Focused Ion Beam Writing of Optical Patterns in Amorphous Silicon Carbide

T.Tsvetkova[1], S.Takahashi[2], A.Zayats[2], P.Dawson[2], R.Turner[2], L.Bischoff[3], O.Angelov[4] and D.Dimova-Malinovska[4]

[1]Institute of Solid State Physics, 72 Tzarigradsko Chaussee, 1784 Sofia, Bulgaria

[2]Queen's University of Belfast, Belfast BT7 1NN, United Kingdom

[3]Forschungszentrum Rossendorf e.V.,P.O.Box 510119, D-01314 Dresden, Germany

[4]Central Laboratory for Solar Energy,72 Tzarigradsko Chaussee,1784 Sofia, Bulgaria

Why using (a-SiC:H) :

- *high transparency in the visible region due to their wide optical band gap (1.8-3.0 eV) ;*
- *mechanical durability and chemical inertness ;*
- *thermal stability and easy preparation ;*
- *Radio-frequency (RF) reactive magnetron sputtering is a convenient method used to prepare a-SiC:H films where low density-of-states material is not required, as it is often the case.*

How to obtain nano-scale optical patterning ?

- ***Generally the Ion Implantation leads to modification of the electronic characteristics of materials (the band gap and related optical and electrical properties).***

- ***Computer-operated focused ion beam (FIB) systems and the possibilities they reveal for fabricating various sophisticated planar structures with nano-size dimensions are the answer.***

- ***Promising results have been obtained when implementing this technique while using a-SiC:H films to develop a new method for high-density optical data storage.***

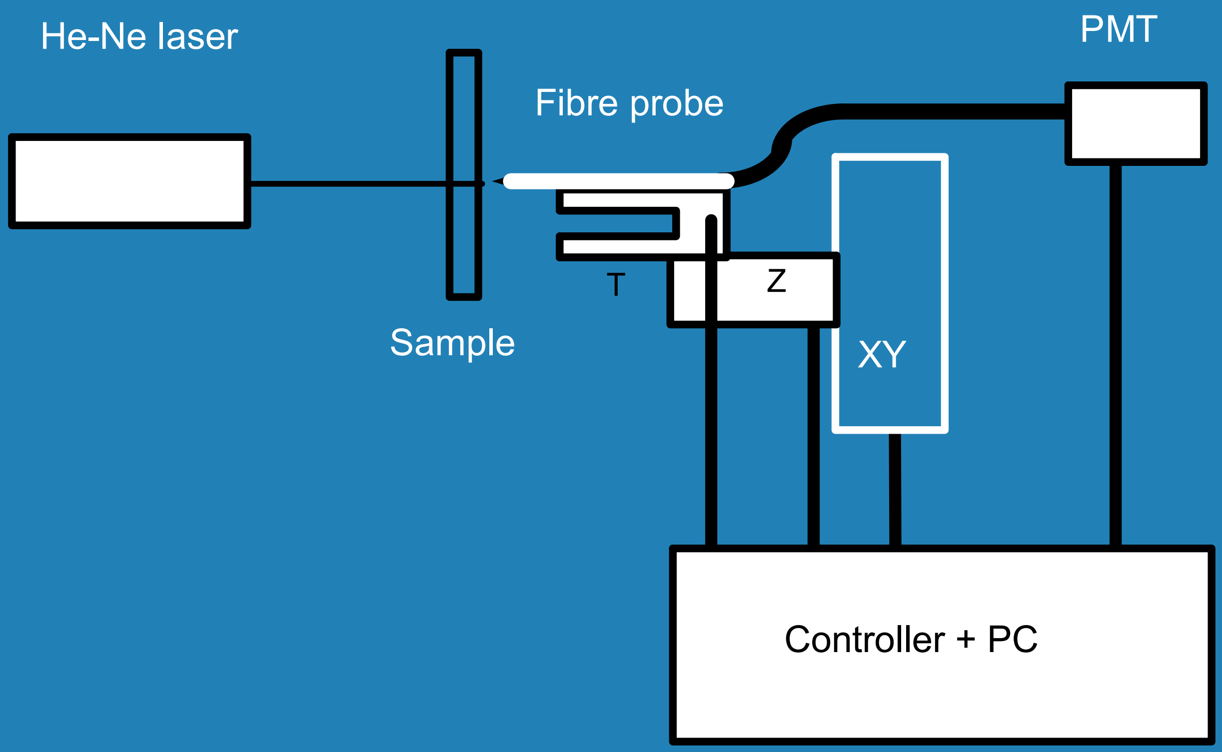
Material preparation

- a-$Si_{1-x}C_x$:H films (x=0.15) were deposited onto Corning glass substrates by RF (13.56 MHz) reactive magnetron sputtering.
- A composite target, composed of mono-crystalline (100) silicon wafer with chips of pure graphite placed on it, was sputtered in an Ar-20%H_2 gas mixture.
- Typical deposition conditions are RF power 150W (power density 1.91 W/cm^2), total gas pressure 1P, substrate temperature 275^{o}C, and graphite-to-silicon target ratio 0.025.
- The film thickness was determined by Talystep profilometer and optical measurements to be ~200 nm.
- Rutherford backscattering spectrometry (RBS) was used to determine the carbon content (x) of the films.

Patterning and characterization techniques:

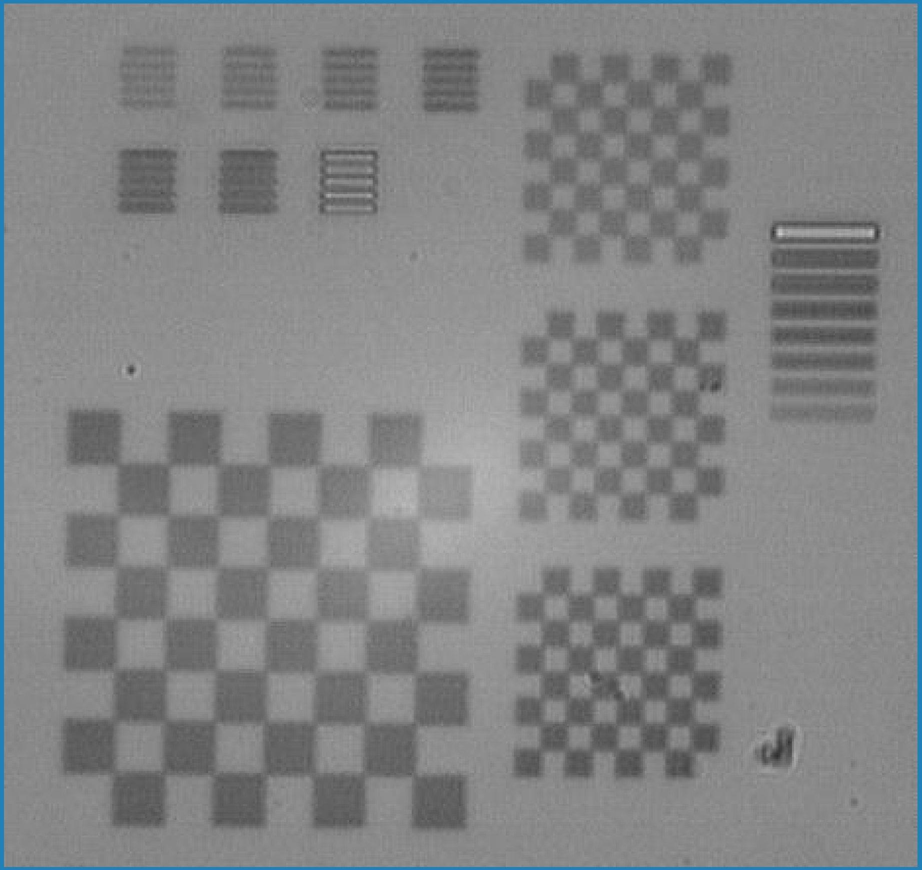
- Focused Ga^{+} ion beam implantation in these samples was performed by computer-operated FIB systems to produce various sophisticated, preliminary designed, optical patterns.
- Two different equipments were used: (a) the focused ion beam system IMSA-Orsay Physics at FZ Rossendorf (FZR),Germany; and (b) the focused ion beam system (FEI TEM-200) at Queen's University of Belfast (QUB), United Kingdom.
- Atomic Force Microscopy (AFM) was applied to analyze the various optical patterns using the AFM equipment at QUB.
- The Scanning Near-Field Optical Microscope (SNOM), also available at QUB, was further used to study the process of optical patterning and to confirm the increased optical absorption in the patterned areas as compared to the non-irradiated ones.

SNOM set up:



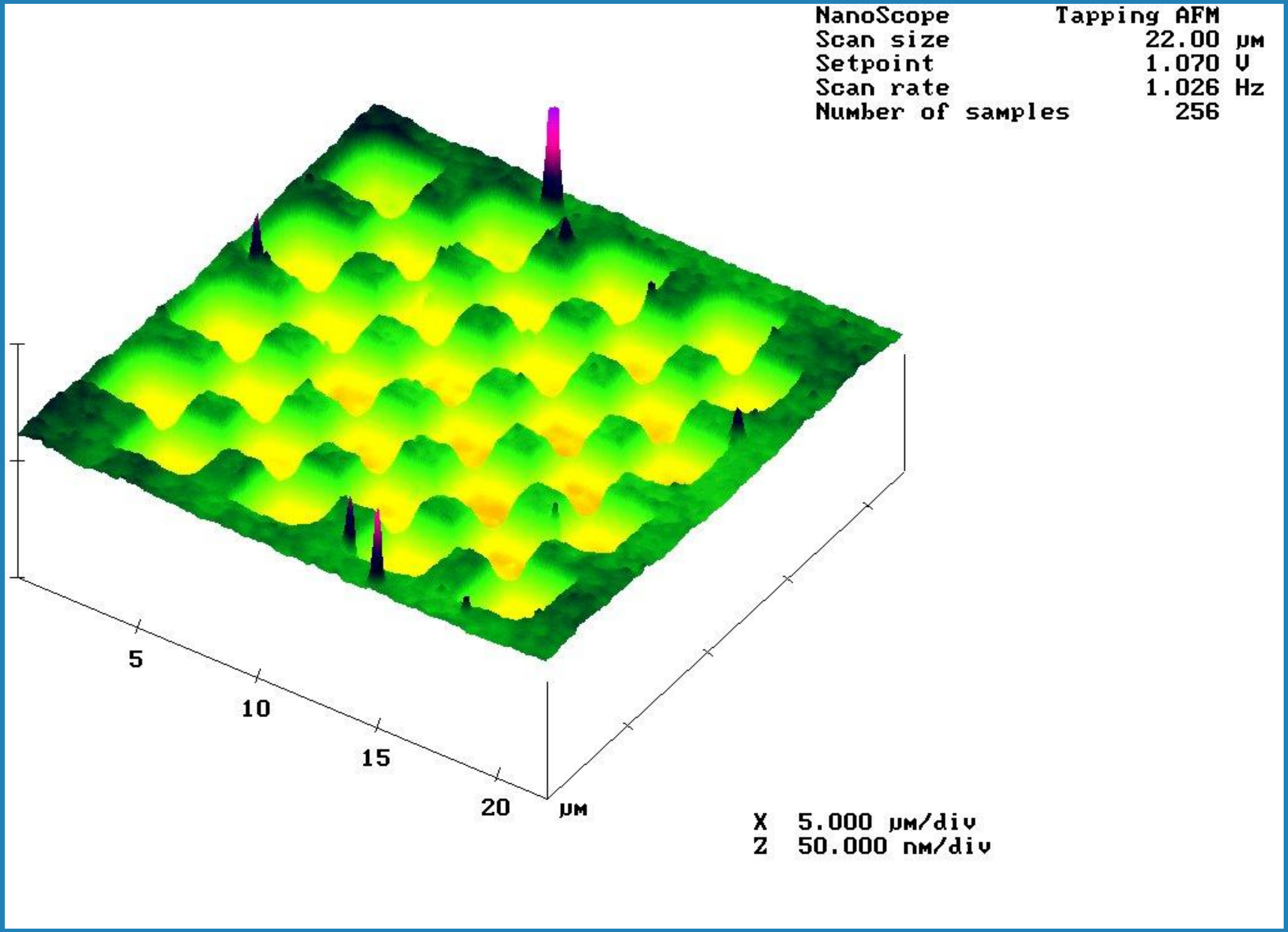
Results:

(I) Micron-scale patterns:

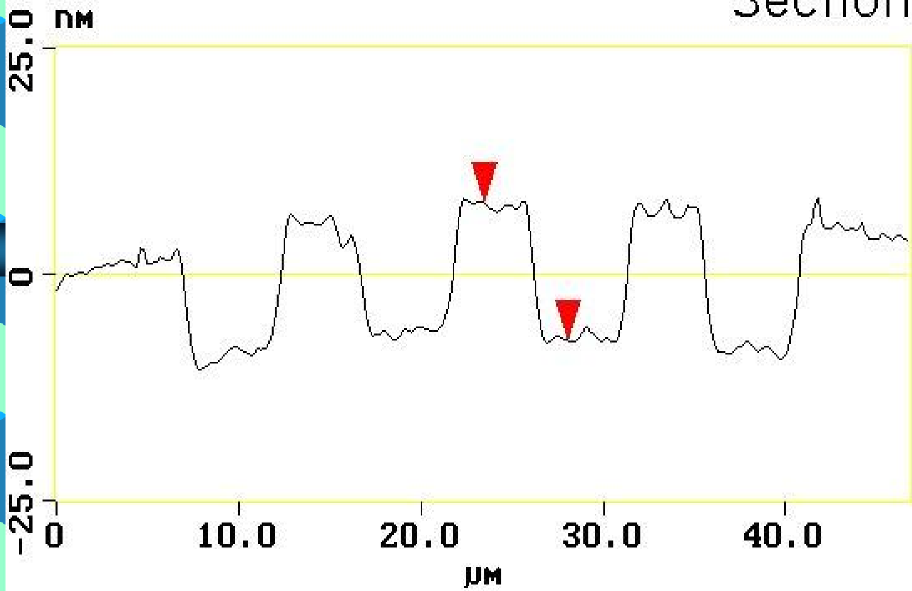


Optical contrast pattern, written with the IMSA-Orsay: FIB using a 15pA Ga beam into a-SiC:H film. The size of the big chess field is 20 x 20 µm^2.

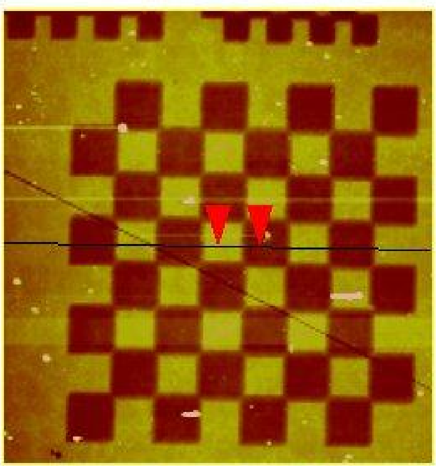
AFM analysis:

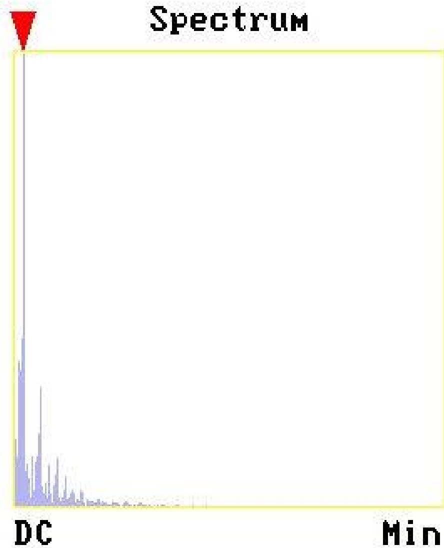


Section Analysis



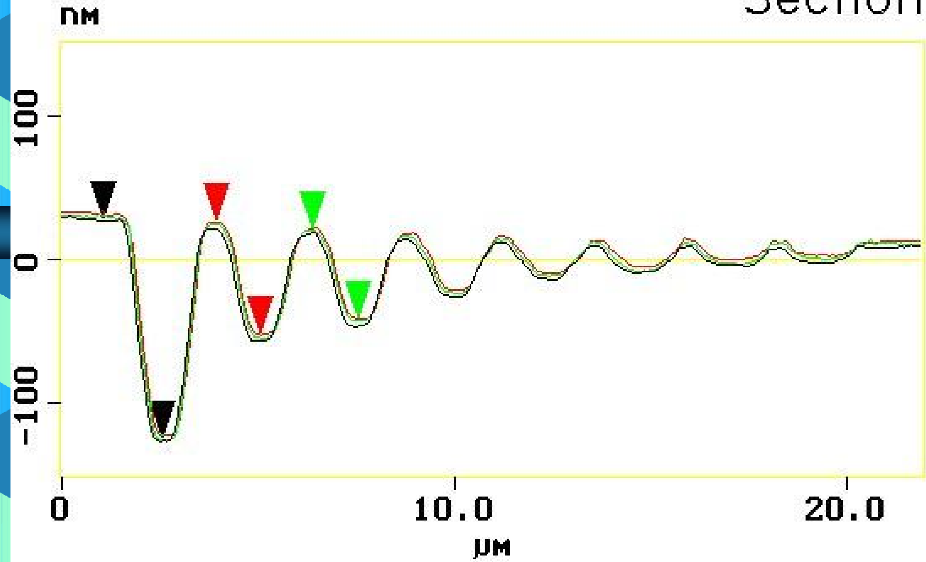
L	4.593 µm
RMS	6.833 nm
lc	9.370 µm
Ra(lc)	1.156 nm
Rmax	10.848 nm
Rz	8.328 nm
Rz Cnt	4



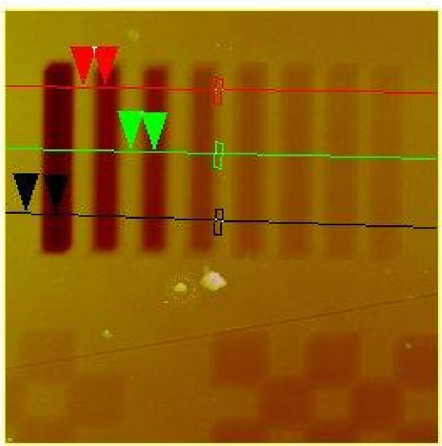


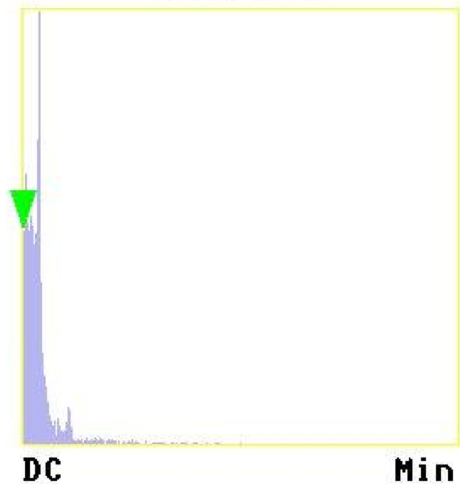
Surface distance	4.593 µm
Horiz distance(L)	4.593 µm
Vert distance	15.030 nm
Angle	0.187 deg
Surface distance	
Horiz distance	
Vert distance	
Angle	
Surface distance	
Horiz distance	
Vert distance	
Angle	
Spectral period	9.370 µm
Spectral freq	2.777 Hz
Spectral RMS amp	0.005 nm

Section Analysis



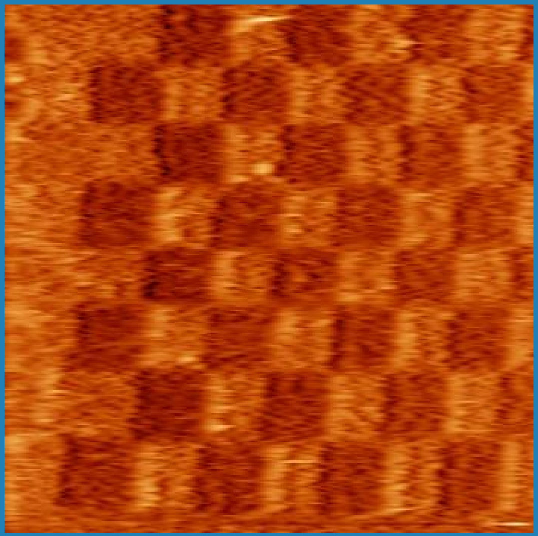
L	1.203 µm
RMS	24.587 nm
lc	DC
Ra(lc)	4.289 nm
Rmax	19.152 nm
Rz	16.388 nm
Rz Cnt	4

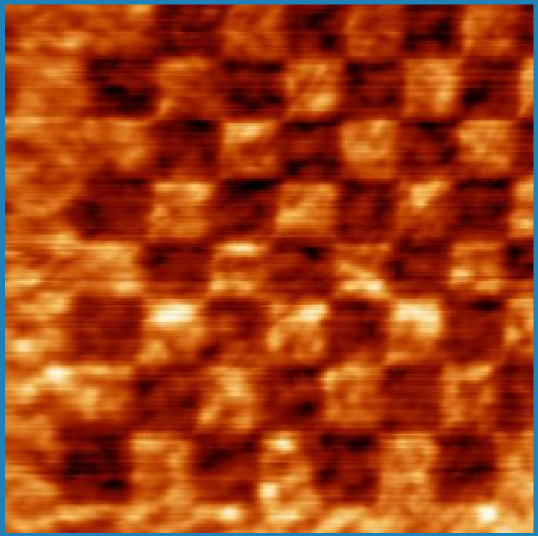




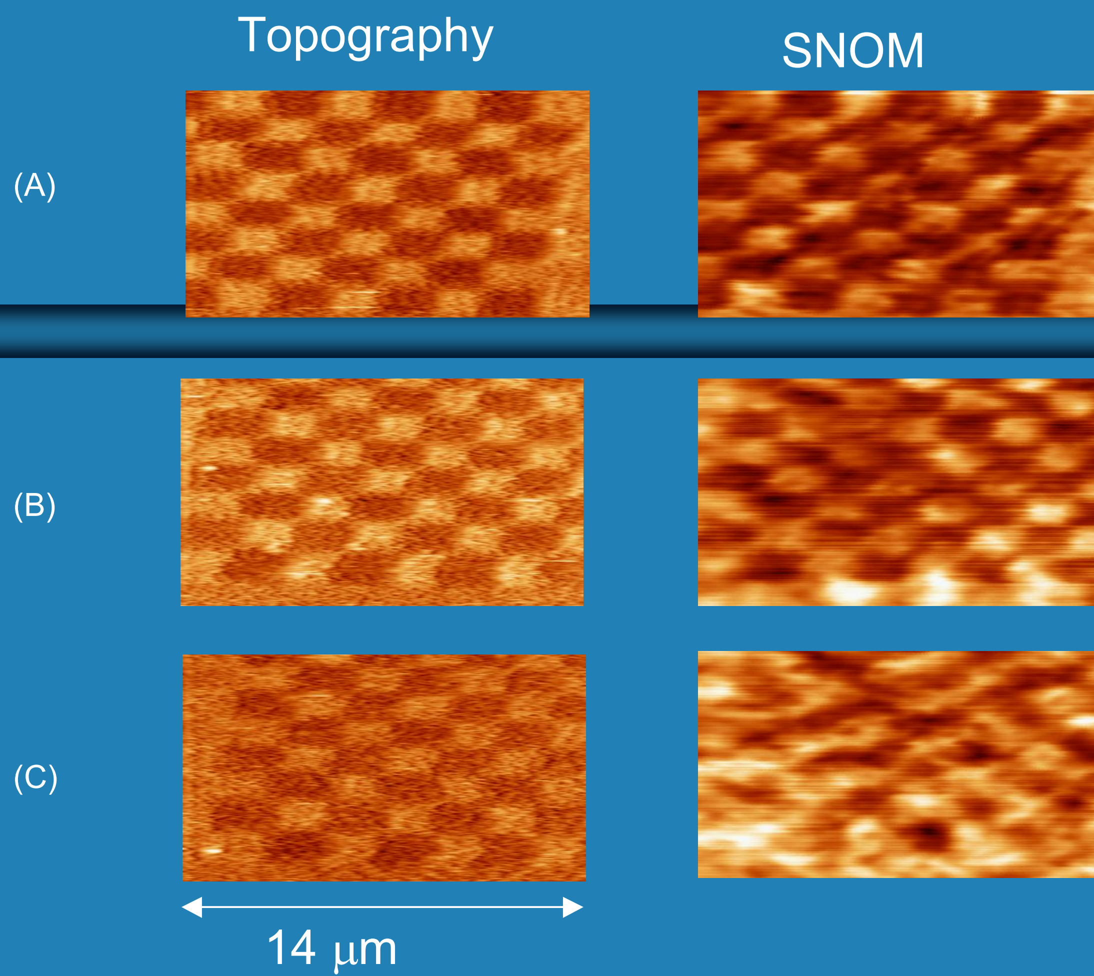
Surface distance	1.121 µm
Horiz distance(L)	1.117 µm
Vert distance	78.437 nm
Angle	4.016 deg
Surface distance	1.206 µm
Horiz distance	1.203 µm
Vert distance	61.846 nm
Angle	2.943 deg
Surface distance	1.563 µm
Horiz distance	1.547 µm
Vert distance	153.30 nm
Angle	5.660 deg
Spectral period	DC
Spectral freq	0 Hz
Spectral RMS amp	8.081 nm

SNOM data:



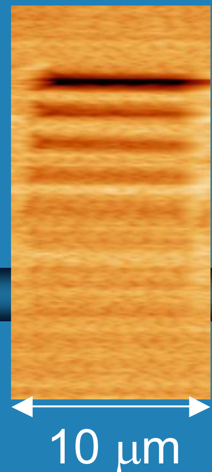


Topographic image (left) and corresponding SNOM image (right) of a chess-board pattern created on a SiC thin film with FIB.

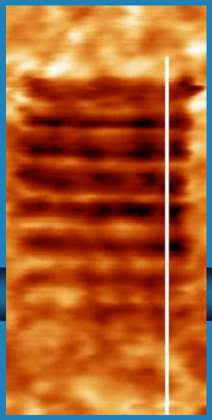


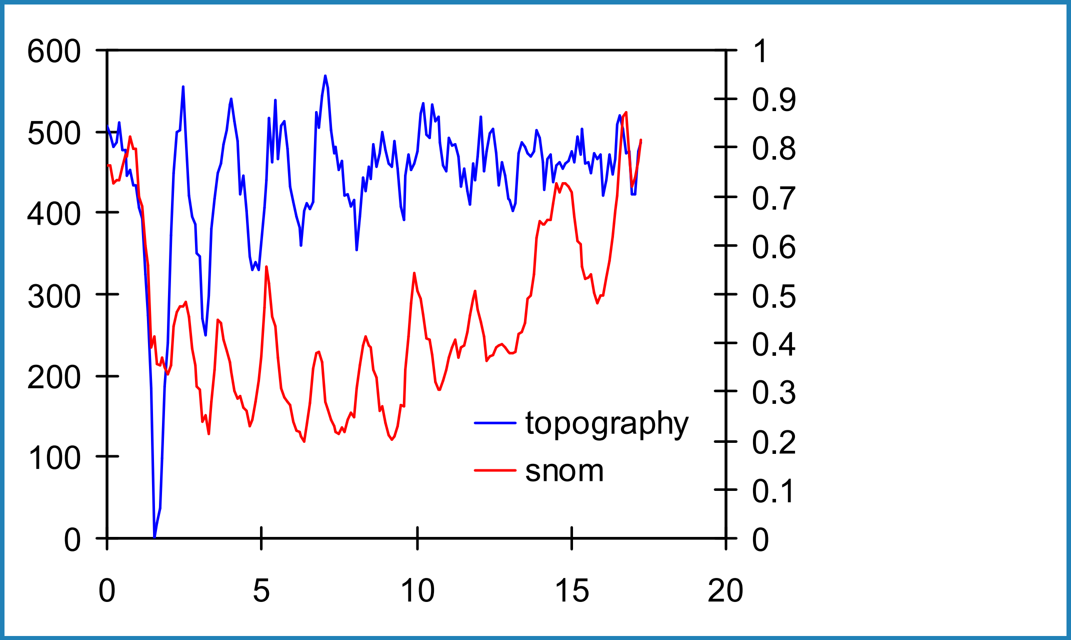
Variation of topographic and optical contrasts of chess board patterns with different FIB process conditions.

Topography



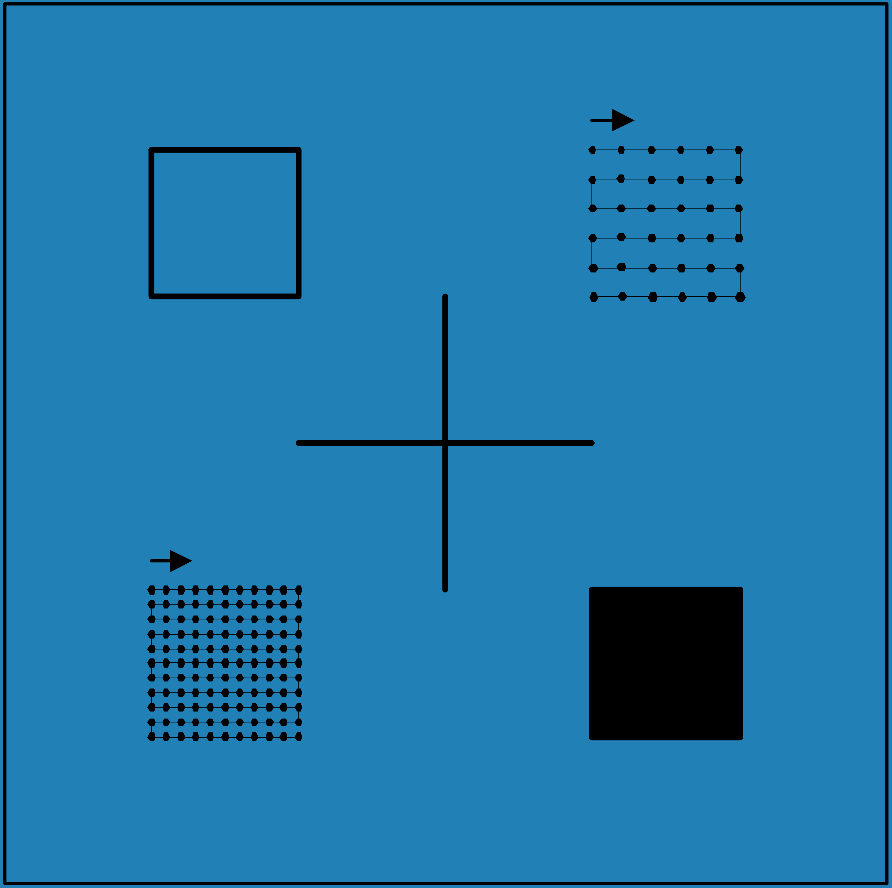
SNOM





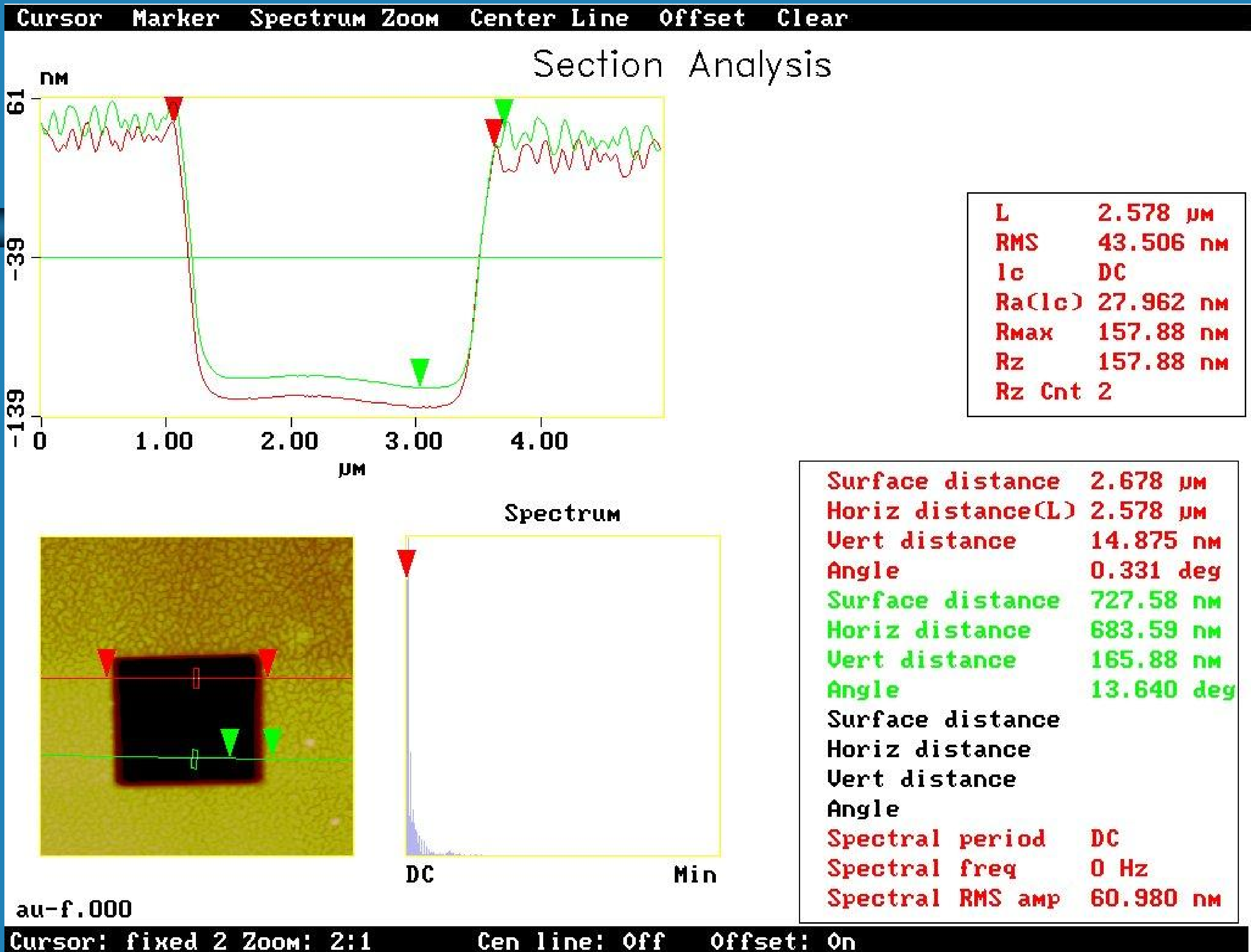
Variation of topographic and optical contrasts of a set of lines with different FIB process conditions. The cross sectional view is taken along the line AB drawn on the SNOM image.

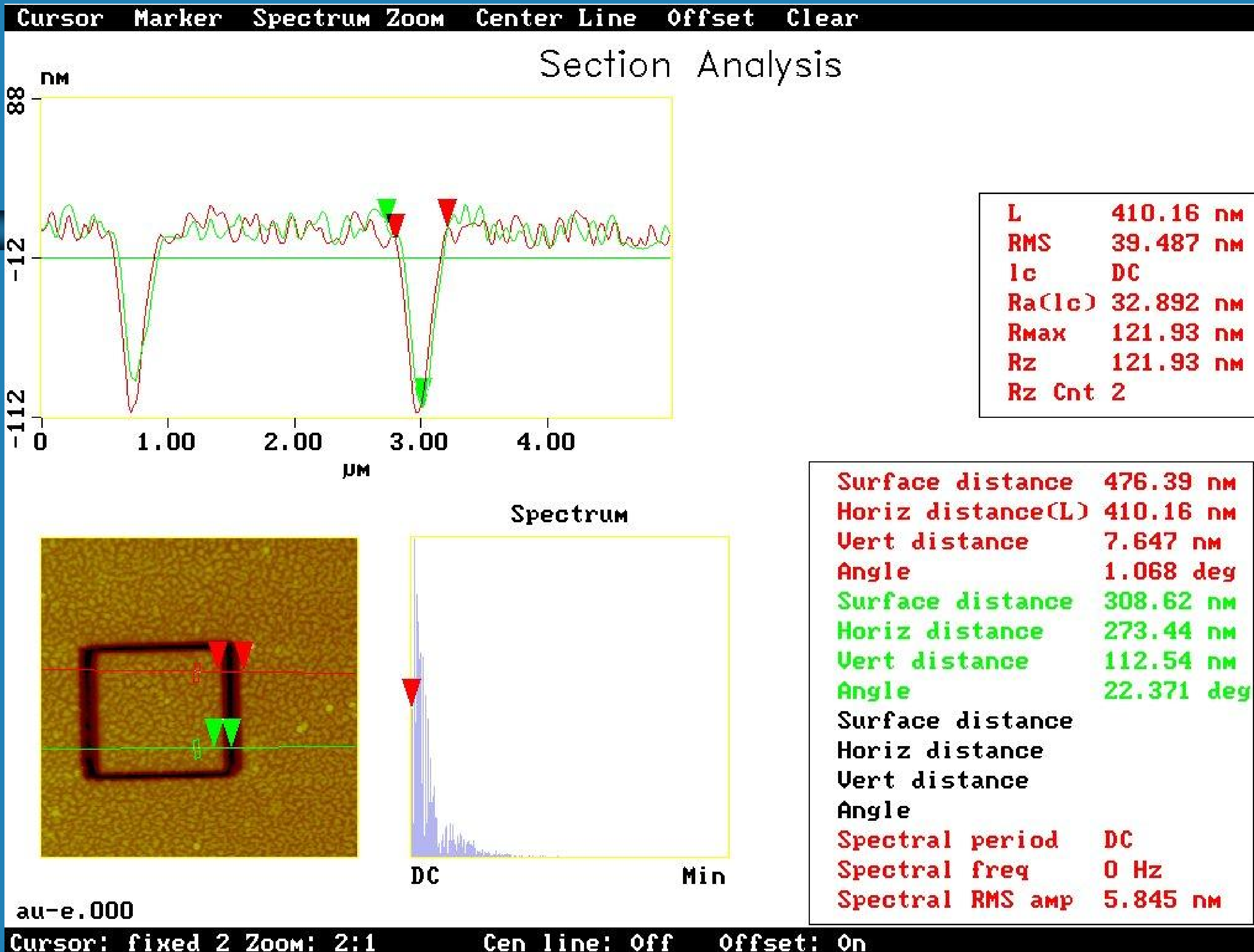
(II) Nano-scale patterns:

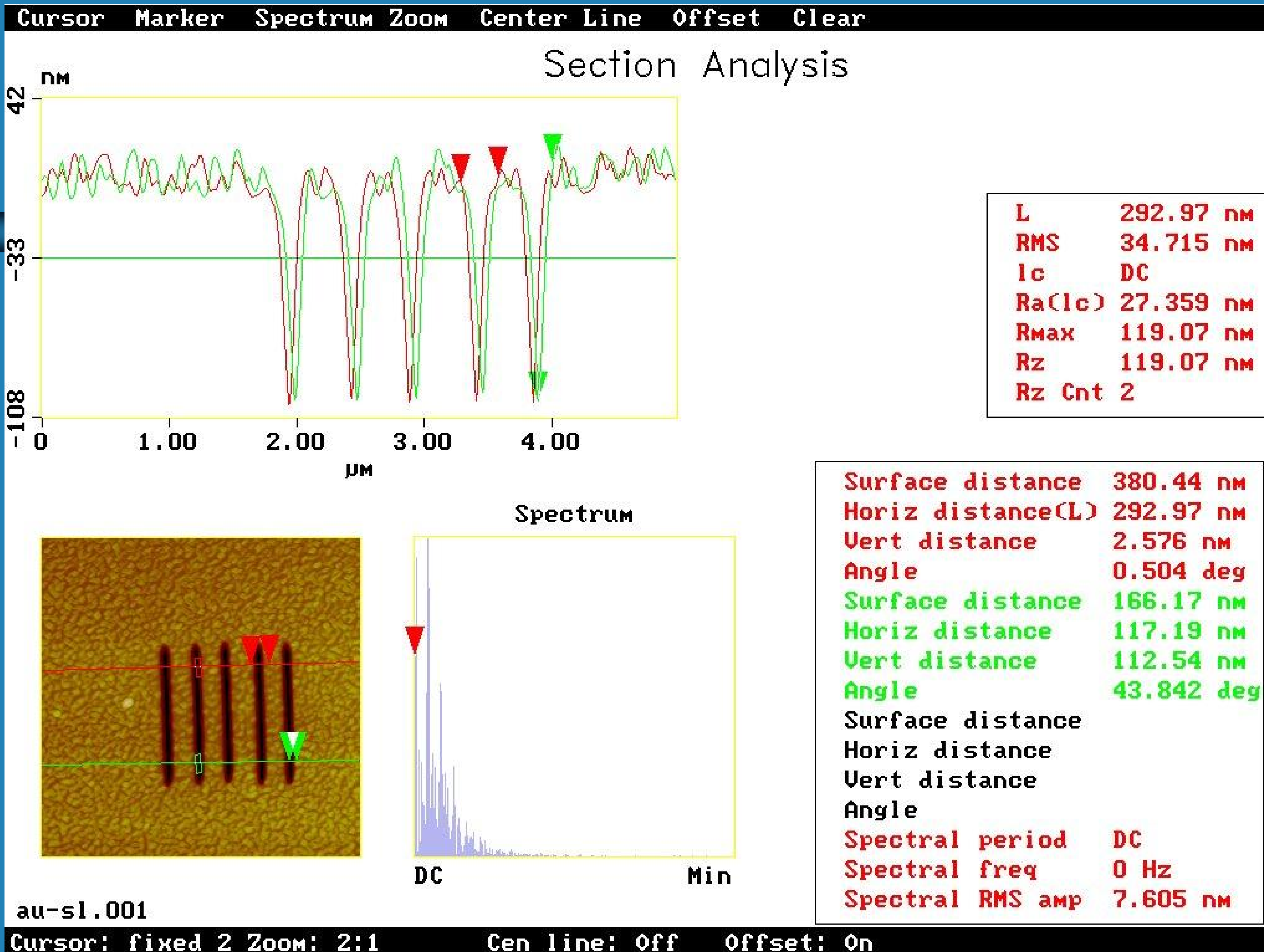


FIB written pattern. The arrows mark the scan directions in the meander like dot matrixes made without blanking within one cycle.

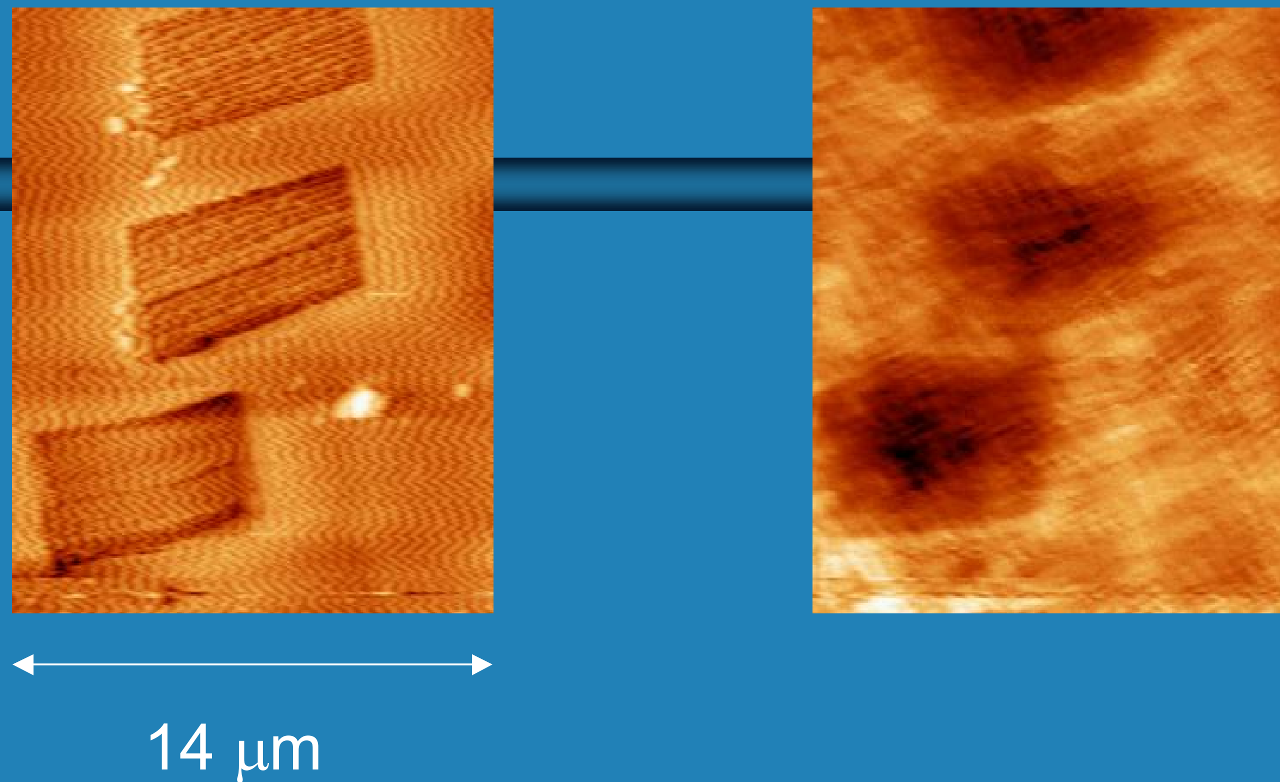
The pixel dwell time was chosen to be 100 µs and 200 repetitions (cycles) were used to achieve a dose of about 1×10^{17} cm^{-2} per pixel.


Cursor Marker Spectrum Zoom Center Line Offset Clear
Section Analysis
nm
61
-39
-139
0
1.00
2.00
3.00
4.00
µm
L 2.578 µm
RMS 43.506 nm
lc DC
Ra(lc) 27.962 nm
Rmax 157.88 nm
Rz 157.88 nm
Rz Cnt 2
Spectrum
DC
Min
Surface distance 2.678 µm
Horiz distance(L) 2.578 µm
Vert distance 14.875 nm
Angle 0.331 deg
Surface distance 727.58 nm
Horiz distance 683.59 nm
Vert distance 165.88 nm
Angle 13.640 deg
Surface distance
Horiz distance
Vert distance
Angle
Spectral period DC
Spectral freq 0 Hz
Spectral RMS amp 60.980 nm
au-f.000
Cursor: fixed 2 Zoom: 2:1
Cen line: Off
Offset: On


Cursor Marker Spectrum Zoom Center Line Offset Clear
Section Analysis
nm
88
-12
-112
0
1.00
2.00
3.00
4.00
μm
L 410.16 nm
RMS 39.487 nm
lc DC
Ra(lc) 32.892 nm
Rmax 121.93 nm
Rz 121.93 nm
Rz Cnt 2
Spectrum
DC
Min
au-e.000
Surface distance 476.39 nm
Horiz distance(L) 410.16 nm
Vert distance 7.647 nm
Angle 1.068 deg
Surface distance 308.62 nm
Horiz distance 273.44 nm
Vert distance 112.54 nm
Angle 22.371 deg
Surface distance
Horiz distance
Vert distance
Angle
Spectral period DC
Spectral freq 0 Hz
Spectral RMS amp 5.845 nm
Cursor: fixed 2 Zoom: 2:1
Cen line: Off
Offset: On

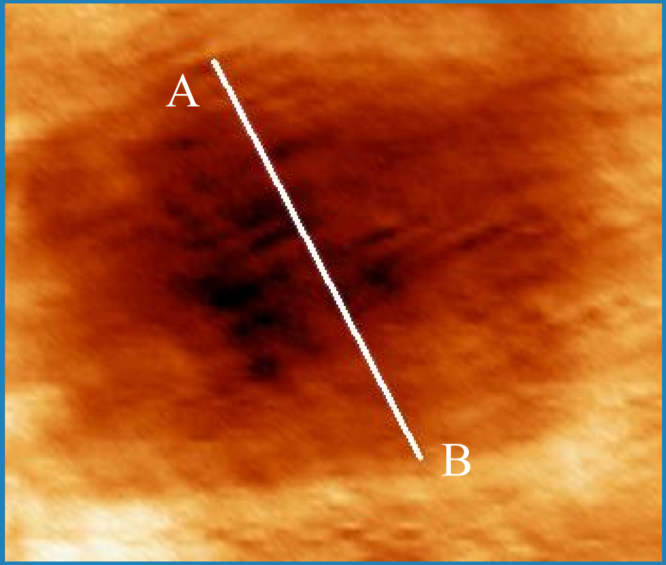

Cursor Marker Spectrum Zoom Center Line Offset Clear
Section Analysis
nm
42
-33
-108
0
1.00
2.00
3.00
4.00
μm
L 292.97 nm
RMS 34.715 nm
lc DC
Ra(lc) 27.359 nm
Rmax 119.07 nm
Rz 119.07 nm
Rz Cnt 2
Spectrum
DC
Min
au-sl.001
Surface distance 380.44 nm
Horiz distance(L) 292.97 nm
Vert distance 2.576 nm
Angle 0.504 deg
Surface distance 166.17 nm
Horiz distance 117.19 nm
Vert distance 112.54 nm
Angle 43.842 deg
Surface distance
Horiz distance
Vert distance
Angle
Spectral period DC
Spectral freq 0 Hz
Spectral RMS amp 7.605 nm
Cursor: fixed 2 Zoom: 2:1 Cen line: Off Offset: On

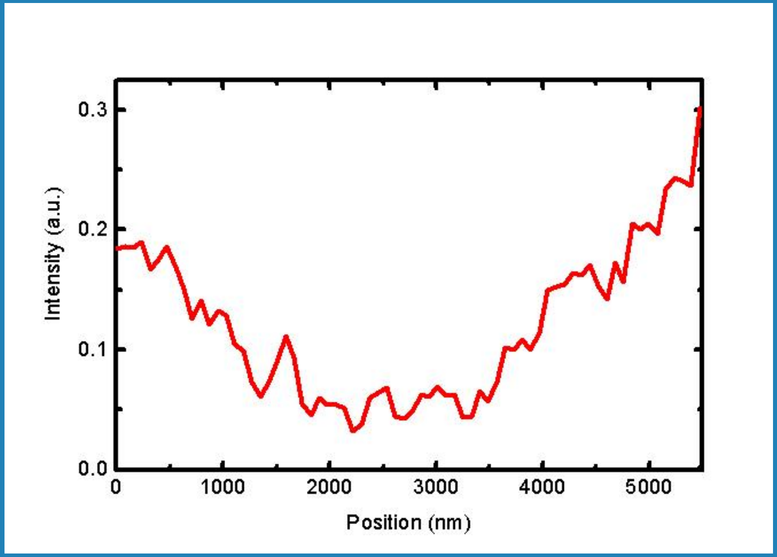
Topography SNOM



Topographic image (left) and corresponding SNOM image (right) of a set of gratings created on SiC coated with a gold layer.

A cross sectional analysis of the SNOM image.



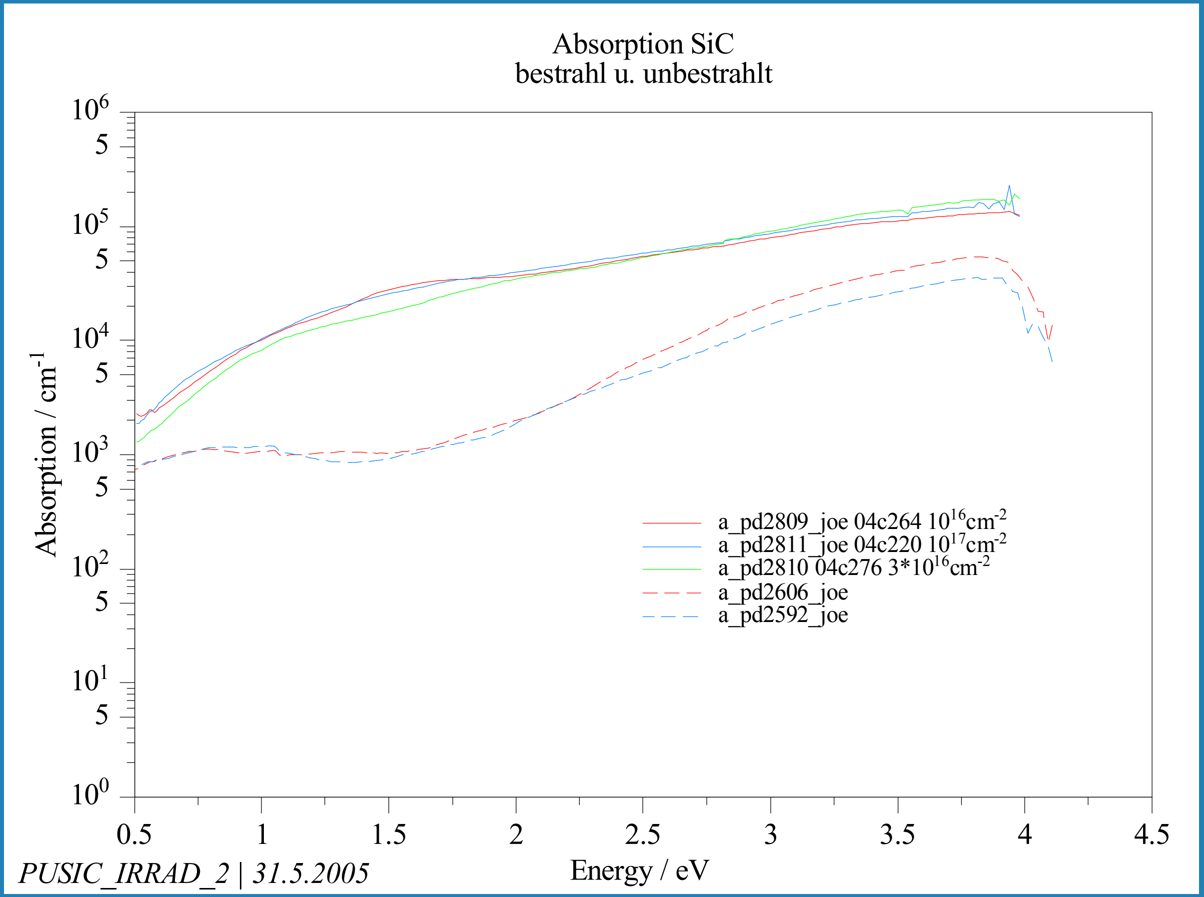


The SNOM image shown here corresponds to the grating located in the left-hand bottom of the SNOM image. The cross section was taken along the line AB drawn in this zoomed-up SNOM image.

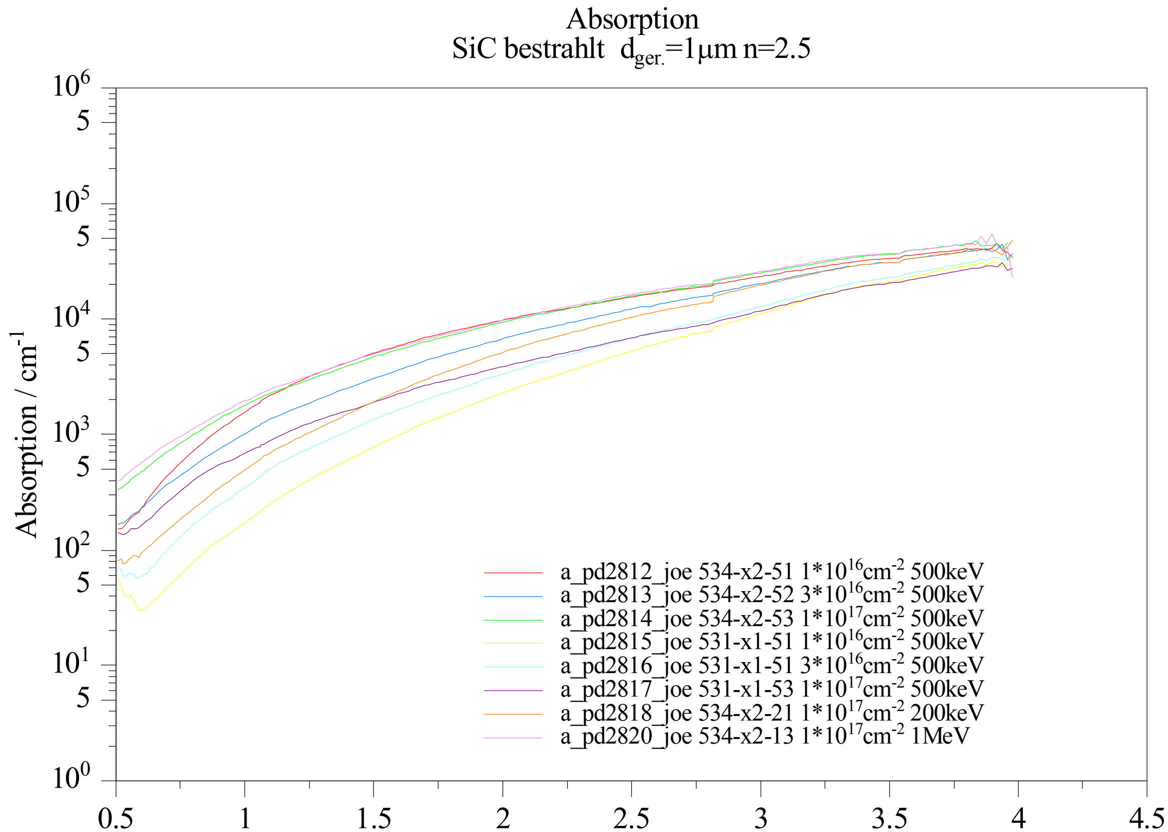
AFM and SNOM Comments

- Direct focused ion beam writing of optical patterns in amorphous silicon carbide (a-SiC:H) is a promising method for high-density optical data storage.
- Although Atomic Force Microscopy (AFM) reveals considerable thickness change (thinning tendency) in the ion-irradiated areas, Scanning Near-Field Optical Microscopy (SNOM) confirms the increase of optical absorption in these areas. This increase is of such considerable size, which provides sufficient optical contrast, so that to justify the effectiveness of the method down to nano-scale optical patterning, obtained here for the first time.
- Further experiments are in run with the aim of eliminating the thin surface conductive layer on the films, while using an additional charge neutralizing e^- beam shower instead. Combination of lower doses ion implantation with subsequent thermal annealing is also envisaged with view of further increase of the cost-effectiveness of the process.

PDS data on the Juelich SiC samples. There is an order of magnitude increase in absorption but not much dependence on the irradiation dose

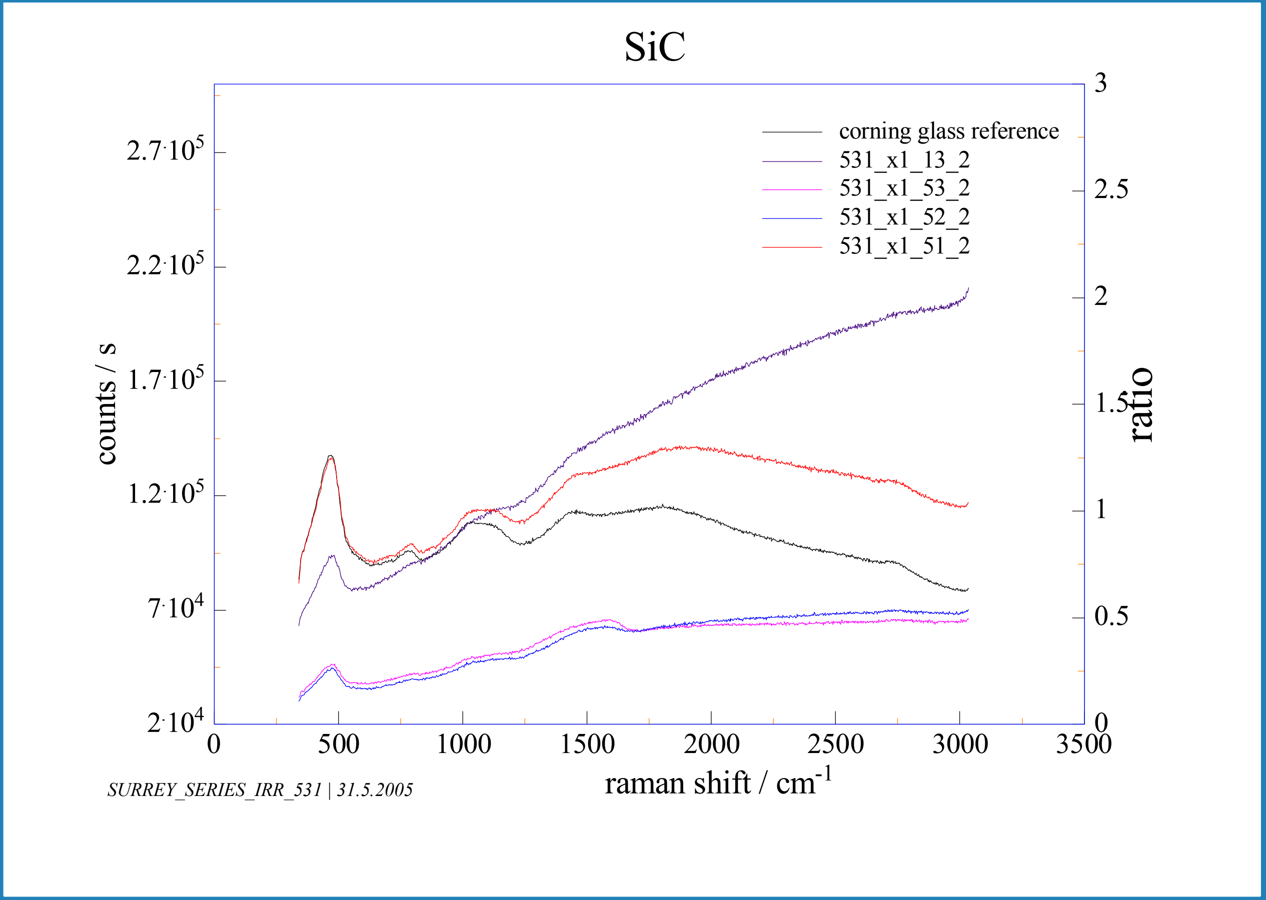


These are the results on the Sofia series; the data evaluation has been made by assuming a film thickness of 1µm. The 531 series has lower absorption and the same dose when compared with the 534 series. Increasing dose leads to increasing absorption in a wide spectral range. Increasing ion energy from 0.2 to 0.5 MeV leads also to an increase of the absorption but further increase to 1 MeV has hardly an additional effect, at least for the high dose of 10^{17} cm^{-2}.

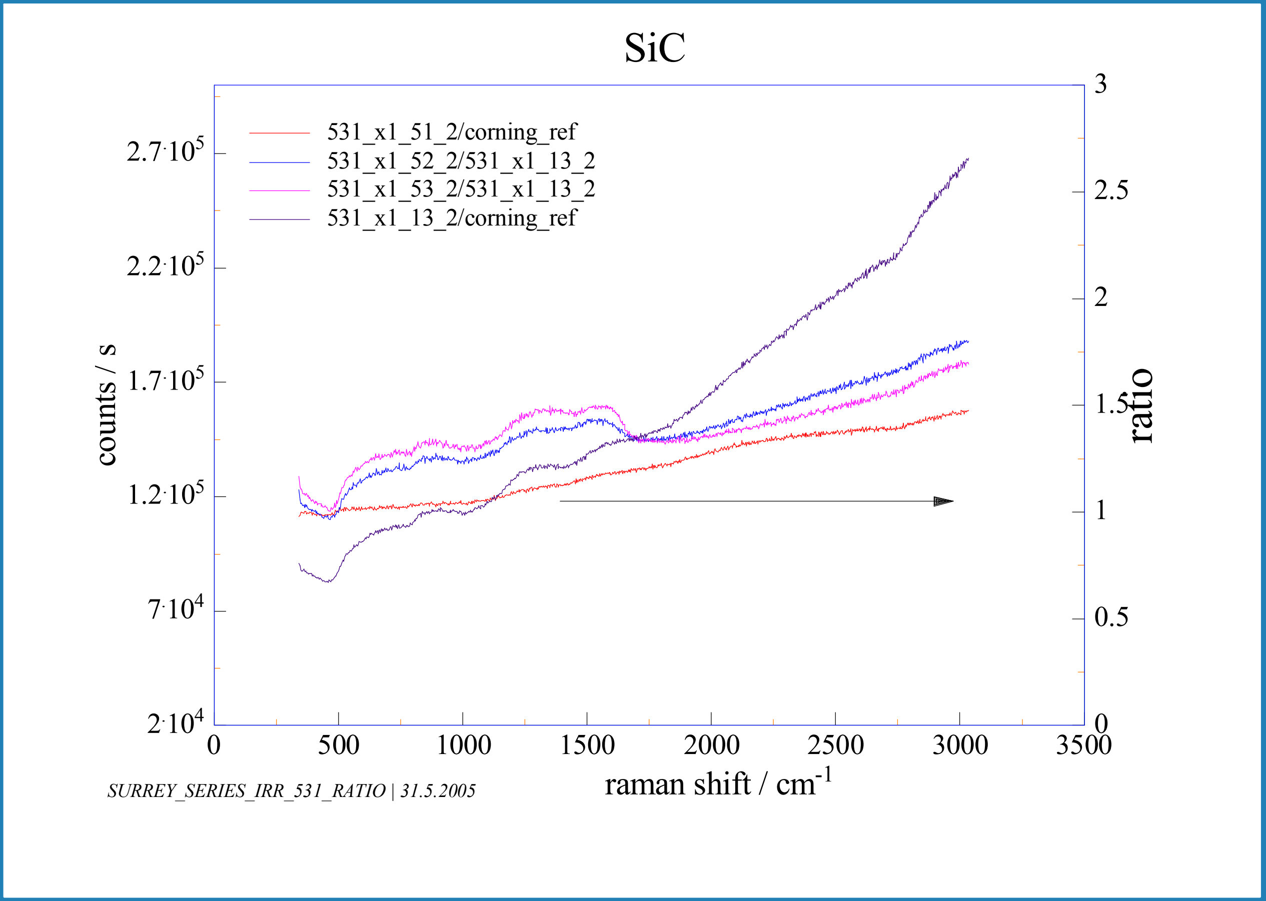


PUSIC_IRRAD_4 | 31.5.2005

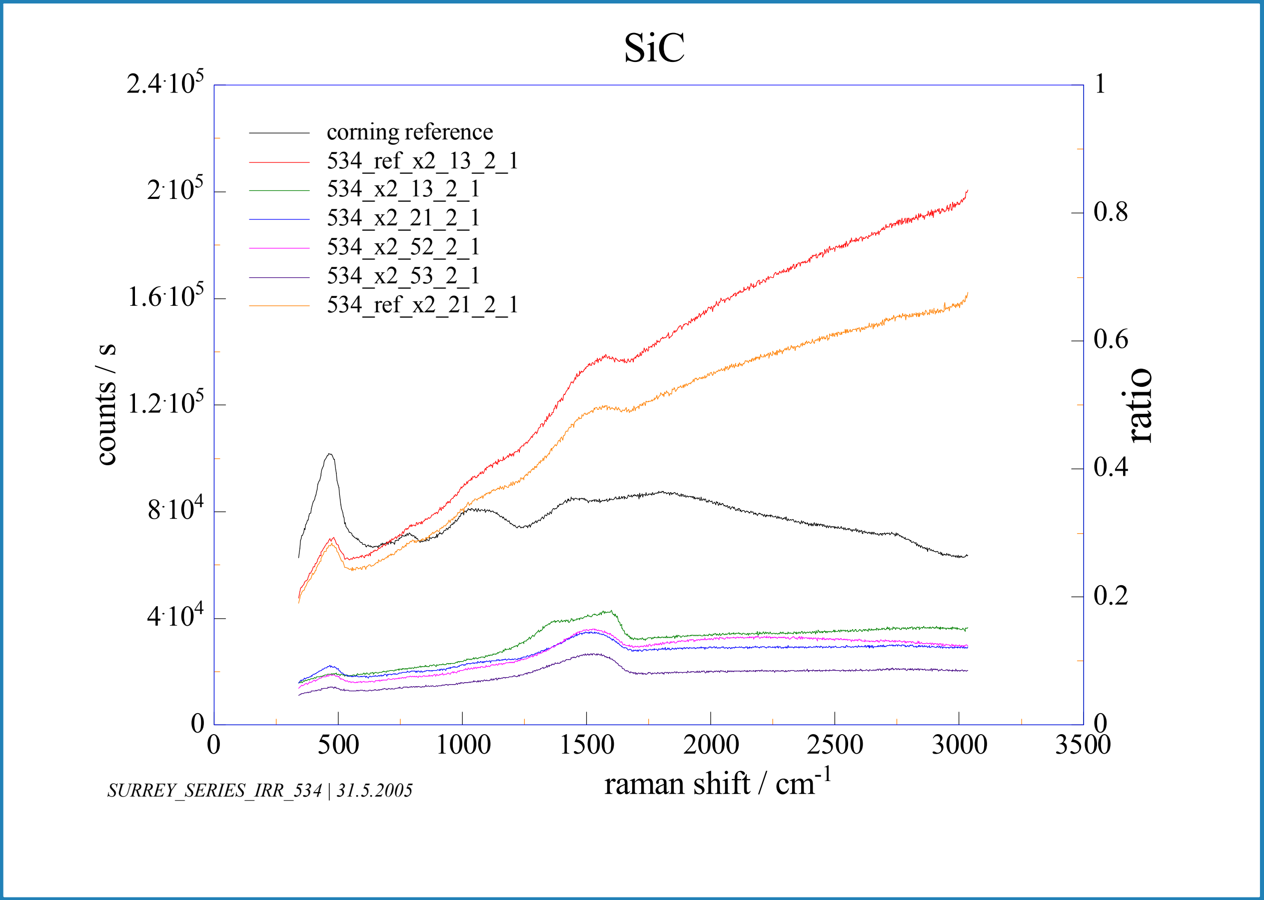
The Raman spectra do not provide an easy accessible information on structural changes. However, in the lower two spectra there is a contribution at 1500 cm^{-1} which is absent in the other spectra. This becomes even more clear in the next slide.



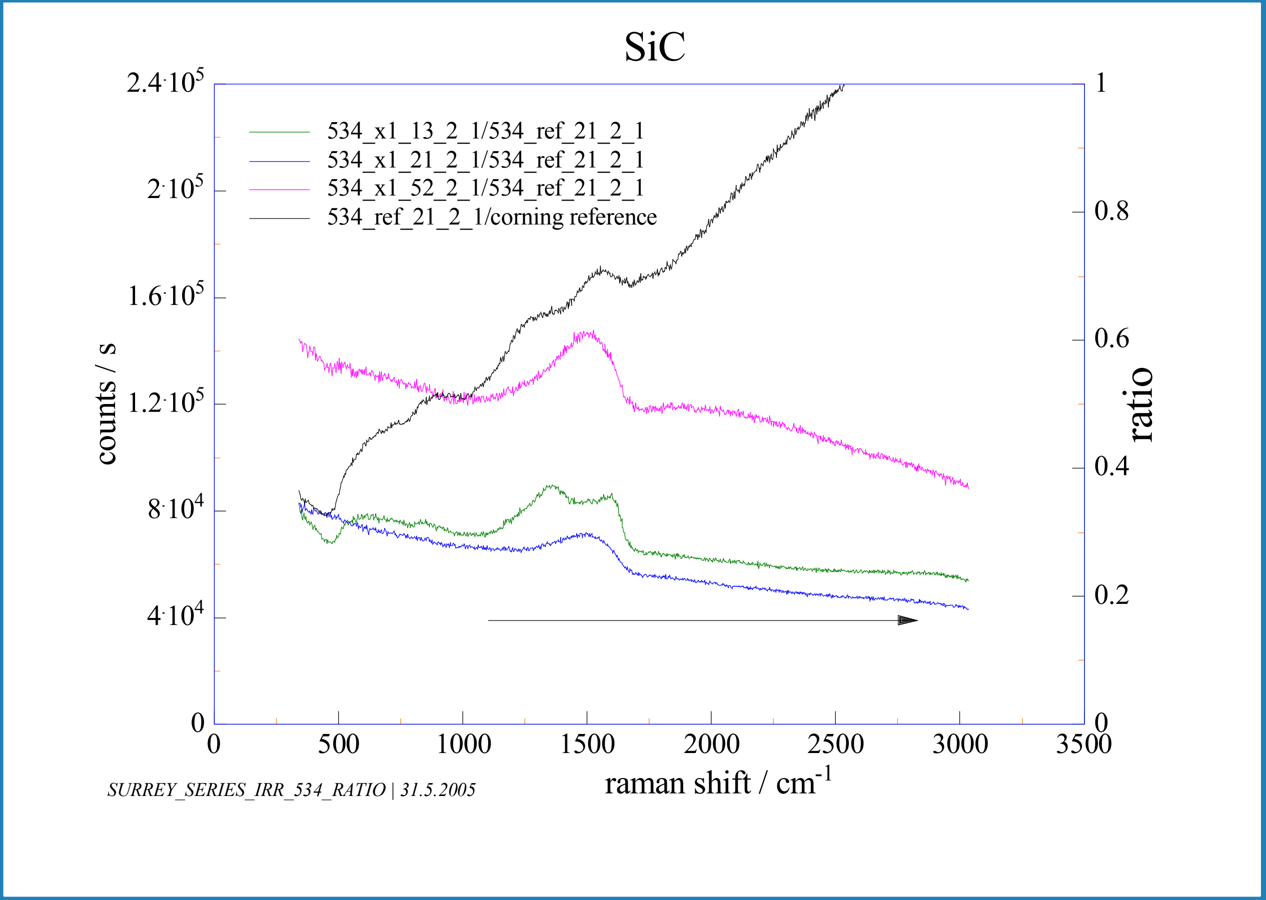
In this figure the ratio of a given spectrum and the reference one is shown. This allows a better qualitative evaluation than a subtraction of the spectra. One can easily see the development of two bands at about 1370 cm^{-1} and 1580 cm^{-1} which can be tentatively attributed to a graphitic phase in the sample. These bands seem to be present also in the non-irradiated sample but of much weaker intensity.



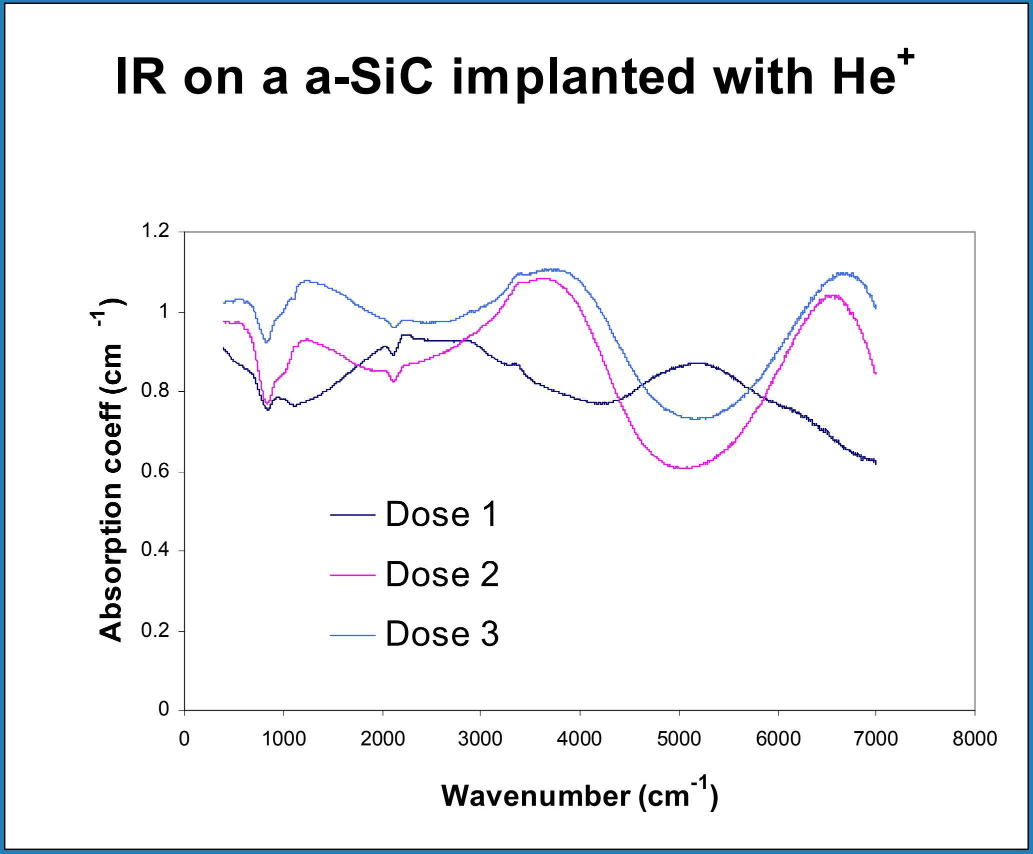
The 534 series exhibit clear extra modes in all samples. However, only in the sample with 1 MeV irradiation a nice splitting of the modes is observed. In all other samples irradiation leads to a broad asymmetric band.



In the plot of the ratio of the spectra taking the 534_21-ref as a reference the two peak structure is clearly visible, but there seems to be graphitic modes already present in the non-irradiated sample.



IR spectra on a-SiC:H implanted with He^+ at an energy of 0.5 MeV and different doses (D1=$1x10^{16}$ cm^{-2}, D2=$3x10^{16}$ cm^{-2} and D3=$1x10^{17}$ cm^{-2}), as subtracted from the spectrum of the reference sample.



Conclusion

In the Julich samples no graphitic mode could be observed. This does not mean that it is not there, but the strong luminescence of this samples may mask it. As the Julich SiC samples exhibit very similar PDS spectra as the high dose Sofia samples it is not straight forward to tell the origin of the absorption enhancement. Still, the generation of graphite clusters may be one cause, but also broken Si-C bonds may be sufficient to generate it.