FEMTOSECOND LASER WRITING IN LASER GLASSES

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Femtolaser Laser Writing

- In the case of a femtosecond laser pulse, the light is absorbed by electrons, and ***the optical excitation ends before the lattice is perturbed***.
- A femtosecond laser pulse is tightly focused inside transparent glasses. At the point of laser focus, ***the laser intensity becomes high enough to cause nonlinear absorption*** (i.e., multiphoton, tunneling, and avalanche ionization, continuum generation).
- If enough laser energy is deposited into the material, ***permanent structural changes*** (i.e., damage – voxels, lines) are produced at the laser focus.

Motivation

- Microstructuring of optically-active glasses*
  - ***Miniaturization*** of photonic components
  - ***Integration*** of active photonic devices
- Room temperature persistent spectral hole burning (PSHB)**
  - Application to ***high-density frequency domain optical storage***
  - Samarium-doped aluminum silicate (inhomogeneous line width, compositional variations, and ease of production)

* K. Hirao, T. Mitsuyu, J. Si, J. Qiu, "Active Glass for Photonic Devices" Springer, 2000.

** H. Song, M. Nogami, "Room temperature hole-burning and sublinear hole-growth dynamics in an Sm^{2+}-doped aluminosilicate glass," J. Non-Cryst. Solids, 297, 113-119 (2002).

Objectives

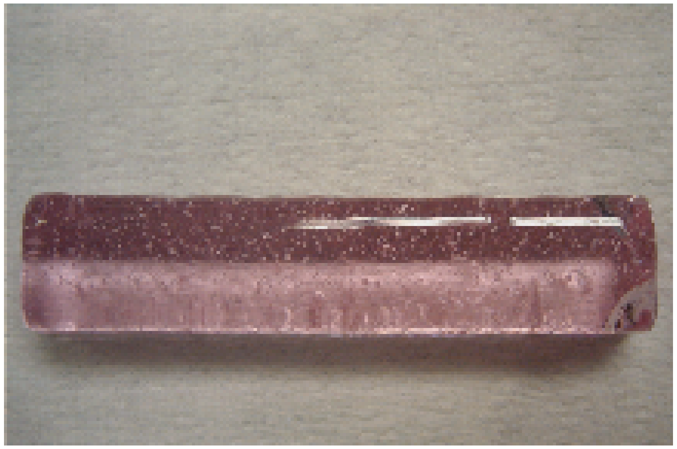
- ***Demonstrate*** writing of dots and lines in optically active glasses
- ***Study*** the evolution of the structures in these glasses
- ***Characterize*** topography and structure generated

Glass Sample Preparation

- Samarium alumino-silicate (SAS) glass*
  - $10Sm_2O_3 \bullet 25Al_2O_3 \bullet 65SiO_2$

- Laser glass - Nd-doped alkali/alkaline earth aluminophosphate glass

Oxide	(mol%)	adj mol%	source
Al_2O_3	10.00	9.82	Al_2O_3
BaO	15.00	14.73	$BaCO_3$
K_2O	15.00	14.73	K_2CO_3
Nd_2O_3	0.00	1.80	Nd_2O_3
P_2O_5	60.00	58.92	P_2O_5
Total	**100.00**		



- Batching, melting, remelting, casting, cooling and annealing

* *Dr. Delbert Day (UMR)*

Femtosecond Laser Writing

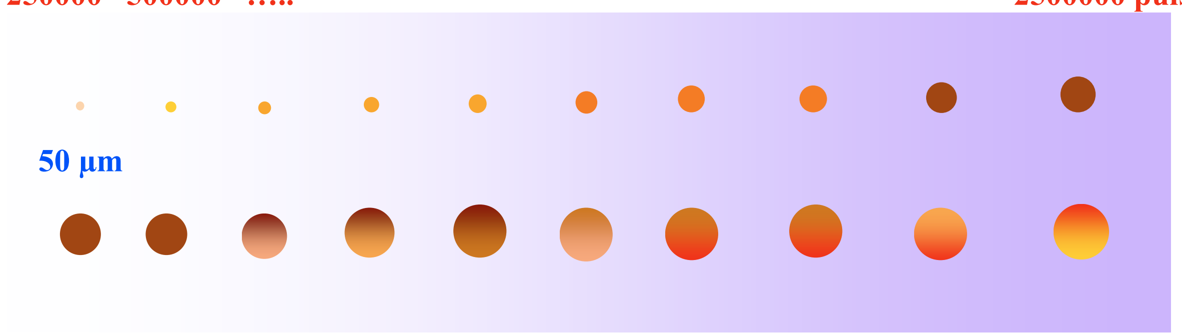
- Coherent RegA Ti-sapphire amplified system
  - Operating at: 250 kHz, 100 fs, 800 nm
- Focusing conditions 0.25 NA
- Estimated spot area 3 μm^2
- Power 0.2 - 0.66 W
- Energy 0.9 - 2.6 μJ
- Fluence 0.56-1.68 $(J/m^2) \times 10^6$
- Room temperature
- Surface/near surface

Written Structures & Characterization

- Lines (3 sets using 0.6, 1.7, and 2.7 µJ, 100 µm apart)

- Dots

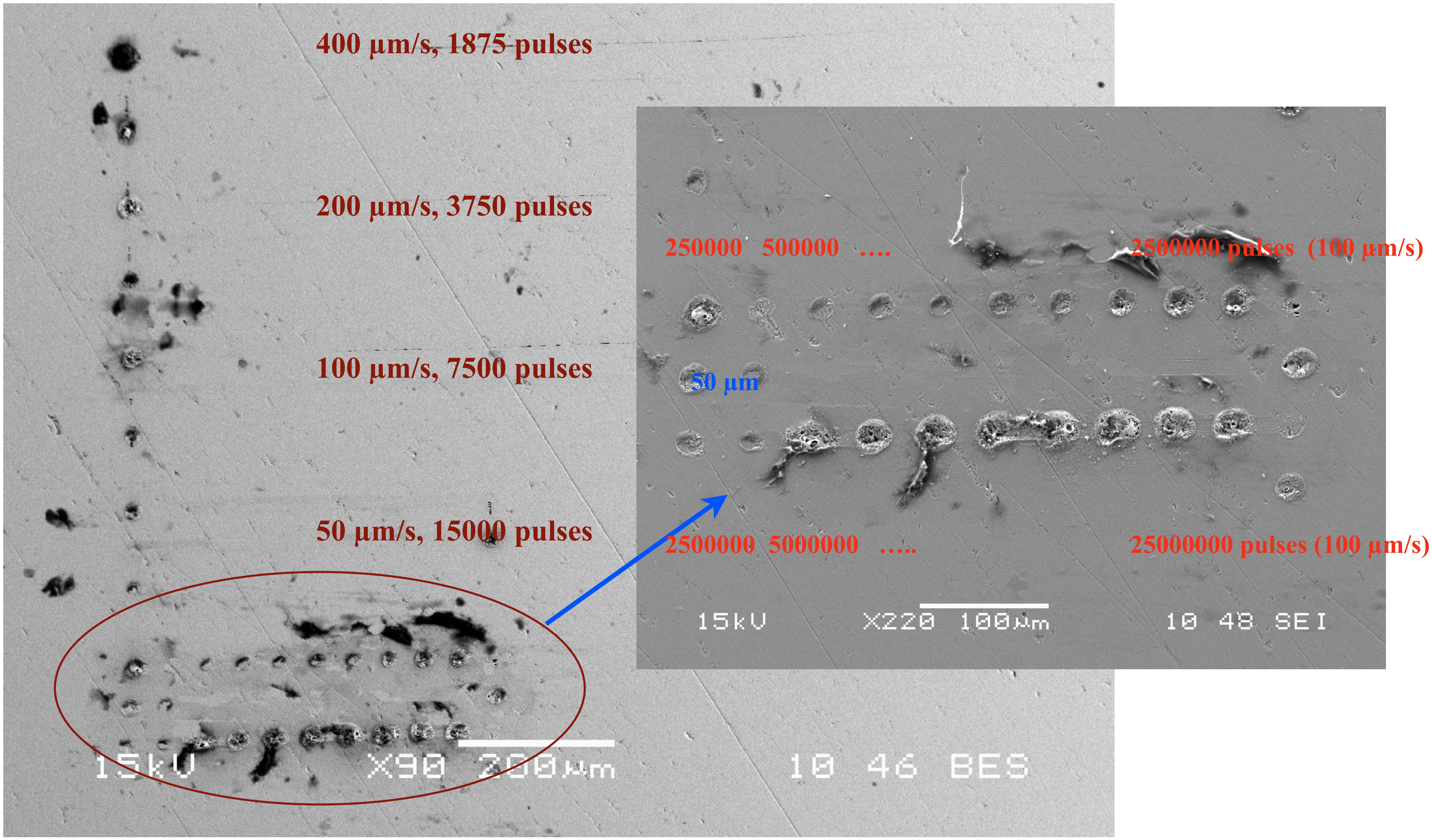
250000 500000 ….. 2500000 pulses (100 µm/s)



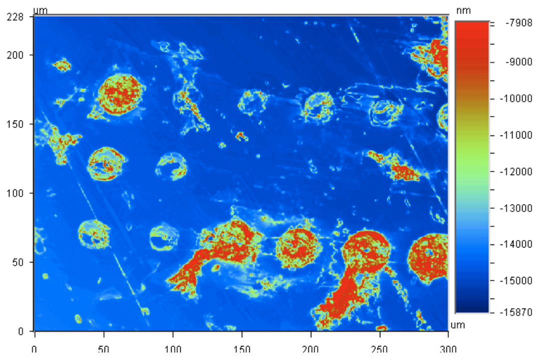
2500000 5000000 ….. 25000000 pulses (100 µm/s)

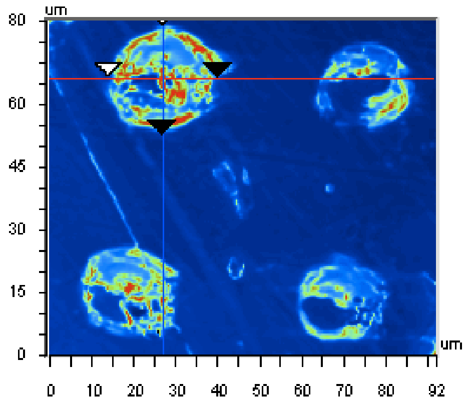
- Characterization
  - Non-contact optical profilometry (□20), AFM, SEM/EDS, micro-Raman

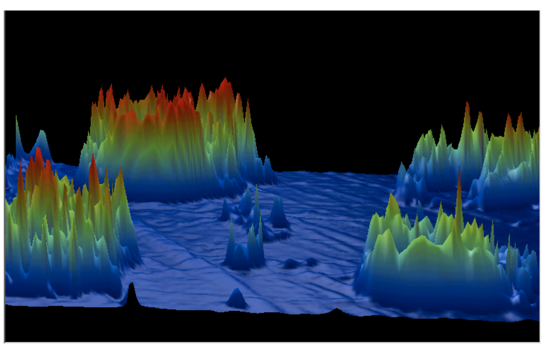
Structures in SAS-Glass



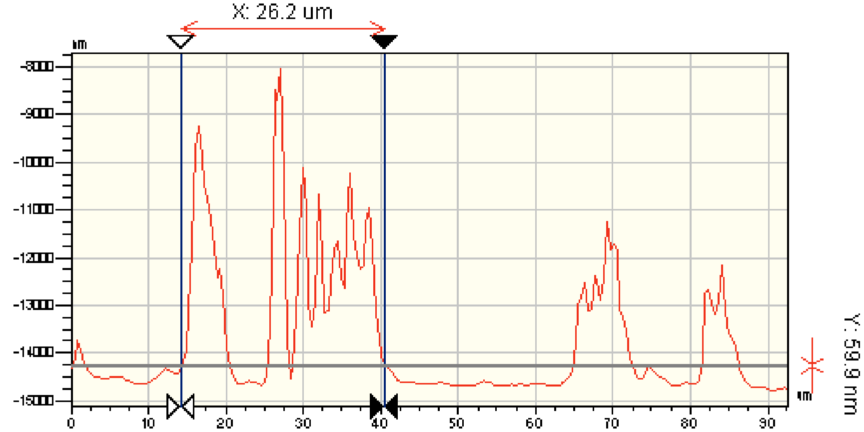
Profilometry



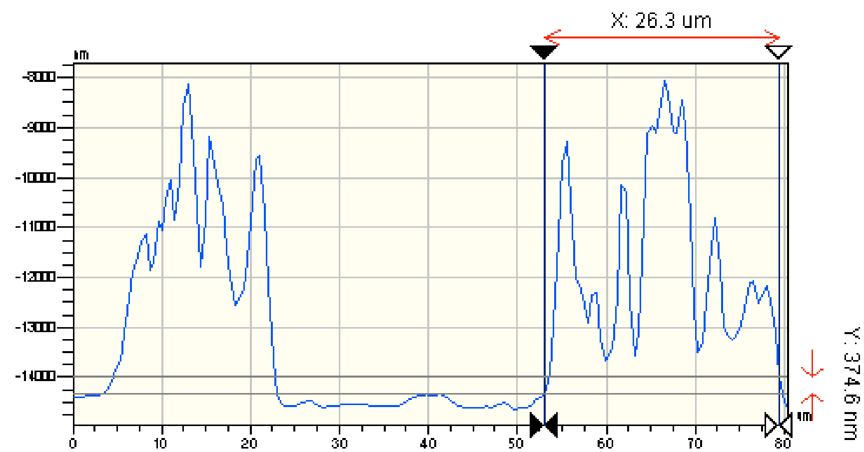




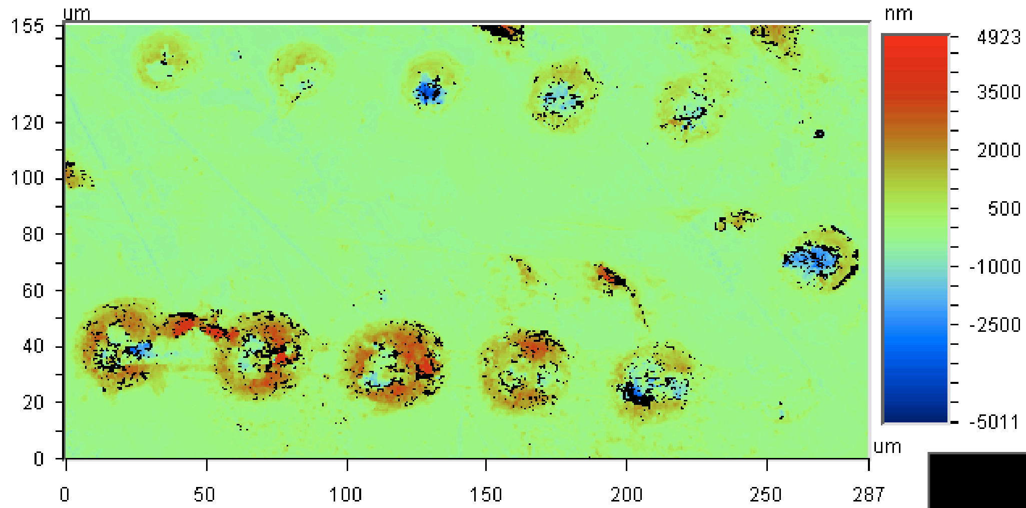
X Profile

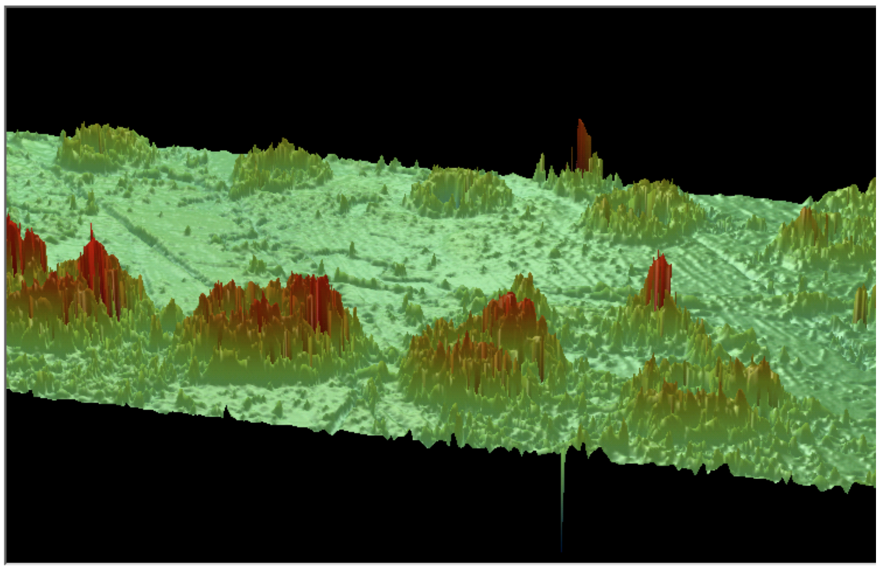


Y Profile

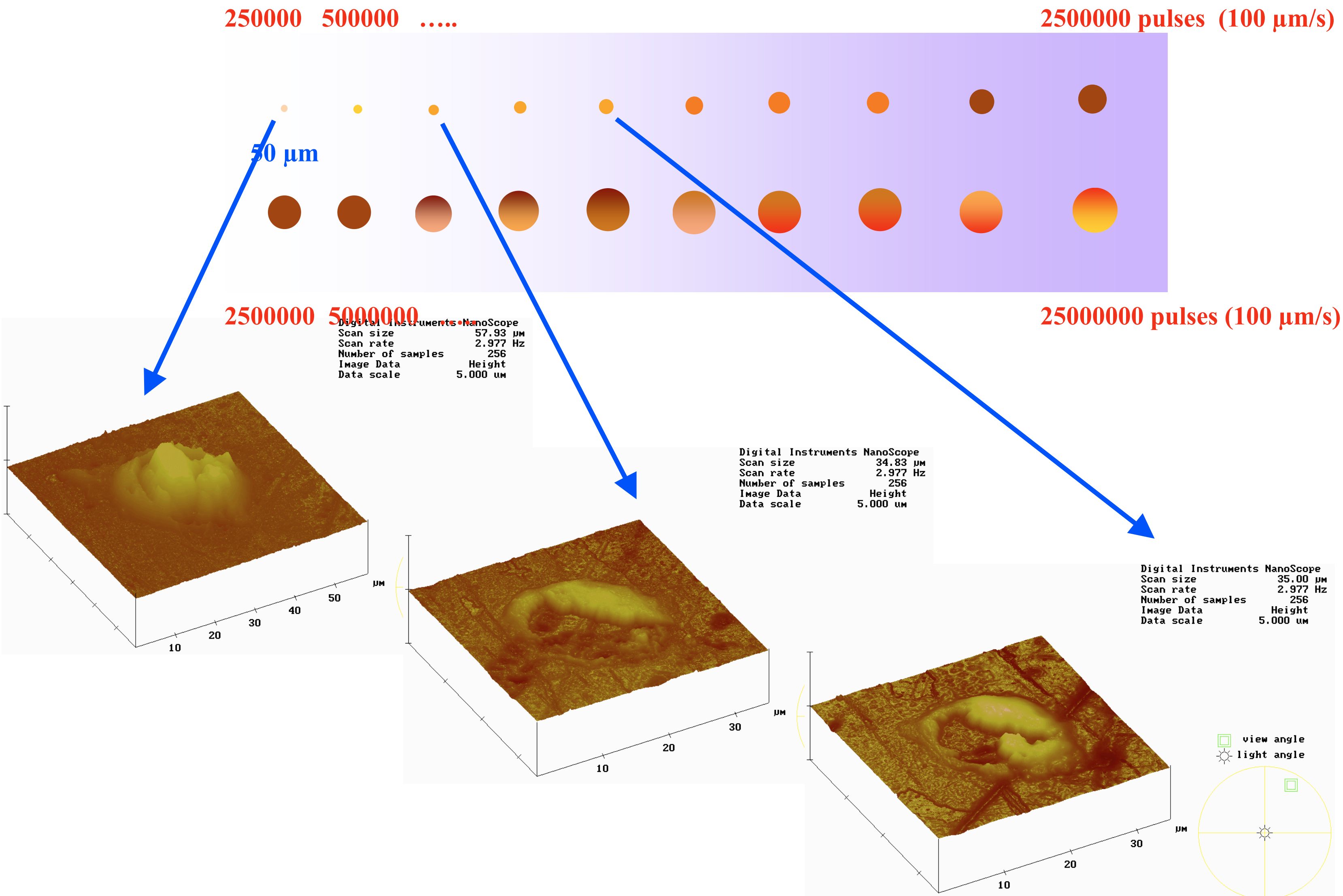


Profilometry (continued)

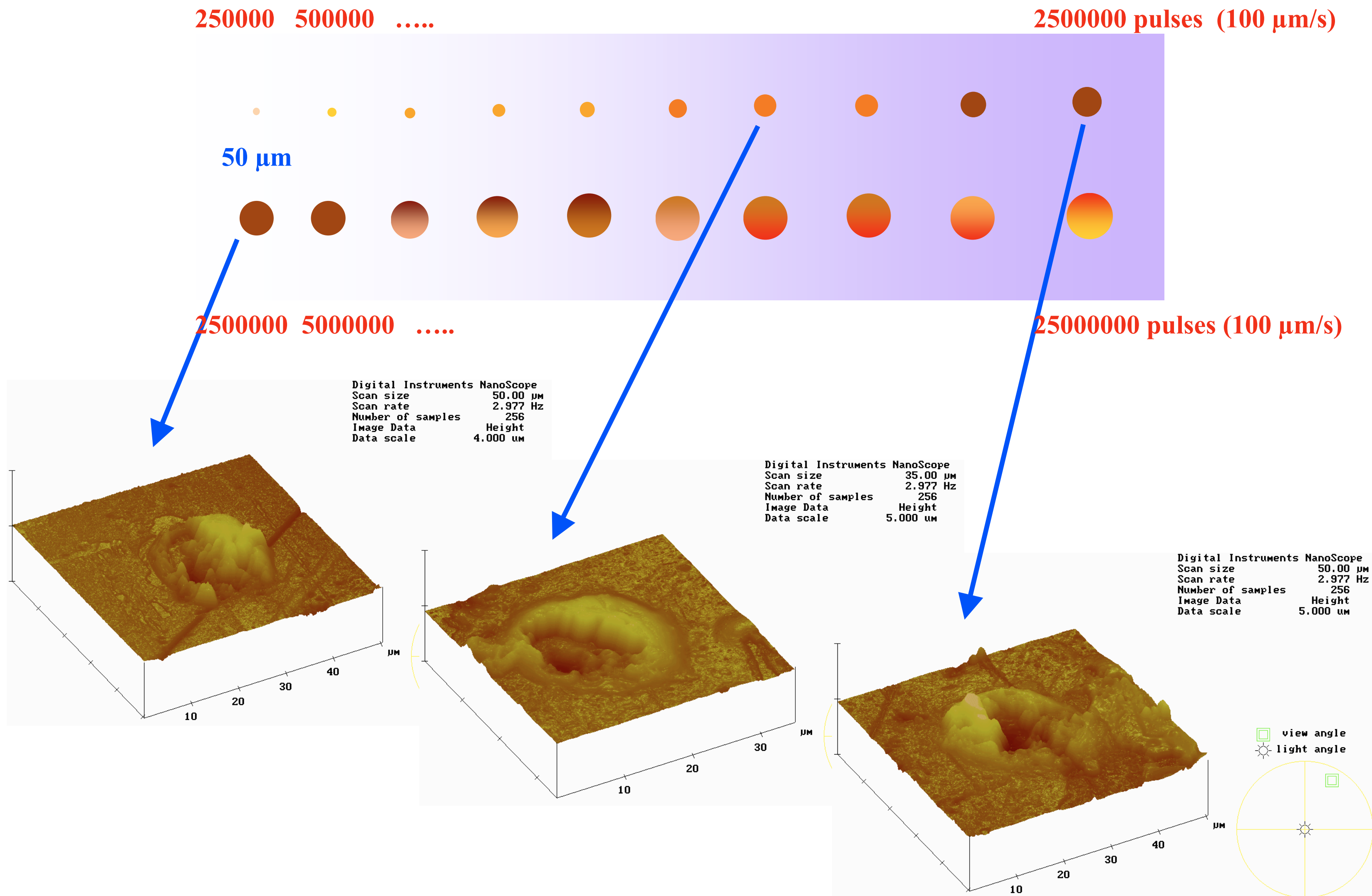




AFM Results

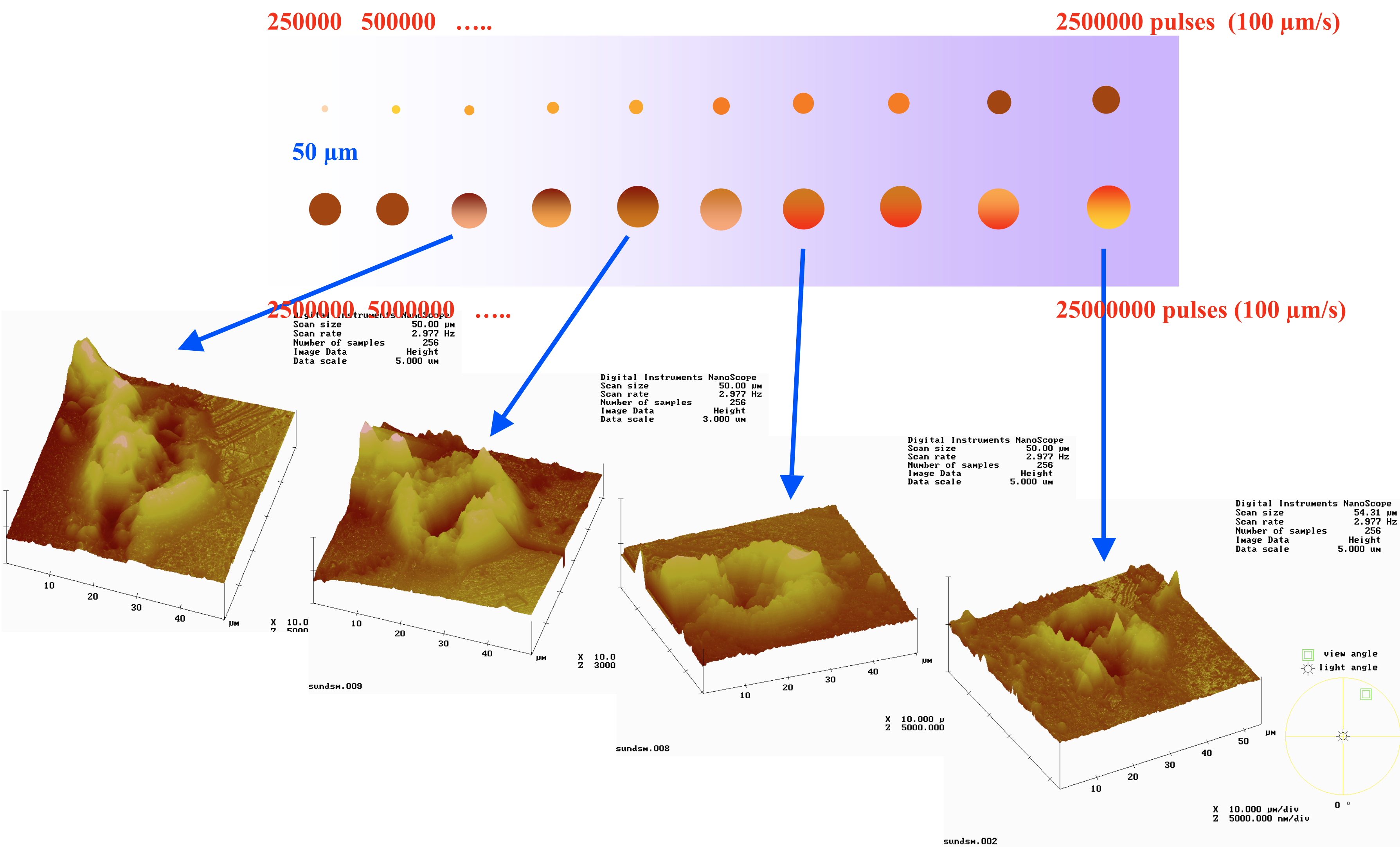

250000 500000 .....
2500000 pulses (100 µm/s)
50 µm
2500000 5000000
25000000 pulses (100 µm/s)
Digital Instruments NanoScope
Scan size 57.93 µm
Scan rate 2.977 Hz
Number of samples 256
Image Data Height
Data scale 5.000 um
Digital Instruments NanoScope
Scan size 34.83 µm
Scan rate 2.977 Hz
Number of samples 256
Image Data Height
Data scale 5.000 um
Digital Instruments NanoScope
Scan size 35.00 µm
Scan rate 2.977 Hz
Number of samples 256
Image Data Height
Data scale 5.000 um
view angle
light angle

AFM Results



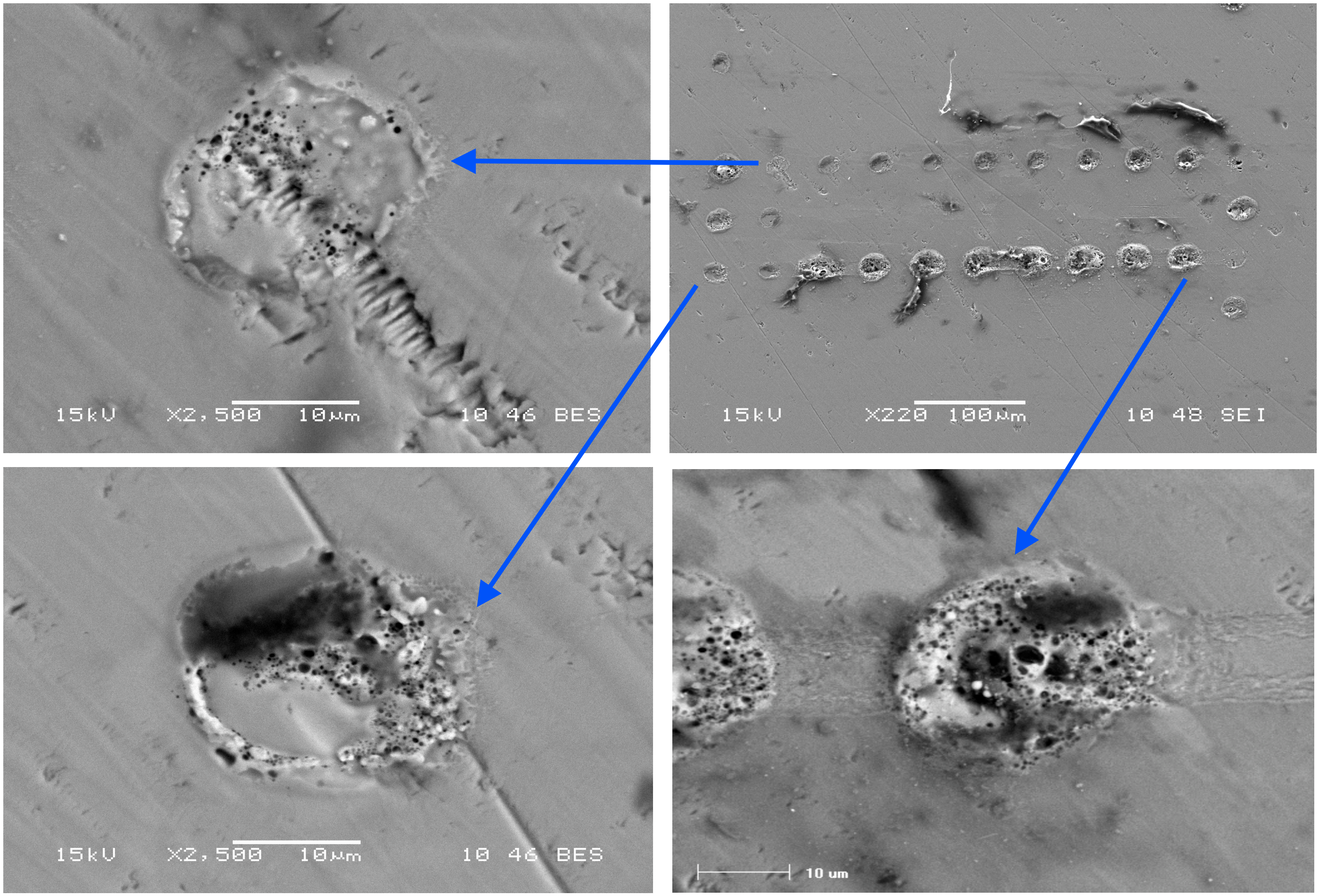
250000 500000 …..
2500000 pulses (100 µm/s)
50 µm
2500000 5000000 …..
25000000 pulses (100 µm/s)
Digital Instruments NanoScope
Scan size 50.00 µm
Scan rate 2.977 Hz
Number of samples 256
Image Data Height
Data scale 4.000 um
Digital Instruments NanoScope
Scan size 35.00 µm
Scan rate 2.977 Hz
Number of samples 256
Image Data Height
Data scale 5.000 um
Digital Instruments NanoScope
Scan size 50.00 µm
Scan rate 2.977 Hz
Number of samples 256
Image Data Height
Data scale 5.000 um
view angle
light angle

AFM Results

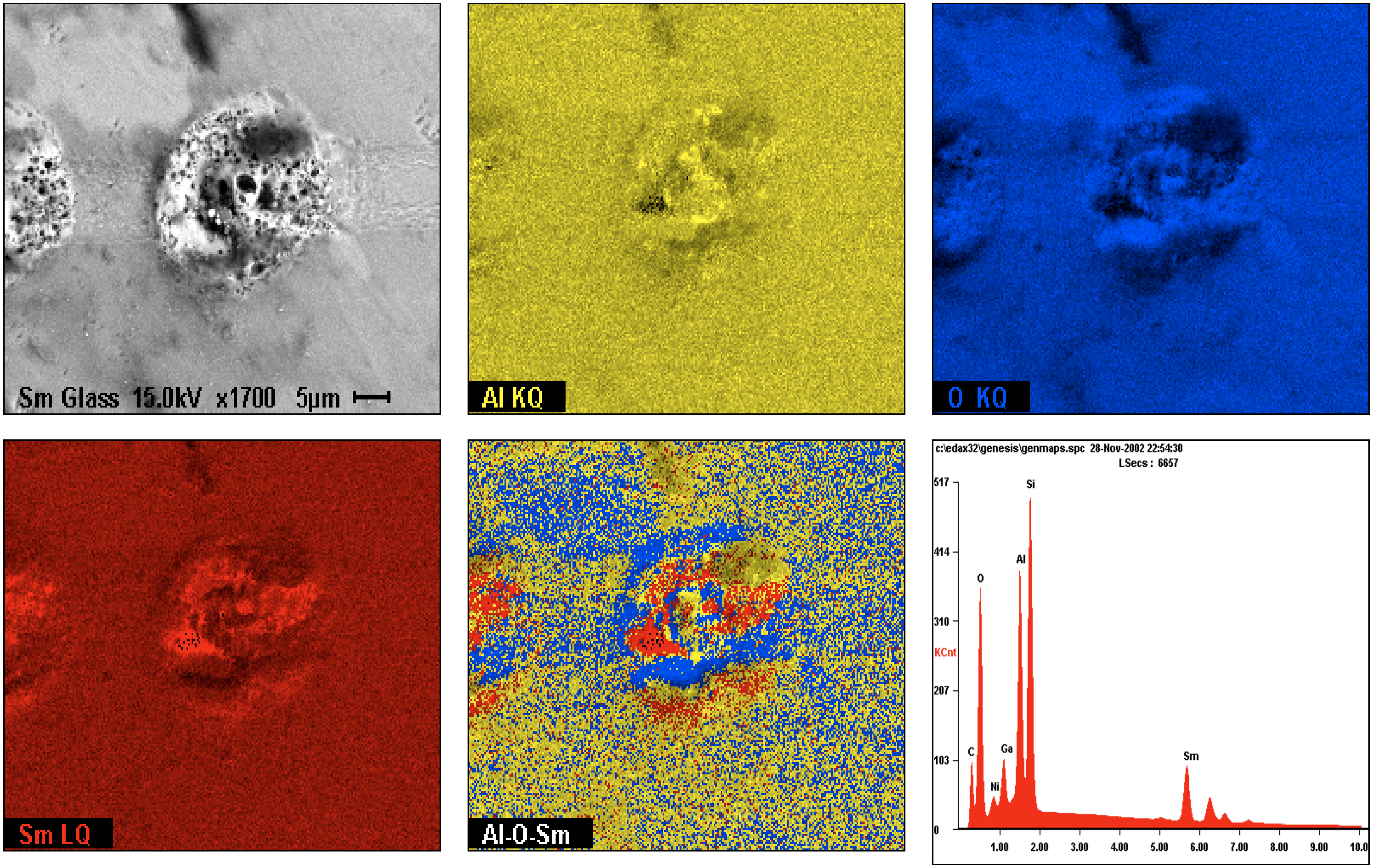


250000 500000 …..
2500000 pulses (100 µm/s)
50 µm
2500000 5000000 …..
25000000 pulses (100 µm/s)
Digital Instruments NanoScope
Scan size 50.00 µm
Scan rate 2.977 Hz
Number of samples 256
Image Data Height
Data scale 5.000 um
Digital Instruments NanoScope
Scan size 50.00 µm
Scan rate 2.977 Hz
Number of samples 256
Image Data Height
Data scale 3.000 um
sundsm.009
Digital Instruments NanoScope
Scan size 50.00 µm
Scan rate 2.977 Hz
Number of samples 256
Image Data Height
Data scale 5.000 um
sundsm.008
Digital Instruments NanoScope
Scan size 54.31 µm
Scan rate 2.977 Hz
Number of samples 256
Image Data Height
Data scale 5.000 um
view angle
light angle
X 10.000 µm/div
Z 5000.000 nm/div
sundsm.002

SEM Results


15kV X2,500 10µm 10 46 BES
15kV X220 100µm 10 48 SEI
15kV X2,500 10µm 10 46 BES
10 um

Elemental Map



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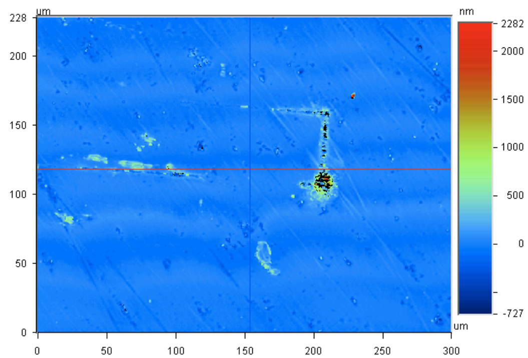
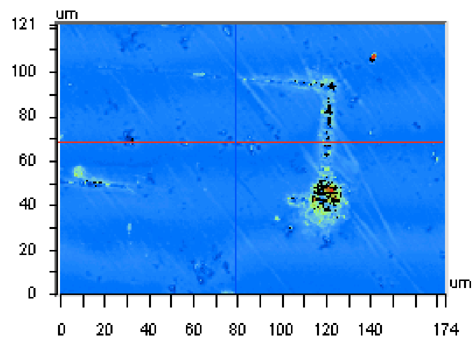
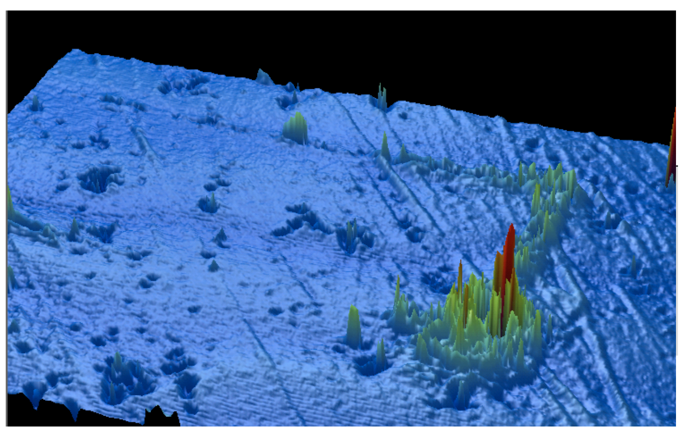
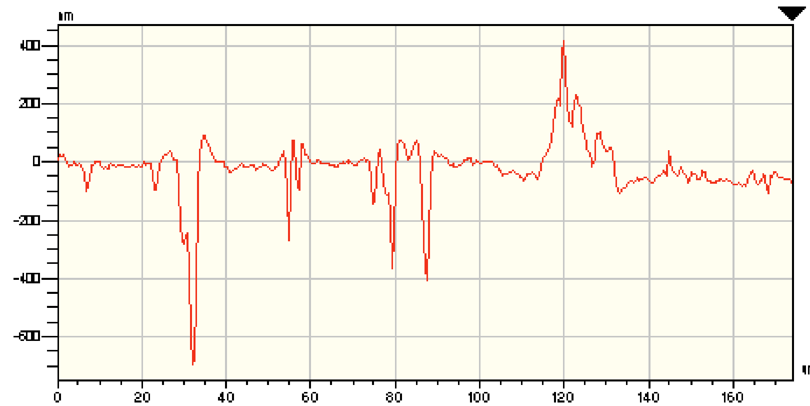
Profilometry - Top Line (0.88W/1875 pulses)

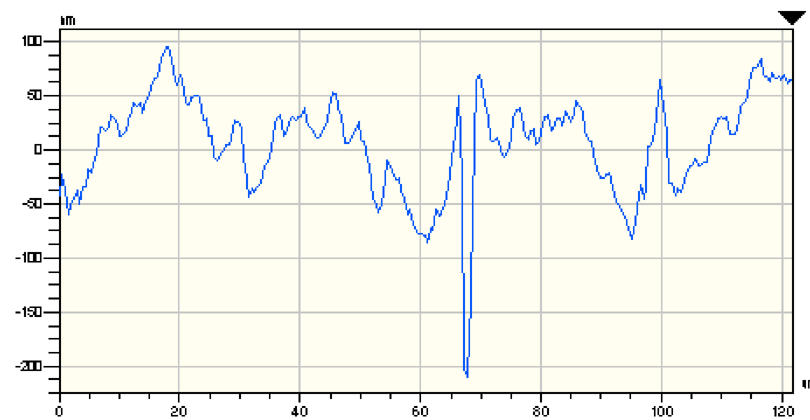








Y Profile



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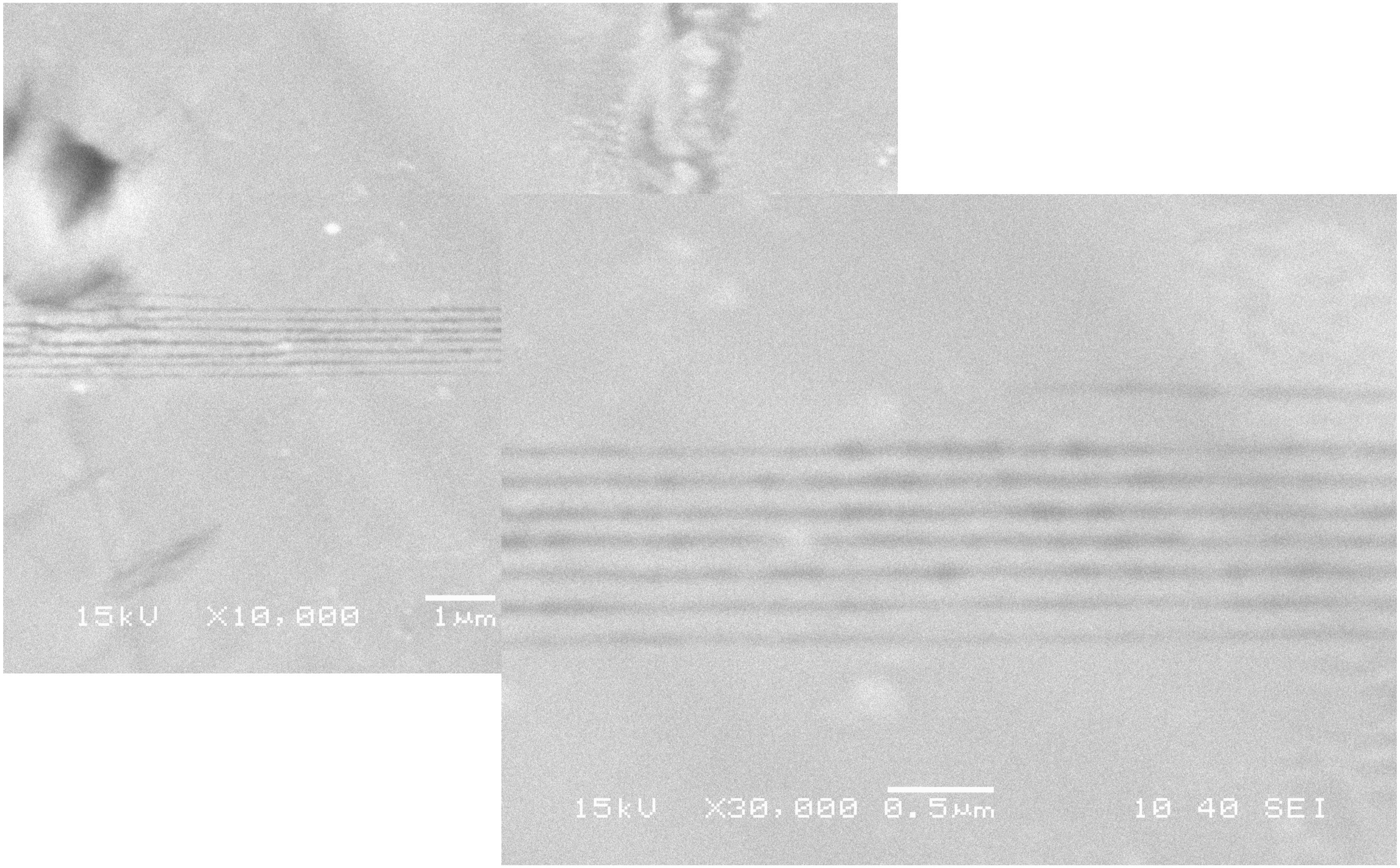
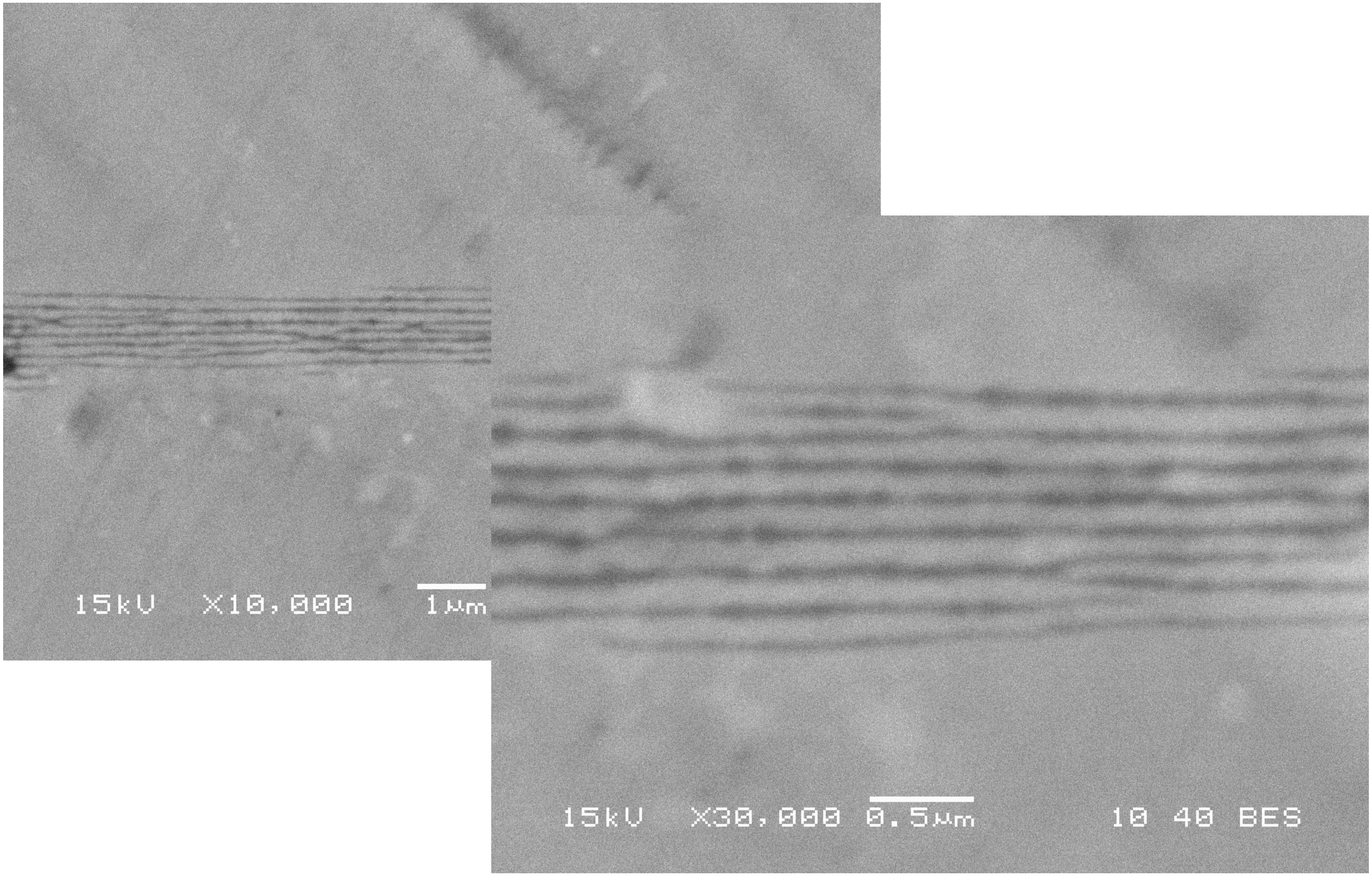
SEM Results – 0.88W/1875 pulses



SEM Results - 0.88W/3750 pulses



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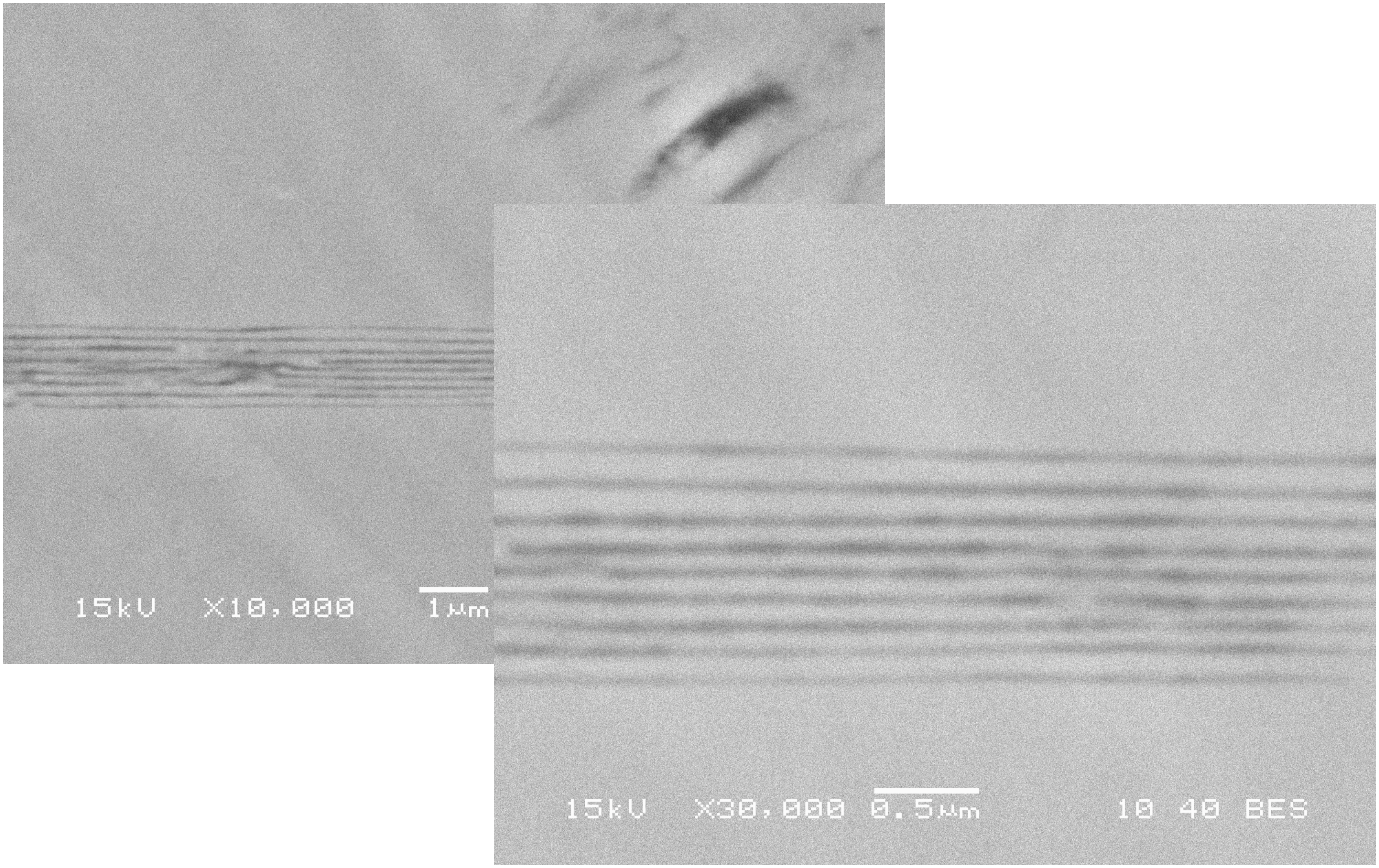
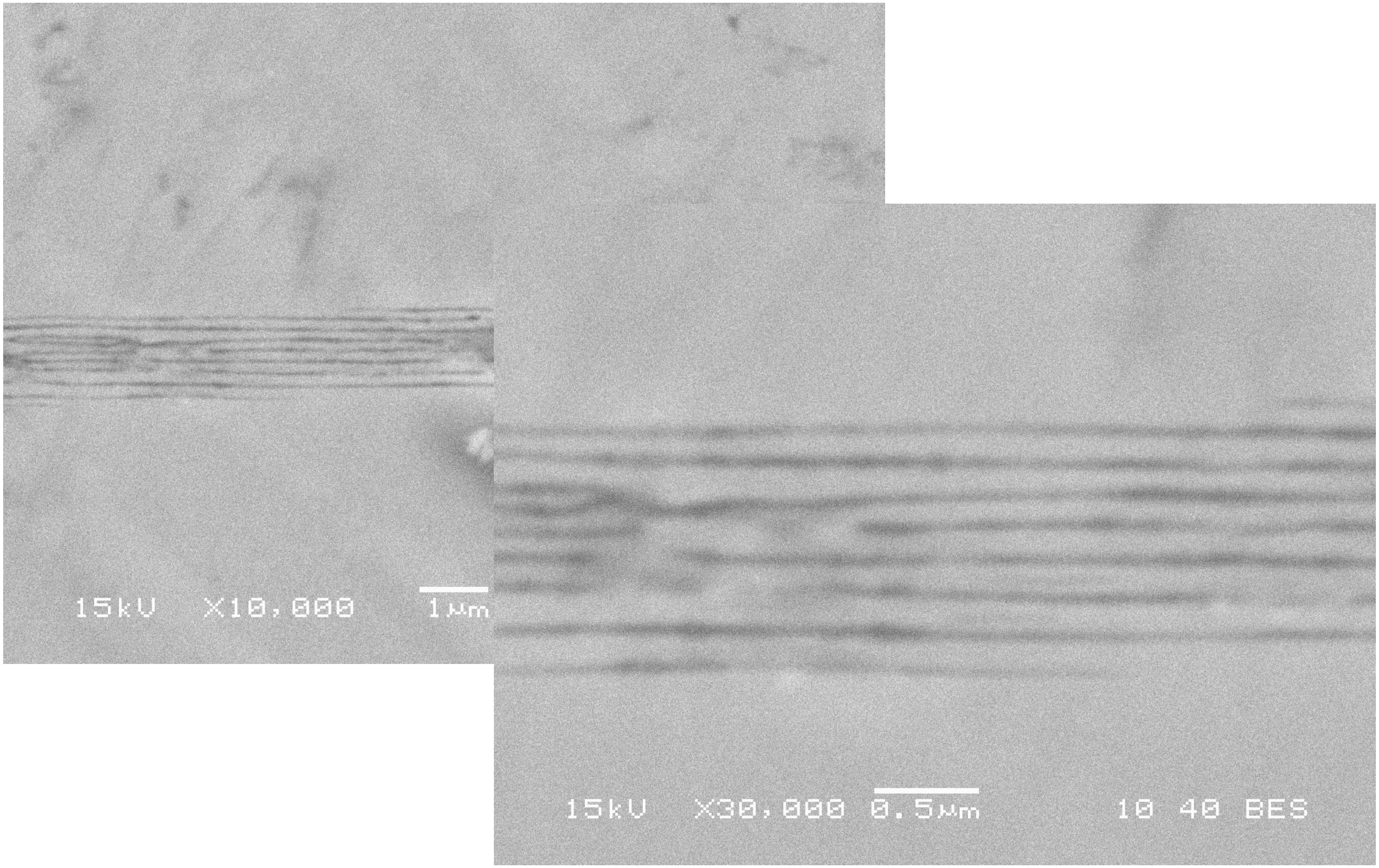
SEM Results - 0.88W/7500 pulses

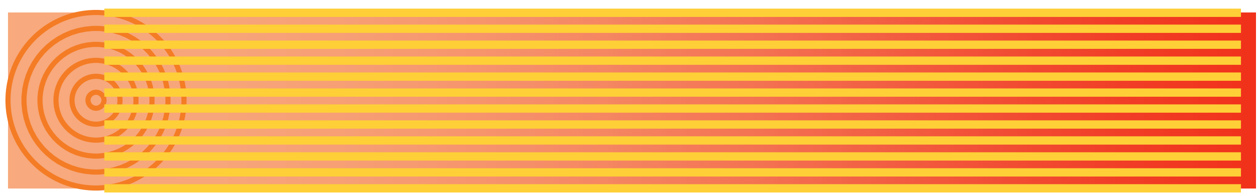


SEM Results - 0.88W/15000 pulses



Submicron Structures

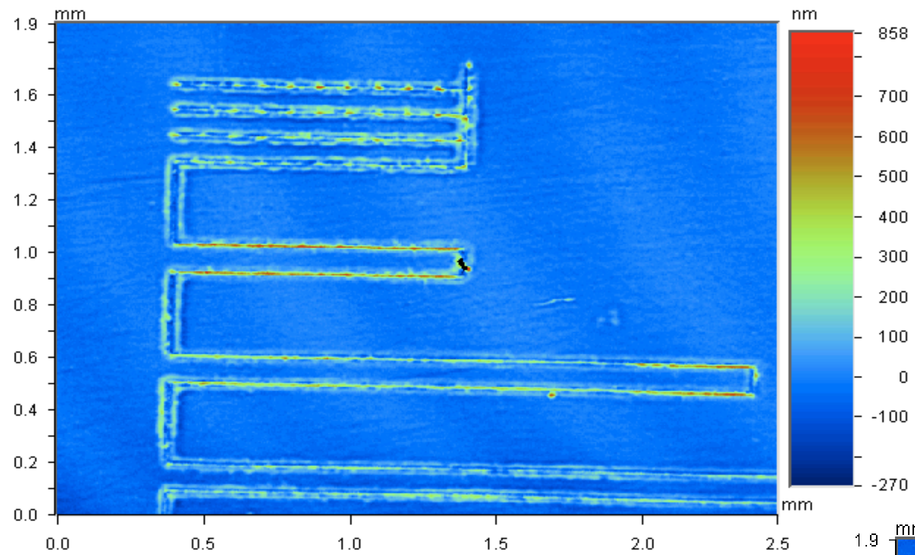
- ***Shock waves?***

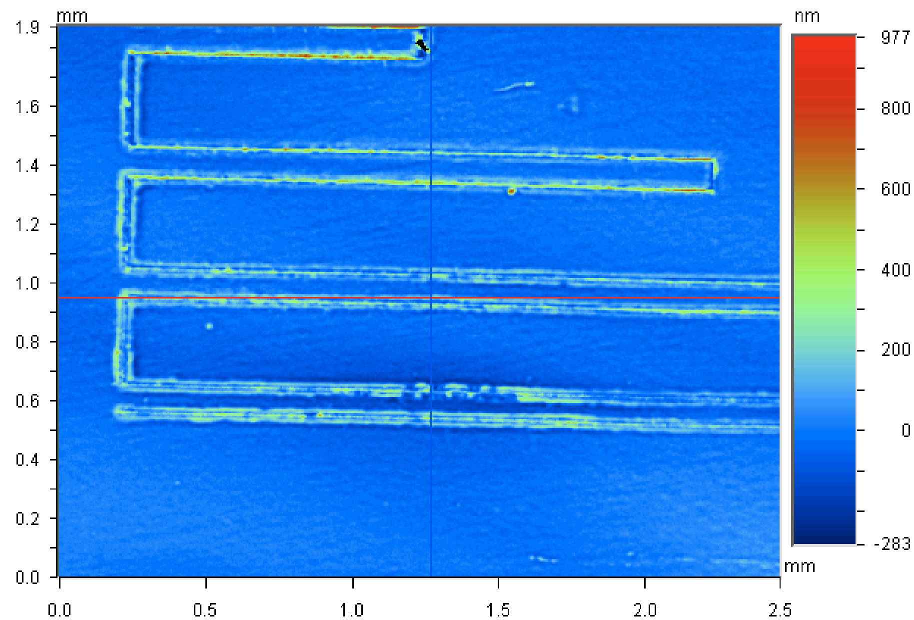


- ***Surface ripples?***

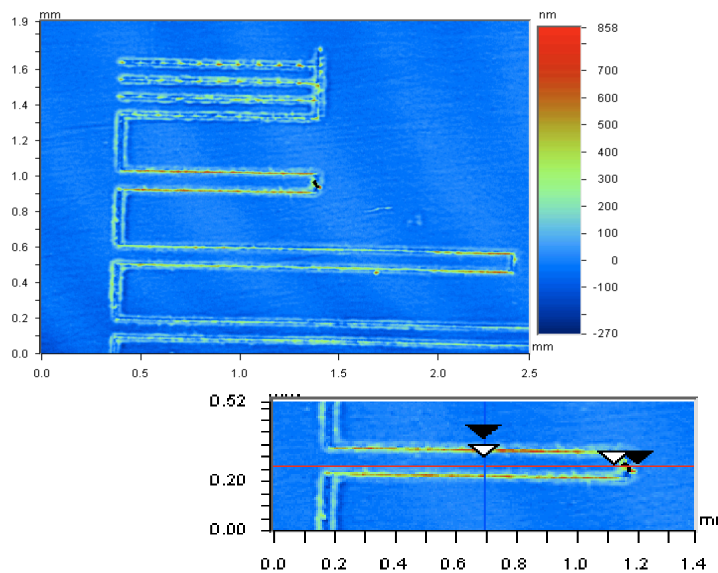
- Samarium □ increasing electronic conductivity - higher thermal conductivity - rapid cooling

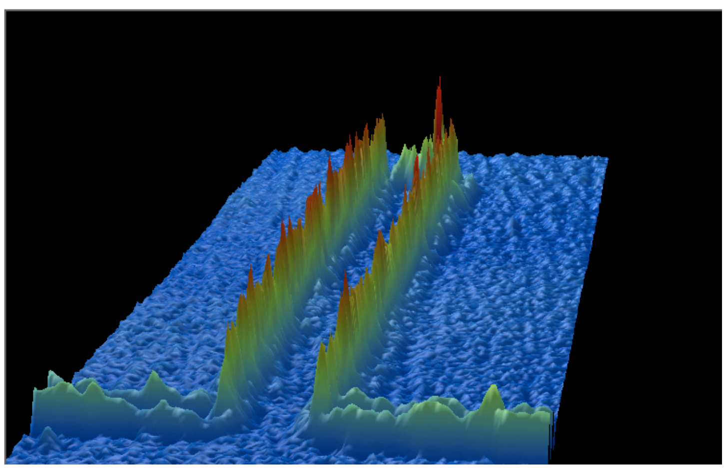
Laser Glass - Profilometry – 0.22 W

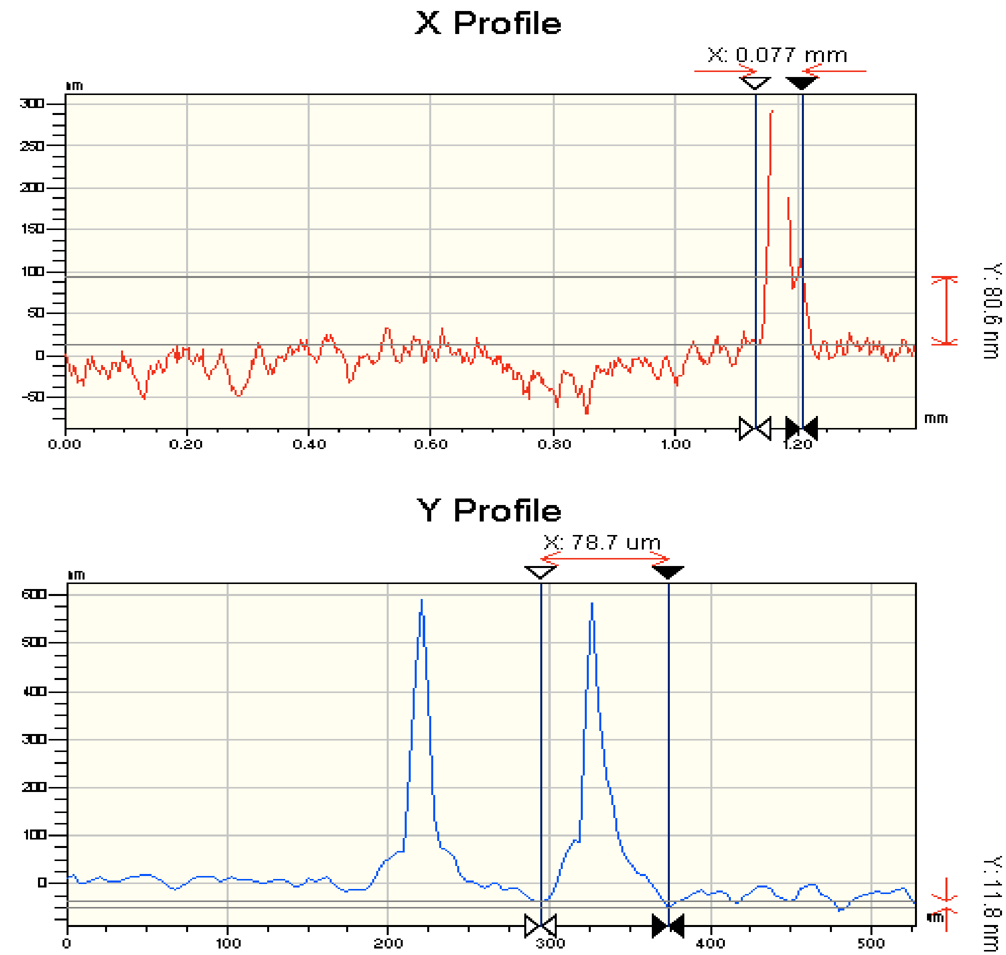




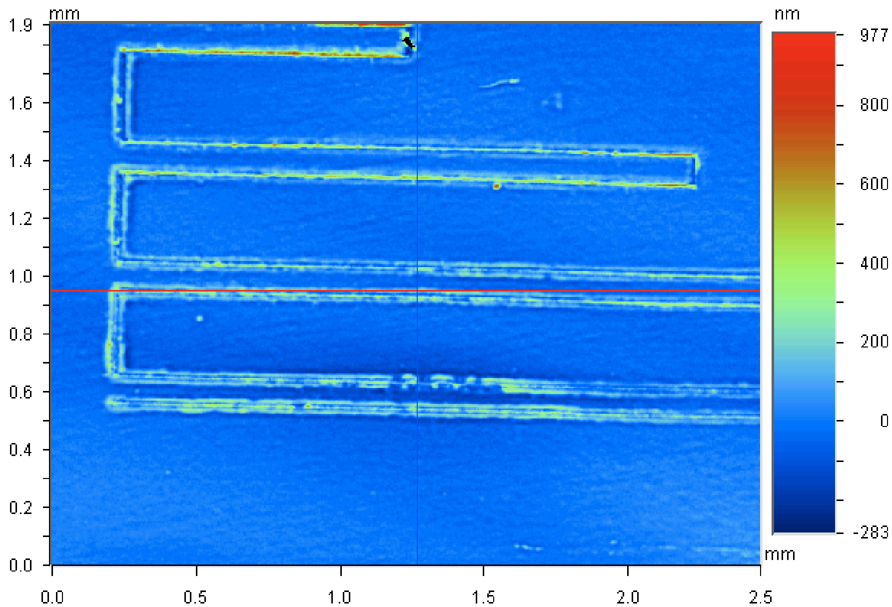
Profilometry (continued) – 0.22 W

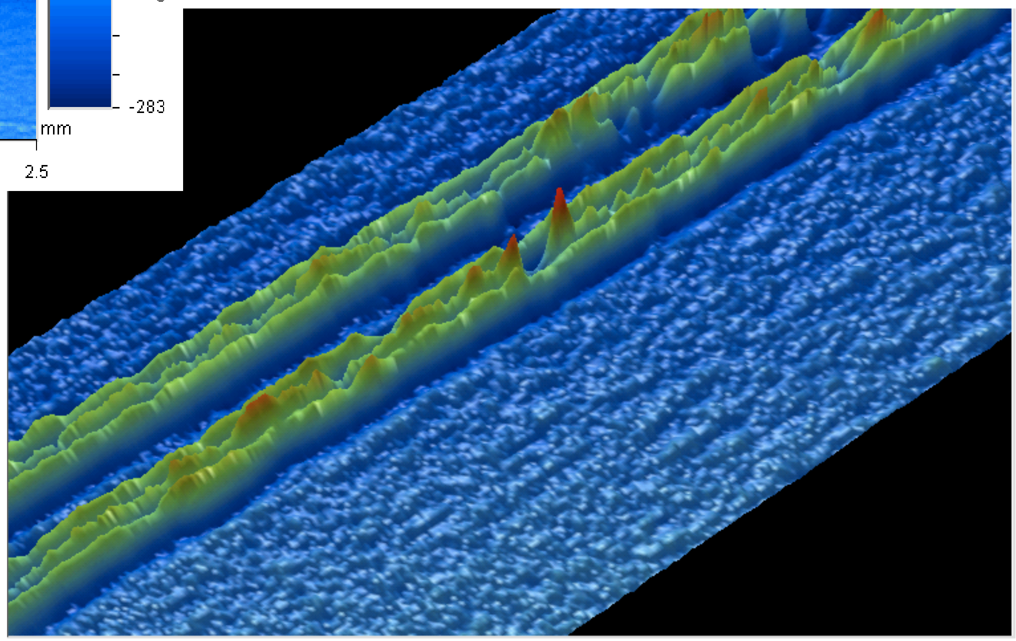






Profilometry (continued) – 0.22 W





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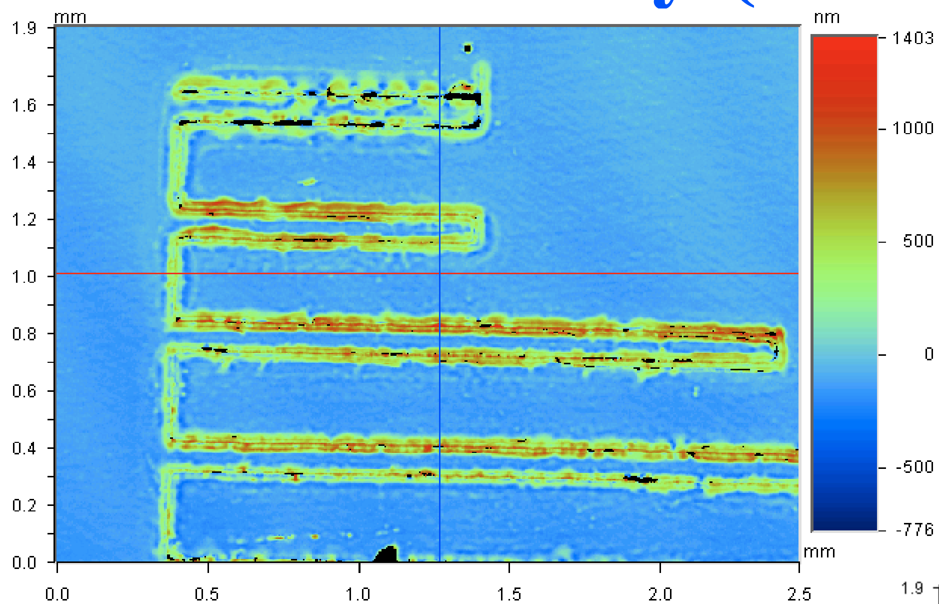
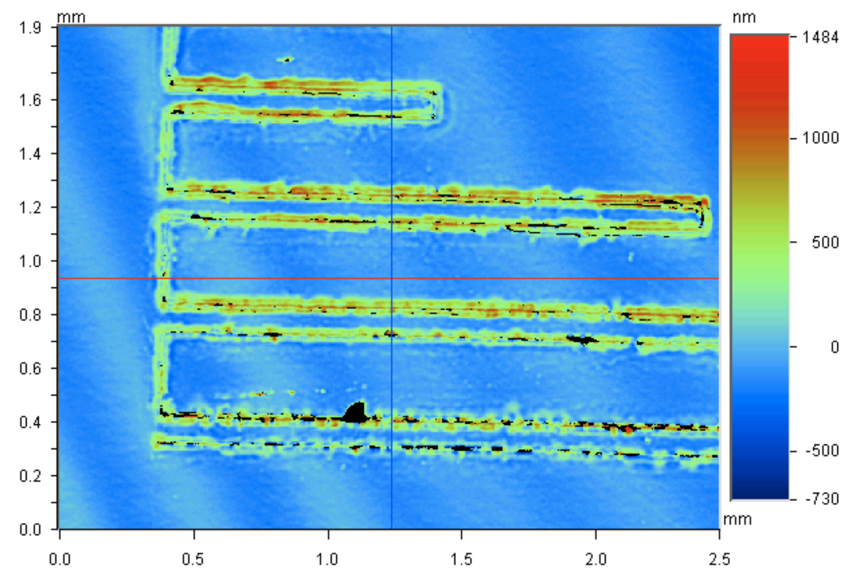
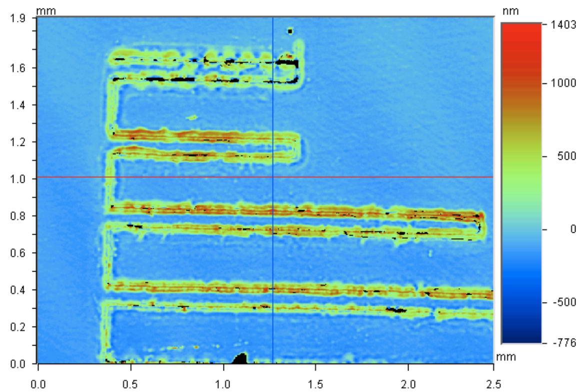
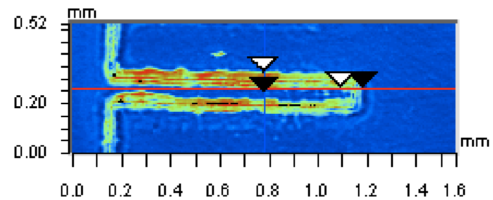
Profilometry (continued) – 0.42 W

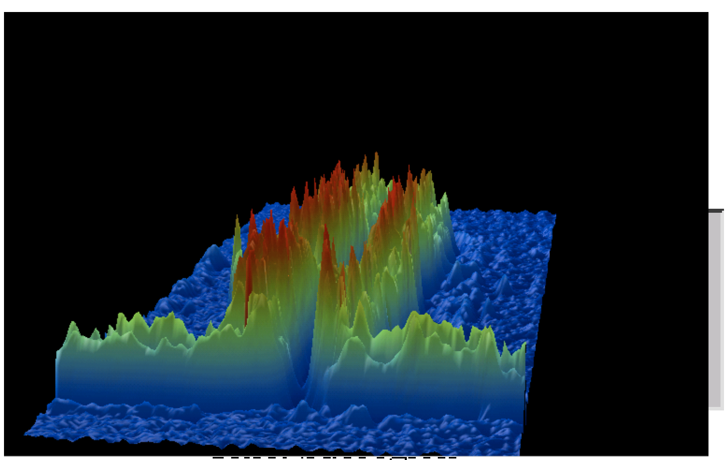


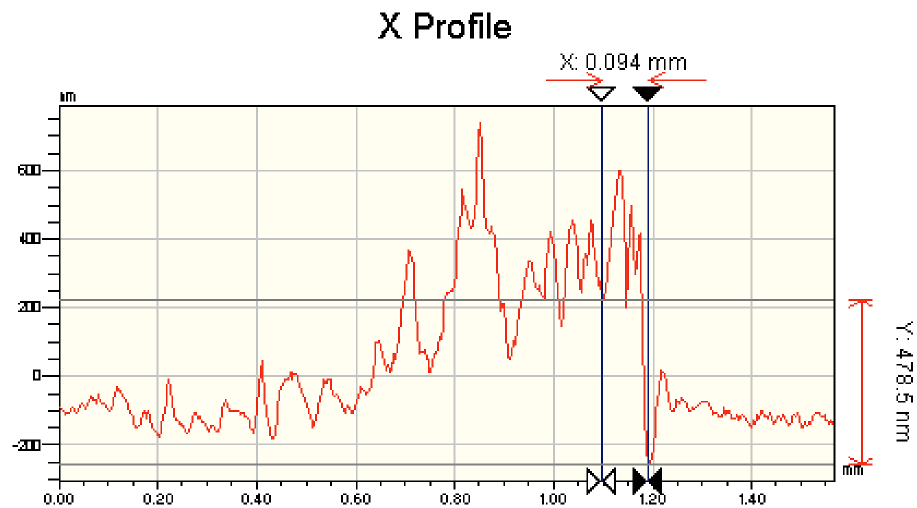


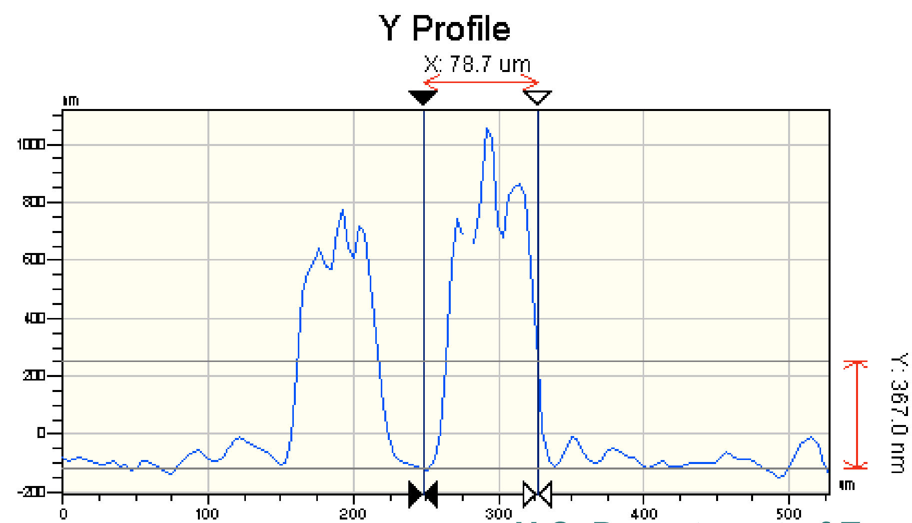
Profilometry (continued) – 0. 42 W



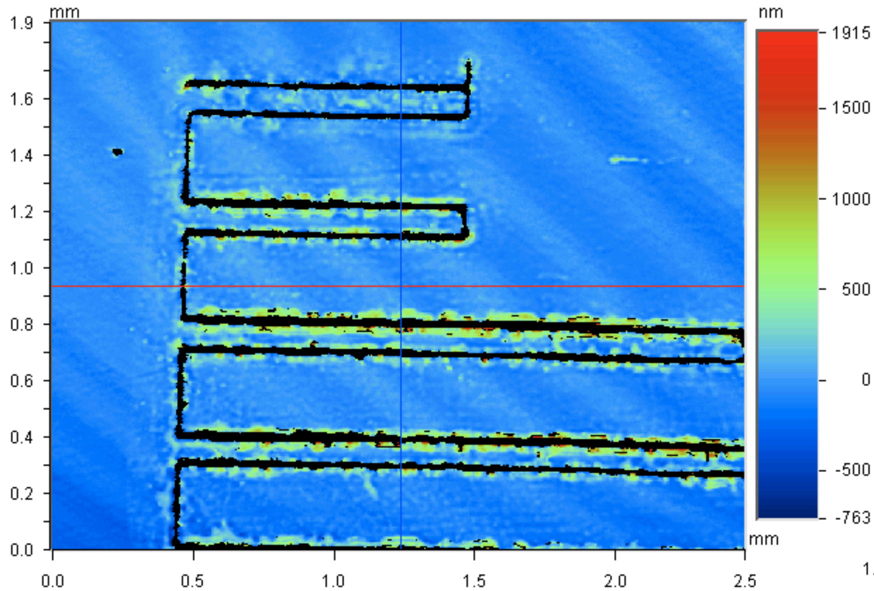


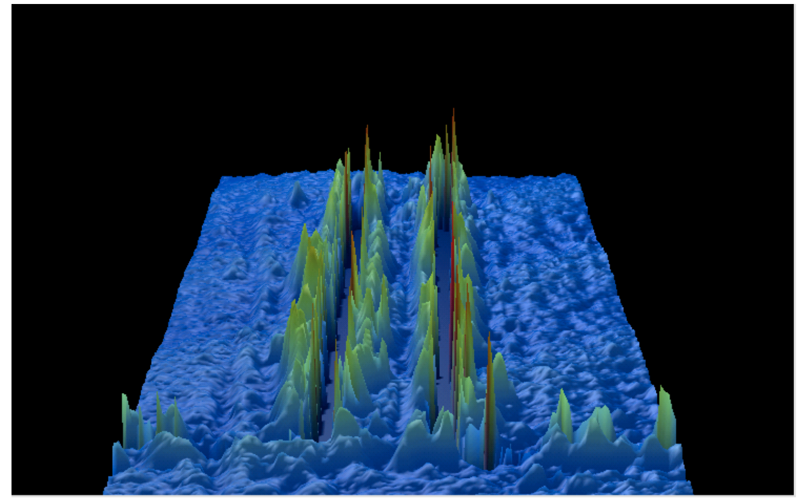


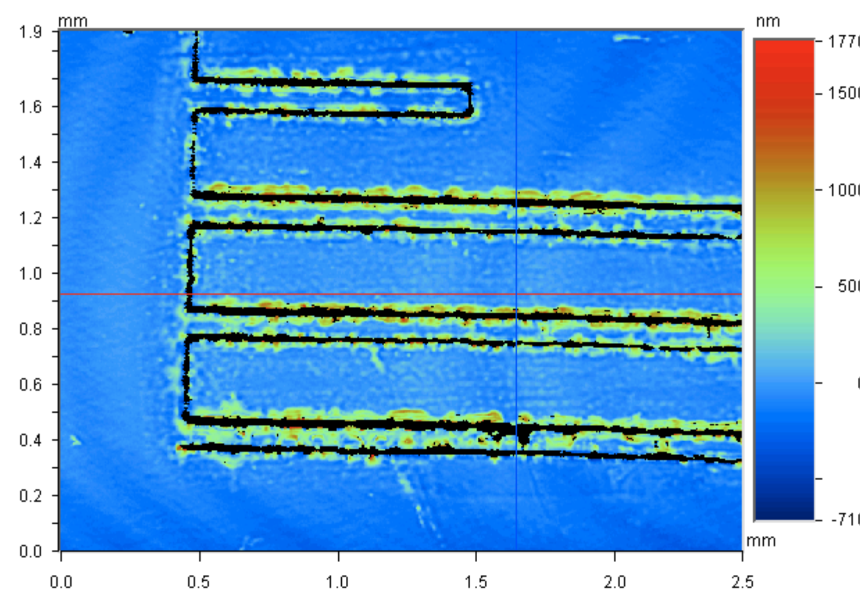




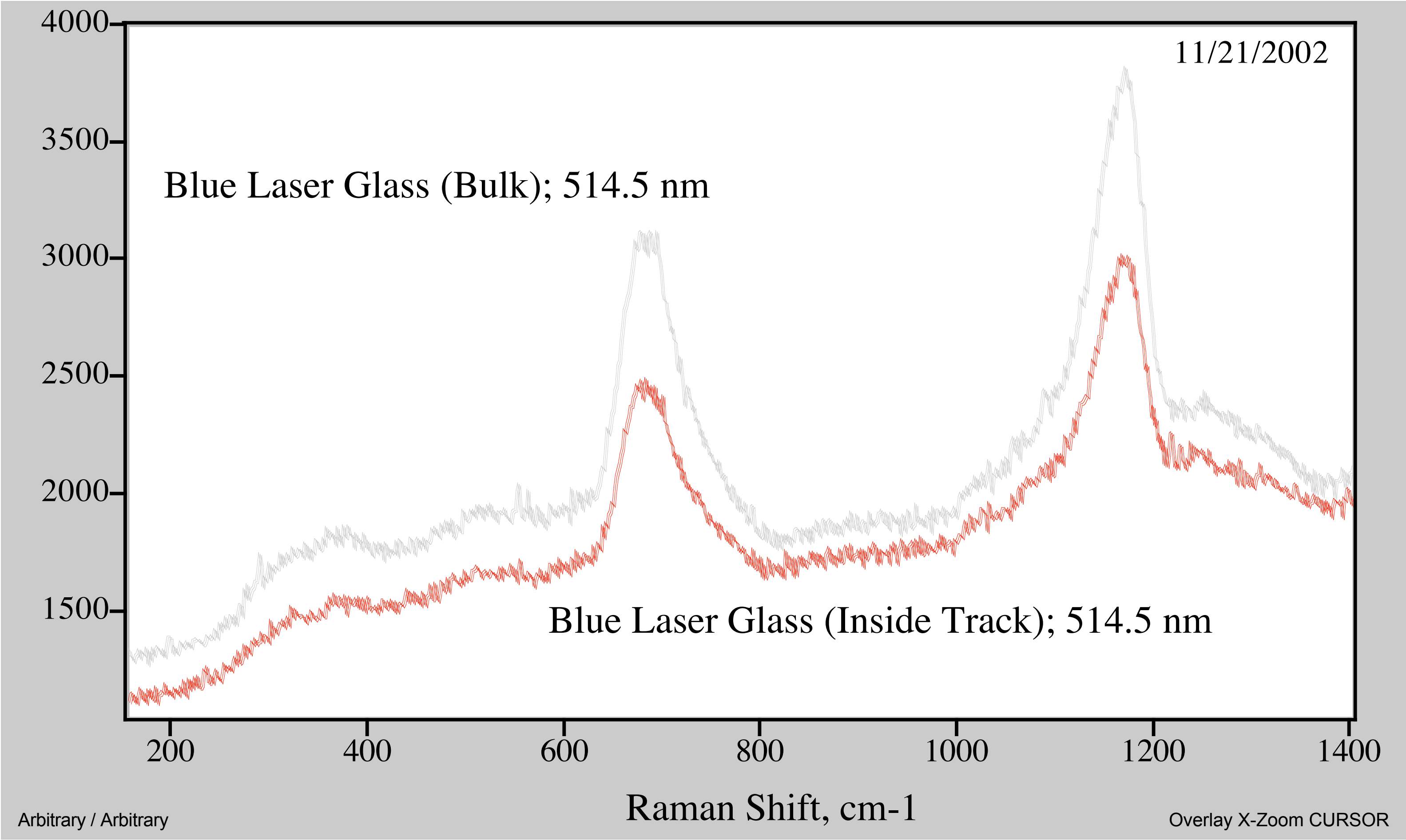
Profilometry (continued) – 0.88 W







Micro-Raman Data



Summary

- Our writing experience in active glasses shows familiar features and sequence of structure evolution- ***cone formation, collapsing, and crater-forming*** in all the samples.

- Substructure formed within lines written in samarium aluminosilicate glass may be ***signatures of shock waves or surface ripples*** frozen in the glass as the writing progresses.

Acknowledgement

- Summer interns Richard Shtiveland (OSU) and Brian Riley (UW) - preparation of the laser glass
- PNNL business development - support
- Department of Energy - support