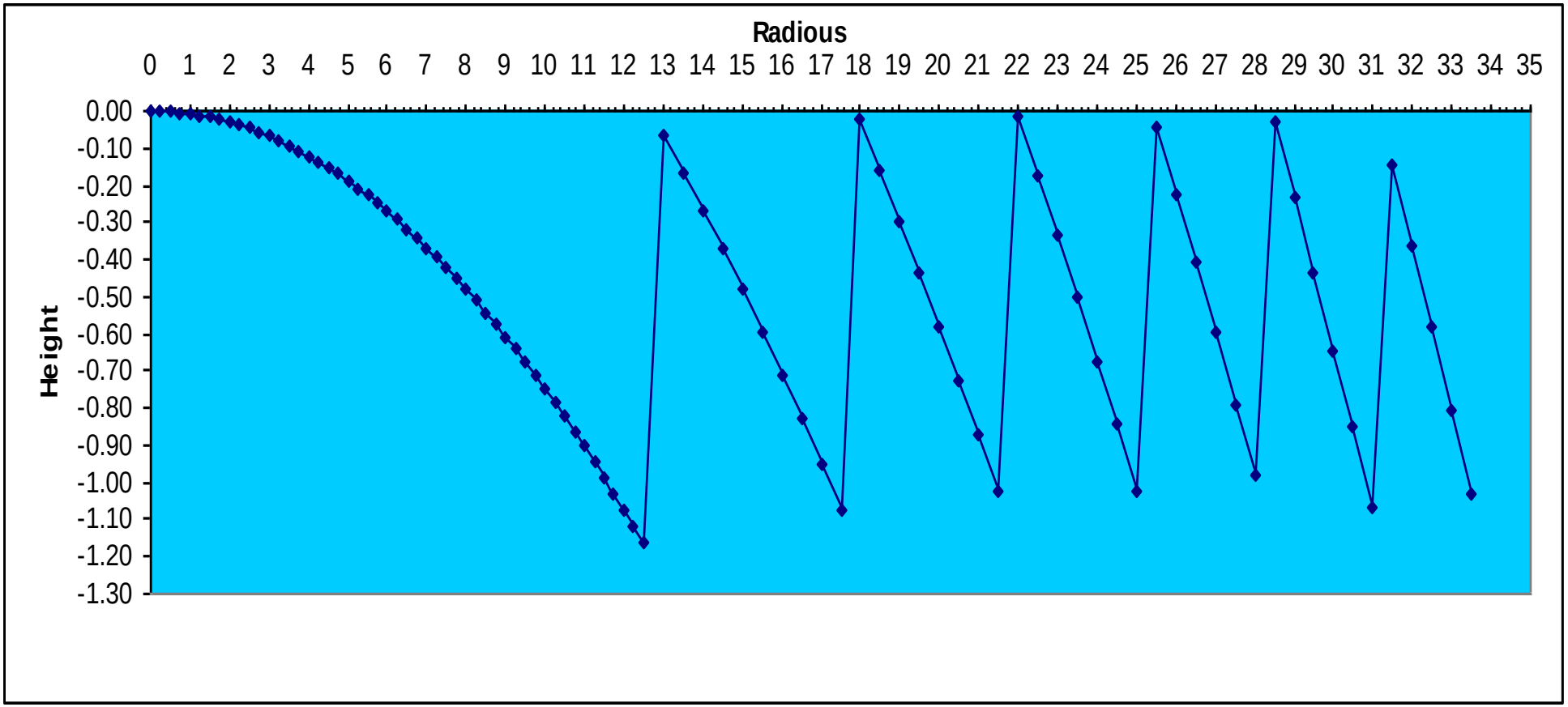
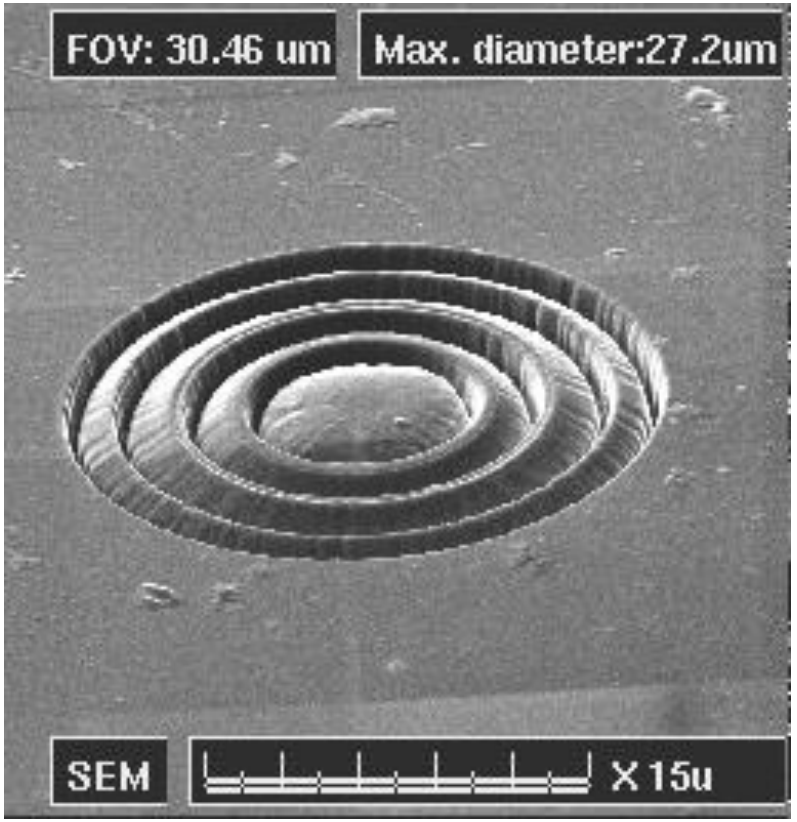
Microlens Fabricated by use of FIBM

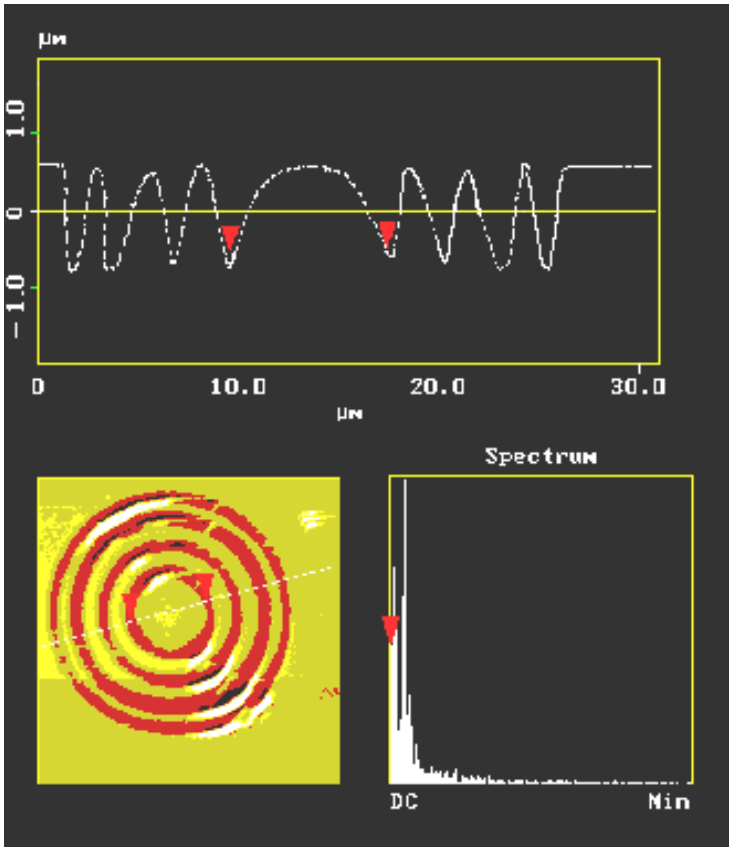
Dr. Fu Yongqi



Designed DOE profile with six annulis

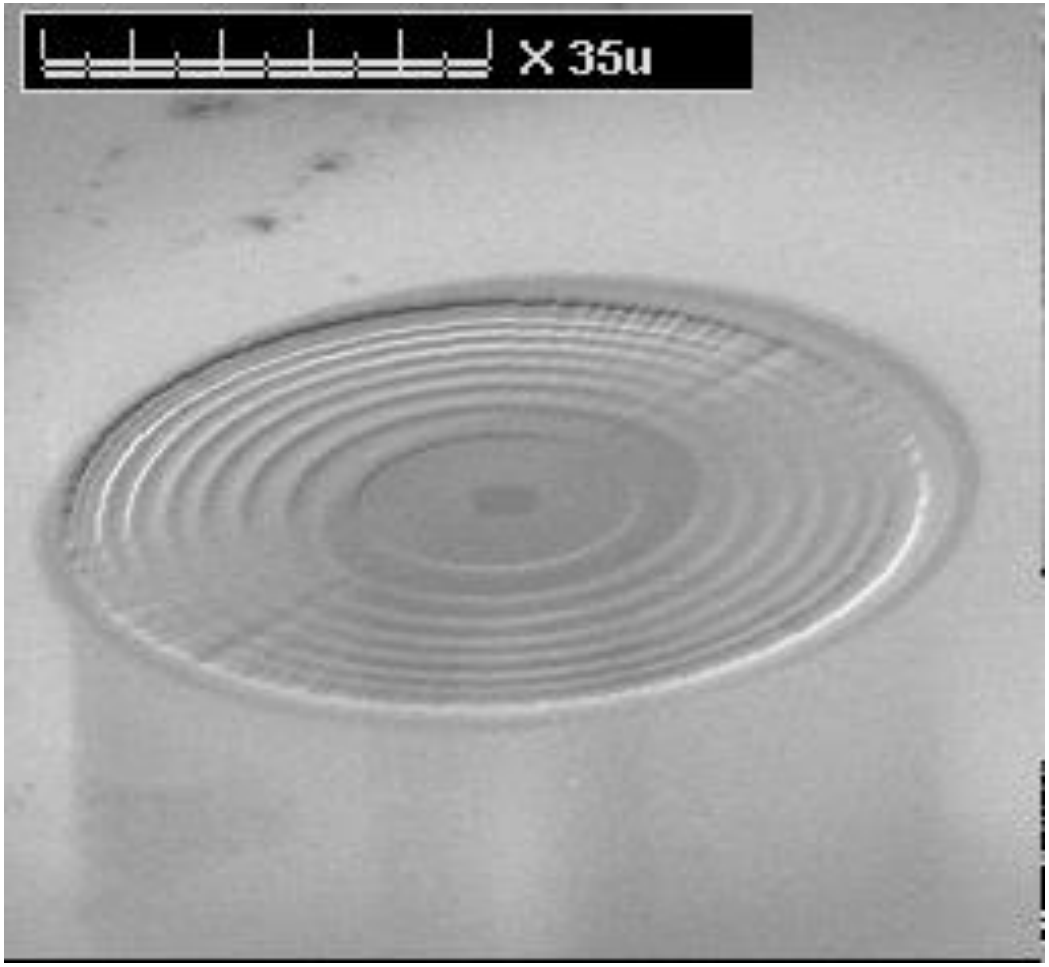


(a)

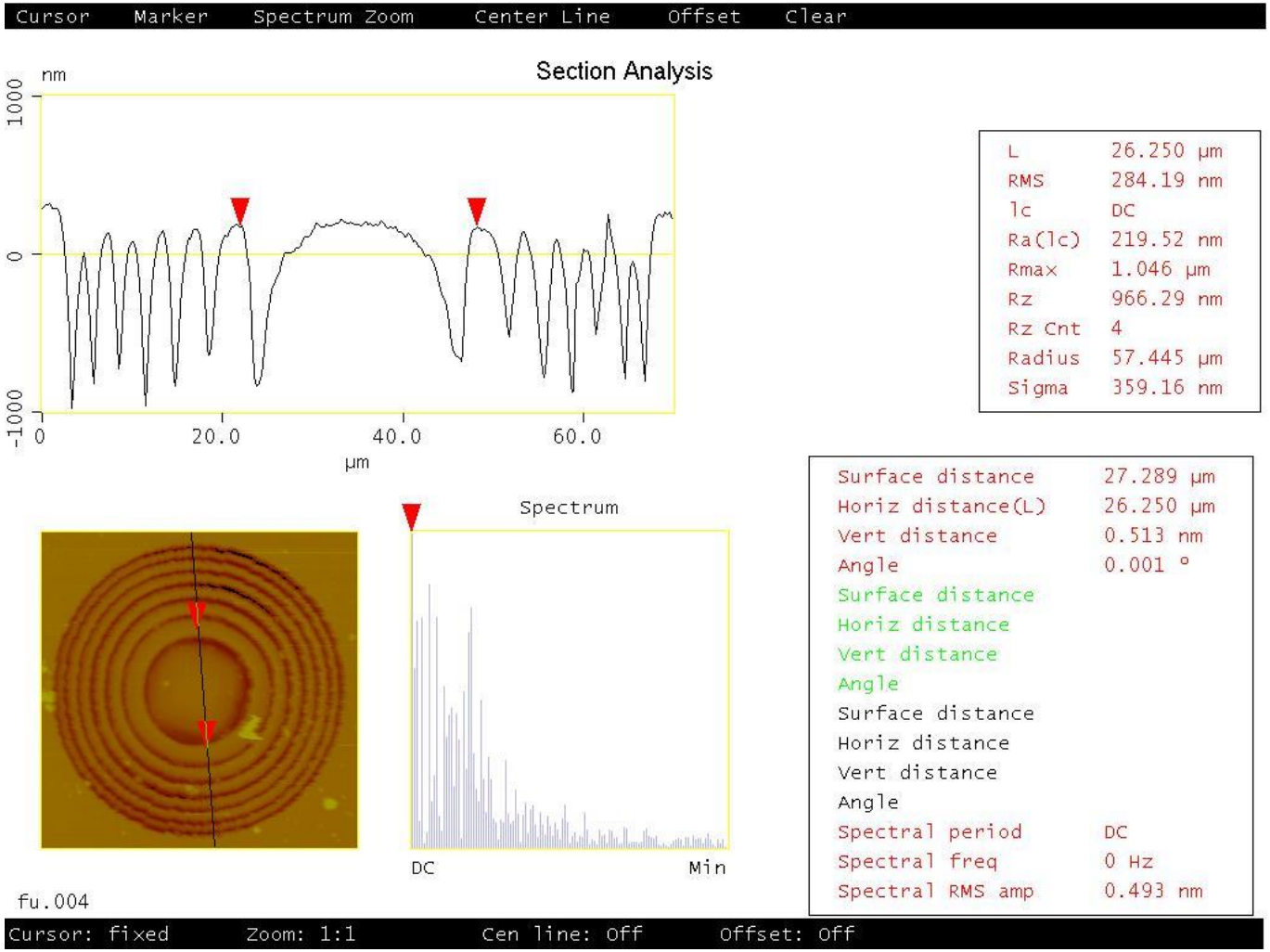


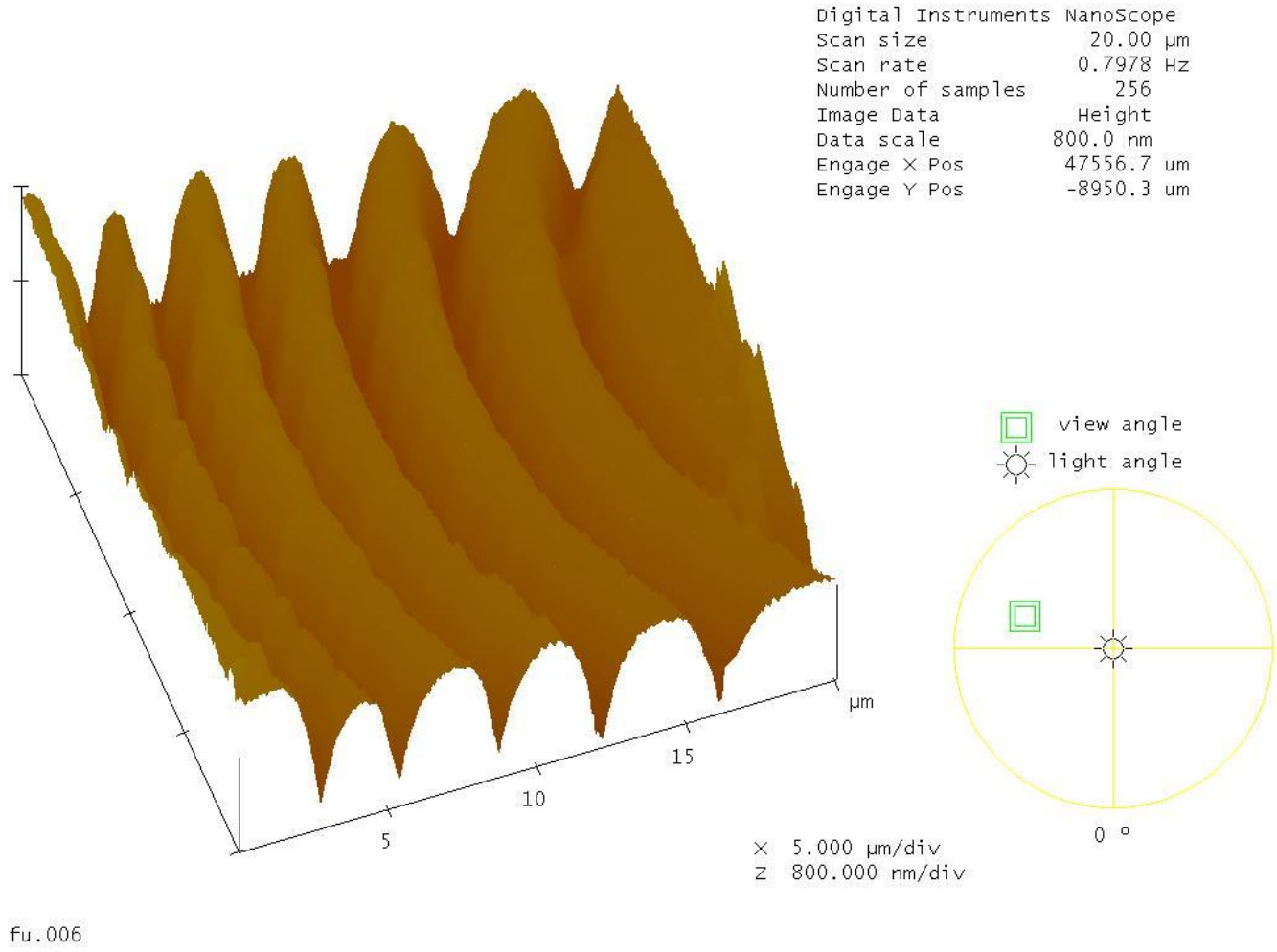
(b)

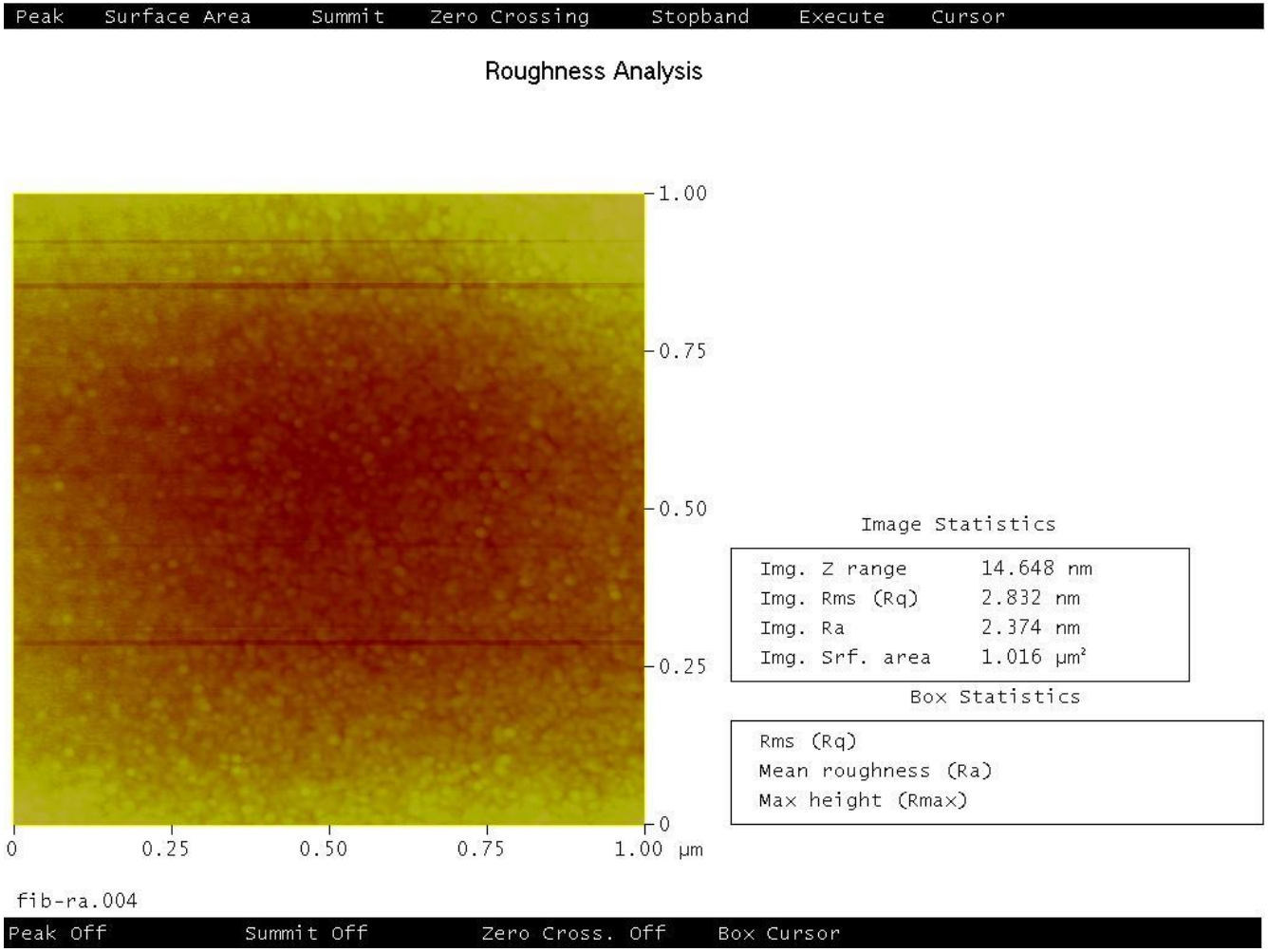
Milled DOEs with continuous relief and designed wavelength of 635nm. (a) micrograph of SEM image in 60° view angle, (b) profile measured by AFM

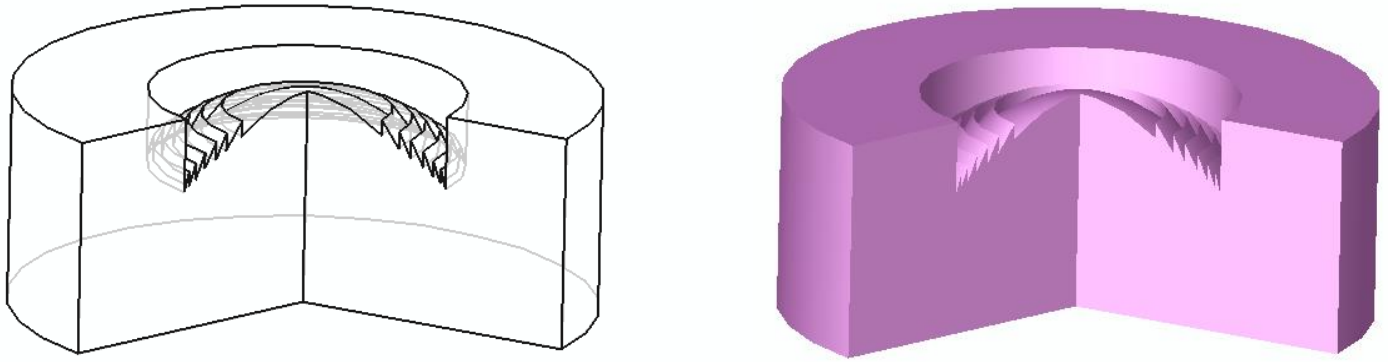


DOE with continuous relief and 7 annulus directly milled on glass substrate

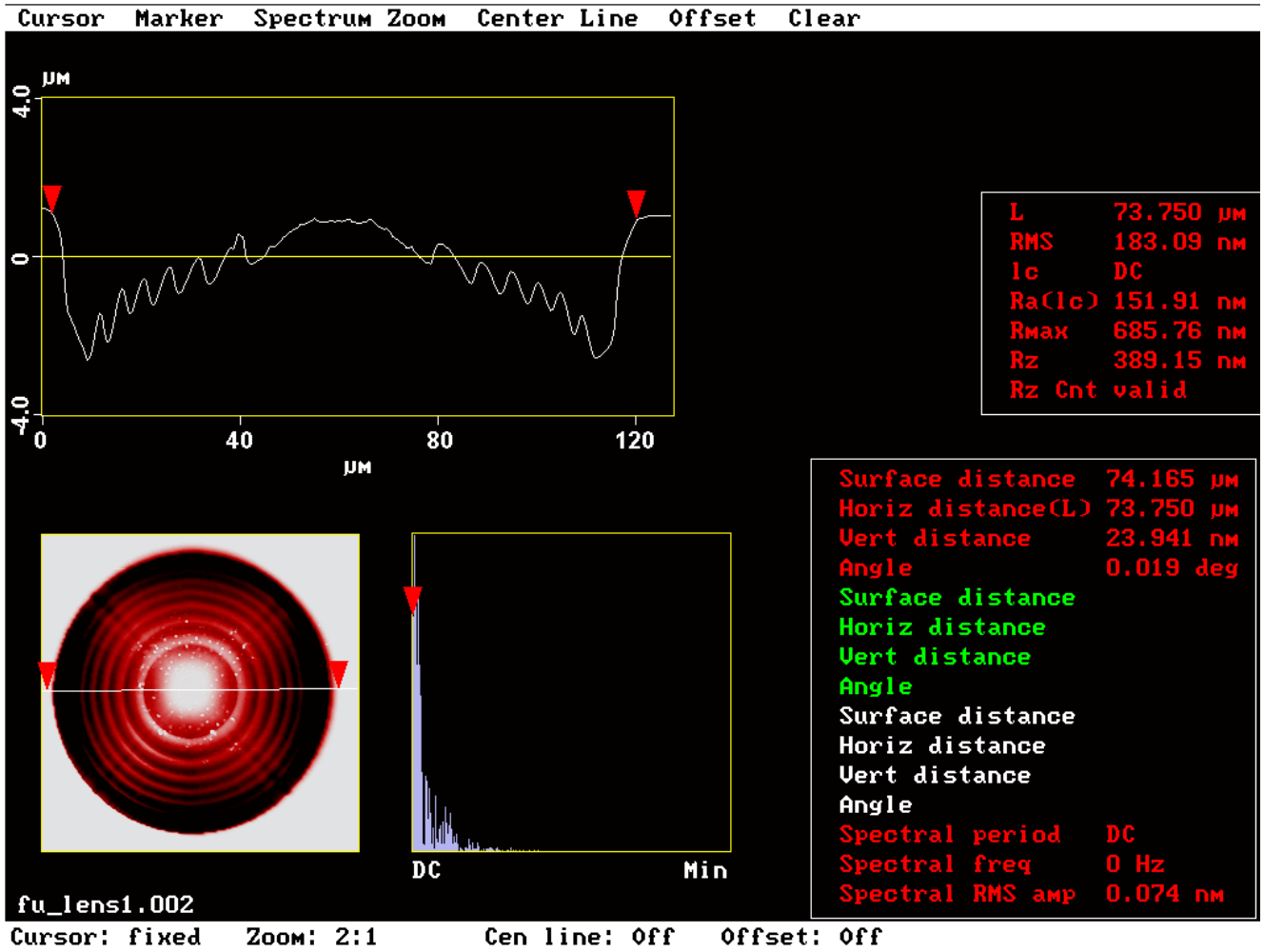

Cursor
Marker
Spectrum Zoom
Center Line
Offset
Clear
Section Analysis
nm
1000
0
-1000
0
20.0
40.0
60.0
µm
L 26.250 µm
RMS 284.19 nm
lc DC
Ra(lc) 219.52 nm
Rmax 1.046 µm
Rz 966.29 nm
Rz Cnt 4
Radius 57.445 µm
Sigma 359.16 nm
Spectrum
DC
Min
Surface distance 27.289 µm
Horiz distance(L) 26.250 µm
Vert distance 0.513 nm
Angle 0.001 °
Surface distance
Horiz distance
Vert distance
Angle
Surface distance
Horiz distance
Vert distance
Angle
Spectral period DC
Spectral freq 0 Hz
Spectral RMS amp 0.493 nm
fu.004
Cursor: fixed
Zoom: 1:1
Cen line: Off
Offset: Off

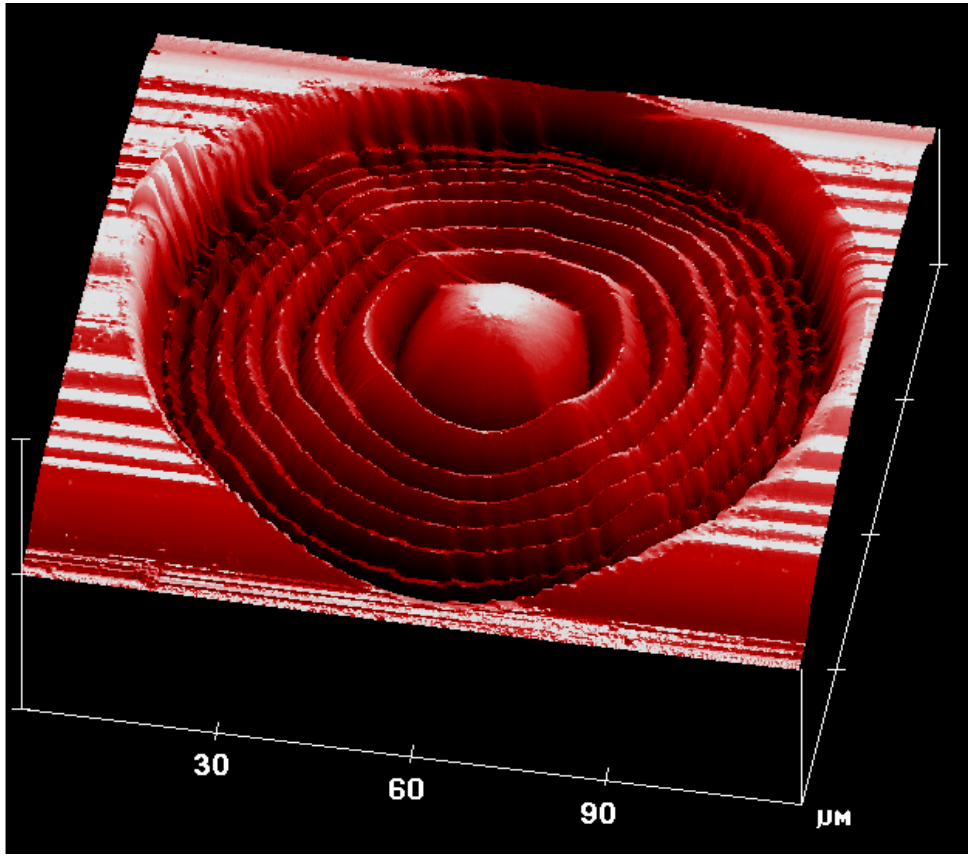

Digital Instruments NanoScope
Scan size 20.00 µm
Scan rate 0.7978 Hz
Number of samples 256
Image Data Height
Data scale 800.0 nm
Engage X Pos 47556.7 um
Engage Y Pos -8950.3 um
view angle
light angle
µm
5
10
15
0 °
X 5.000 µm/div
Z 800.000 nm/div
fu.006


Peak Surface Area Summit Zero Crossing Stopband Execute Cursor
Roughness Analysis
1.00
0.75
0.50
0.25
0
0
0.25
0.50
0.75
1.00 µm
Image Statistics
Img. Z range 14.648 nm
Img. Rms (Rq) 2.832 nm
Img. Ra 2.374 nm
Img. Srf. area 1.016 µm²
Box Statistics
Rms (Rq)
Mean roughness (Ra)
Max height (Rmax)
fib-ra.004
Peak Off Summit Off Zero Cross. Off Box Cursor

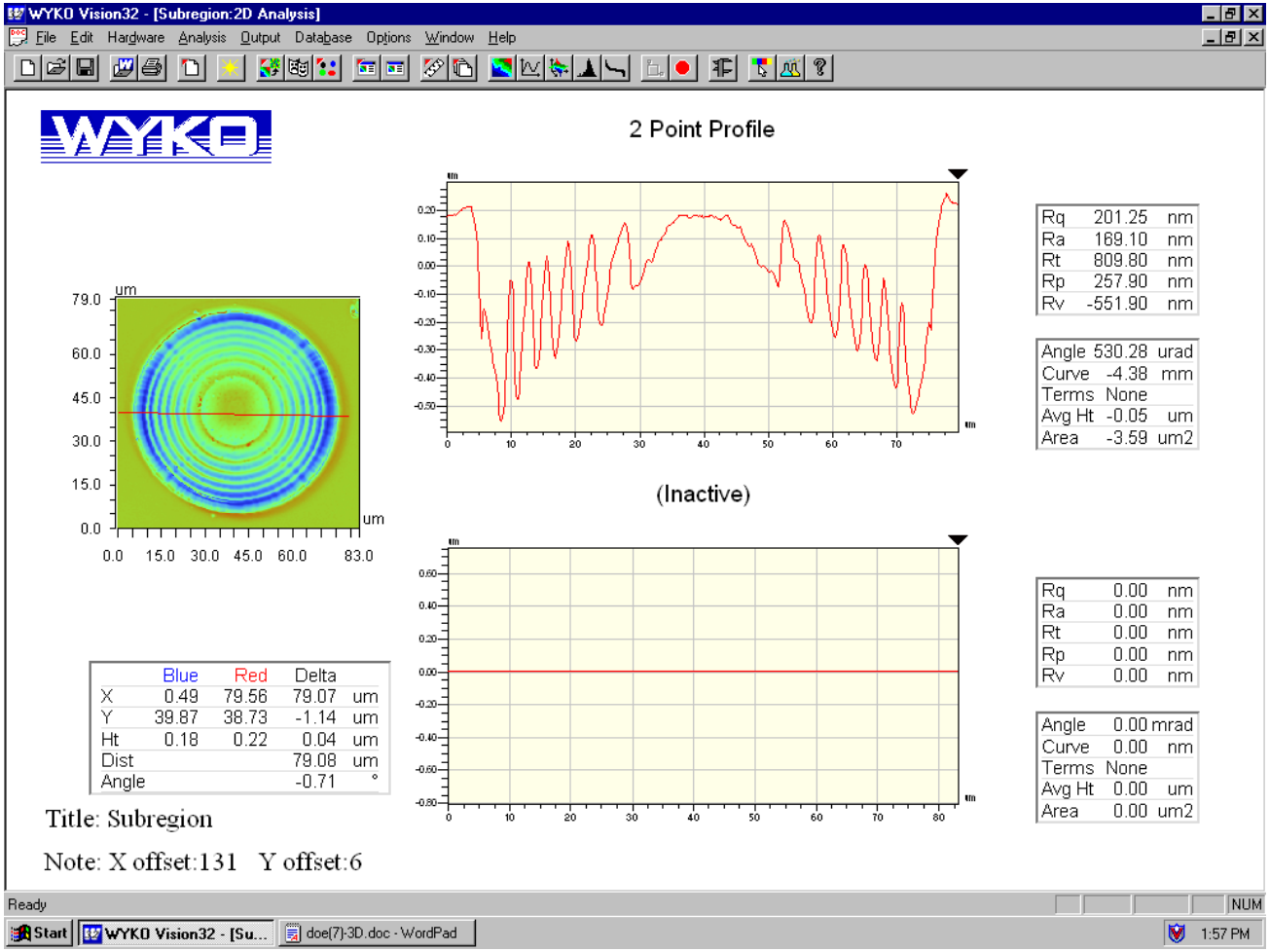


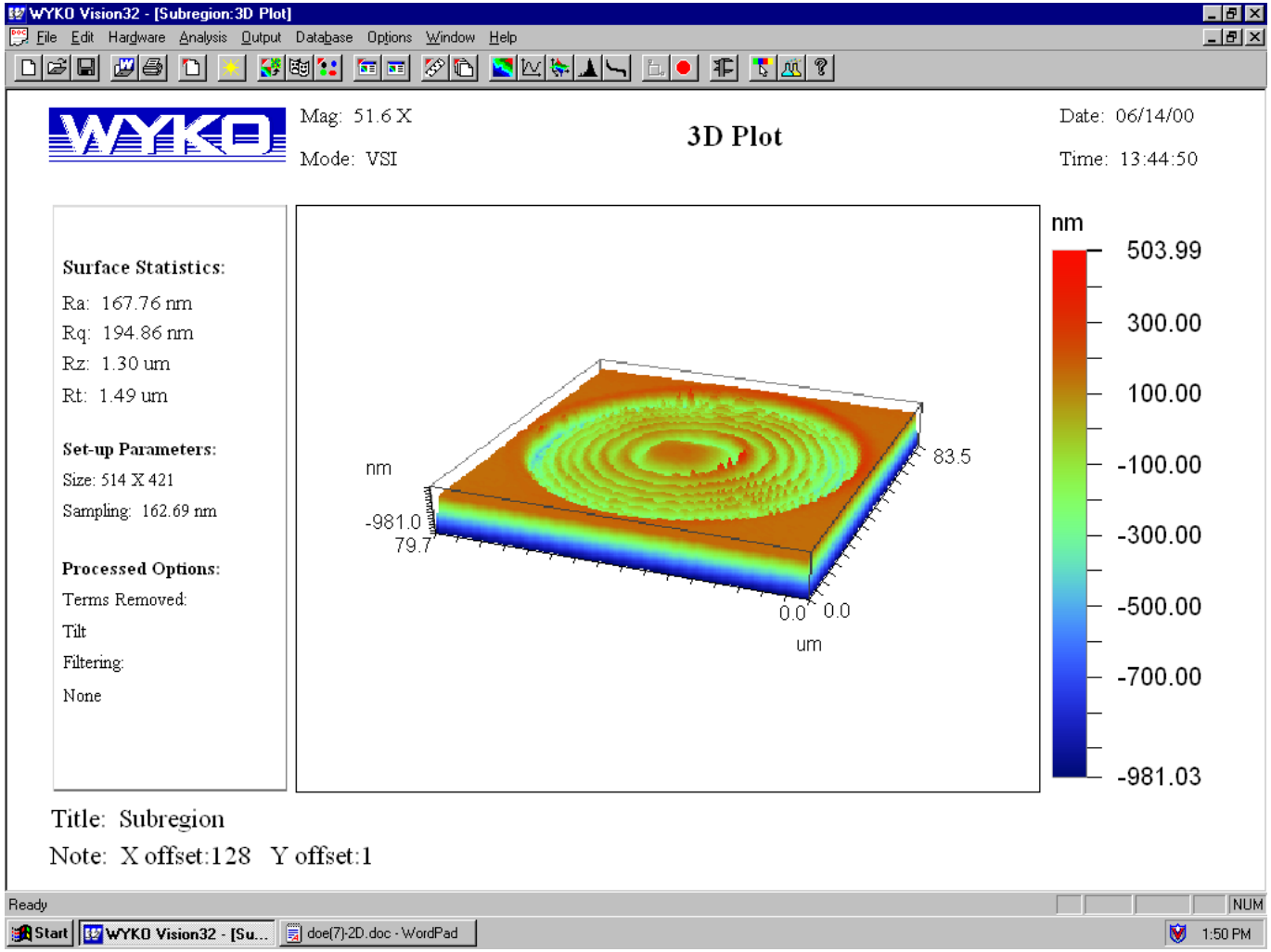
3D model with section view

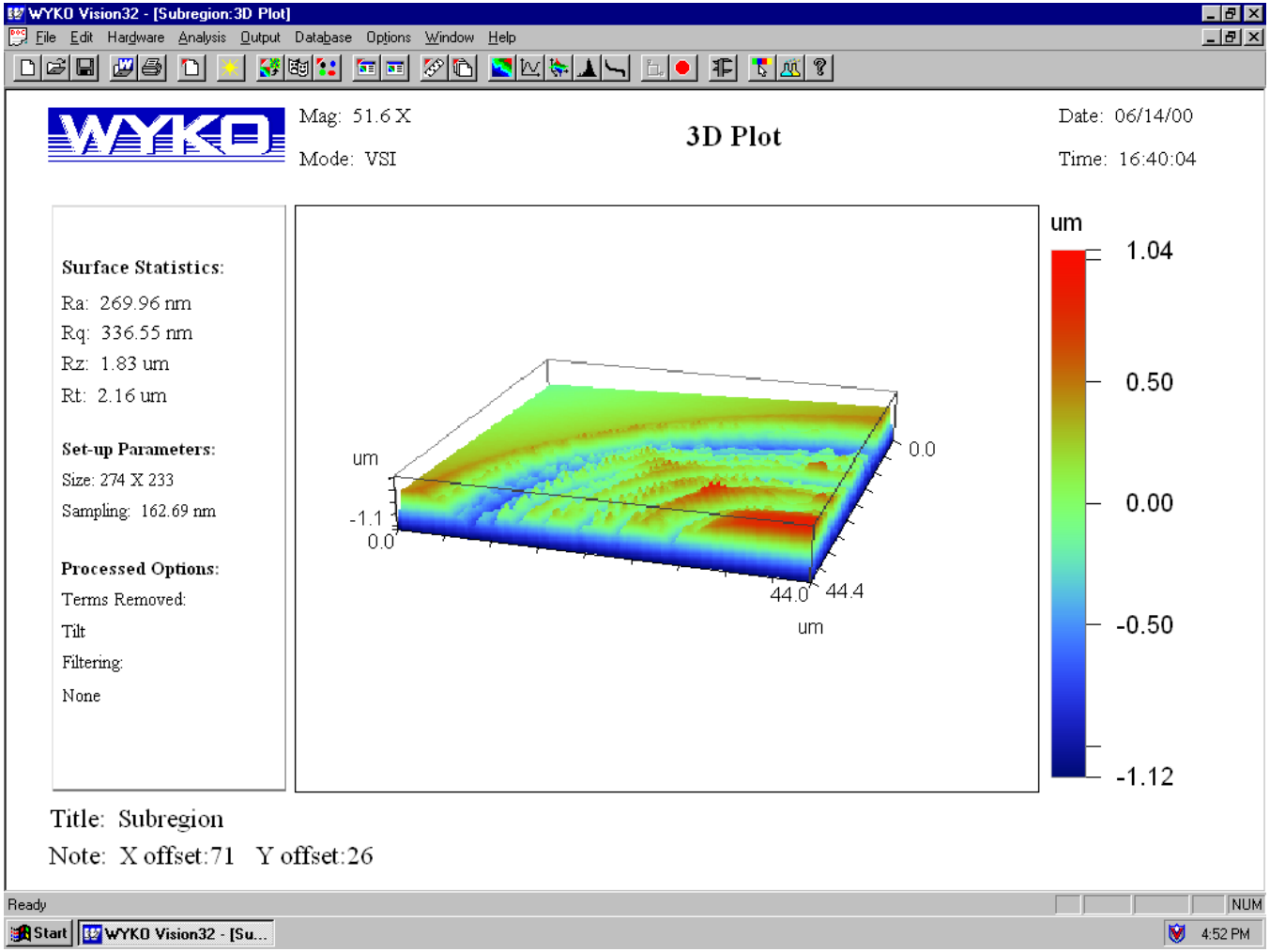

Cursor Marker Spectrum Zoom Center Line Offset Clear
μm
4.0
0
-4.0
0
40
80
120
μm
L 73.750 μm
RMS 183.09 nm
lc DC
Ra(lc) 151.91 nm
Rmax 685.76 nm
Rz 389.15 nm
Rz Cnt valid
Surface distance 74.165 μm
Horiz distance(L) 73.750 μm
Vert distance 23.941 nm
Angle 0.019 deg
Surface distance
Horiz distance
Vert distance
Angle
Surface distance
Horiz distance
Vert distance
Angle
Spectral period DC
Spectral freq 0 Hz
Spectral RMS amp 0.074 nm
DC
Min
fu_lens1.002
Cursor: fixed Zoom: 2:1 Cen line: Off Offset: Off

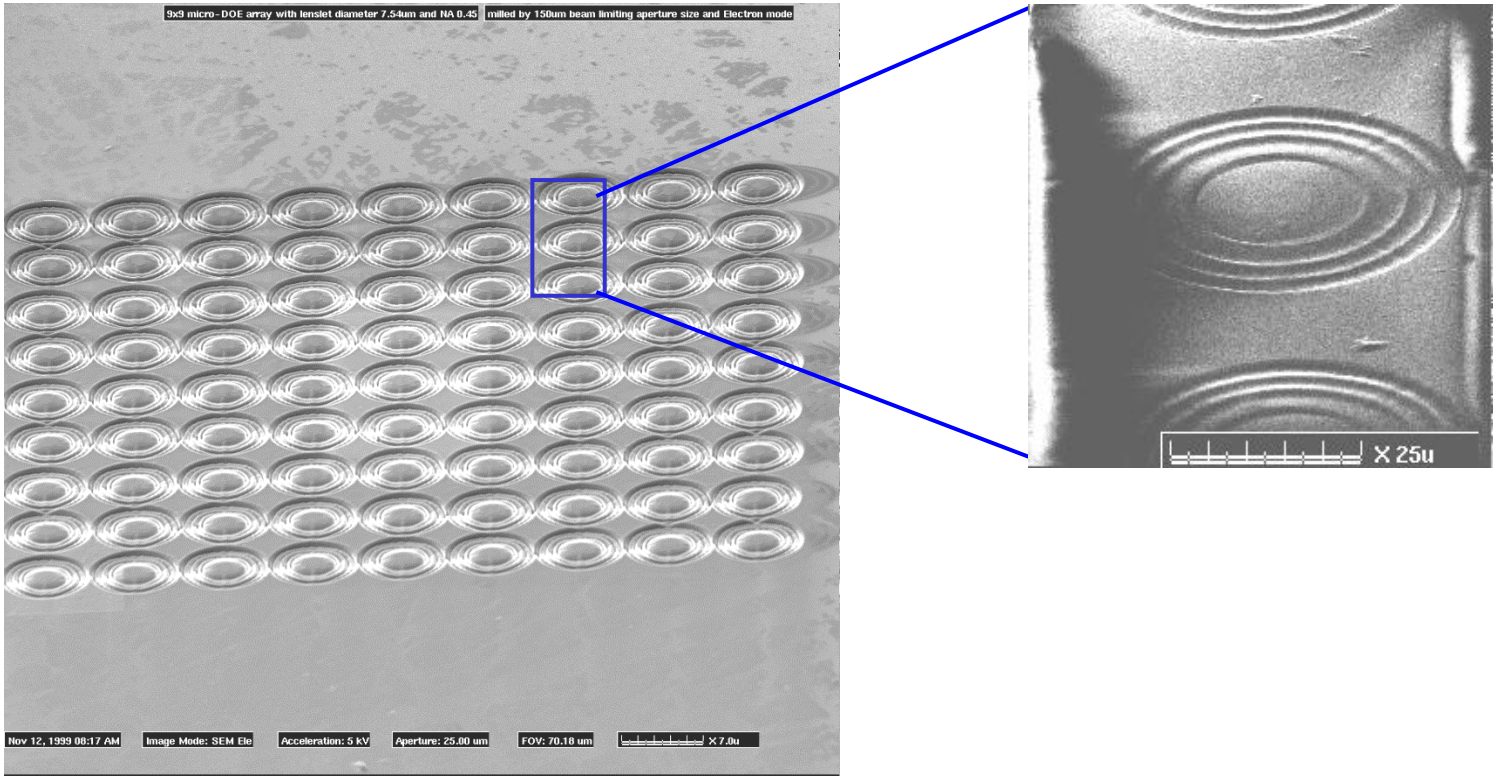


DOE's with continuous relief directly milled onto BK7 glass substrate by FIB, 3D micrograph measured by AFM

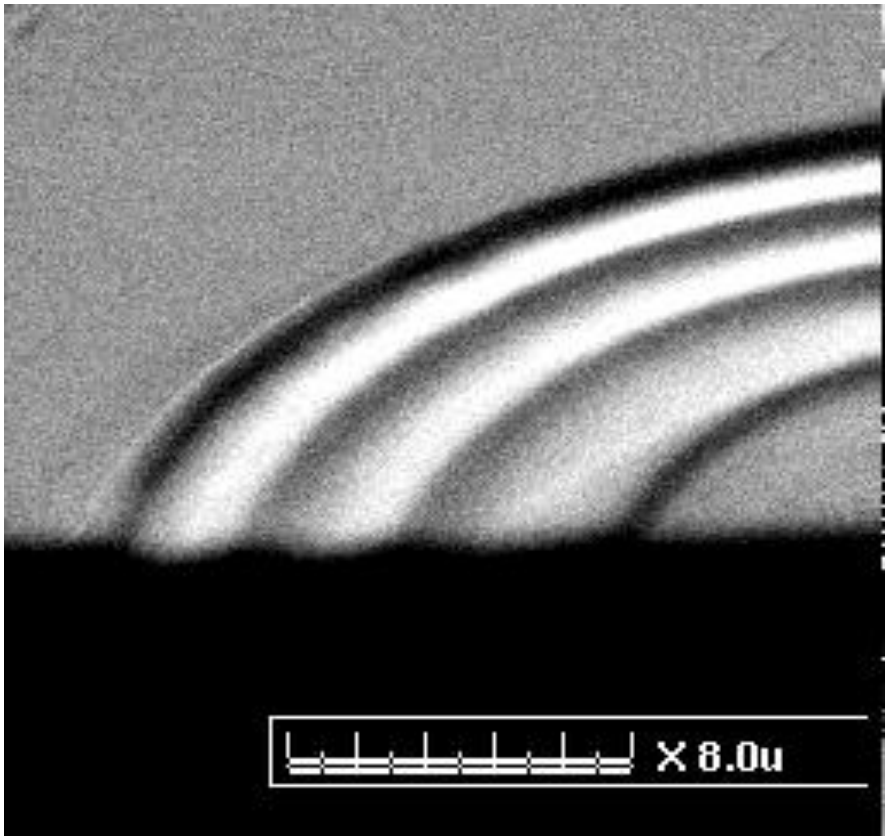

WYKO Vision32 - [Subregion:2D Analysis]
File Edit Hardware Analysis Output Database Options Window Help
WYKO
2 Point Profile
um
79.0
60.0
45.0
30.0
15.0
0.0
0.0 15.0 30.0 45.0 60.0 83.0
um
Rq 201.25 nm
Ra 169.10 nm
Rt 809.80 nm
Rp 257.90 nm
Rv -551.90 nm
Angle 530.28 urad
Curve -4.38 mm
Terms None
Avg Ht -0.05 um
Area -3.59 um2
(Inactive)
Rq 0.00 nm
Ra 0.00 nm
Rt 0.00 nm
Rp 0.00 nm
Rv 0.00 nm
Angle 0.00 mrad
Curve 0.00 nm
Terms None
Avg Ht 0.00 um
Area 0.00 um2
Blue Red Delta
X 0.49 79.56 79.07 um
Y 39.87 38.73 -1.14 um
Ht 0.18 0.22 0.04 um
Dist 79.08 um
Angle -0.71 °
Title: Subregion
Note: X offset:131 Y offset:6
Ready
NUM
Start
WYKO Vision32 - [Su...
doe(7)-3D.doc - WordPad
1:57 PM


WYKO Vision32 - [Subregion:3D Plot]
File Edit Hardware Analysis Output Database Options Window Help
WYKO
Mag: 51.6 X
Mode: VSI
3D Plot
Date: 06/14/00
Time: 13:44:50
Surface Statistics:
Ra: 167.76 nm
Rq: 194.86 nm
Rz: 1.30 um
Rt: 1.49 um
Set-up Parameters:
Size: 514 X 421
Sampling: 162.69 nm
Processed Options:
Terms Removed:
Tilt
Filtering:
None
nm
-981.0
79.7
83.5
0.0
0.0
um
nm
503.99
300.00
100.00
-100.00
-300.00
-500.00
-700.00
-981.03
Title: Subregion
Note: X offset:128 Y offset:1
Ready
NUM
Start
WYKO Vision32 - [Su...
doe(7)-2D.doc - WordPad
1:50 PM

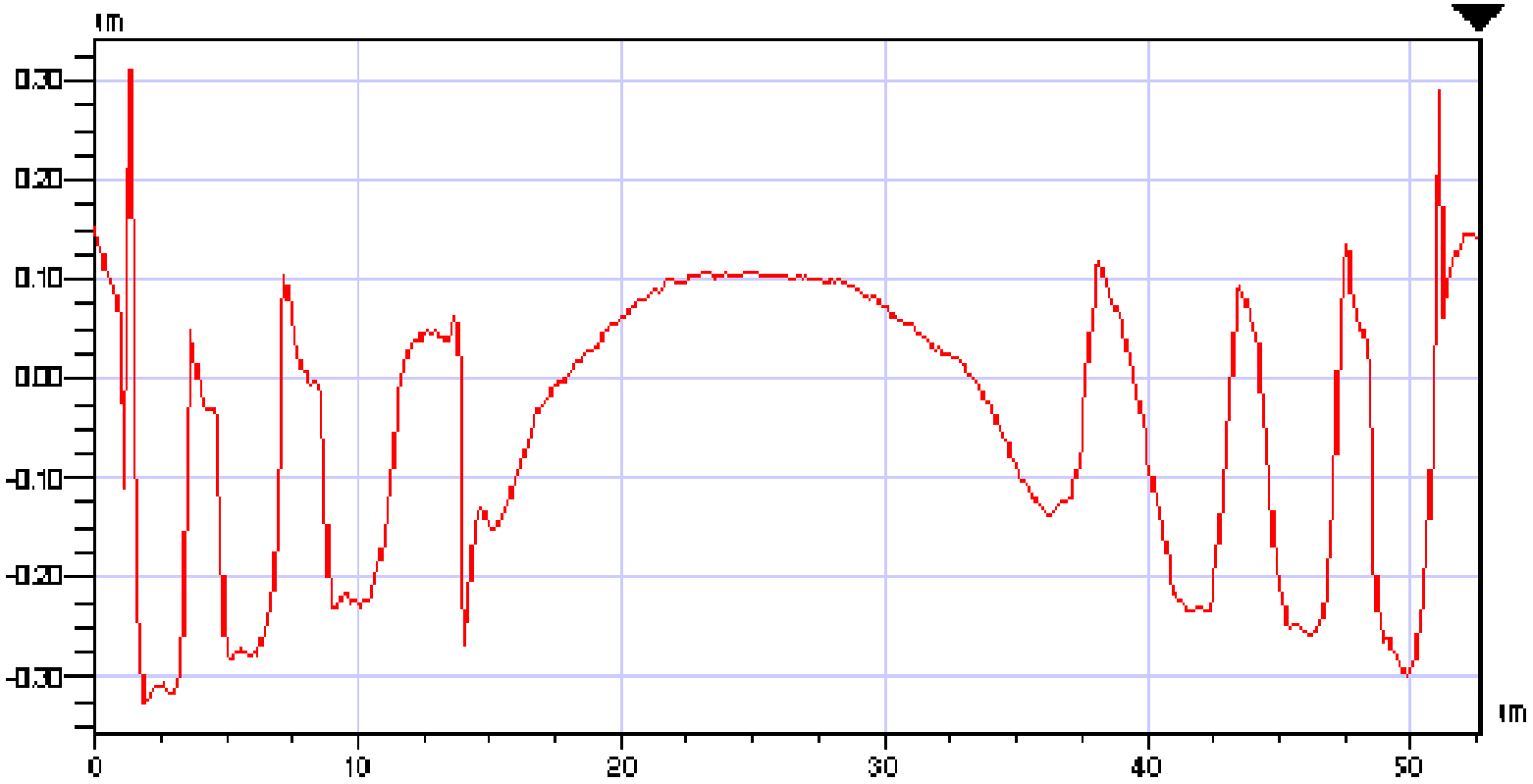

WYKO Vision32 - [Subregion:3D Plot]
File Edit Hardware Analysis Output Database Options Window Help
Mag: 51.6 X
Mode: VSI
3D Plot
Date: 06/14/00
Time: 16:40:04
Surface Statistics:
Ra: 269.96 nm
Rq: 336.55 nm
Rz: 1.83 um
Rt: 2.16 um
Set-up Parameters:
Size: 274 X 233
Sampling: 162.69 nm
Processed Options:
Terms Removed:
Tilt
Filtering:
None
um
1.04
0.50
0.00
-0.50
-1.12
um
-1.1
0.0
0.0
44.0
44.4
um
Title: Subregion
Note: X offset:71 Y offset:26
Ready
NUM
Start
WYKO Vision32 - [Su...
4:52 PM

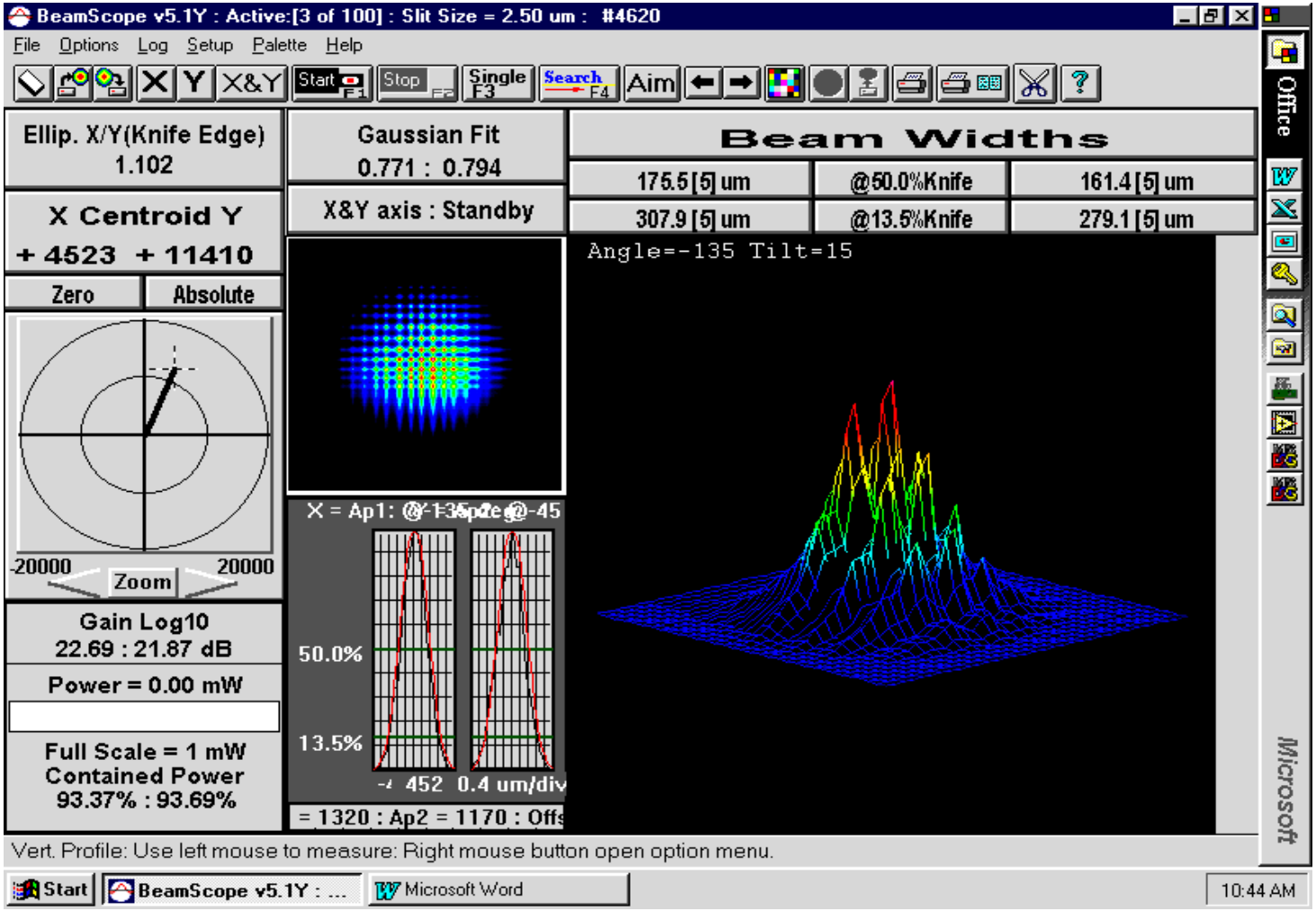


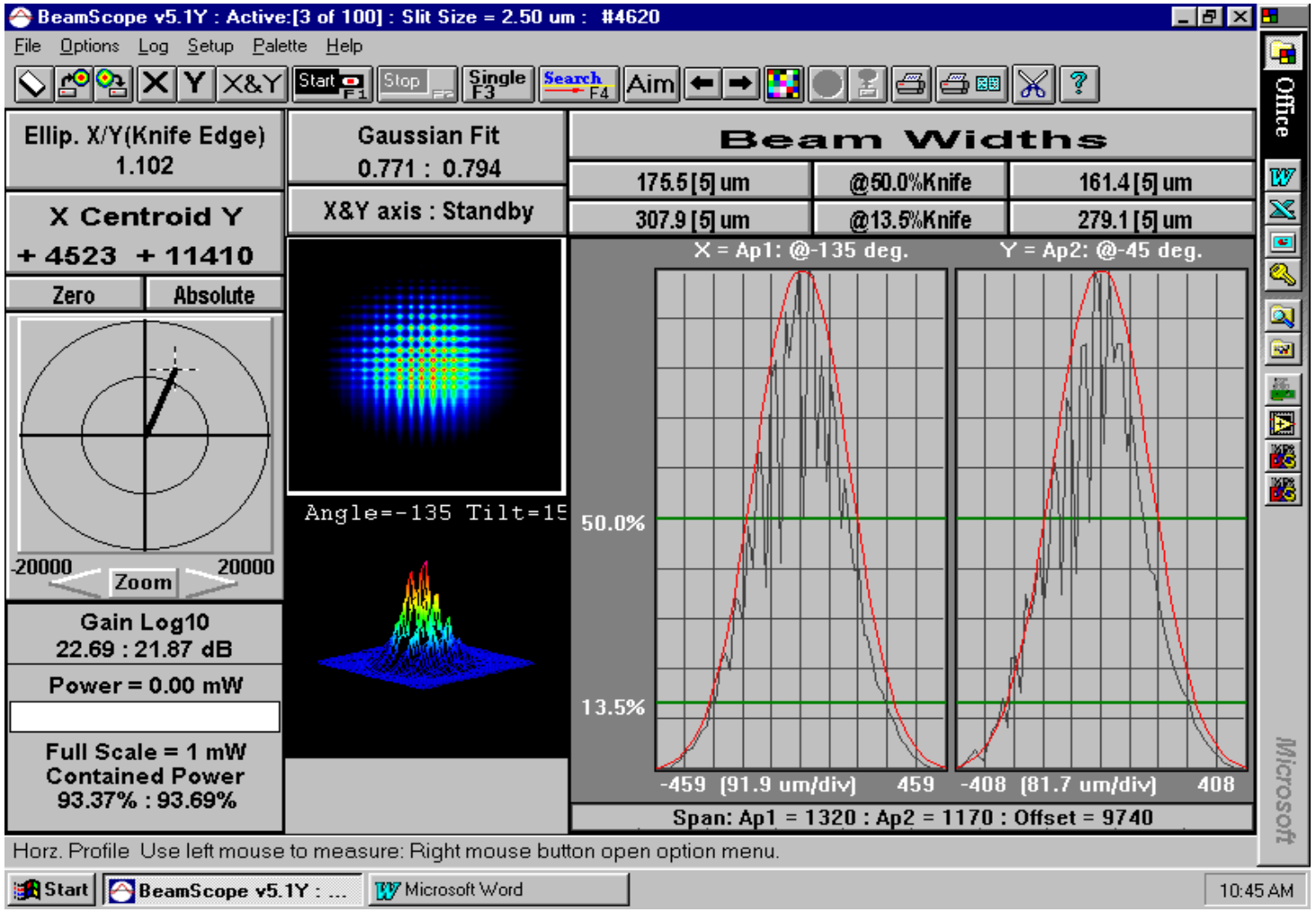
10x10 micro-DOEs array fabricated by focused ion beam milling (FIBM) directly in BK7 glass substrate

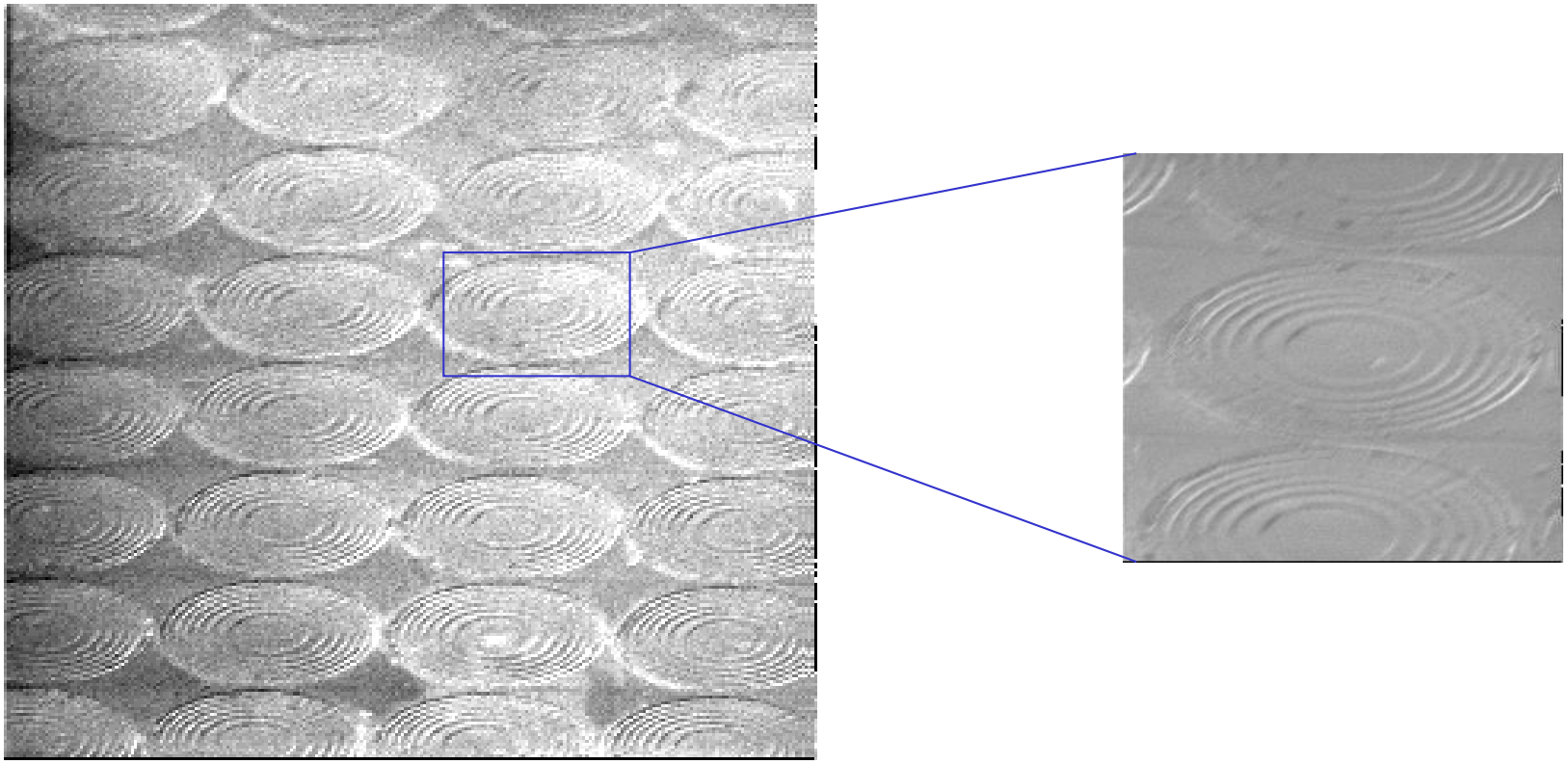


Cross-section view of DOE with 3 annulus

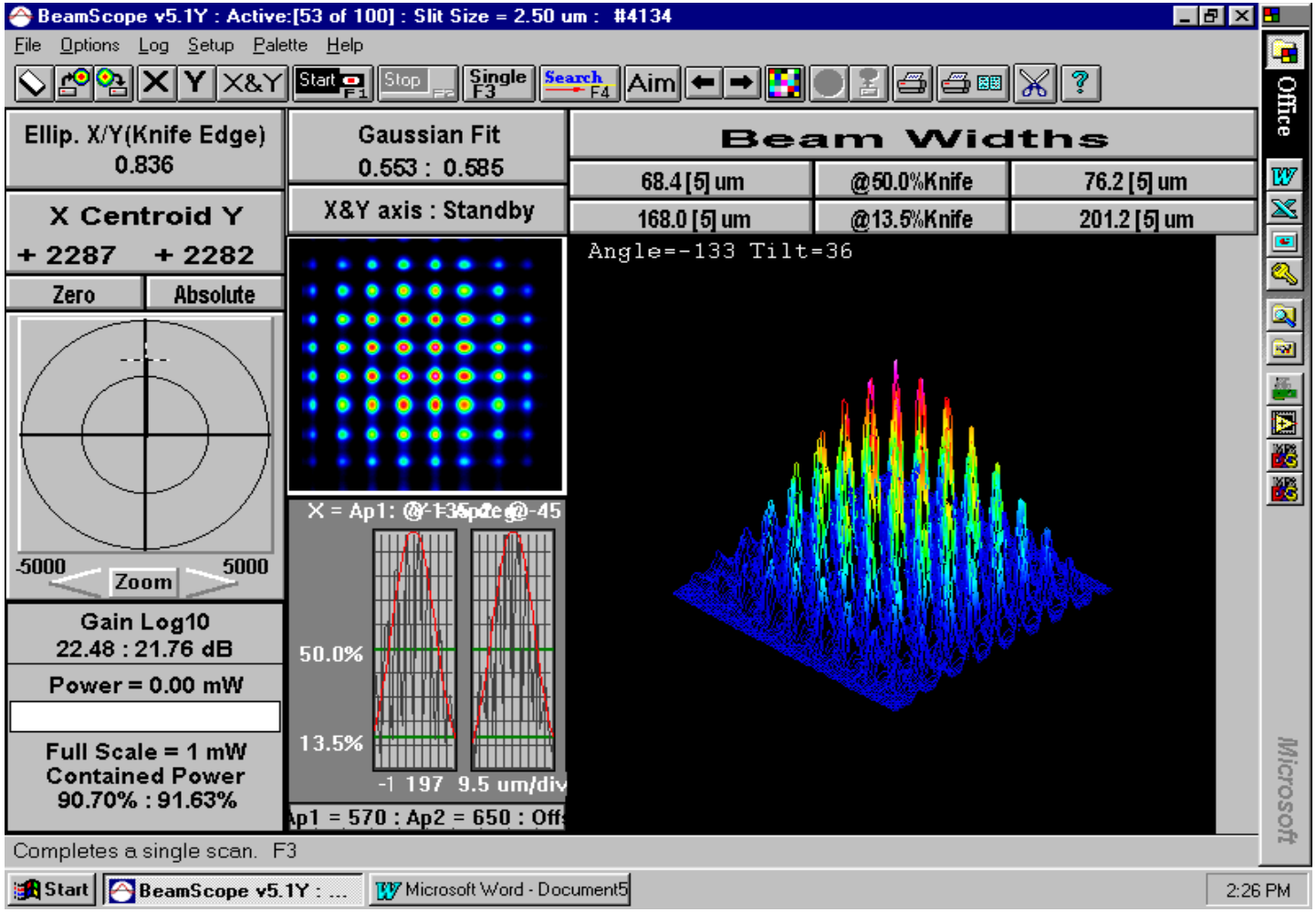

m
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
0
10
20
30
40
50
m

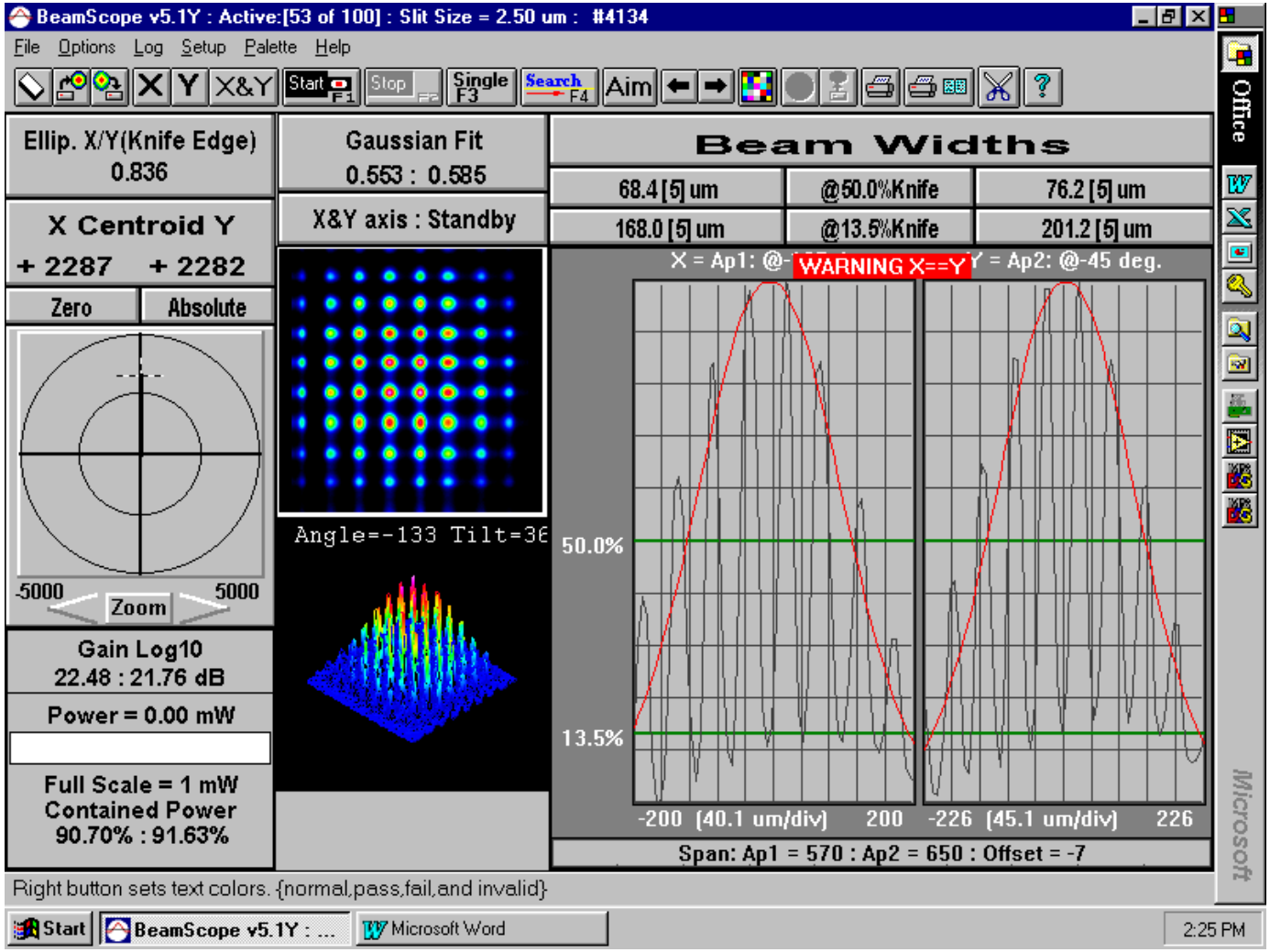

BeamScope v5.1Y : Active:[3 of 100] : Slit Size = 2.50 um : #4620
File Options Log Setup Palette Help
Start F1 Stop F2 Single F3 Search F4 Aim
X&Y
Ellip. X/Y(Knife Edge)
1.102
Gaussian Fit
0.771 : 0.794
X&Y axis : Standby
Beam Widths
175.5 [5] um
@50.0%Knife
161.4 [5] um
307.9 [5] um
@13.5%Knife
279.1 [5] um
X Centroid Y
+ 4523 + 11410
Zero
Absolute
Angle=-135 Tilt=15
-20000
Zoom
20000
Gain Log10
22.69 : 21.87 dB
Power = 0.00 mW
Full Scale = 1 mW
Contained Power
93.37% : 93.69%
50.0%
13.5%
452 0.4 um/div
= 1320 : Ap2 = 1170 : Offs
Vert. Profile: Use left mouse to measure: Right mouse button open option menu.
Start
BeamScope v5.1Y : ...
Microsoft Word
10:44 AM
Office
Microsoft

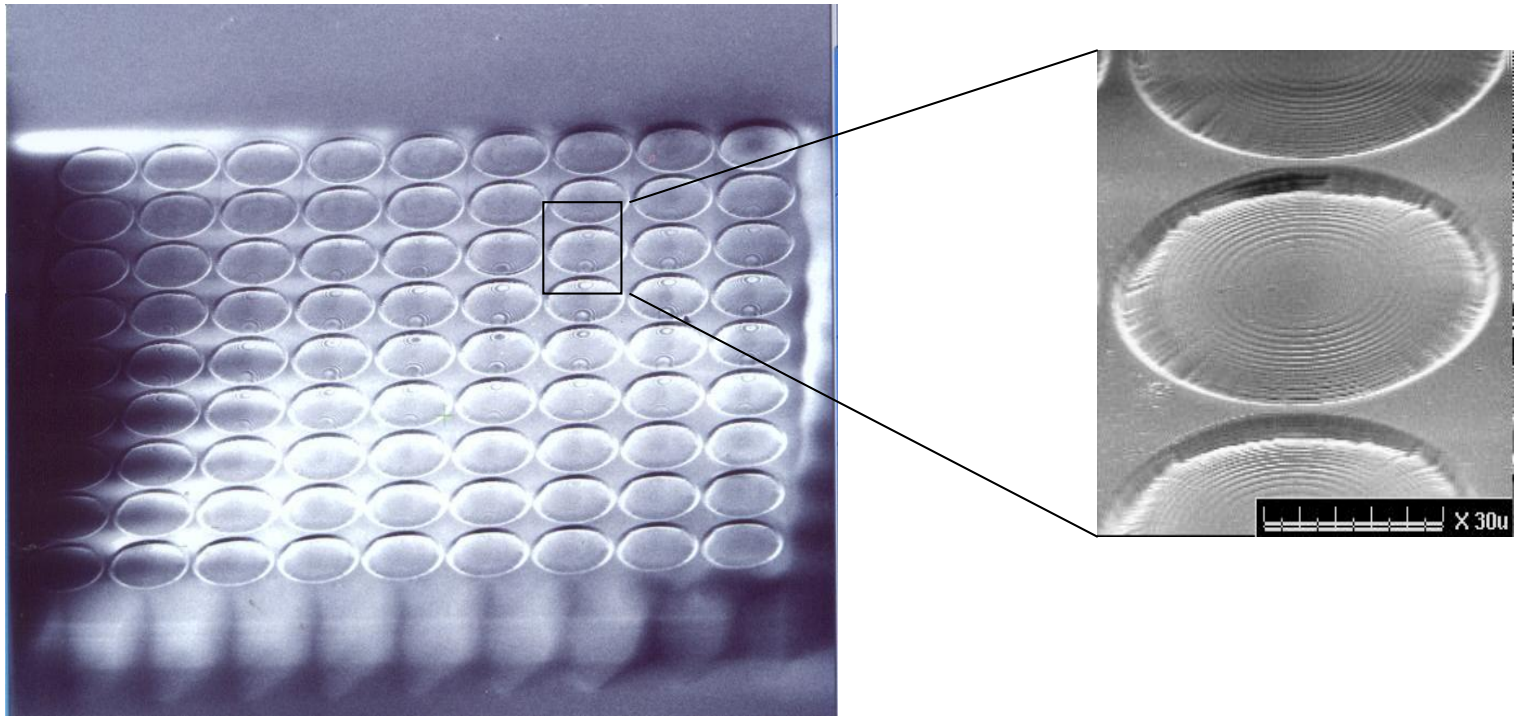

BeamScope v5.1Y : Active:[3 of 100] : Slit Size = 2.50 um : #4620
File Options Log Setup Palette Help
X&Y Start F1 Stop F2 Single F3 Search F4 Aim
Ellip. X/Y(Knife Edge)
1.102
Gaussian Fit
0.771 : 0.794
Beam Widths
175.5 [5] um
@50.0%Knife
161.4 [5] um
307.9 [5] um
@13.5%Knife
279.1 [5] um
X Centroid Y
+ 4523 + 11410
X&Y axis : Standby
Zero
Absolute
-20000
Zoom
20000
Angle=-135 Tilt=15
X = Ap1: @-135 deg.
Y = Ap2: @-45 deg.
50.0%
13.5%
Gain Log10
22.69 : 21.87 dB
Power = 0.00 mW
Full Scale = 1 mW
Contained Power
93.37% : 93.69%
-459 (91.9 um/div) 459
-408 (81.7 um/div) 408
Span: Ap1 = 1320 : Ap2 = 1170 : Offset = 9740
Horz. Profile Use left mouse to measure: Right mouse button open option menu.
Start
BeamScope v5.1Y : ...
Microsoft Word
10:45 AM
Office
Microsoft



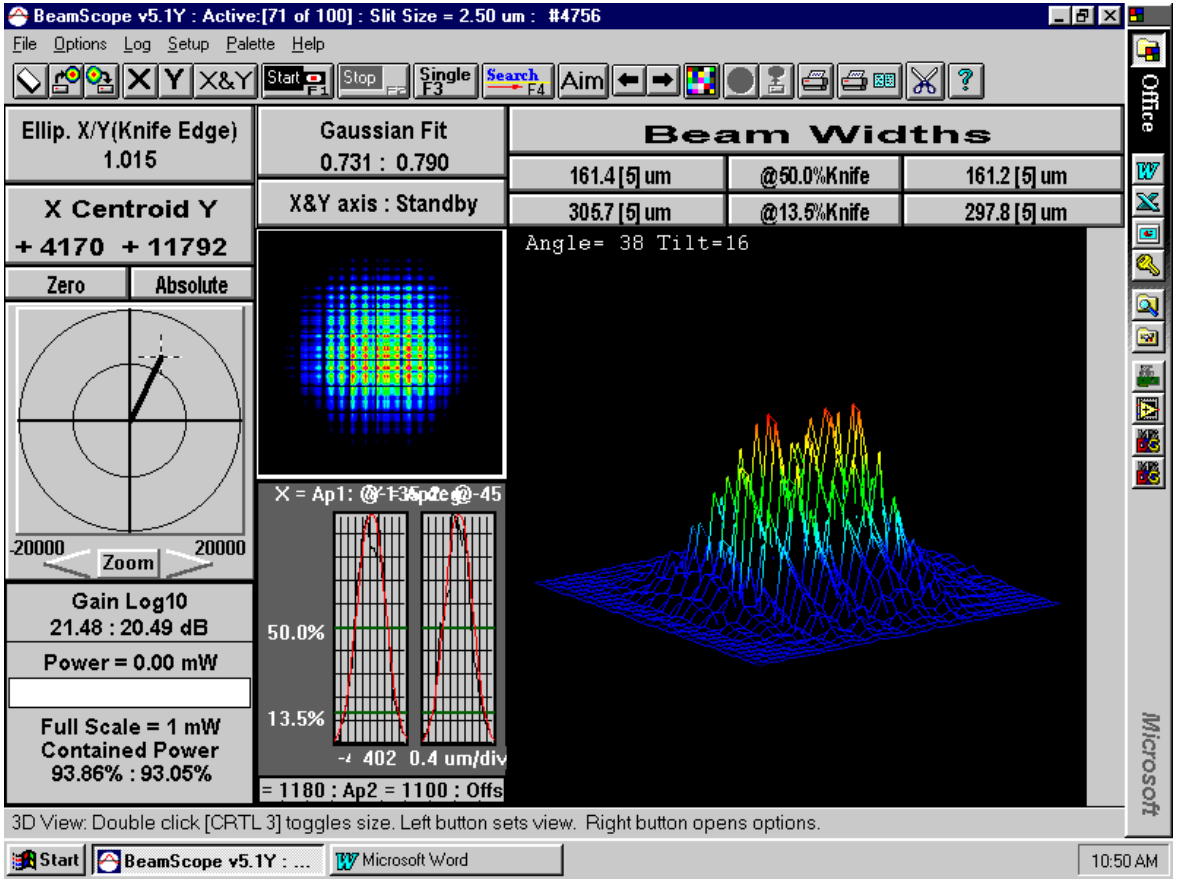
10x10 micro-DOEs arraywith 6 annulus fabricated by focused ion beam milling (FIBM) directly in BK7 glass substrate


BeamScope v5.1Y : Active:[53 of 100] : Slit Size = 2.50 um : #4134
File Options Log Setup Palette Help
X&Y Start Stop Single Search Aim
Ellip. X/Y(Knife Edge)
0.836
Gaussian Fit
0.553 : 0.585
Beam Widths
68.4 [5] um
@50.0%Knife
76.2 [5] um
168.0 [5] um
@13.5%Knife
201.2 [5] um
X&Y axis : Standby
X Centroid Y
+ 2287 + 2282
Zero
Absolute
Angle=-133 Tilt=36
-5000
Zoom
5000
Gain Log10
22.48 : 21.76 dB
Power = 0.00 mW
Full Scale = 1 mW
Contained Power
90.70% : 91.63%
50.0%
13.5%
-1 197 9.5 um/div
Ap1 = 570 : Ap2 = 650 : Off
Completes a single scan. F3
Start
BeamScope v5.1Y : ...
Microsoft Word - Document5
2:26 PM
Office
Microsoft

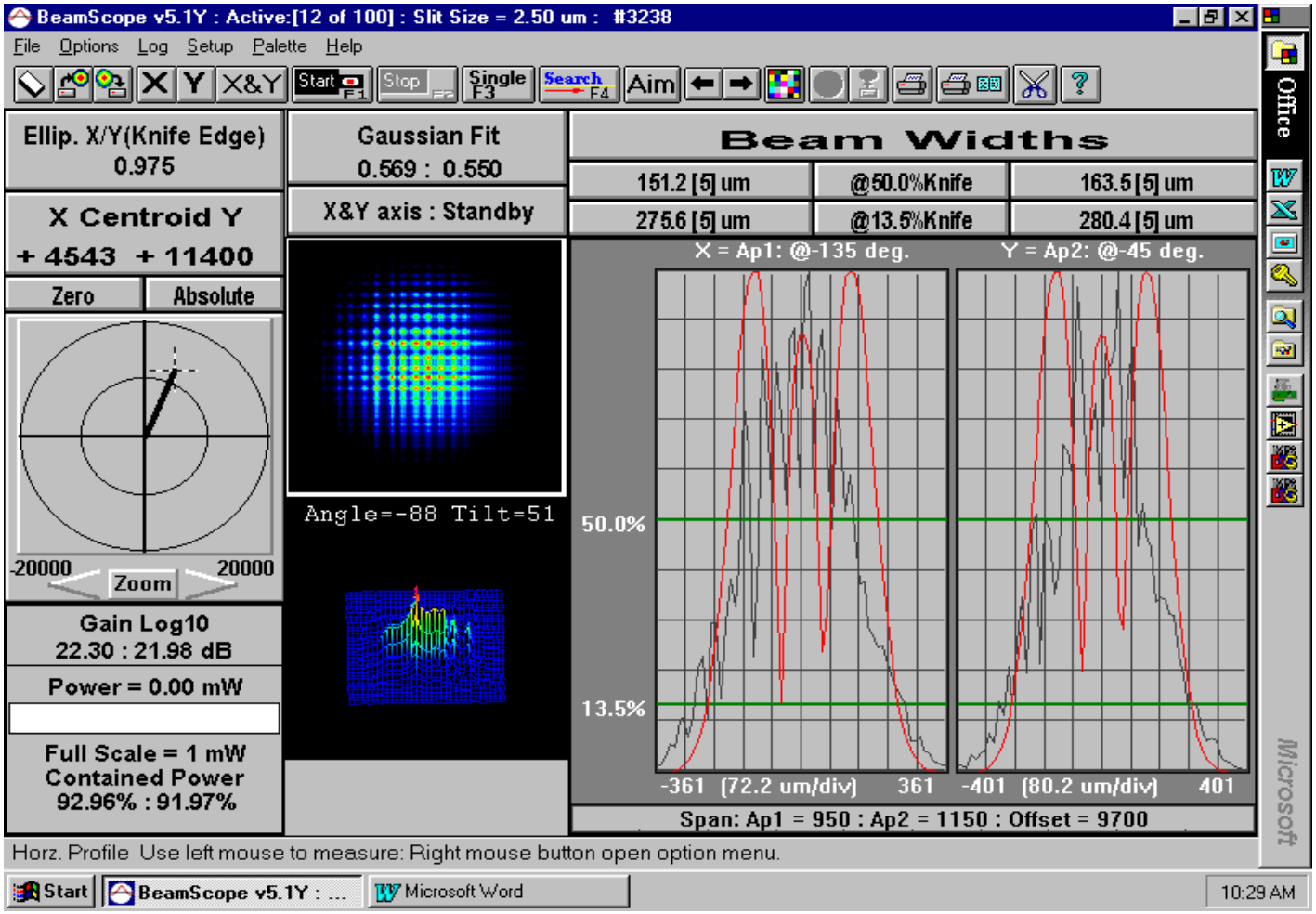

BeamScope v5.1Y : Active:[53 of 100] : Slit Size = 2.50 um : #4134
File Options Log Setup Palette Help
X Y X&Y Start F1 Stop F2 Single F3 Search F4 Aim
Ellip. X/Y(Knife Edge)
0.836
Gaussian Fit
0.553 : 0.585
X&Y axis : Standby
Beam Widths
68.4 [5] um
@50.0%Knife
76.2 [5] um
168.0 [5] um
@13.5%Knife
201.2 [5] um
X Centroid Y
+ 2287 + 2282
Zero
Absolute
-5000
Zoom
5000
Angle=-133 Tilt=36
WARNING X==Y
Y = Ap2: @-45 deg.
50.0%
13.5%
Gain Log10
22.48 : 21.76 dB
Power = 0.00 mW
Full Scale = 1 mW
Contained Power
90.70% : 91.63%
-200 (40.1 um/div) 200
-226 (45.1 um/div) 226
Span: Ap1 = 570 : Ap2 = 650 : Offset = -7
Right button sets text colors. {normal,pass,fail,and invalid}
Start
BeamScope v5.1Y : ...
Microsoft Word
2:25 PM
Office
Microsoft

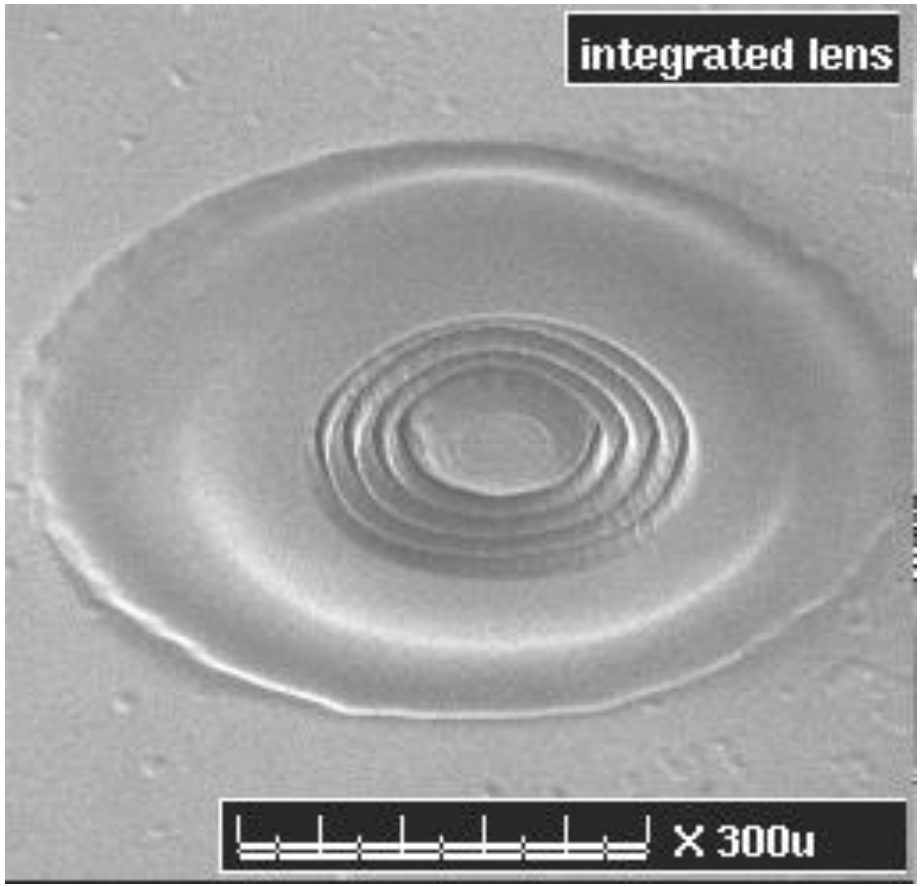


9x9 micro-refractive lens array with f-number 5, diameter of 60 μm and *NA* =0.1 fabricated by focused ion beam milling (FIBM) directly in BK7 glass substrate

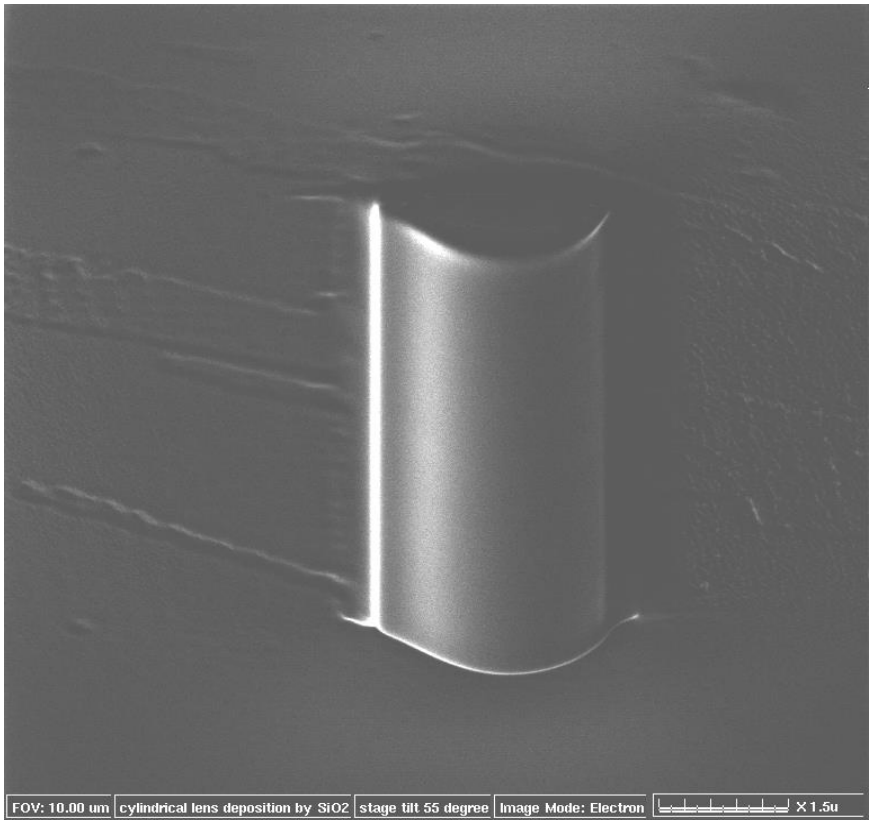


Beam profile of the 9x9 micro-refractive lens array measured by BeamScope-P5™


BeamScope v5.1Y : Active:[12 of 100] : Slit Size = 2.50 um : #3238
File Options Log Setup Palette Help
Start F1
Stop F2
Single F3
Search F4
Aim
Ellip. X/Y(Knife Edge)
0.975
X Centroid Y
+ 4543 + 11400
Zero
Absolute
-20000
Zoom
20000
Gain Log10
22.30 : 21.98 dB
Power = 0.00 mW
Full Scale = 1 mW
Contained Power
92.96% : 91.97%
Gaussian Fit
0.569 : 0.550
X&Y axis : Standby
Angle=-88 Tilt=51
Beam Widths
151.2 [5] um
@50.0%Knife
163.5 [5] um
275.6 [5] um
@13.5%Knife
280.4 [5] um
X = Ap1: @-135 deg.
Y = Ap2: @-45 deg.
50.0%
13.5%
-361 (72.2 um/div) 361
-401 (80.2 um/div) 401
Span: Ap1 = 950 : Ap2 = 1150 : Offset = 9700
Horz. Profile Use left mouse to measure: Right mouse button open option menu.
Start
BeamScope v5.1Y : ...
Microsoft Word
10:29 AM
Office
Microsoft



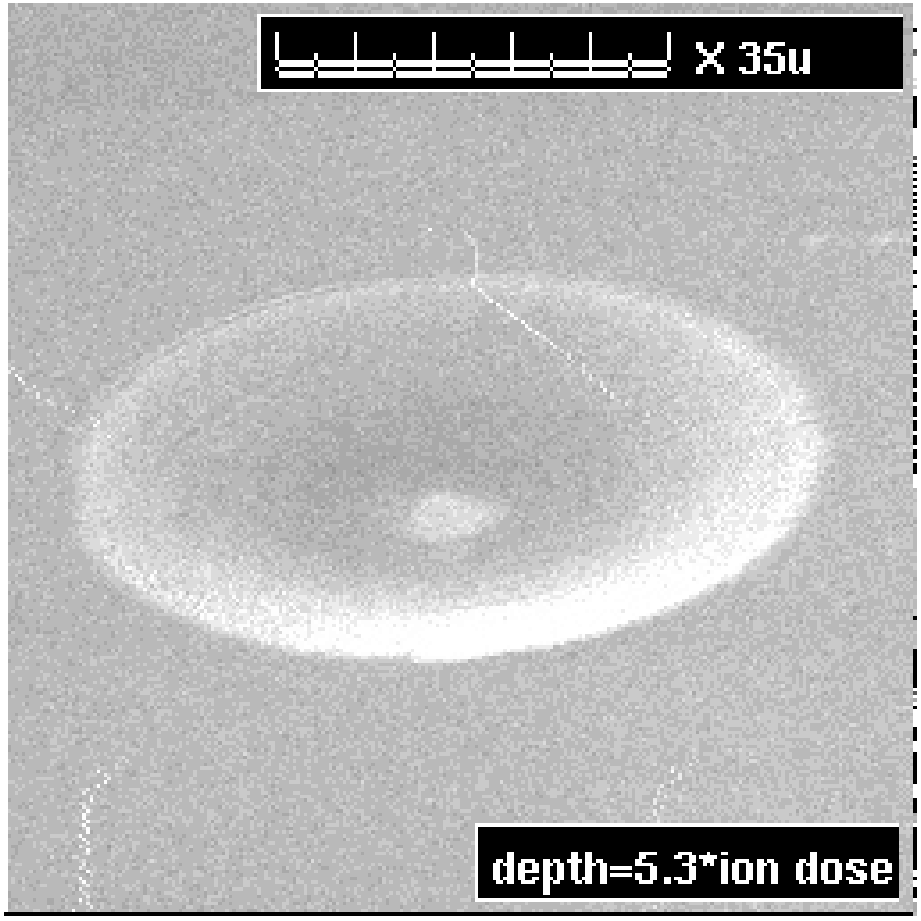
Integrated lens with NA=0.35, and o.5 for refractive and diffractive respectively, fabricated by deposition SiO_2 and milling

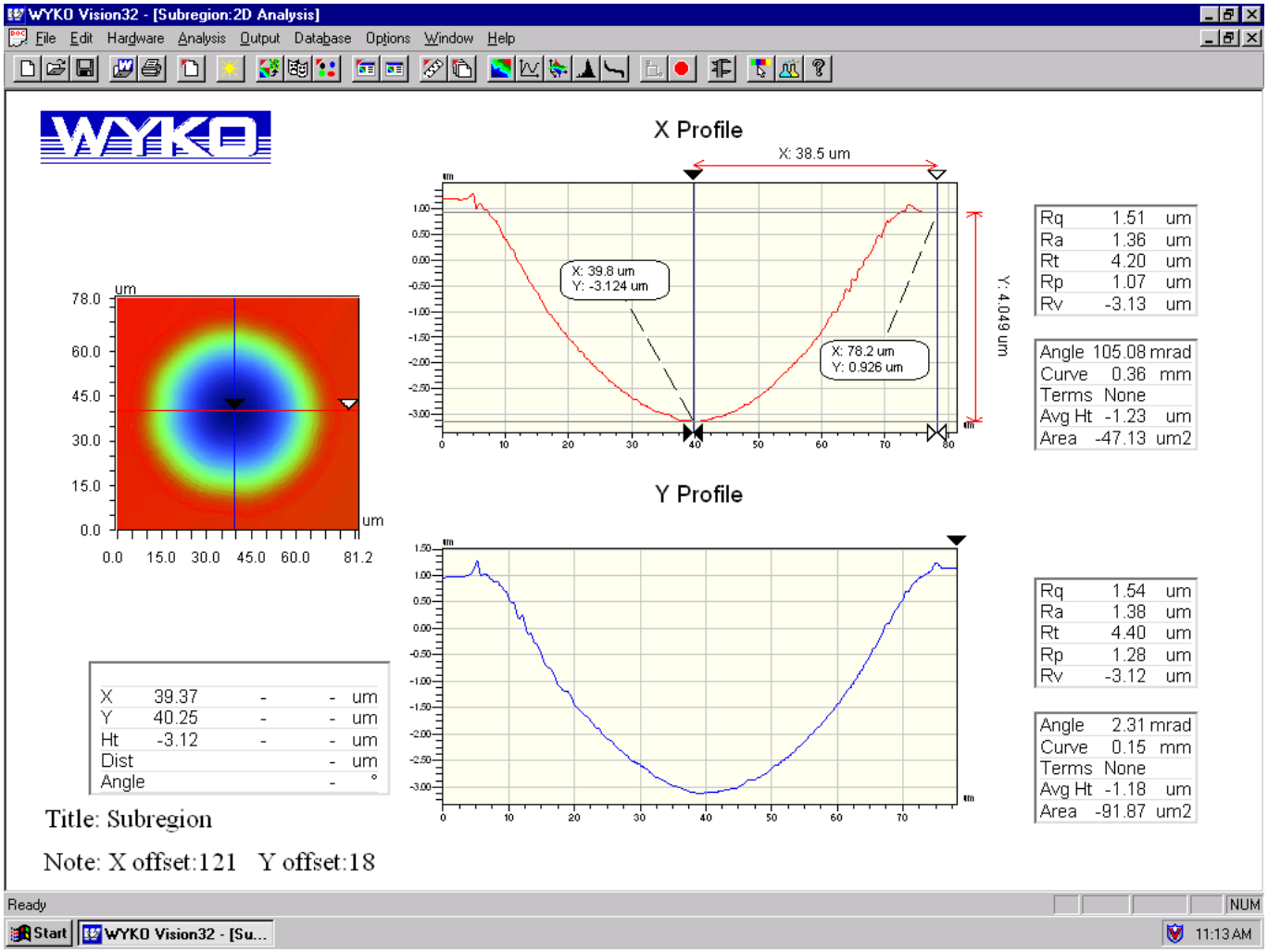


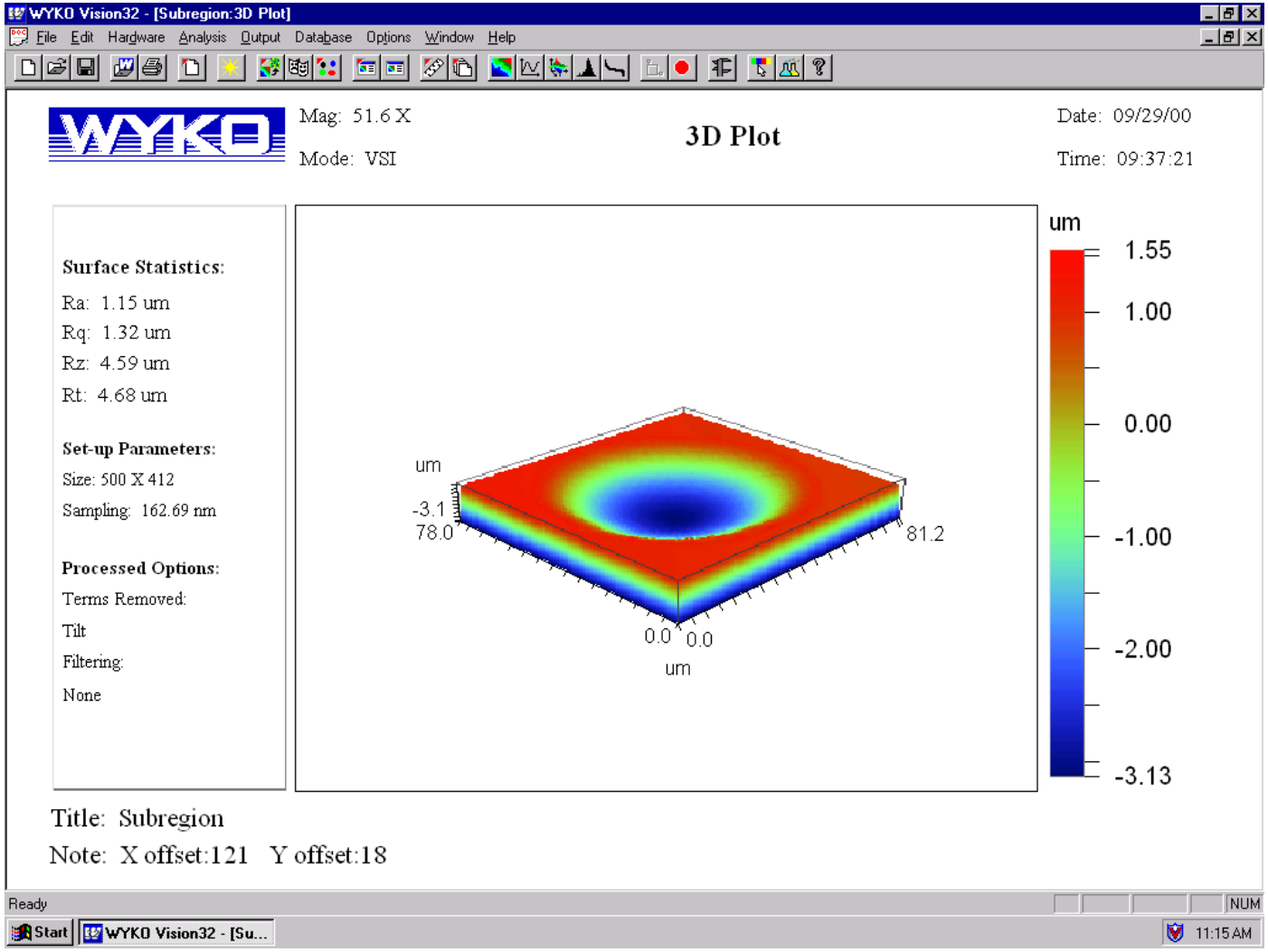
Micro-cylindrical lens with size of 3x8x0.9 μm directly deposited on glass substrate by FIB SiO_2 deposition

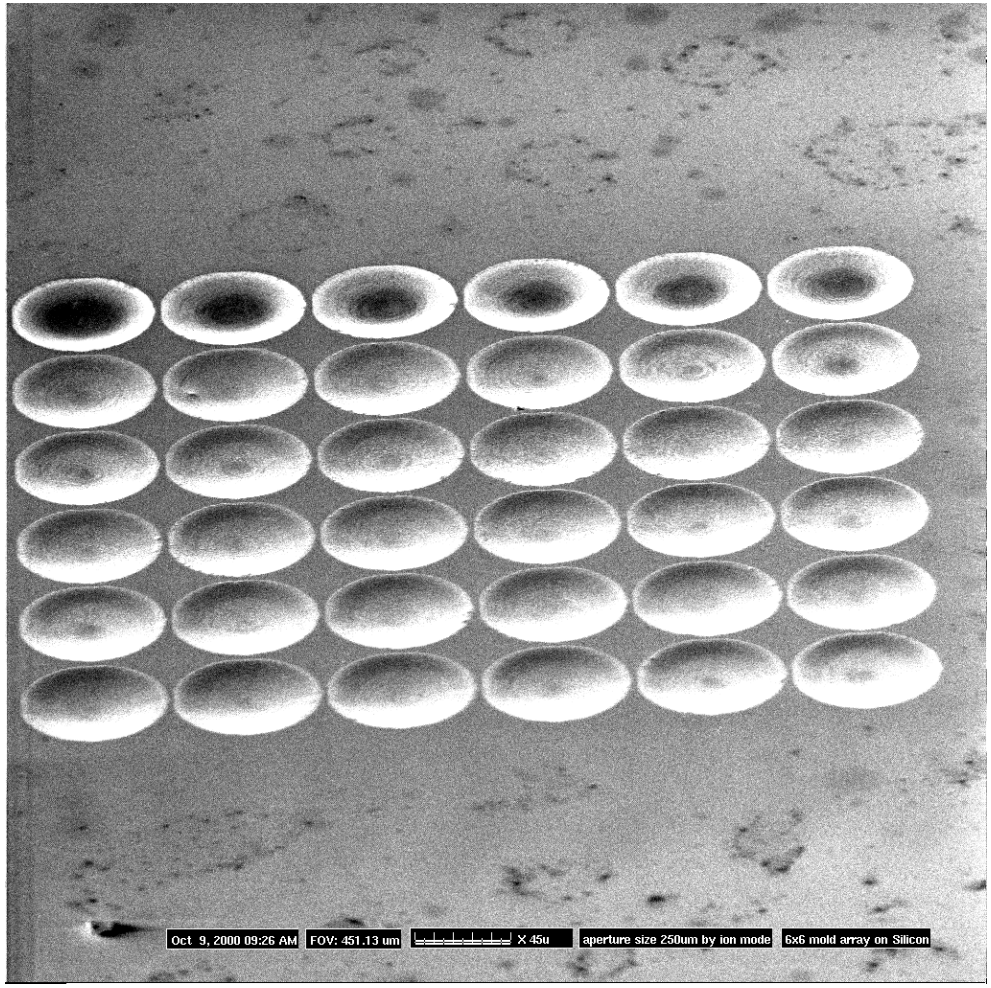
SEM micrograph of microlens in 60° view angle with f#= 6, NA = 0.1, and diameter of 10 micron fabricated by SiO_2 deposition on glass substrate

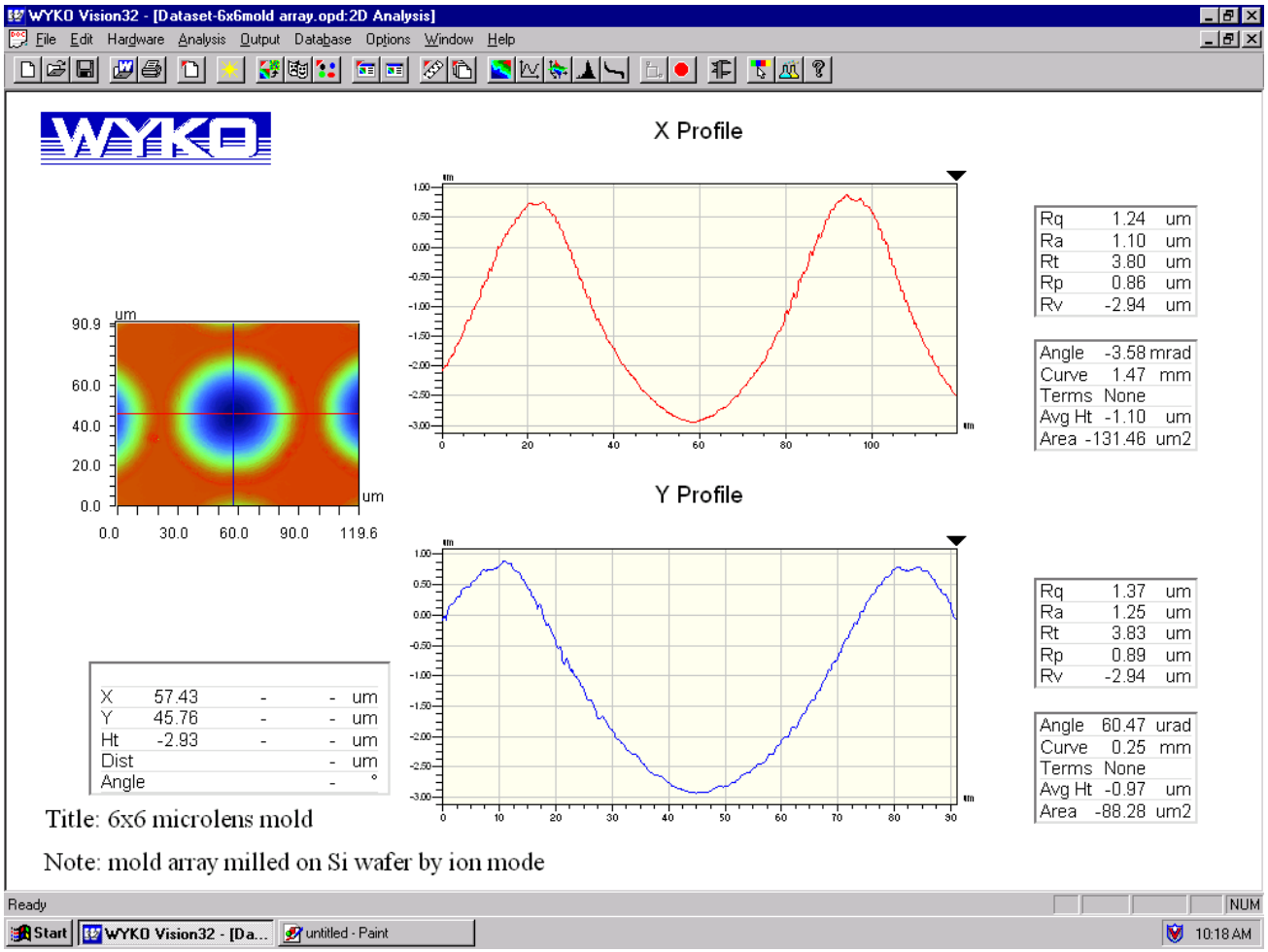
Microlens mold fabricated using FIBM

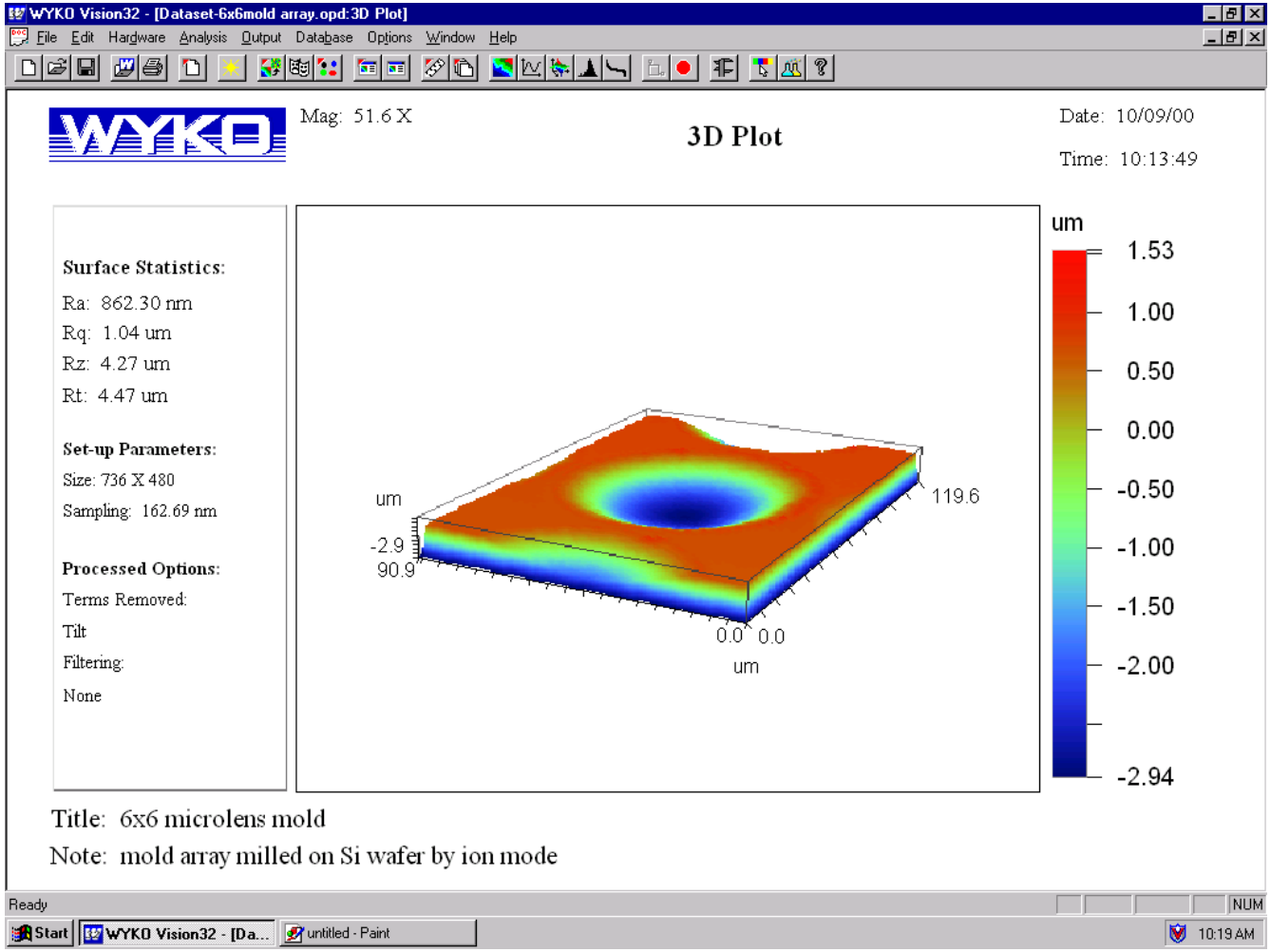


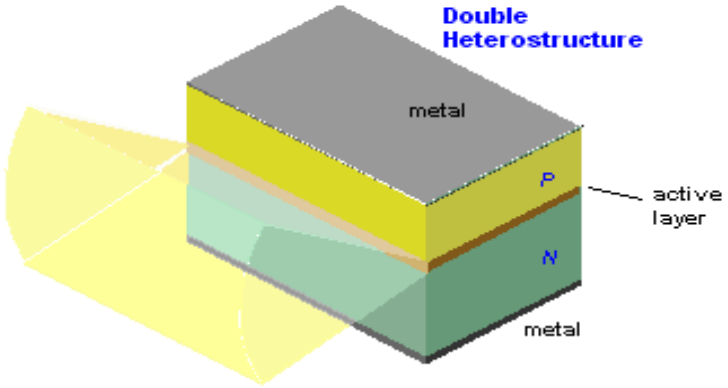

WYKO Vision32 - [Subregion:2D Analysis]
File Edit Hardware Analysis Output Database Options Window Help
WYKO
X Profile
X: 38.5 um
X: 39.8 um
Y: -3.124 um
X: 78.2 um
Y: 0.926 um
Y: 4.049 um
Rq 1.51 um
Ra 1.36 um
Rt 4.20 um
Rp 1.07 um
Rv -3.13 um
Angle 105.08 mrad
Curve 0.36 mm
Terms None
Avg Ht -1.23 um
Area -47.13 um2
um
78.0
60.0
45.0
30.0
15.0
0.0
0.0 15.0 30.0 45.0 60.0 81.2
um
Y Profile
X 39.37 - - um
Y 40.25 - - um
Ht -3.12 - - um
Dist - um
Angle - °
Rq 1.54 um
Ra 1.38 um
Rt 4.40 um
Rp 1.28 um
Rv -3.12 um
Angle 2.31 mrad
Curve 0.15 mm
Terms None
Avg Ht -1.18 um
Area -91.87 um2
Title: Subregion
Note: X offset:121 Y offset:18
Ready
NUM
Start
WYKO Vision32 - [Su...
11:13 AM

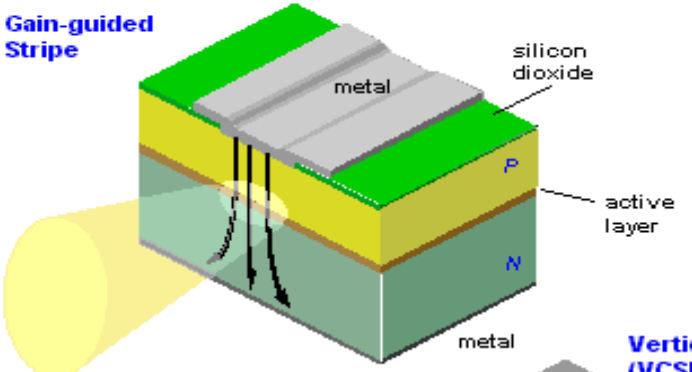

WYKO Vision32 - [Subregion:3D Plot]
File Edit Hardware Analysis Output Database Options Window Help
Mag: 51.6 X
Mode: VSI
3D Plot
Date: 09/29/00
Time: 09:37:21
Surface Statistics:
Ra: 1.15 um
Rq: 1.32 um
Rz: 4.59 um
Rt: 4.68 um
Set-up Parameters:
Size: 500 X 412
Sampling: 162.69 nm
Processed Options:
Terms Removed:
Tilt
Filtering:
None
um
-3.1
78.0
81.2
0.0
0.0
um
um
1.55
1.00
0.00
-1.00
-2.00
-3.13
Title: Subregion
Note: X offset:121 Y offset:18
Ready
NUM
Start
WYKO Vision32 - [Su...
11:15 AM

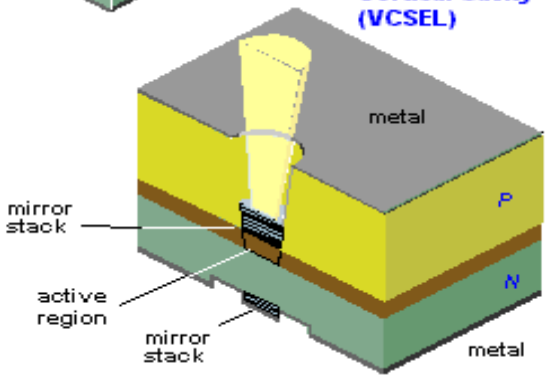

Oct 9, 2000 09:26 AM
FOV: 451.13 um
X 45u
aperture size 250um by ion mode
6x6 mold array on Silicon

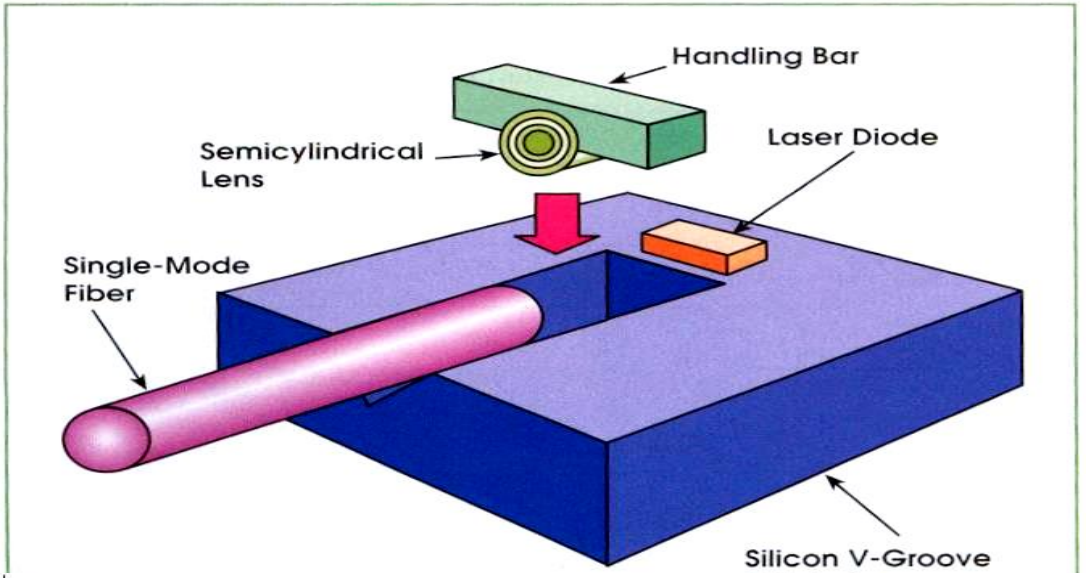

WYKO Vision32 - [Dataset-6x6mold array.opd:2D Analysis]
File Edit Hardware Analysis Output Database Options Window Help
WYKO
X Profile
Rq 1.24 um
Ra 1.10 um
Rt 3.80 um
Rp 0.86 um
Rv -2.94 um
Angle -3.58 mrad
Curve 1.47 mm
Terms None
Avg Ht -1.10 um
Area -131.46 um2
Y Profile
Rq 1.37 um
Ra 1.25 um
Rt 3.83 um
Rp 0.89 um
Rv -2.94 um
Angle 60.47 urad
Curve 0.25 mm
Terms None
Avg Ht -0.97 um
Area -88.28 um2
X 57.43 - - um
Y 45.76 - - um
Ht -2.93 - - um
Dist - um
Angle - °
Title: 6x6 microlens mold
Note: mold array milled on Si wafer by ion mode
Ready
NUM
Start
WYKO Vision32 - [Da...
untitled - Paint
10:18 AM

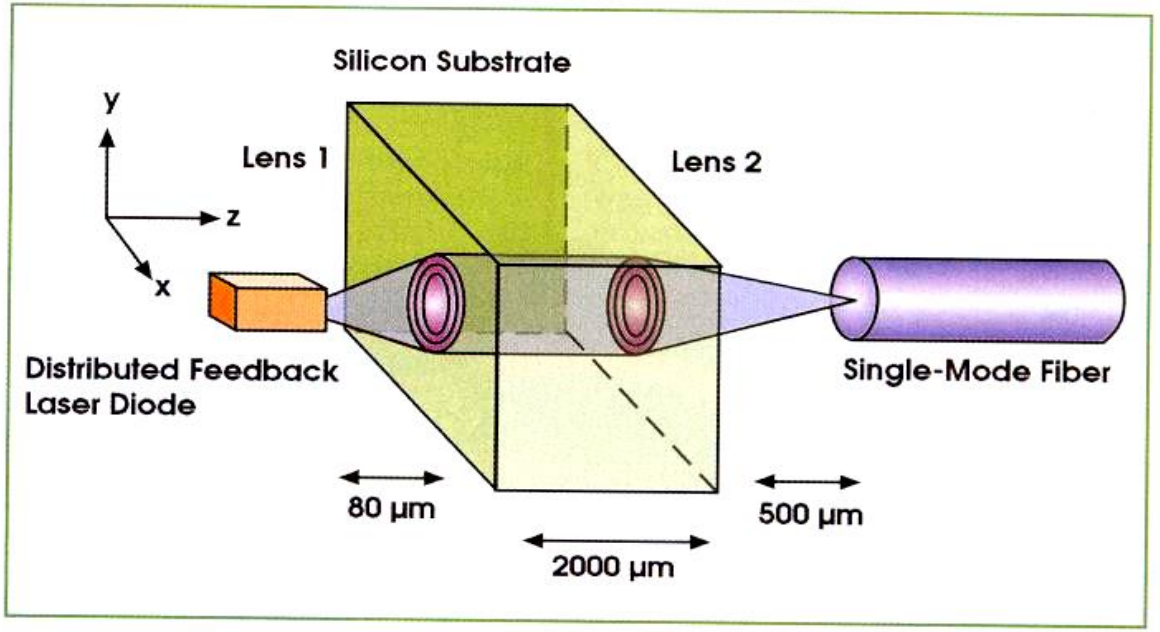

WYKO Vision32 - [Dataset-6x6mold array.opd:3D Plot]
File Edit Hardware Analysis Output Database Options Window Help
WYKO
Mag: 51.6 X
3D Plot
Date: 10/09/00
Time: 10:13:49
Surface Statistics:
Ra: 862.30 nm
Rq: 1.04 um
Rz: 4.27 um
Rt: 4.47 um
Set-up Parameters:
Size: 736 X 480
Sampling: 162.69 nm
Processed Options:
Terms Removed:
Tilt
Filtering:
None
um
-2.9
90.9
119.6
0.0
0.0
um
um
1.53
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
-2.94
Title: 6x6 microlens mold
Note: mold array milled on Si wafer by ion mode
Ready
NUM
Start
WYKO Vision32 - [Da...
untitled - Paint
10:19 AM





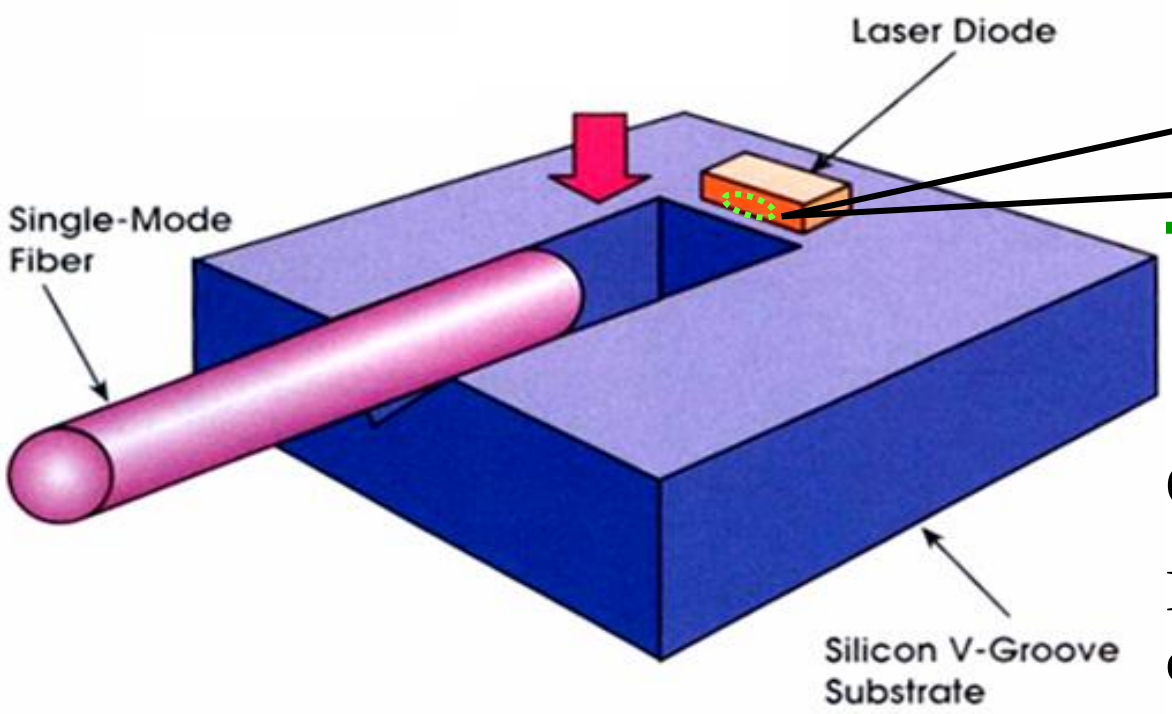


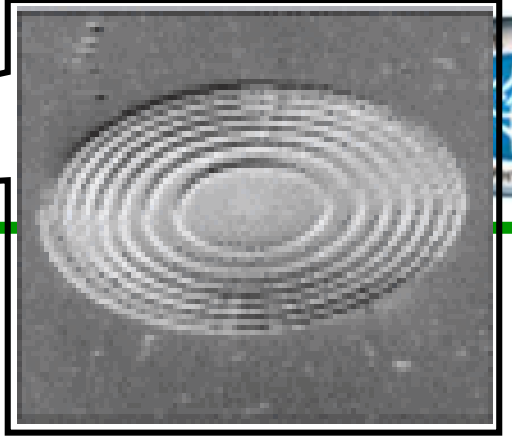




Conventional concept: isolated components for fiber coupling

Figure 2. *The diffractive microlens focuses the laser output into a single-mode fiber. Monte Carlo simulations suggest an 89 percent probability of a better than −5-dB total coupling loss for a passively aligned module.*

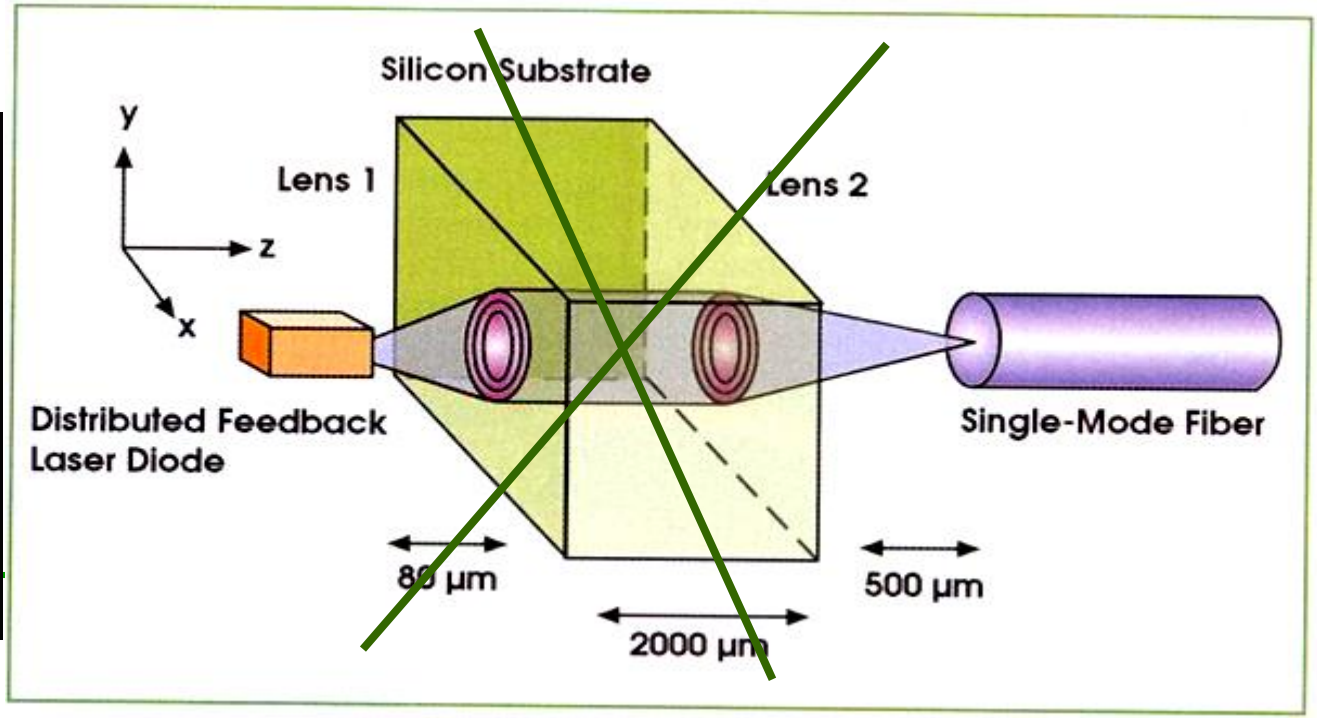




Our approach:

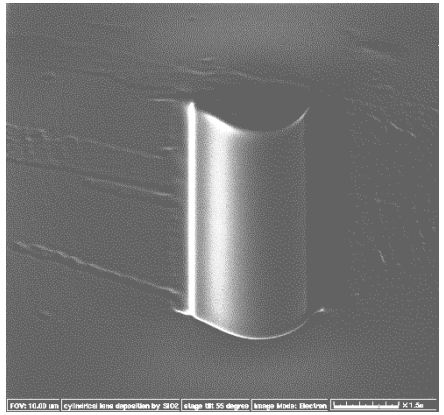
Directly integrate diffractive lens on emitting facet of laser diode.

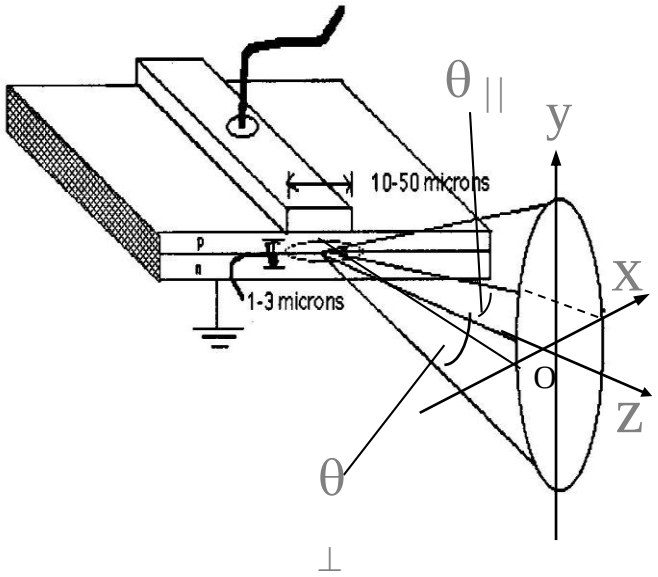
Our integrated device



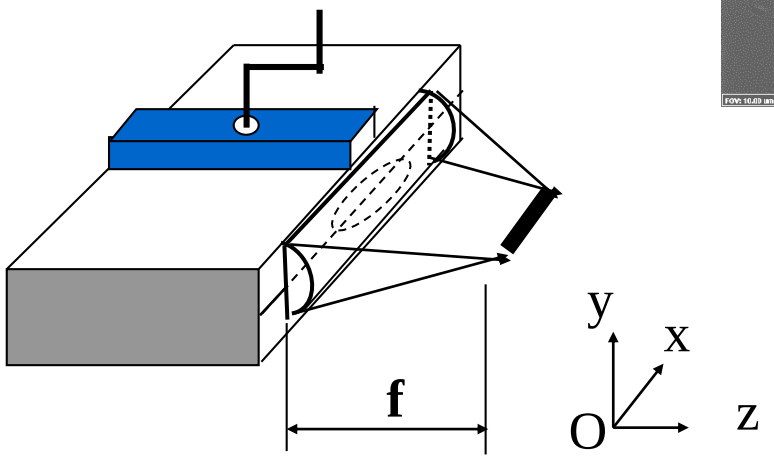
Micro-cylindrical lens integrated with LD

One of our deposited micro-elliptical lens by FIB with material SiO_2



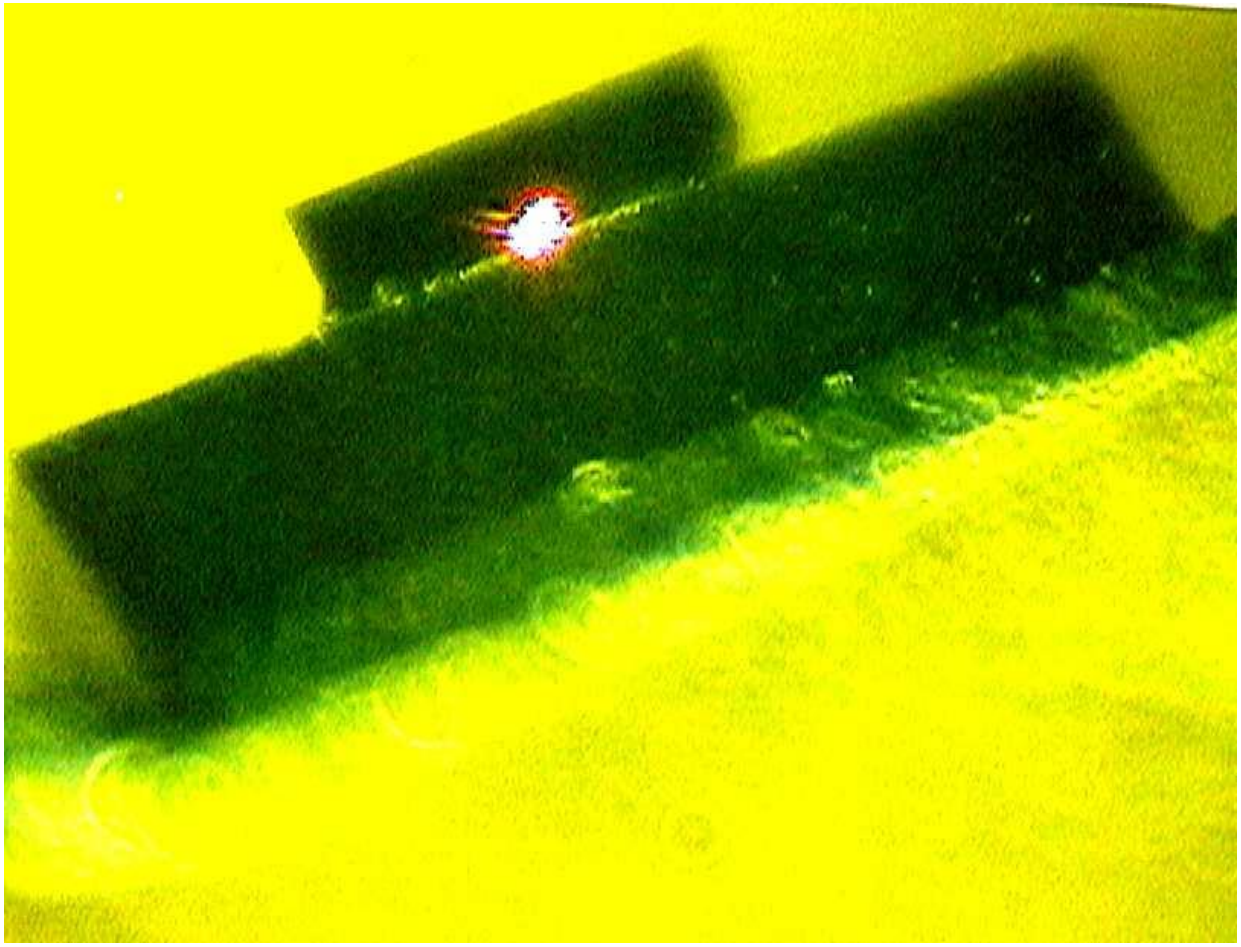


(a)

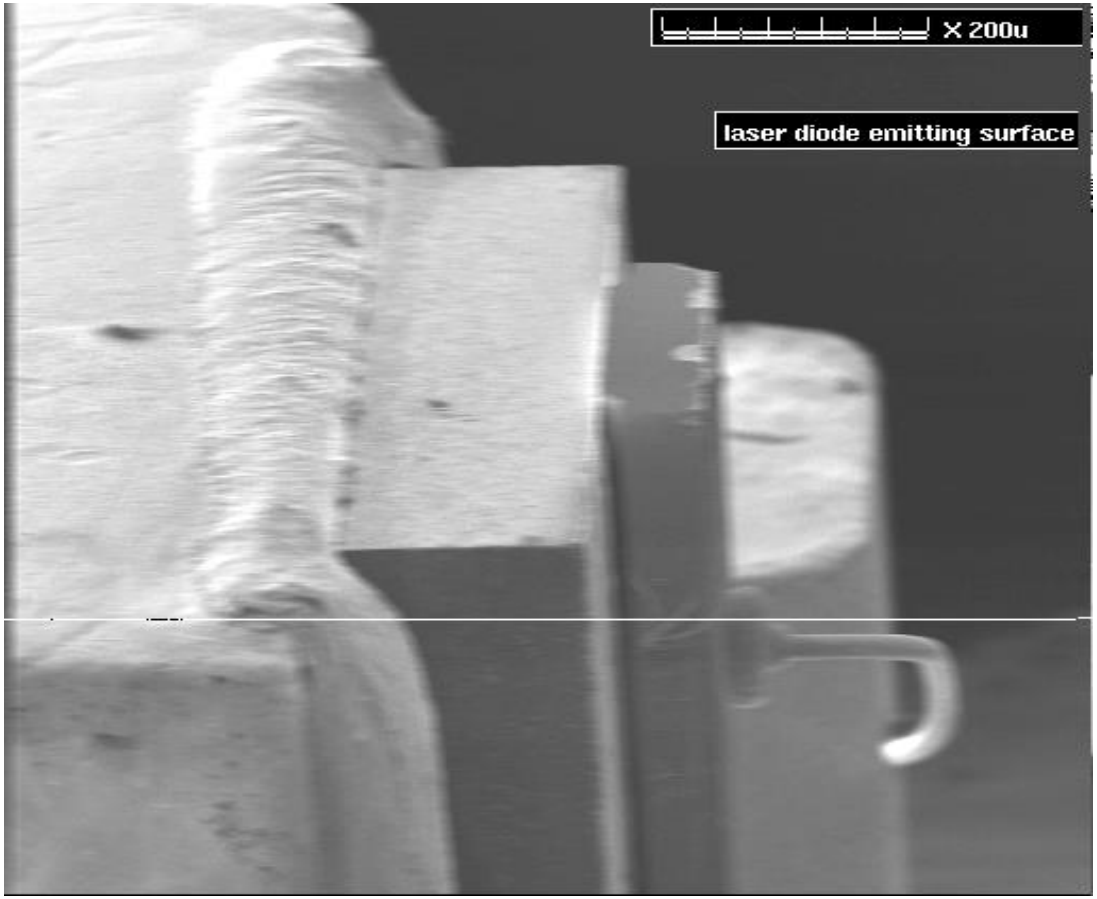


(b)

(a) diagram of original laser diode; (b) integrated micro-cylindrical lens with the laser diode. The microlens with size 50×5×0.85 μm^3 covered on the emitting facet, ***NA***=0.33.

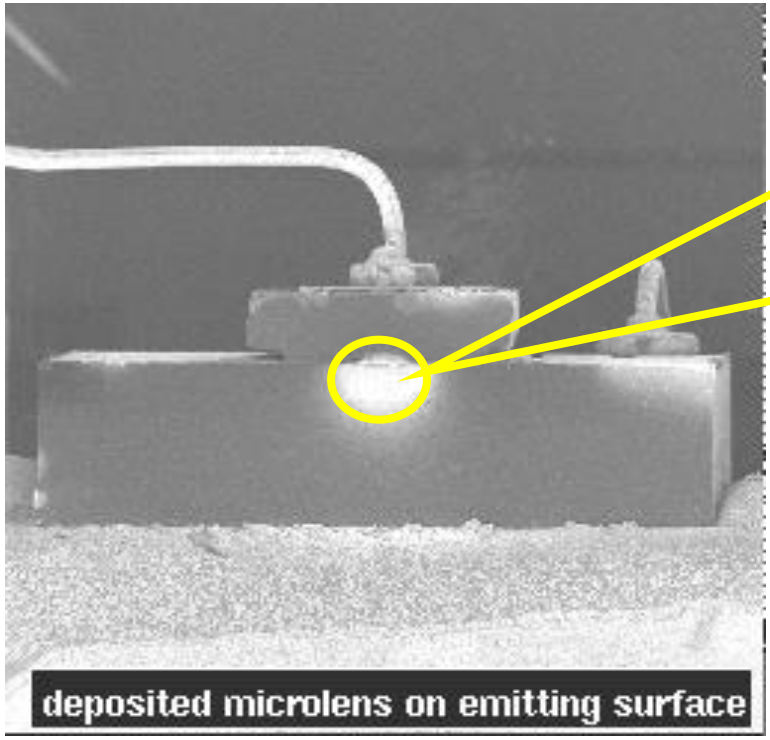


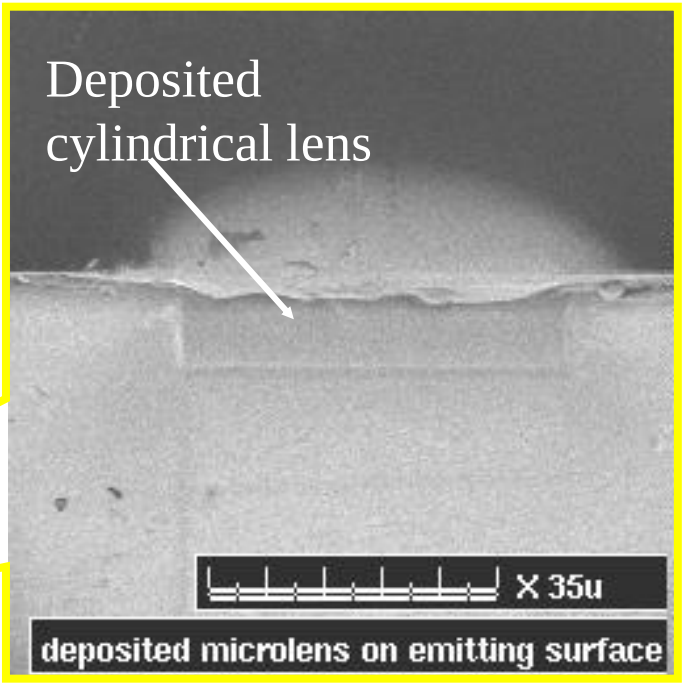
Original laser diode emitting



Side view of laser diode before FIB processing

Micro-cylindrical lens integrated with LD





SEM micrograph of the deposited micro-cylindrical lens on emitting surface of laser diode.

集成结构示意图

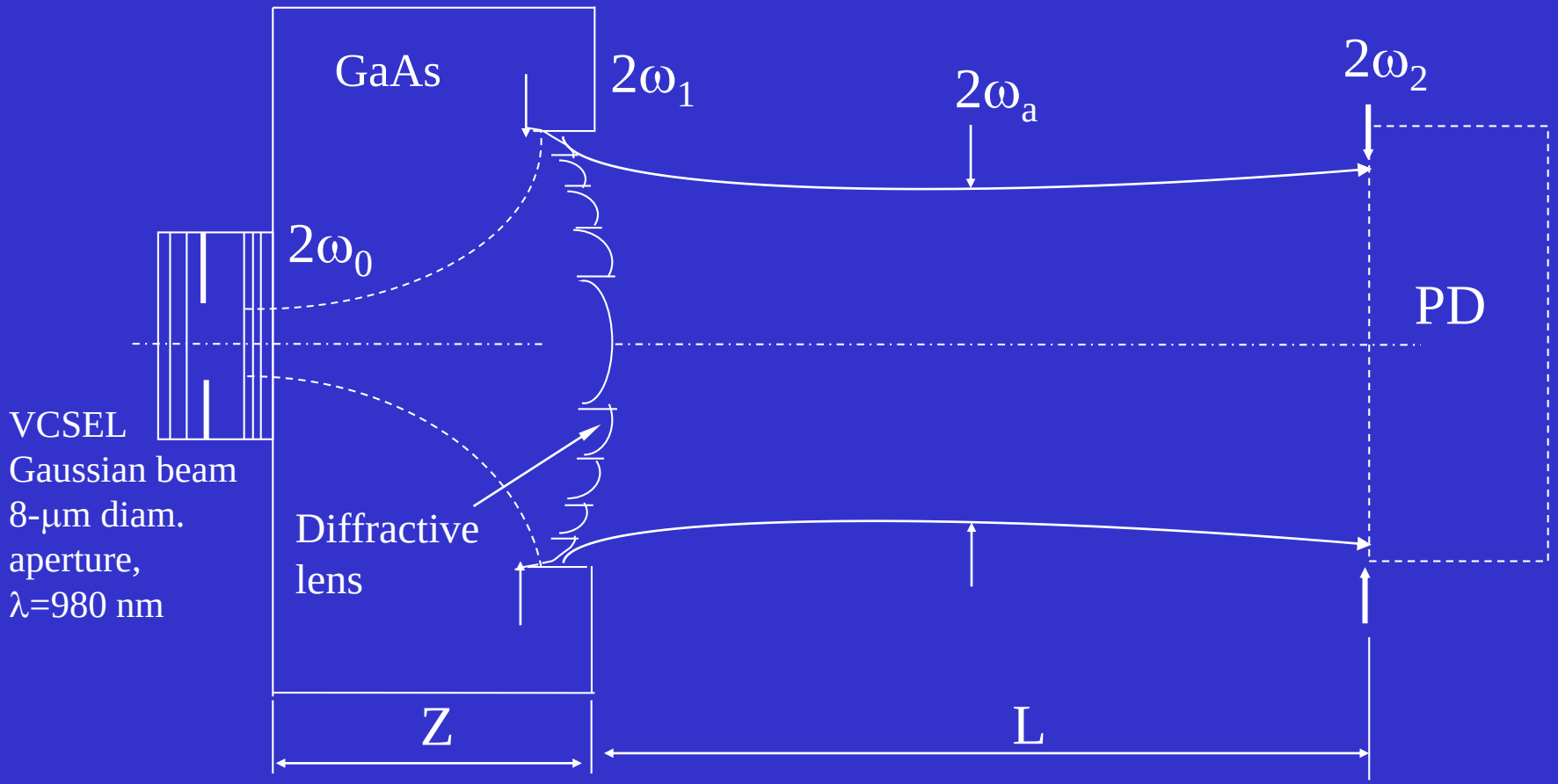


Fig.1. Schematic diagram of single-VCSEL integrated with hybrid microlens combined with spherical lens and diffractive lens on the same side for collimating.

设计参数 f=230 μm, NA=0.29, 浮雕深度: 0.4 μm

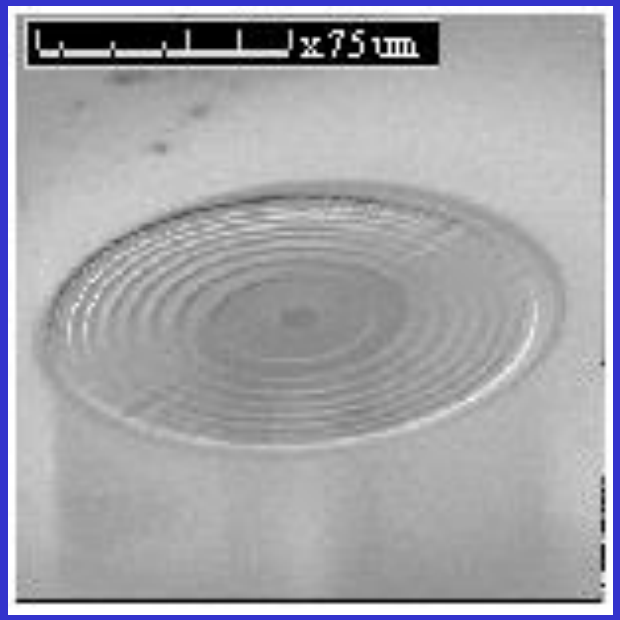


Fig.2 Diffractive lens with continuous relief directly milled onto backside of VCSEL with GaAs substrate by FIB. SEM image in 30° view angle.

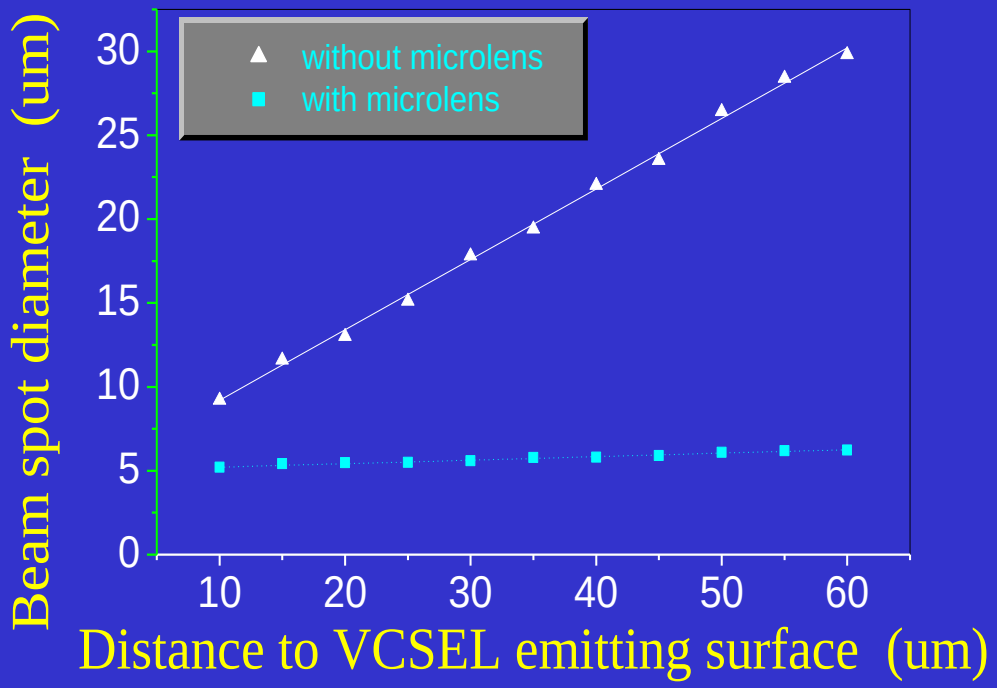
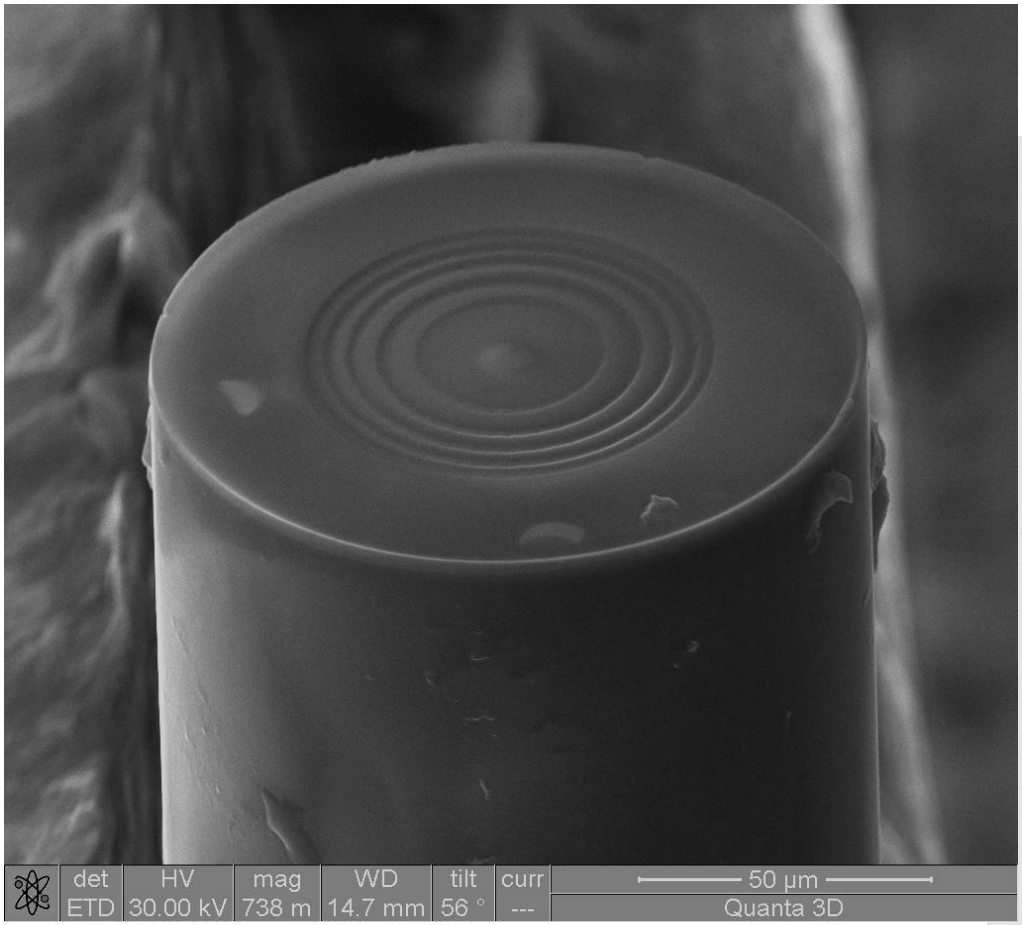
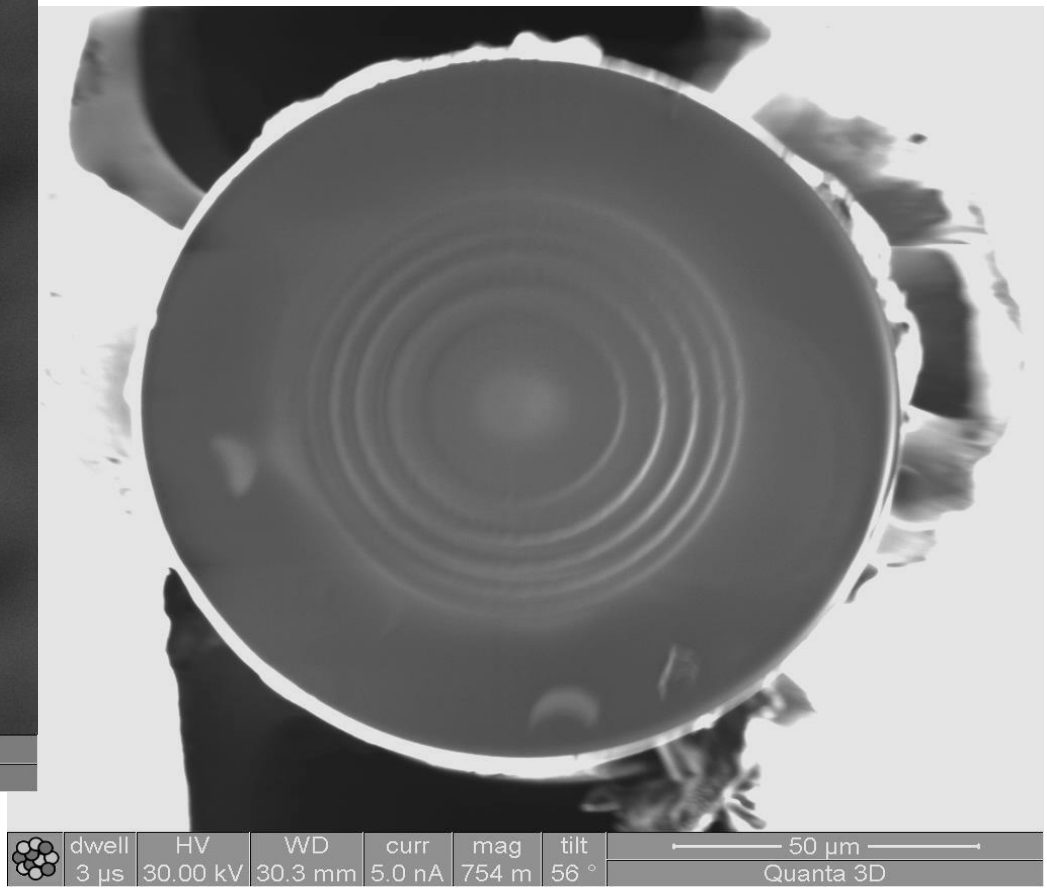


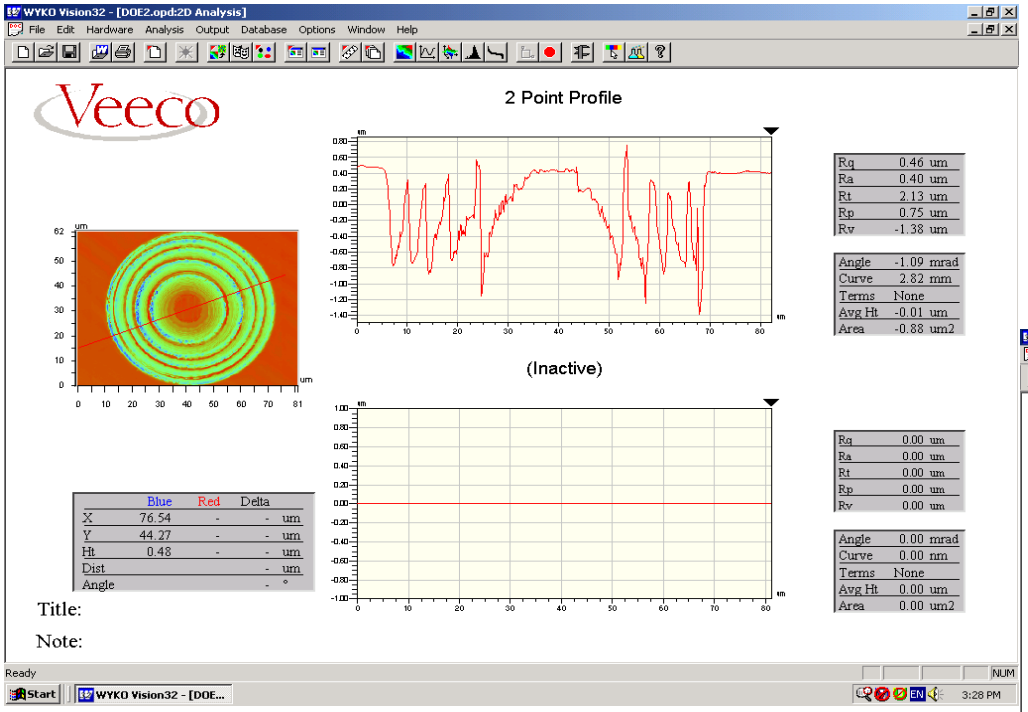
Fig.3 Far-field angle (half divergence angle) measured by BeamScope-P5™ beam scanner, the angle calculated in terms of incline angle of the lines, is 0.6° and 12° with and without microlens respectively.

FIB在光纤端面直写衍射微透镜实验结果

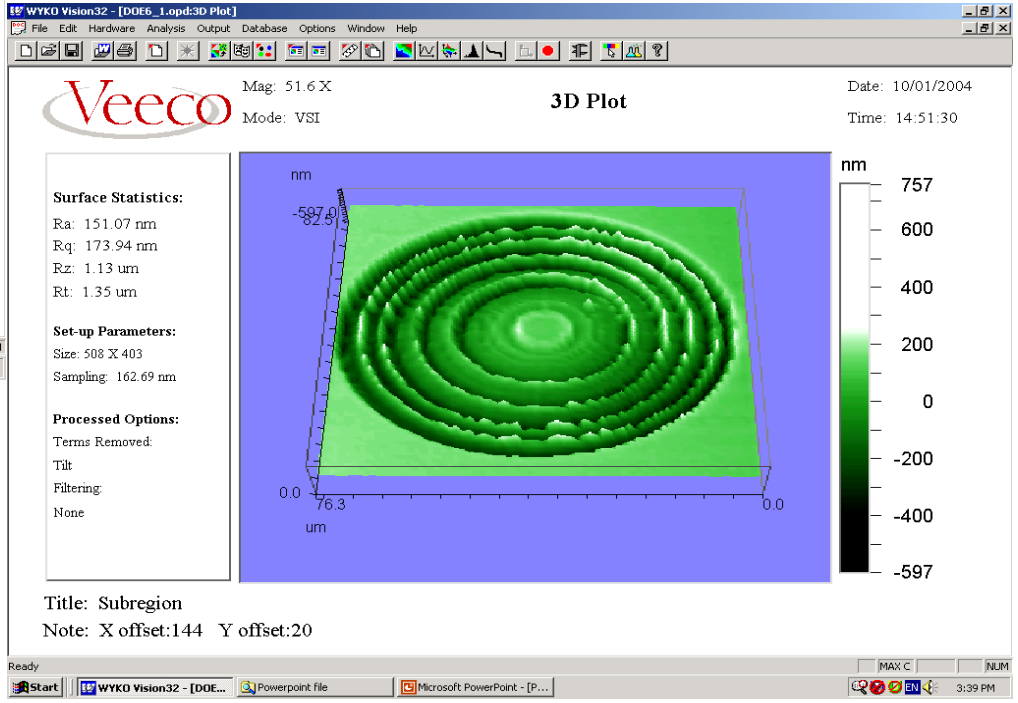




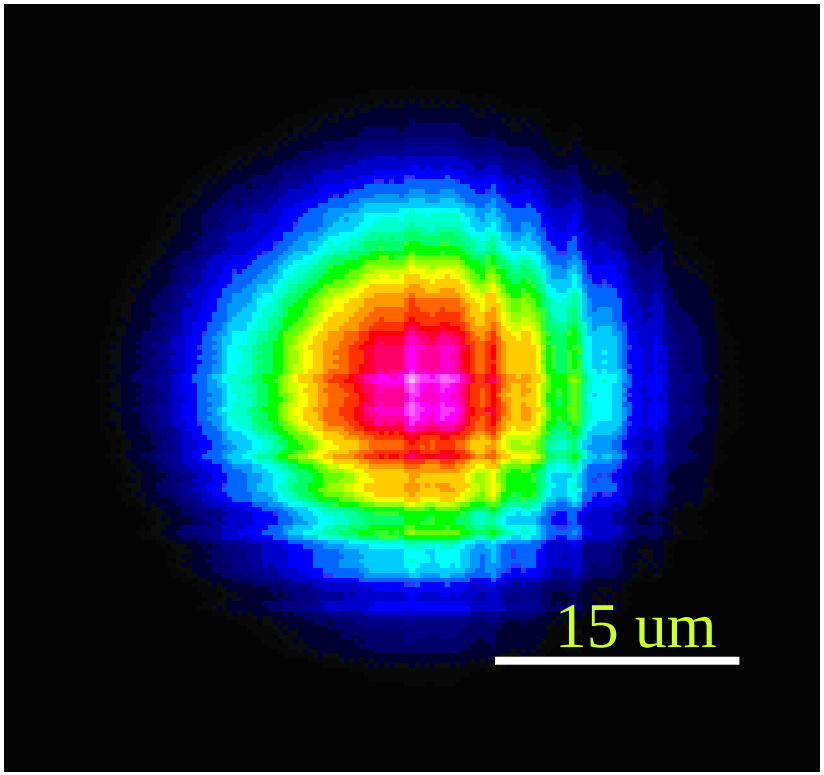
Veeco干涉仪测量结果

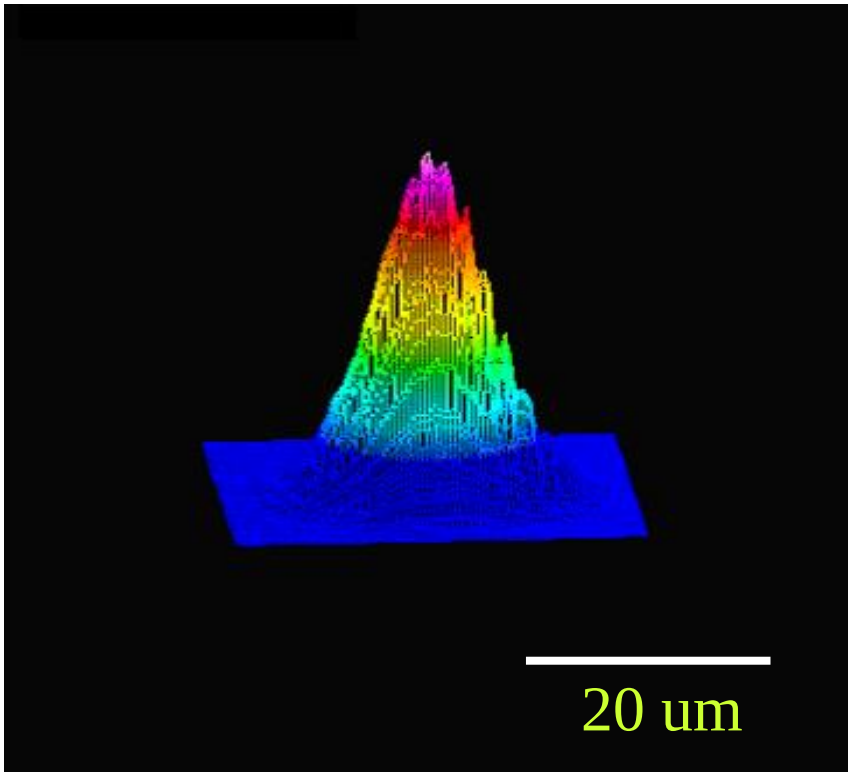


Characterization results using WYKO interferometer



实验结果:集成DOE聚焦性能测试



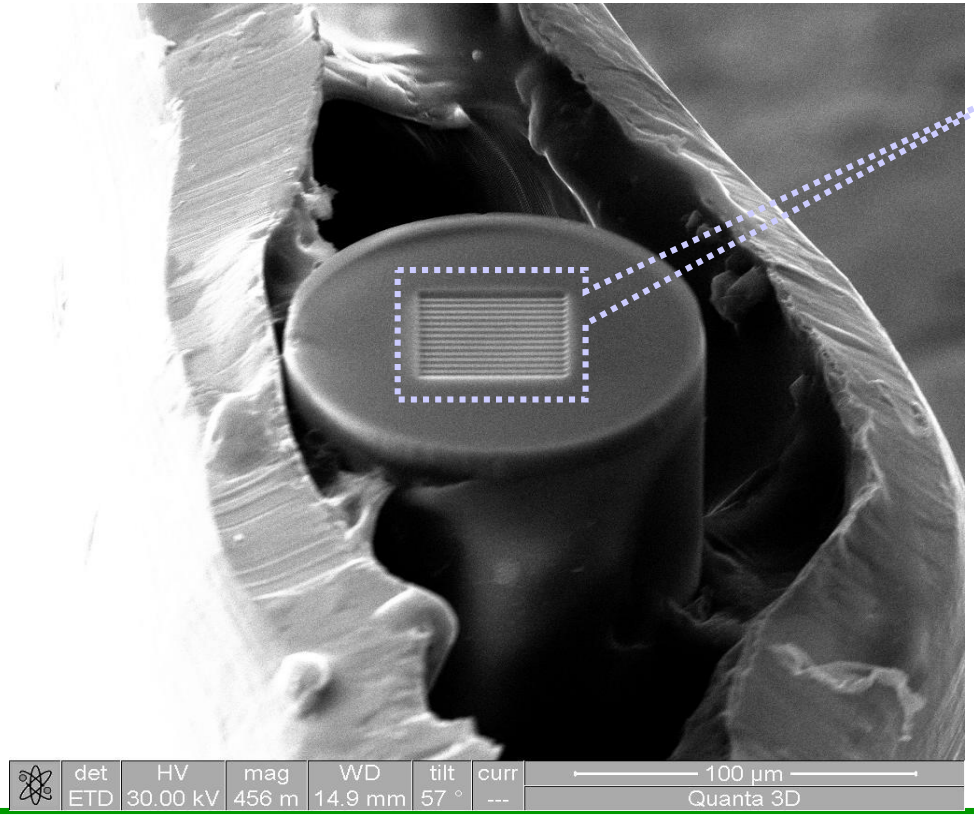


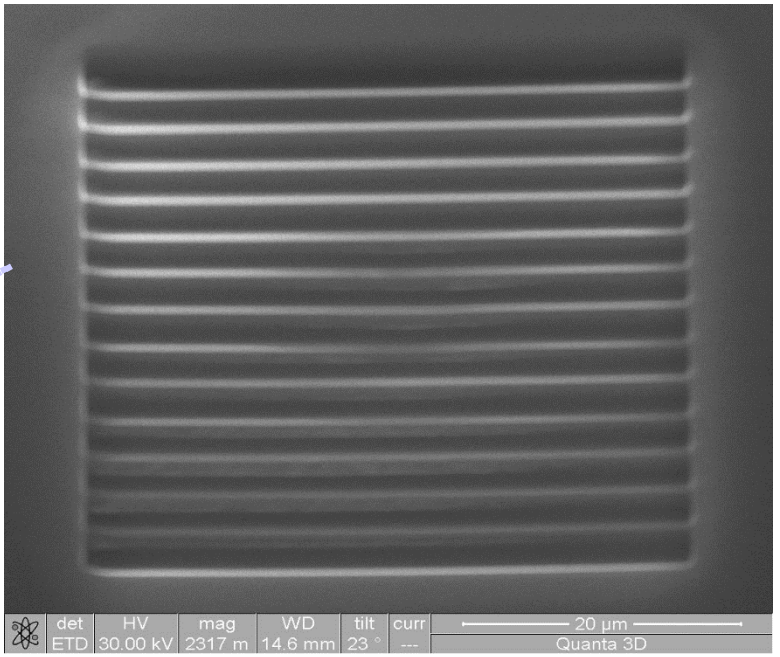
Beam profile (2D & 3D) captured at focal plane

Beam scanner: BeamScope-P5™

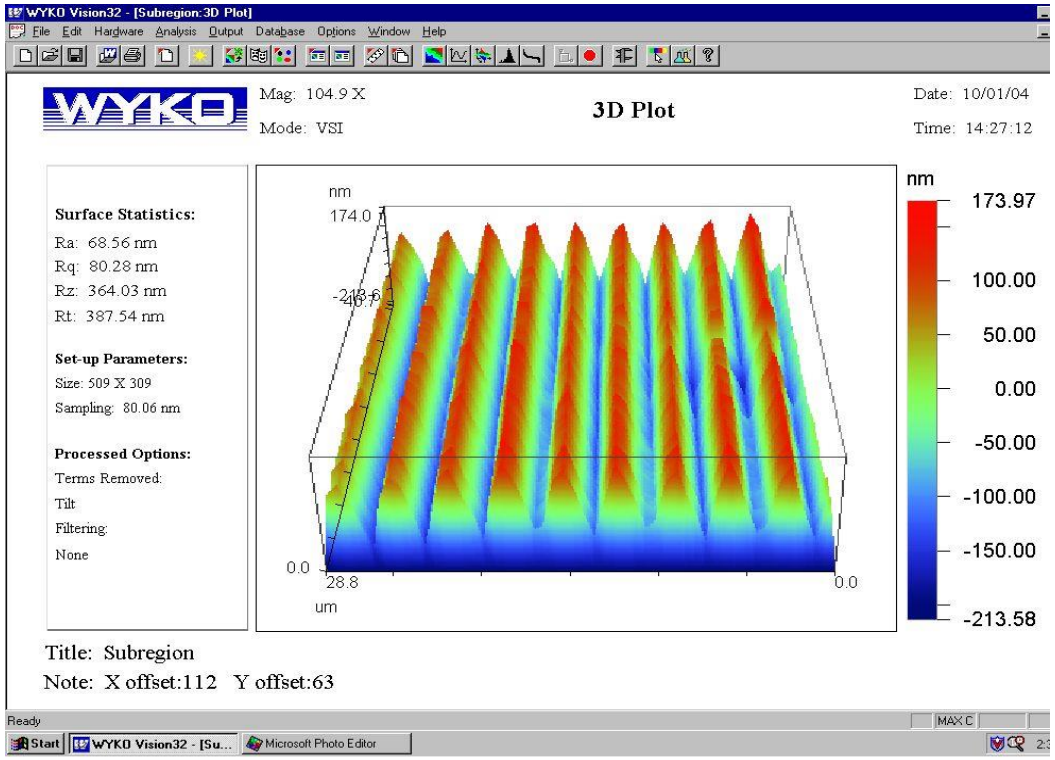
FIB在光纤端面直写闪耀光栅实验结果

Integrated blaze grating on single mode fiber

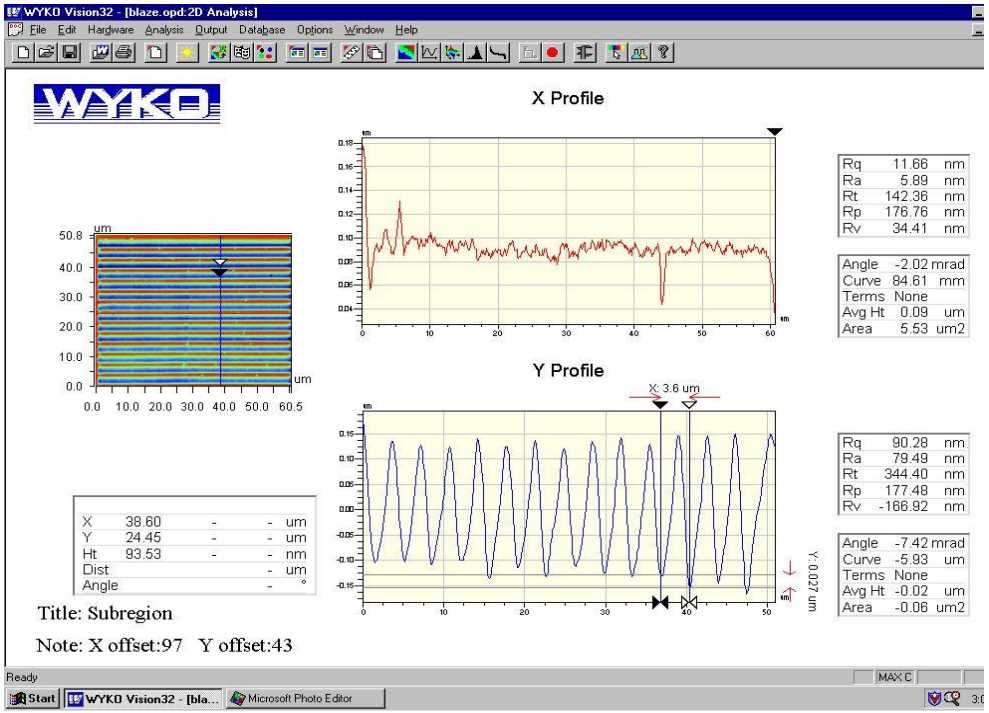




实验结果

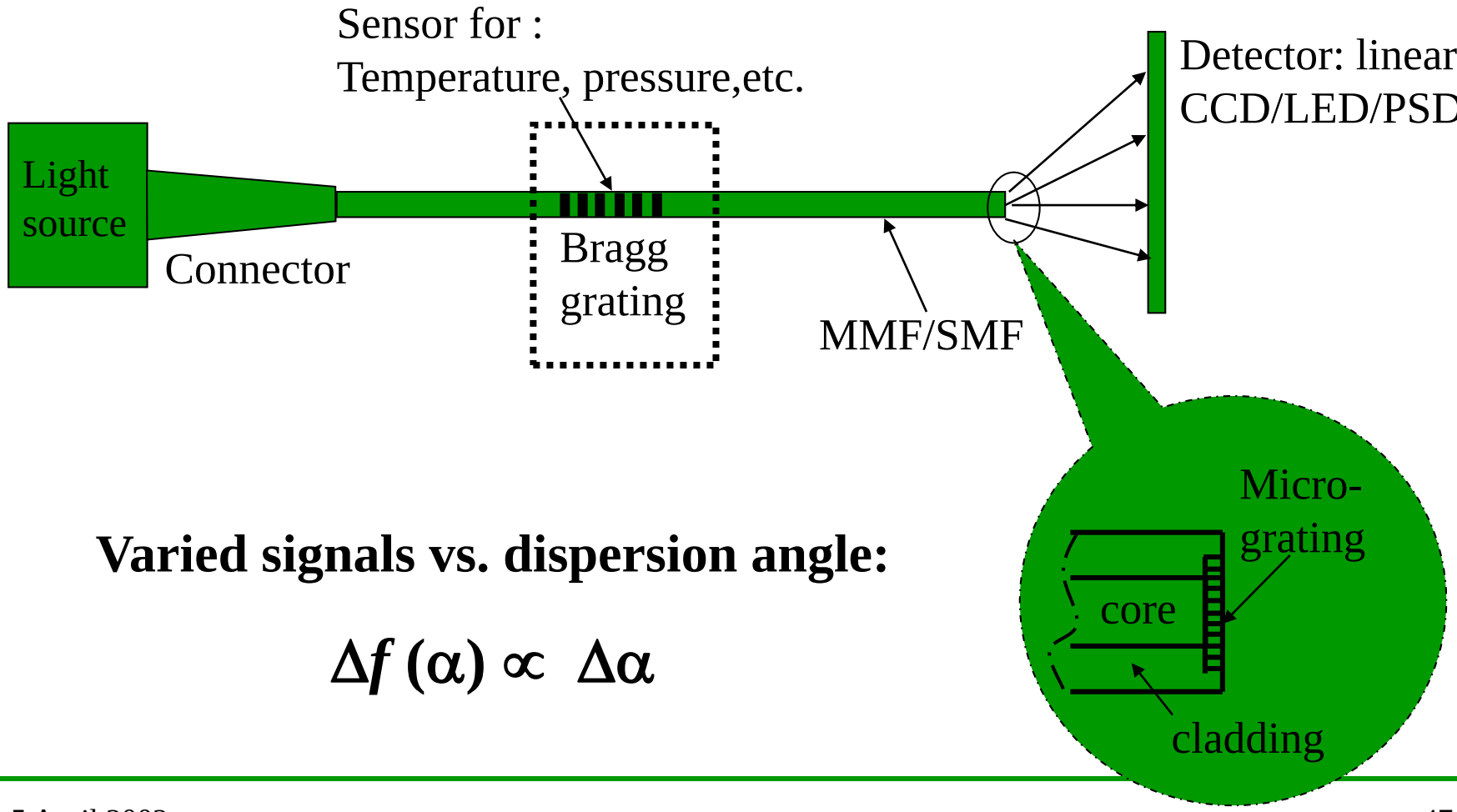


Characterization of the blaze grating by WYKO



Possible application: strain/thermal sensing

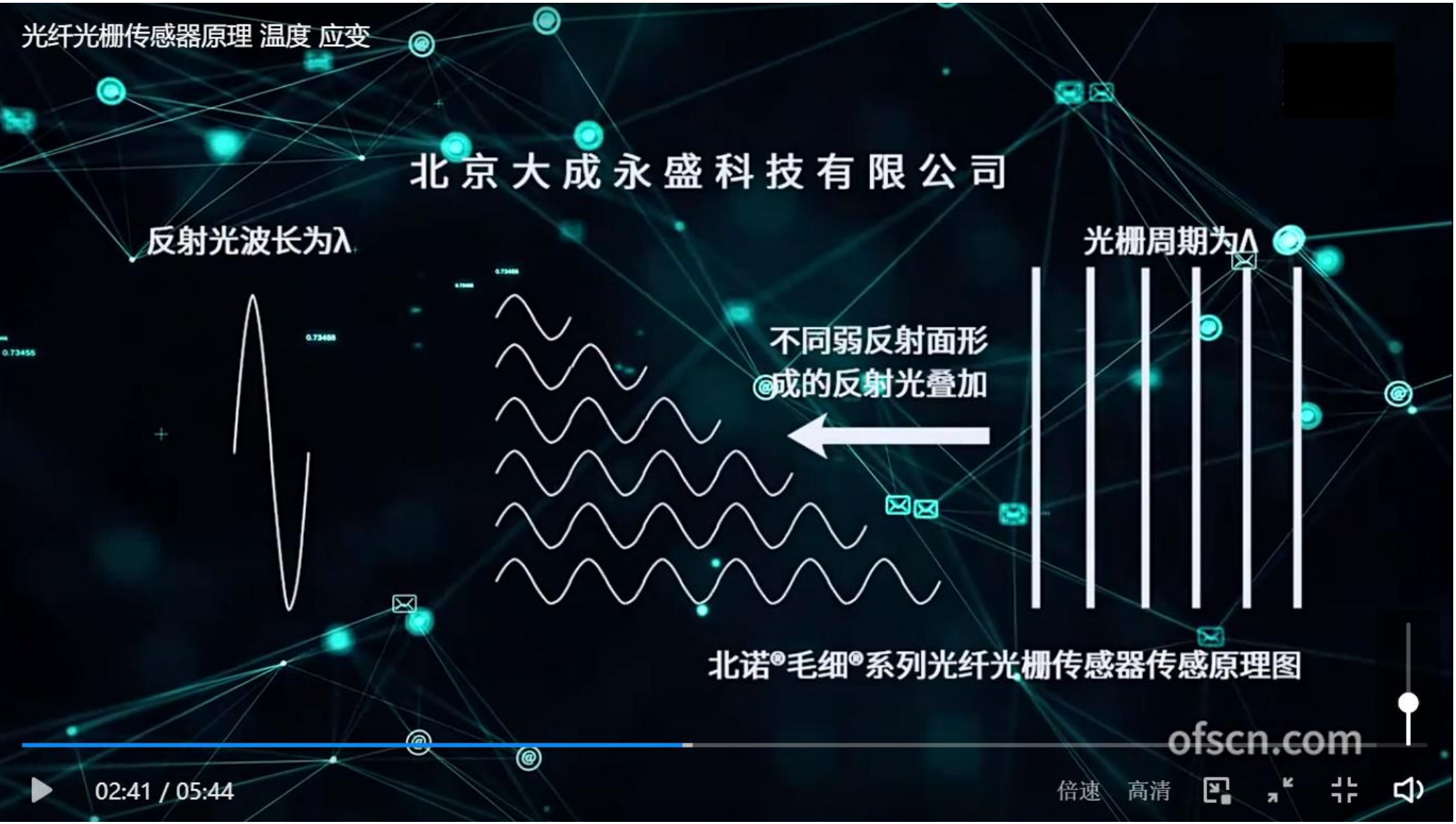
Integrated fiber system for strain/temperature sensing



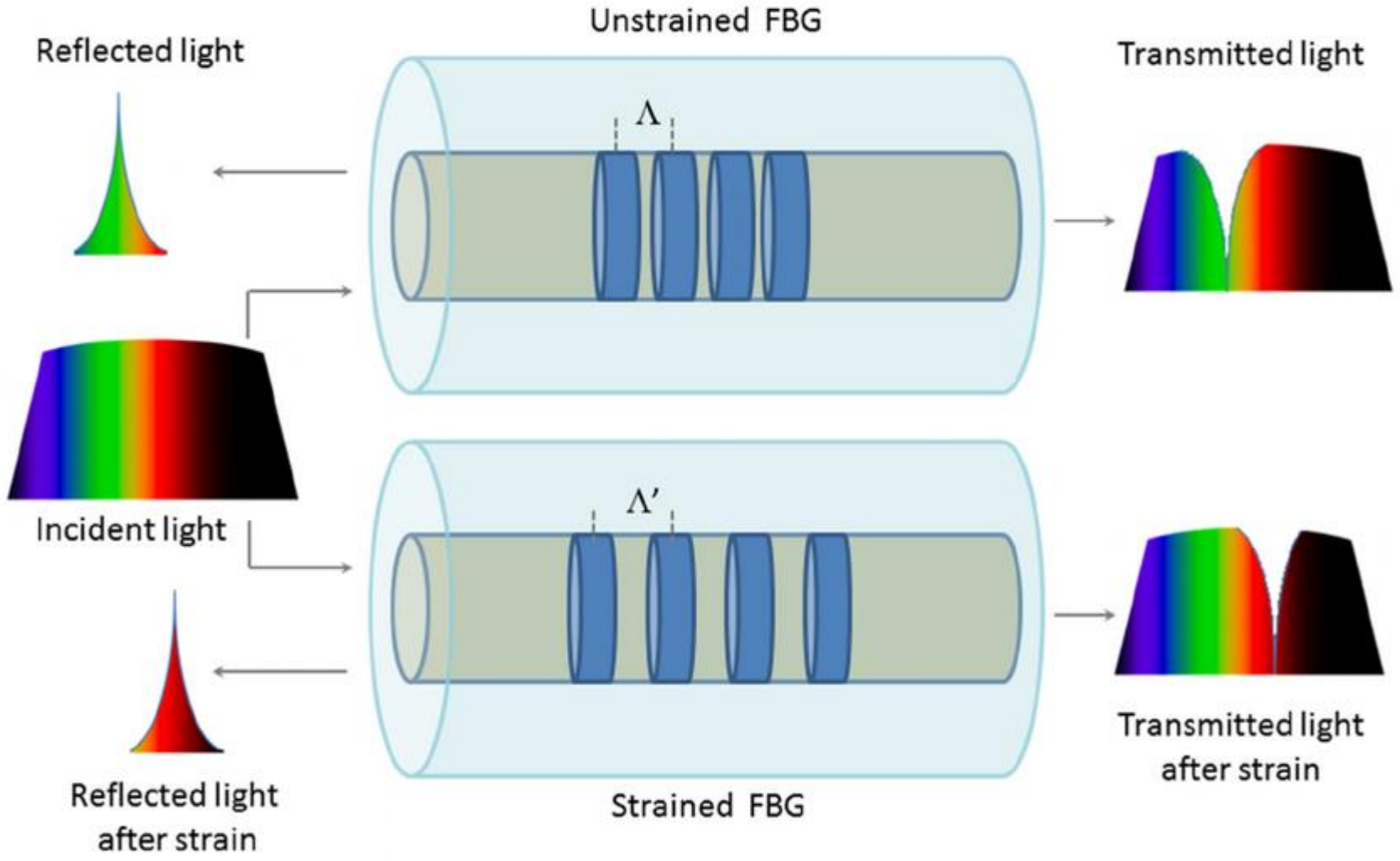
Varied signals vs. dispersion angle:

$$\Delta f(\alpha) \propto \Delta\alpha$$

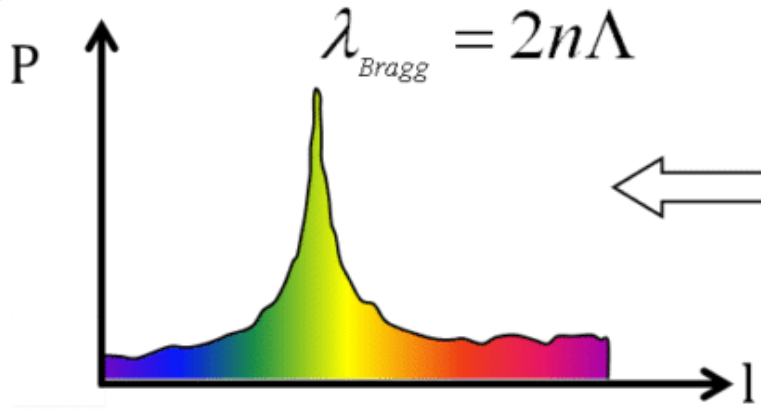
光纤布拉格光栅工作原理

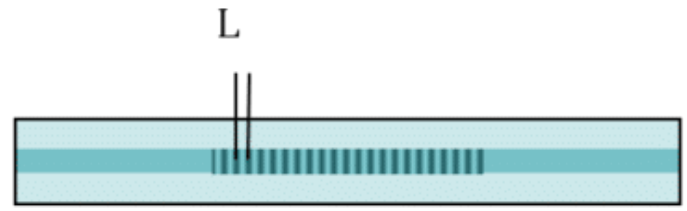


光纤布拉格光栅工作原理



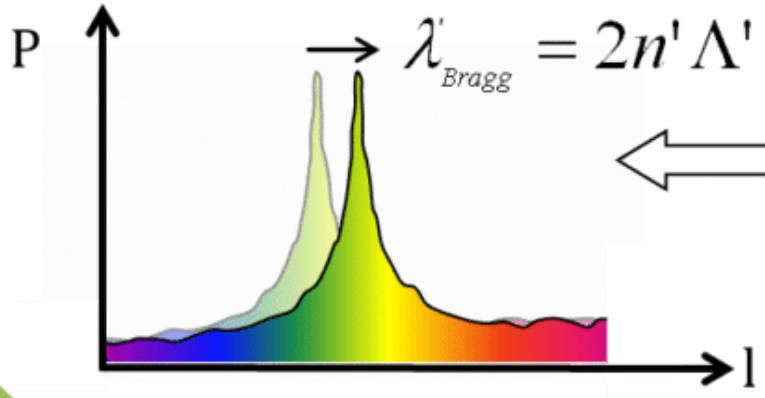
光纤布拉格光栅工作原理

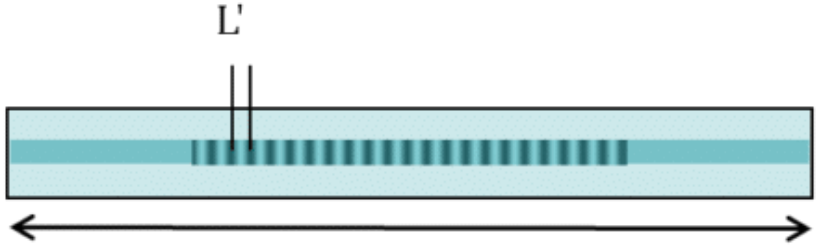




Unstrained FBG

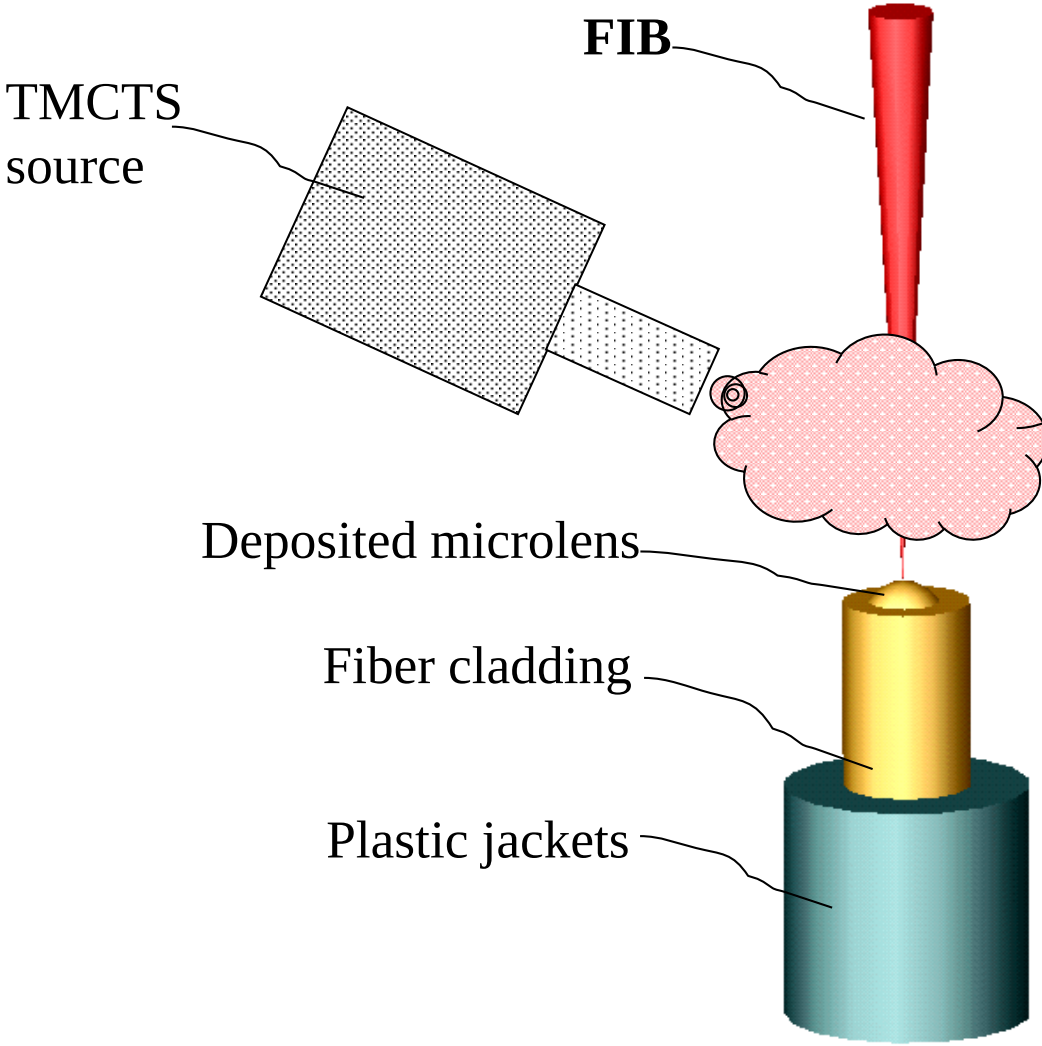
$$\Delta\lambda B = \lambda B\ (1 - P_e)\ \Delta\varepsilon + \lambda B\ (\alpha_f - \xi)\ \Delta T$$





Strained FBG

Microlens fabricated by FIB deposition



Fifth approach:
Deposition method

THE END