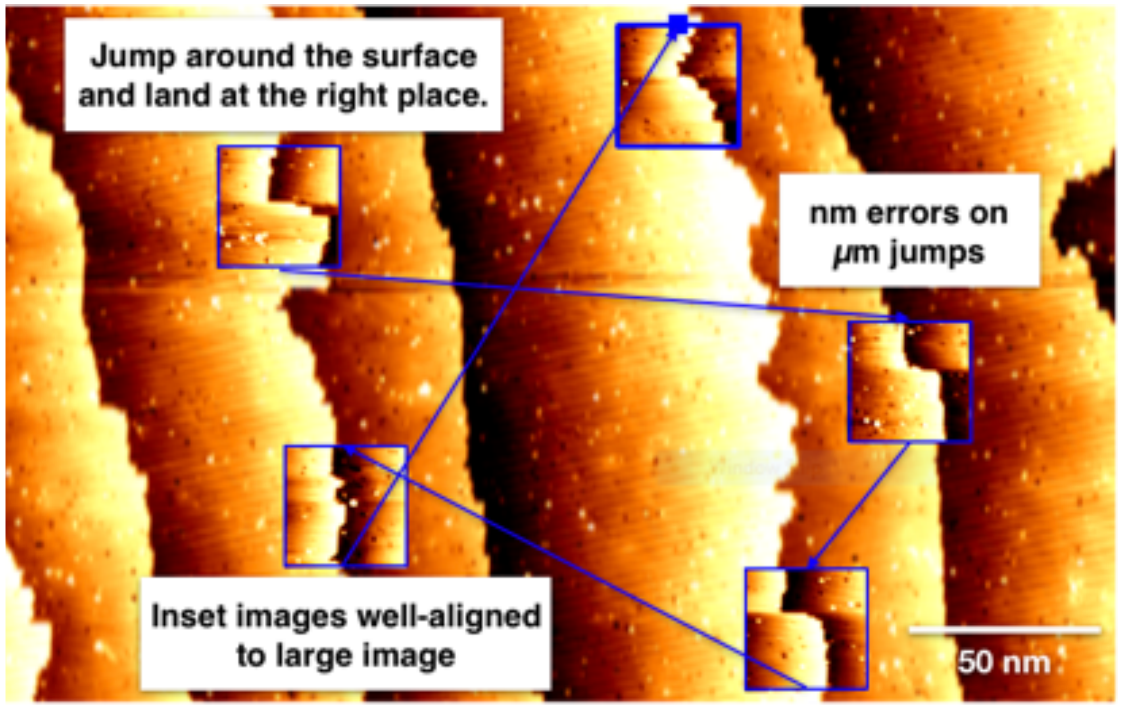


- The Sample Map GUI shows the relative position of different images and patterns. Topography, dI/dz and dI/dV images can be combined here.

CHC: real-time position correction






Jump around the surface and land at the right place.

nm errors on μm jumps

Inset images well-aligned to large image

- CHC – creep and hysteresis correction – is used to correct tip motion on ZyVector.
- Automated drift correction is also included in ZyVector.
- Z creep, instead of taking minutes or hours to settle, takes seconds.
- For *μ*m-scale jumps, hysteresis errors reduced from 100’s nm to nm.

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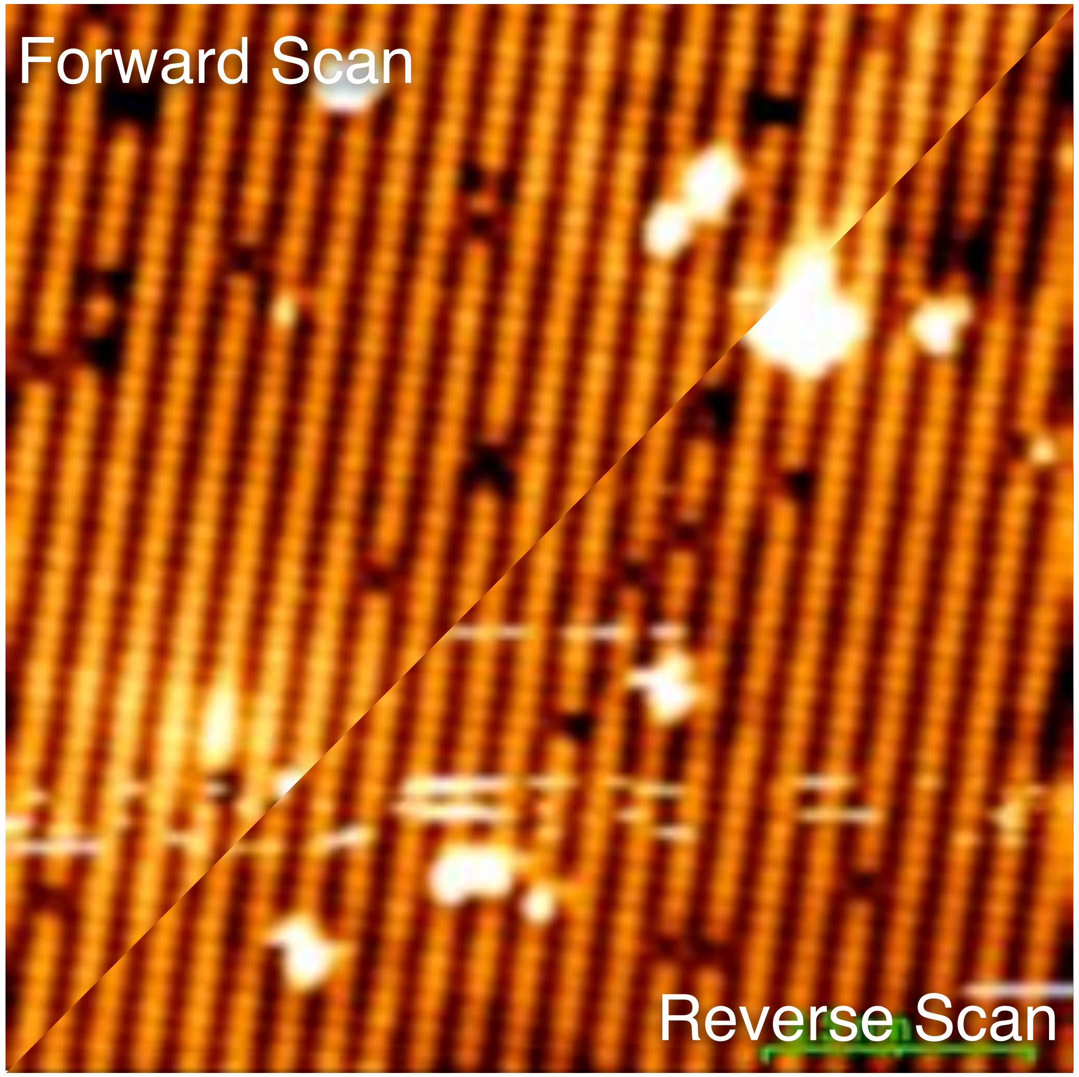
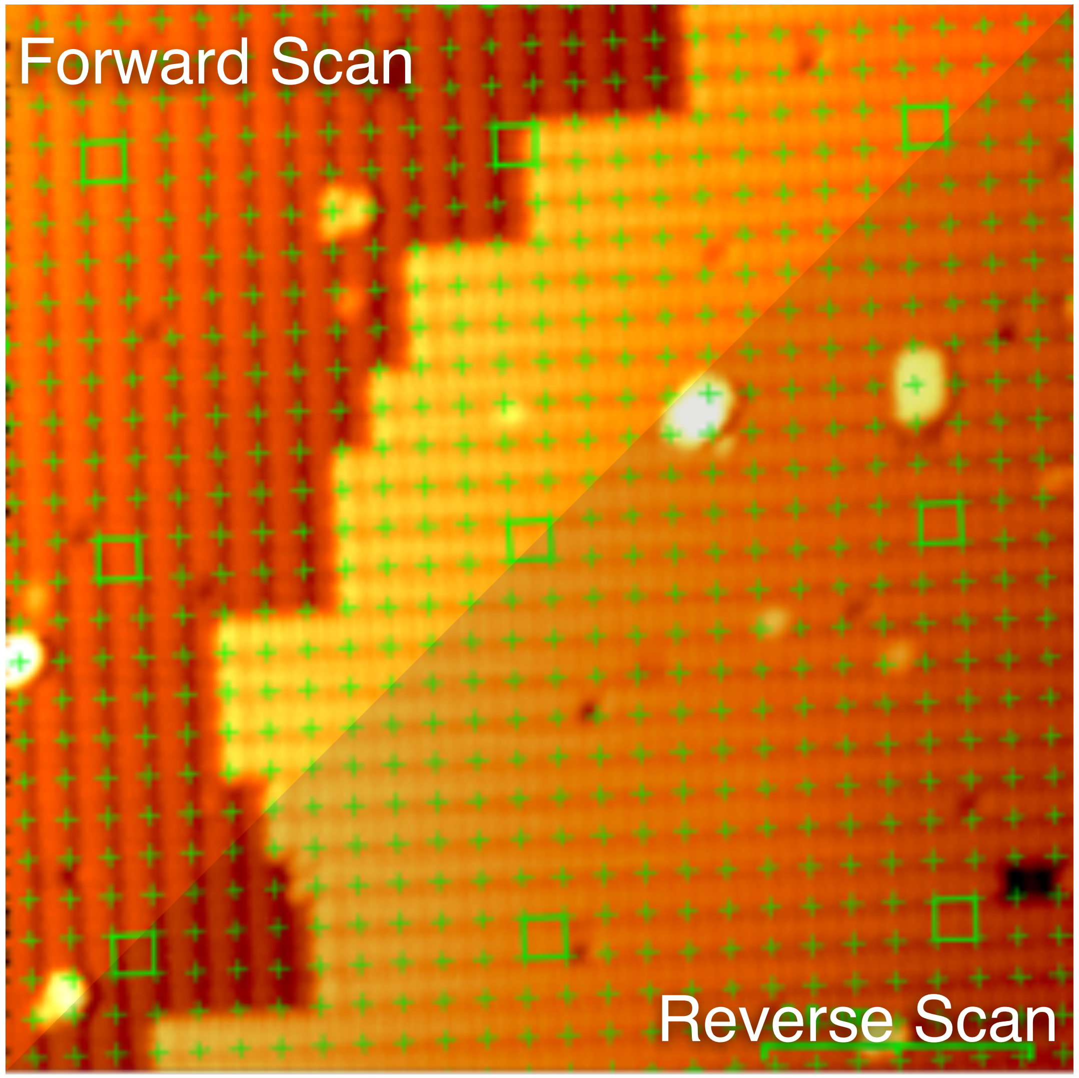
Distortion-free Imaging

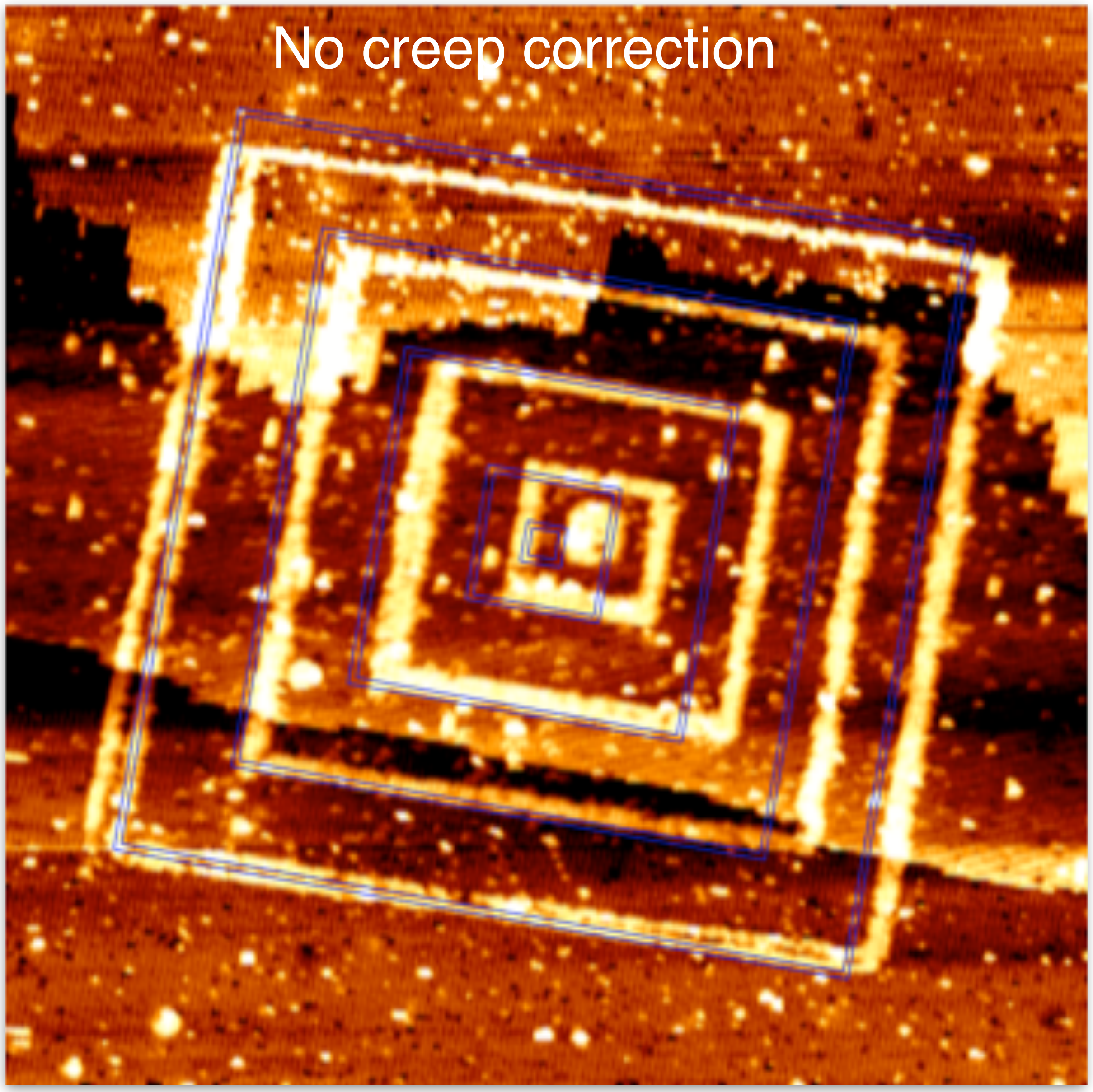


No creep correction:
Forward/Backward offset : 3.6 Å



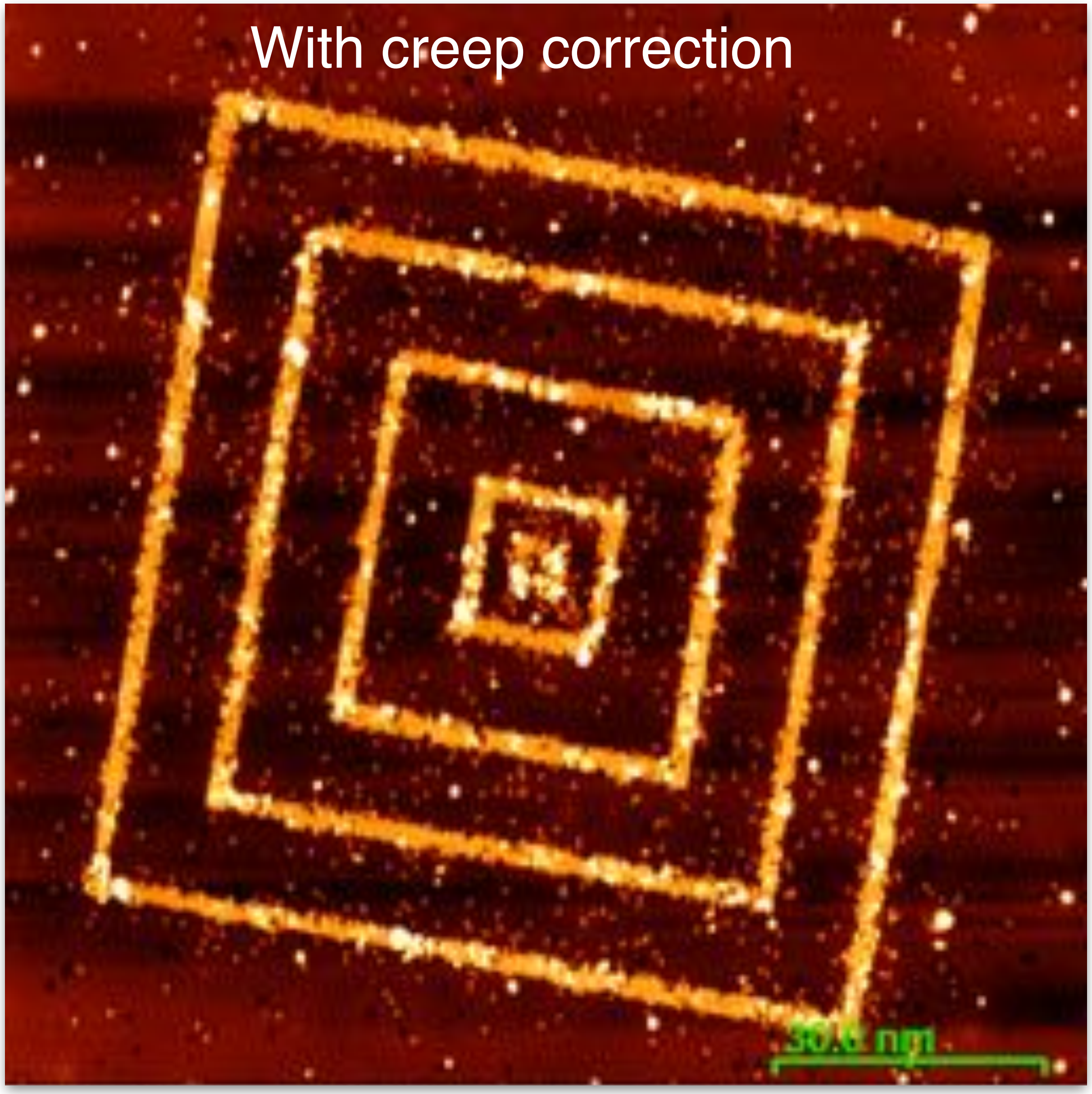
Corrected creep:
Forward/Backward offset: 0 Å

Creep correction for patterning



No creep correction

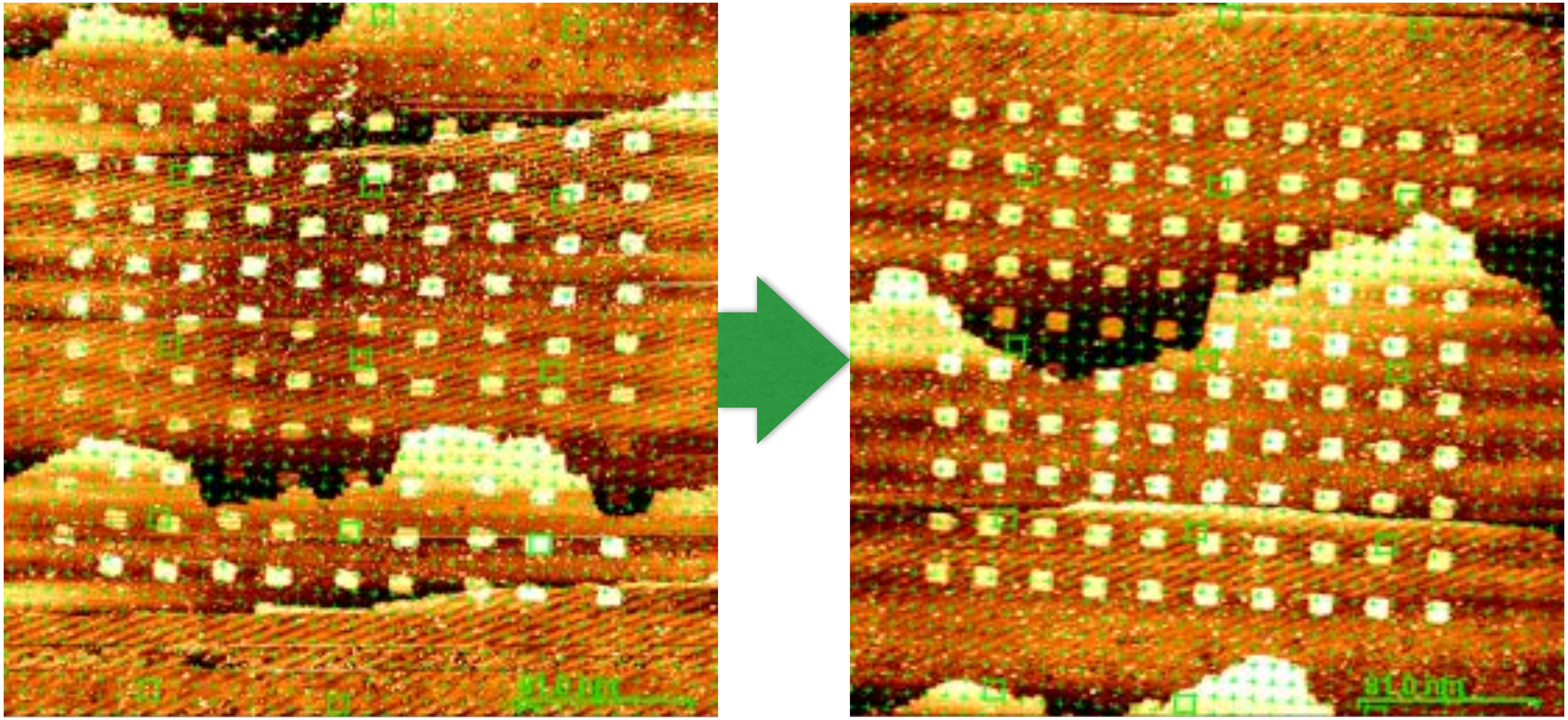
Paired lines are not adjacent.
Squares are not square.
Squares are not concentric.



With creep correction

Paired lines adjacent.
Squares are square.
Squares are concentric.

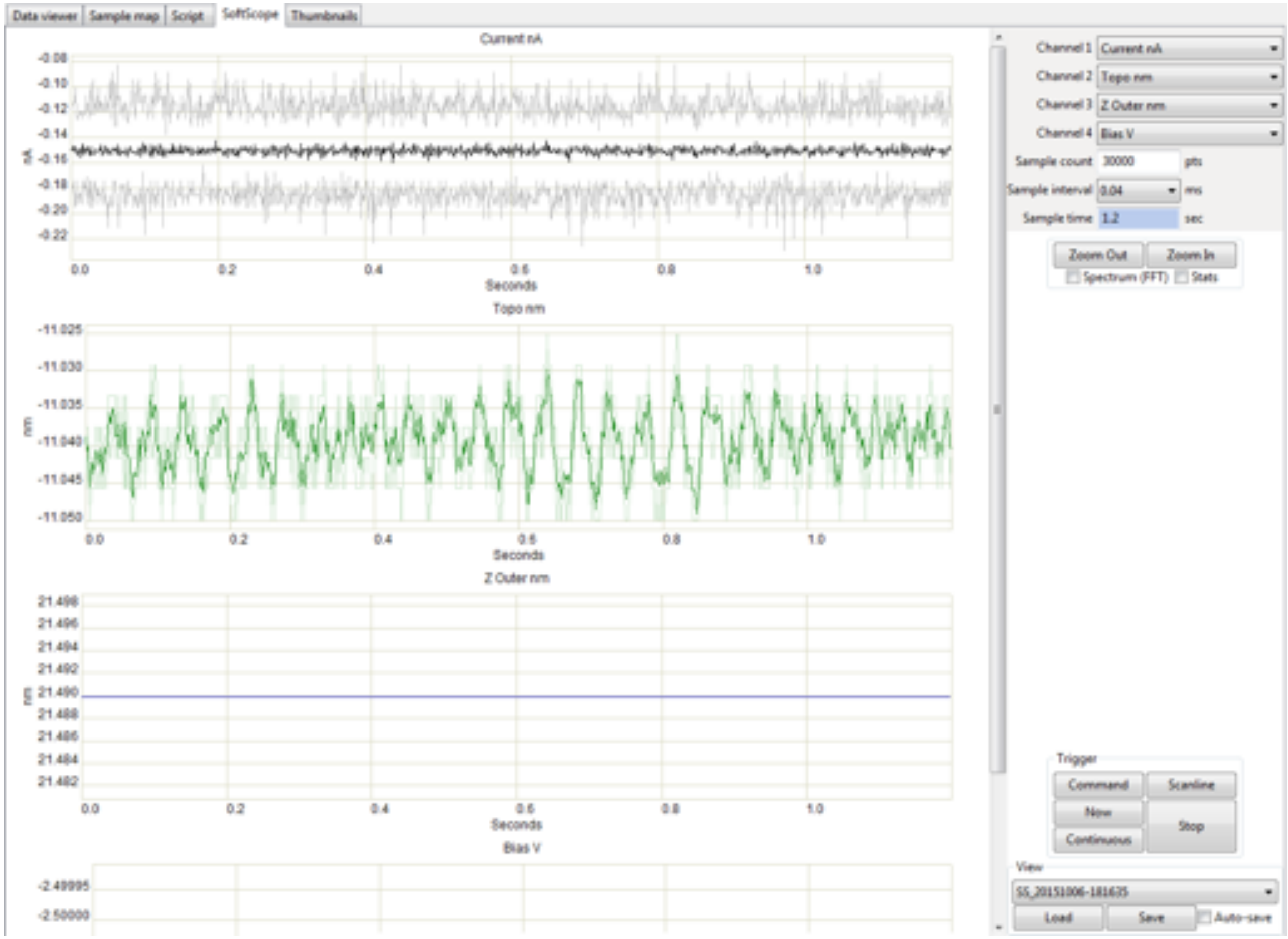
Atomically Precise Arrays



Drawing arrays of boxes for quantum devices is a hard alignment problem.

Automated array drawing requires careful correction not only of creep, but also thermal drift and hysteresis.
The box position error here is at most 1 px – 0.768 nm.

Softscope - live view of data channels



Channel 1 Current nA

Channel 2 Topo nm

Channel 3 Z Outer nm

Channel 4 Bias V

Sample count 30000 pts

Sample interval 0.04 ms

Sample time 1.2 sec

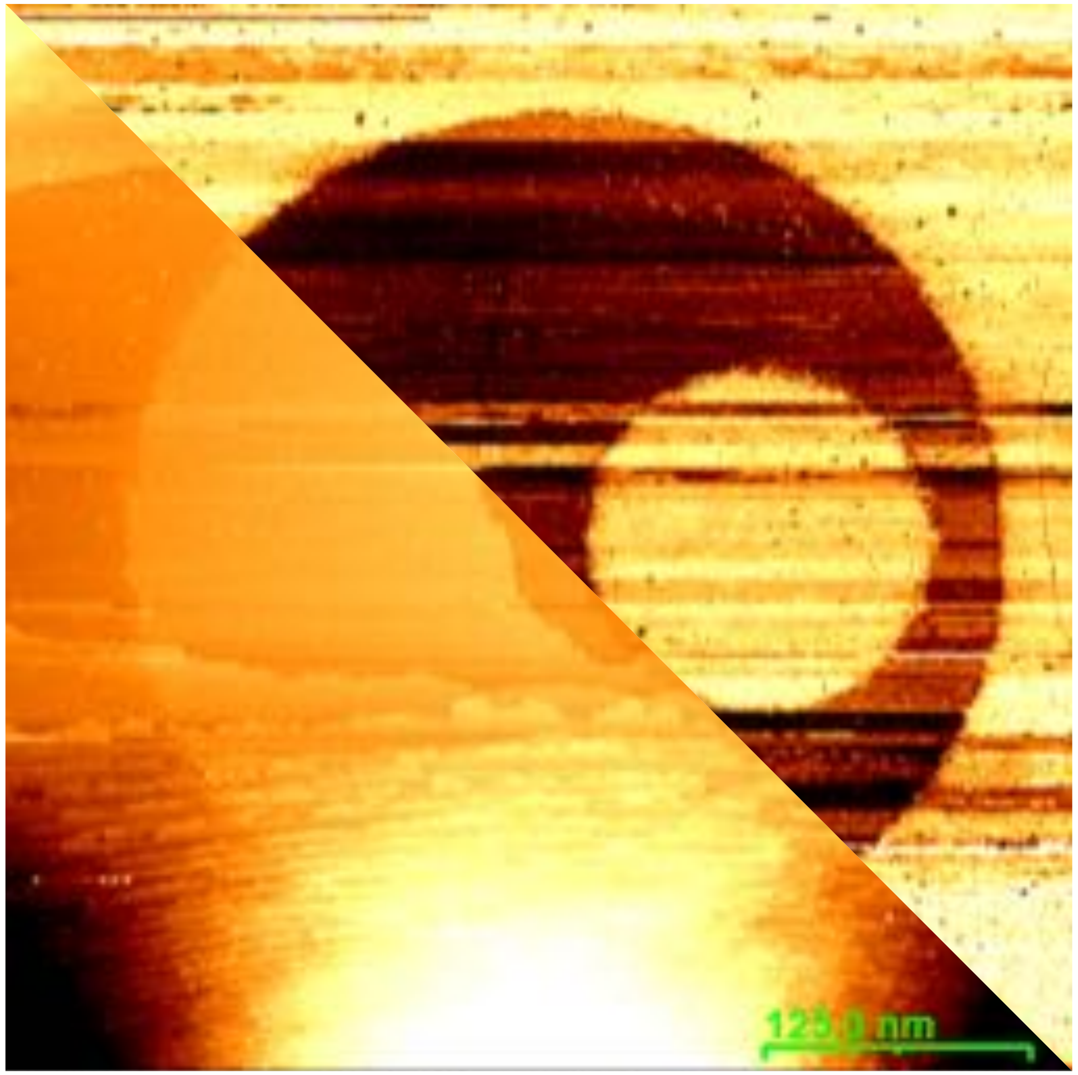
□ Spectrum (FFT) □ Stats

View

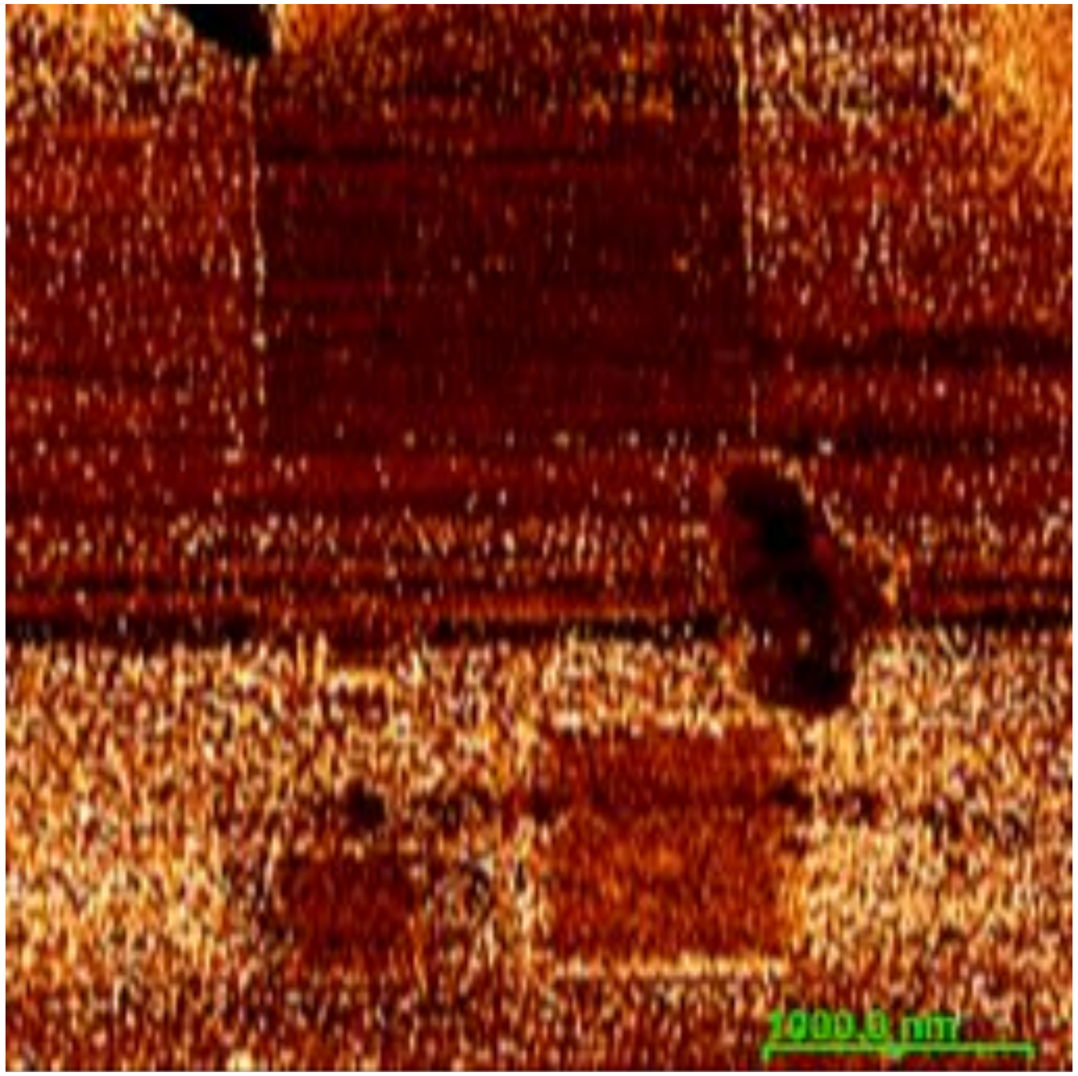
SS_20151006-181635

□ Auto-save

Image modes for pattern detection

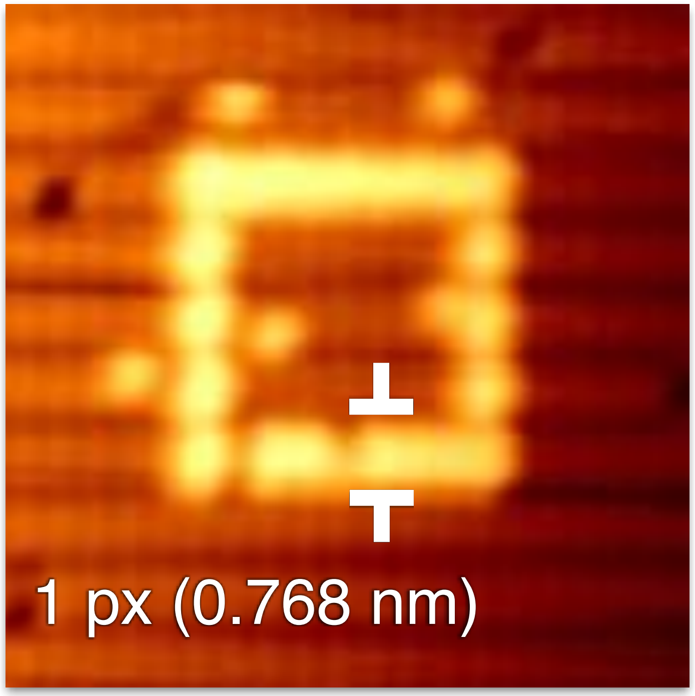


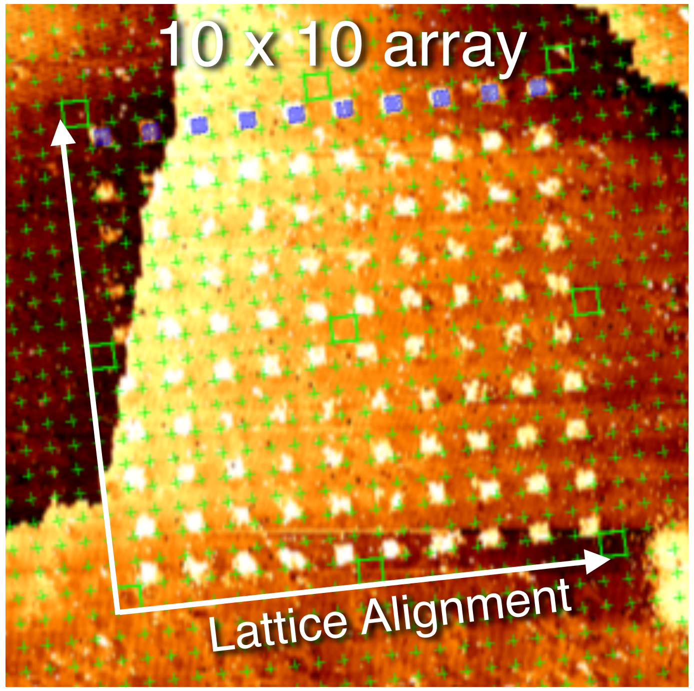
As dI/dZ is a measure of the surface electronic properties, it shows surface features such as lithography patches with good contrast, even on rough surfaces.

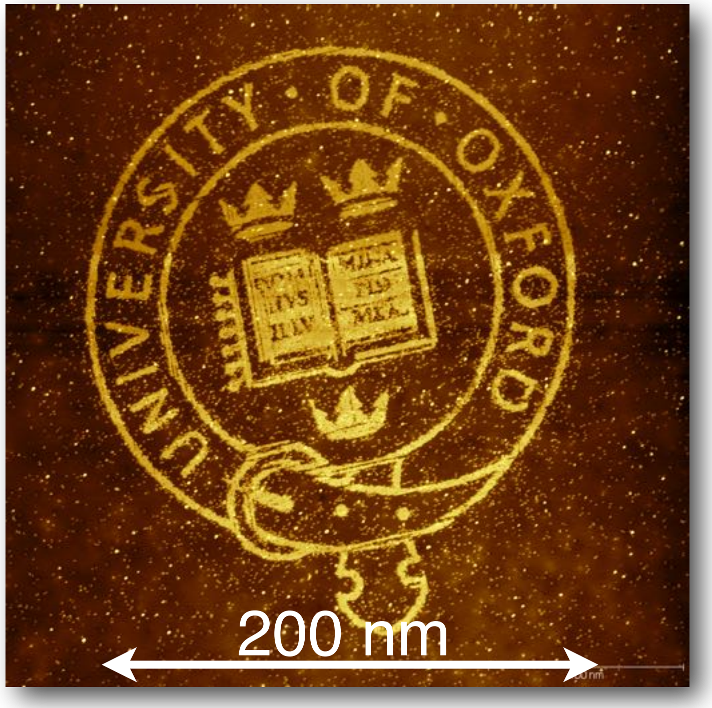


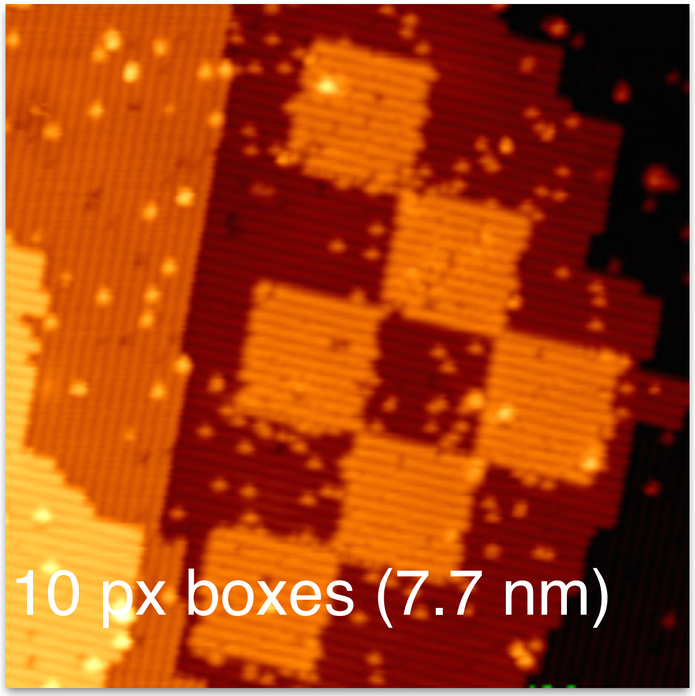
For observing buried structures, we use dI/dV imaging to give contrast of the P-doped regions, even under 20 nm of overgrown Si.

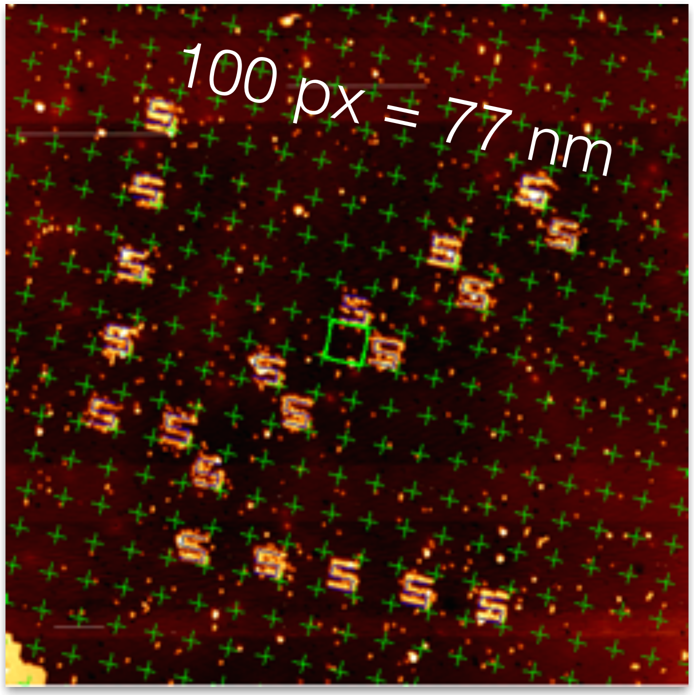
What would you like to draw?

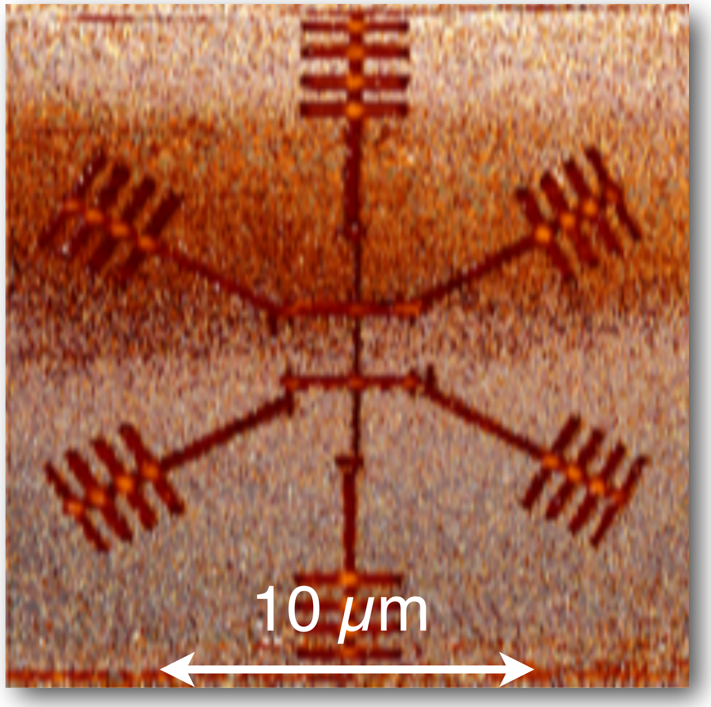












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Powerful scripting allows for lattice-aligned Atomically Precise Patterning