APPENDIX - D

Alloys and samples examined in cross-section with the microbeam

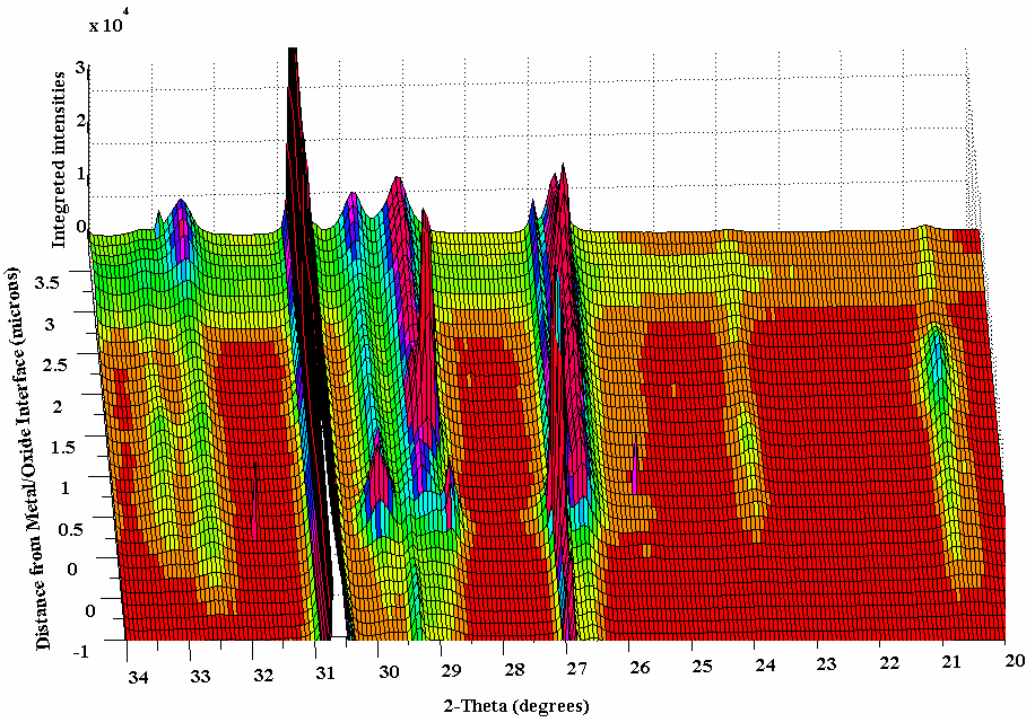
Alloys Examined with Microbeam Synchrotron Radiation - water samples

Alloys Examined	*Sample designation*	*Exposure time (days)*	*Weight Gain (mg/dm2)*	*Oxide thickness (µm)*
Zr-0.2Fe-0.1Cr (L)	11-4	210	41	2.73
Zr-0.2Fe-0.1Cr (L)	11-1T-2 and 11-1L-2	409	124.9	8.3
Zr-0.2Fe-0.1Cr (L)	12-1	415.5	55	3.7
Zr-0.4Fe-0.2Cr (H)	14-2	354	43.4	2.89
Zr-0.5Cr	21-4	90	701	46.73
Zr-0.5Cr	21-3	90	725.6	48.37
Zr-0.5Cr	21-12	28	53	3.53
Zr-0.5Cr-0.2Fe	22-9	83.3	86.4	5.76
Zr-0.5Cr-0.2Fe	22-15	116	55	3.67
Zr-1.0Cr-0.2Fe	23-15	146	430.6	28.71
Zr-1.0Cr-0.2Fe	24-2	270	67.6	4.51
Zr-1.0Cu	33-10	173.3	42.4	2.83
Zr-1.0Cu	33-1L-2	409	103.6	6.9
Zr-1Cu-0.5Mo	34-3	210	168.5	11.23
Reference Sponge Zr	41-9	69.3	51.6	3.44
Reference Crystal Bar Zr	42-10	69.3	91.2	6.08
Reference Zircaloy-4	43-10	176.1	53.9	3.59
Zr-0.2Sn	WL11-7	60	115.48	7.70
Zr-1.2Sn	WL14-8	60	196.2	13.08
Zr-0.2Nb	WL21-7	616	105.46	7.03
Zr-1.5Nb	WL42-1	646	129.98	8.67
Zr-0.4Nb-0.4Sn	WL32-7	616	89.68	5.98

The figures are a collection of diffraction patterns, showing diffracted intensities (in arbitrary units) versus two-theta diffraction angle as a function of position in the cross sectional samples, with the µ-beam translating from the metal, across the metal/oxide interface and inward the oxide layer, to the oxide/water interface.

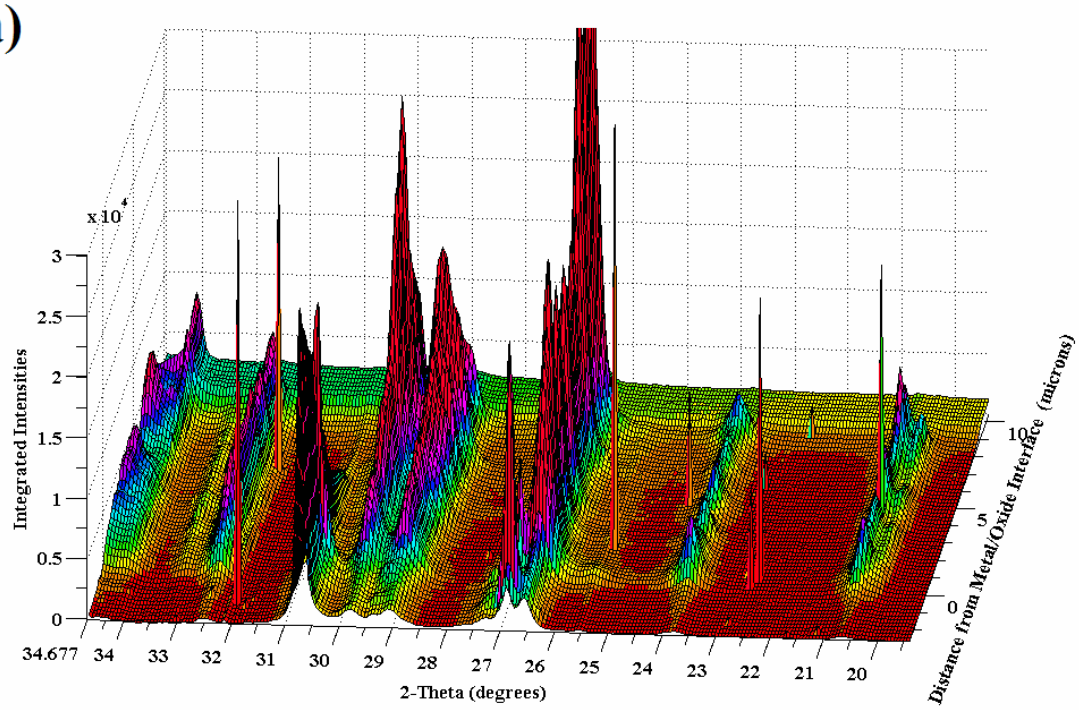
3d-plots summarizing the microbeam experiments for the water 360°C samples

11-4

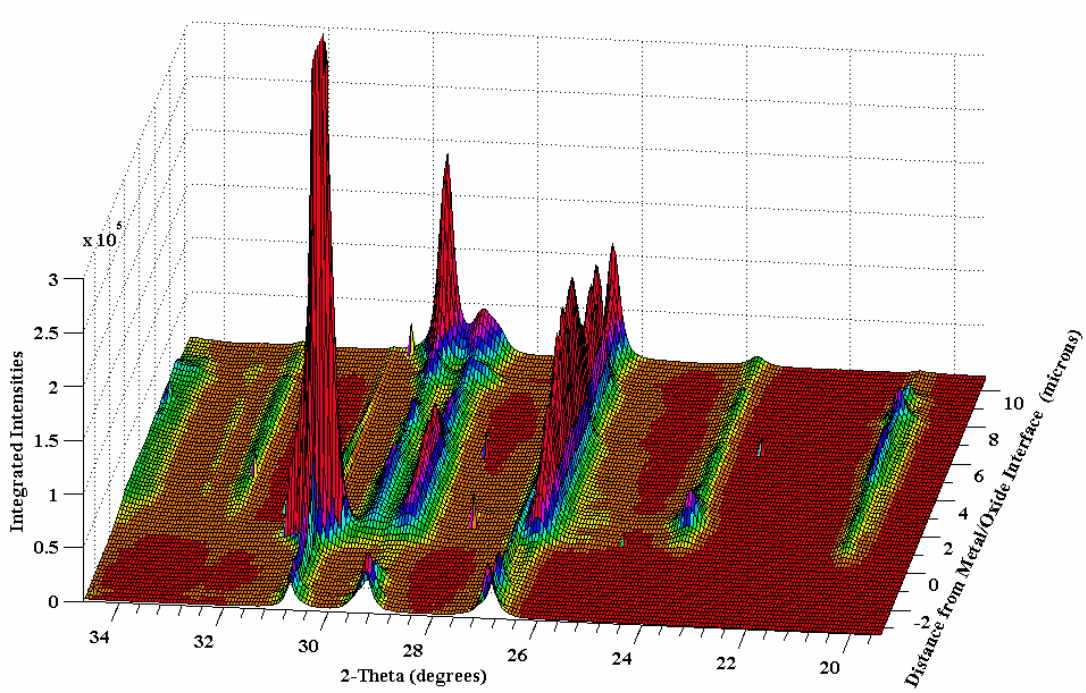


11-1T and 11-1L

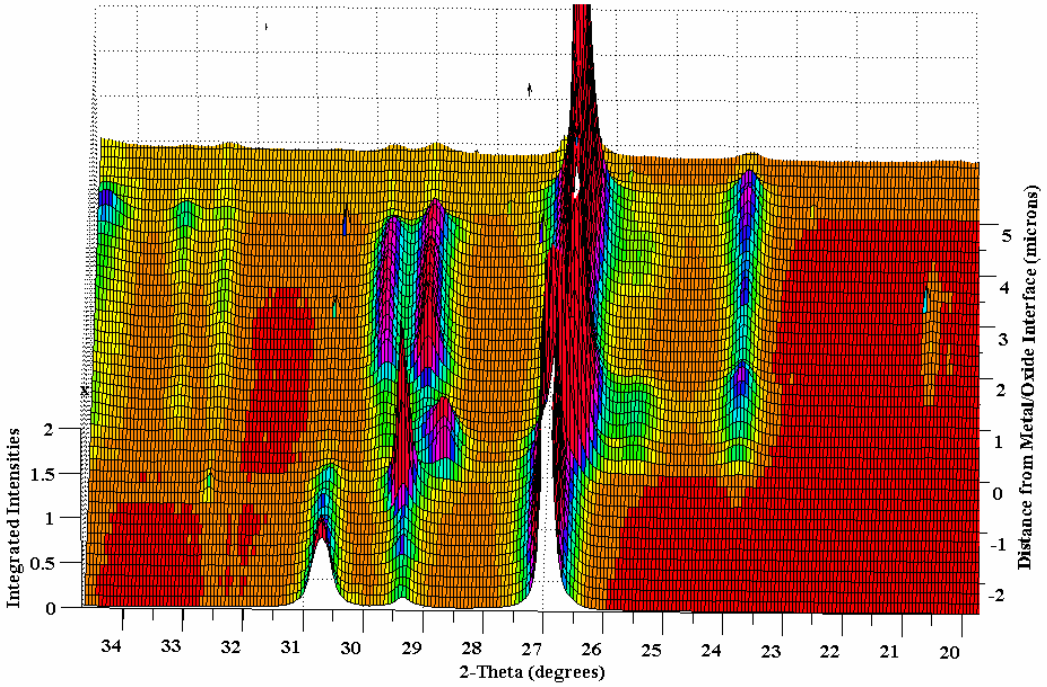
a)



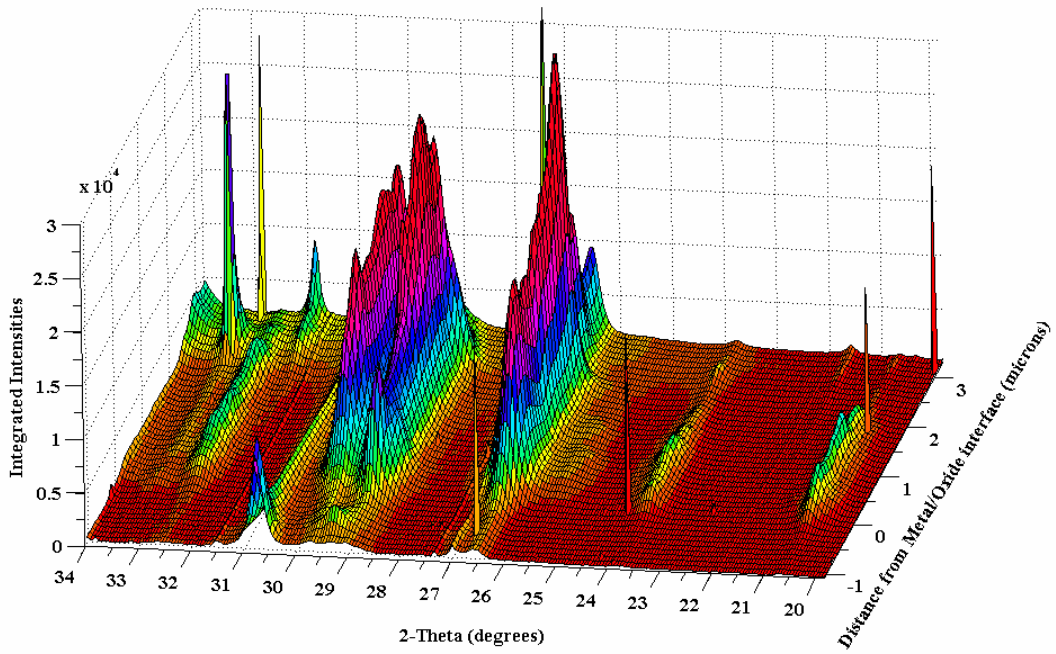
b)



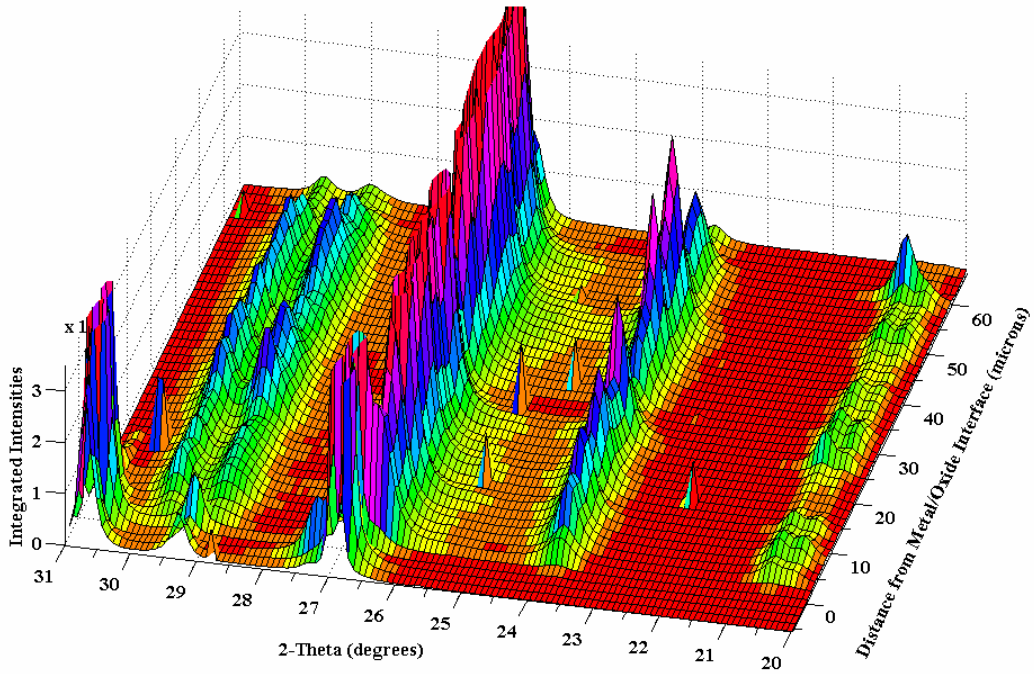
12-1


Integrated Intensities
2
1.5
1
0.5
0
34 33 32 31 30 29 28 27 26 25 24 23 22 21 20
2-Theta (degrees)
5 4 3 2 1 0 -1 -2
Distance from Metal/Oxide Interface (microns)

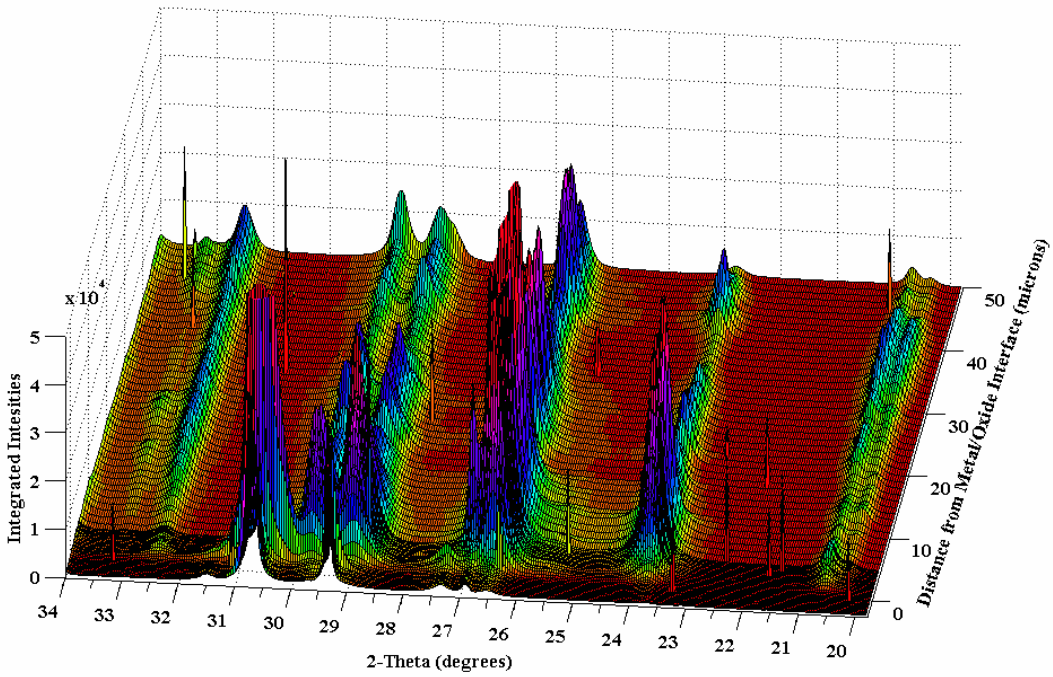
14-2


x 10
Integrated Intensities
3
2.5
2
1.5
1
0.5
0
34 33 32 31 30 29 28 27 26 25 24 23 22 21 20
2-Theta (degrees)
3 2 1 0 -1
Distance from Metal/Oxide interface (microns)

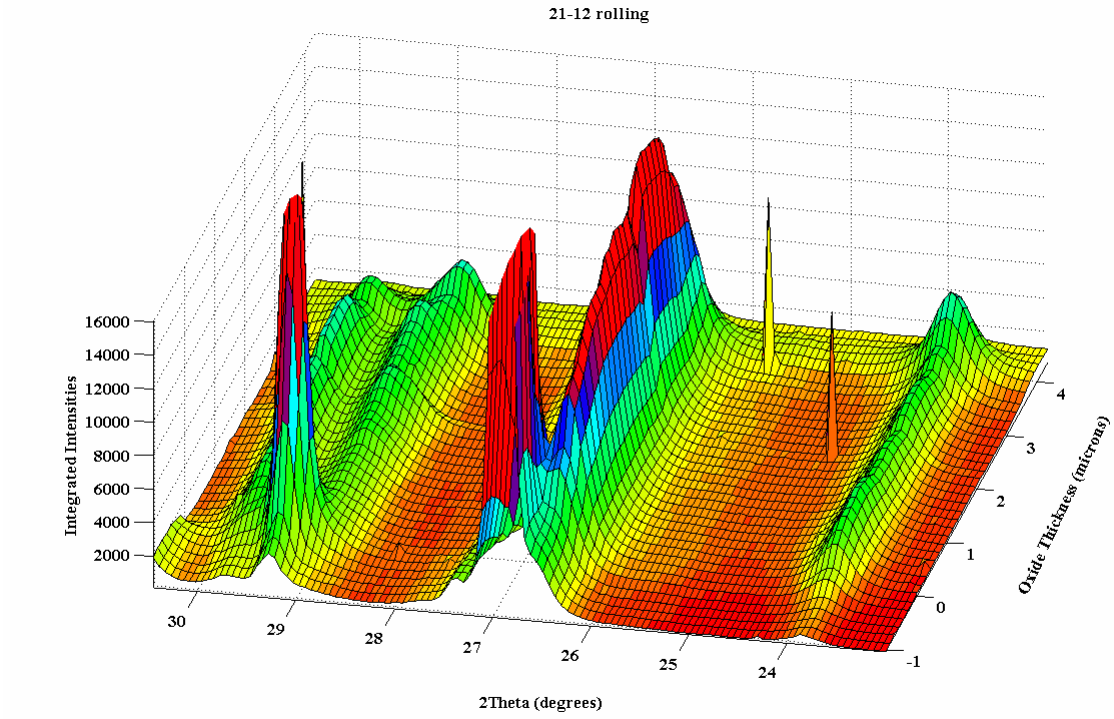
21-4


x 1
Integrated Intensities
0
1
2
3
31
30
29
28
27
26
25
24
23
22
21
20
2-Theta (degrees)
0
10
20
30
40
50
60
Distance from Metal/Oxide Interface (microns)

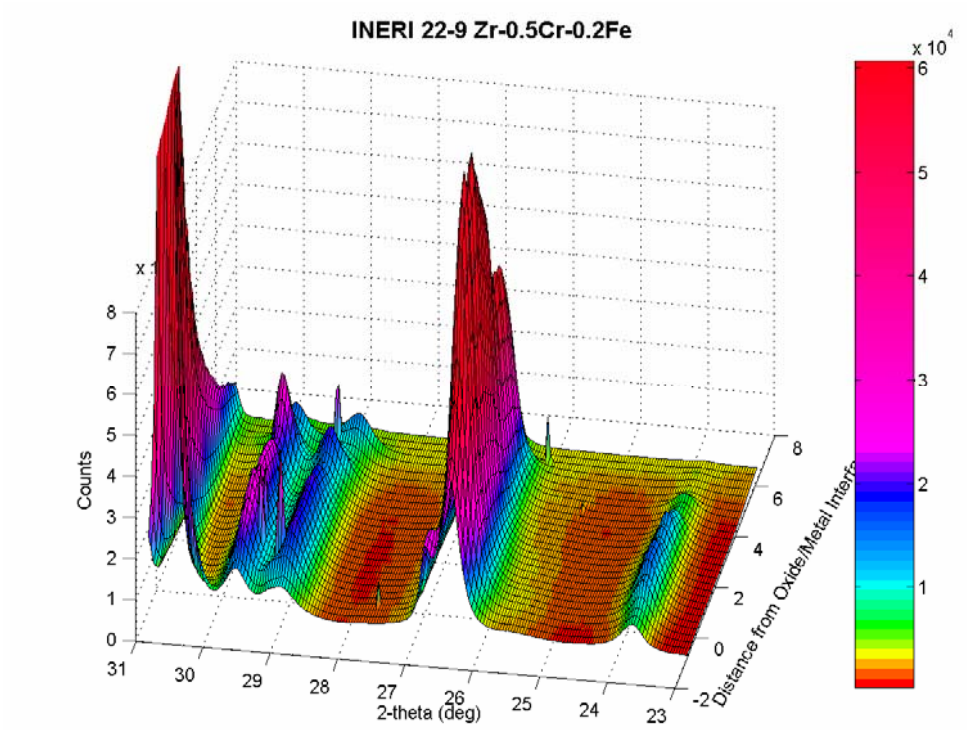
21-3


x 10
4
Integrated Intesities
0
1
2
3
4
5
34
33
32
31
30
29
28
27
26
25
24
23
22
21
20
2-Theta (degrees)
0
10
20
30
40
50
Distance from Metal/Oxide Interface (microns)

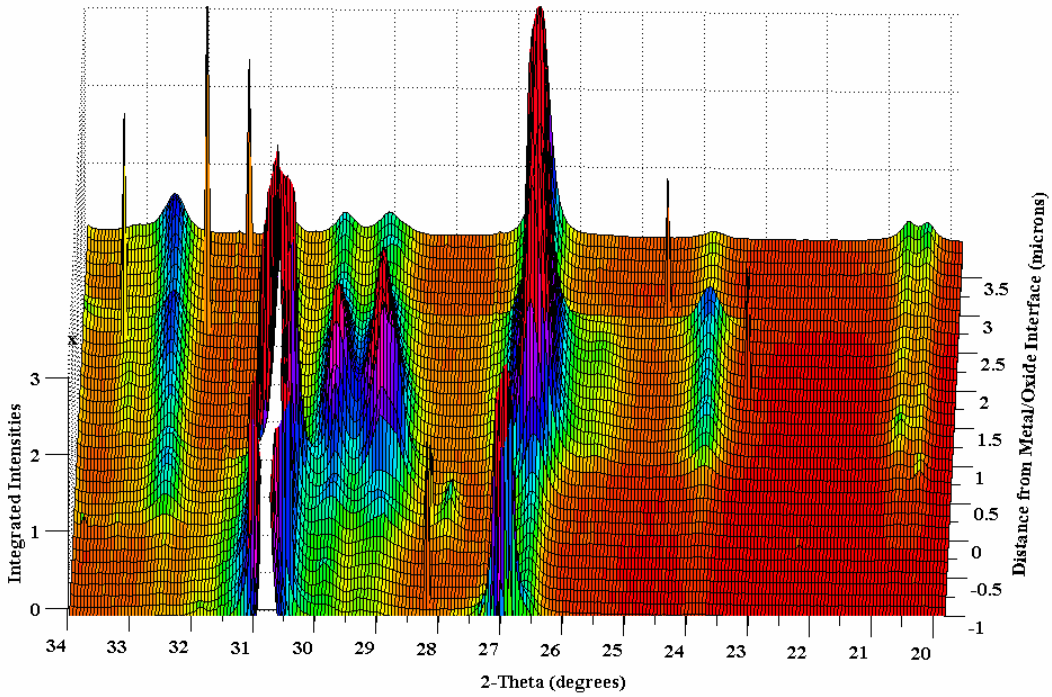
21-12


21-12 rolling
Integrated Intensities
16000
14000
12000
10000
8000
6000
4000
2000
30
29
28
27
26
25
24
2Theta (degrees)
4
3
2
1
0
-1
Oxide Thickness (microns)

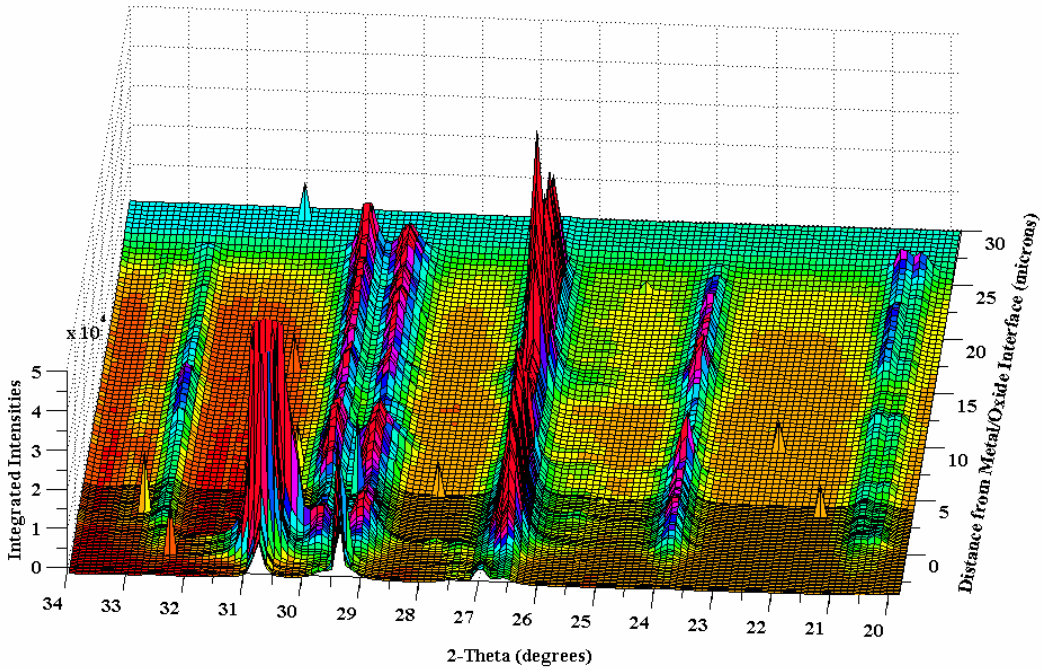
22-9


INERI 22-9 Zr-0.5Cr-0.2Fe
x 10^4
6
5
4
3
2
1
Counts
8
7
6
5
4
3
2
1
0
31
30
29
28
27
26
25
24
23
2-theta (deg)
8
6
4
2
0
-2
Distance from Oxide/Metal Interf

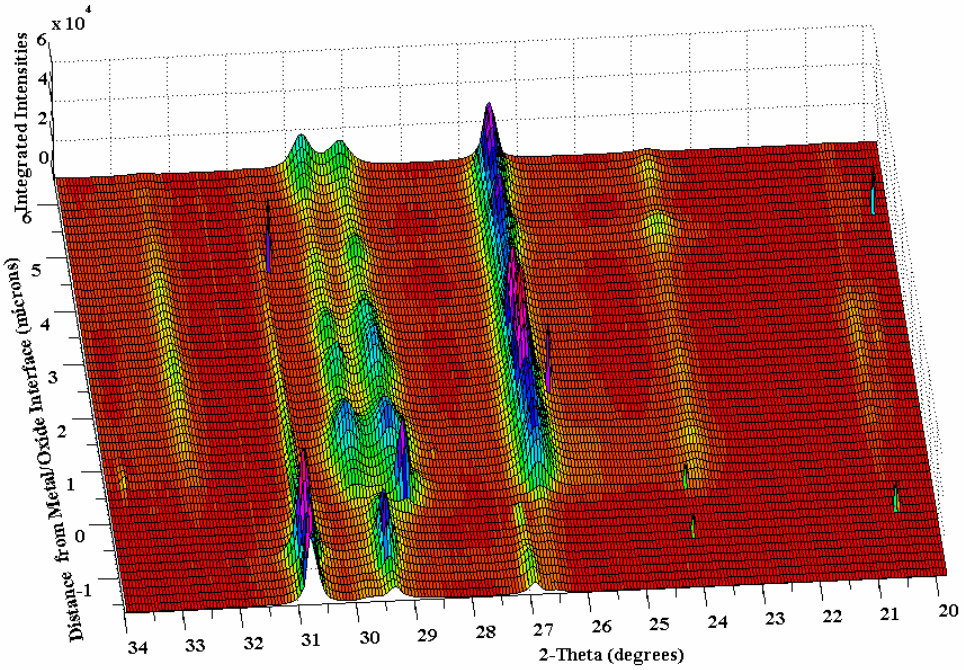
22-15


Integrated Intensities
0
1
2
3
34
33
32
31
30
29
28
27
26
25
24
23
22
21
20
2-Theta (degrees)
Distance from Metal/Oxide Interface (microns)
-1
-0.5
0
0.5
1
1.5
2
2.5
3
3.5

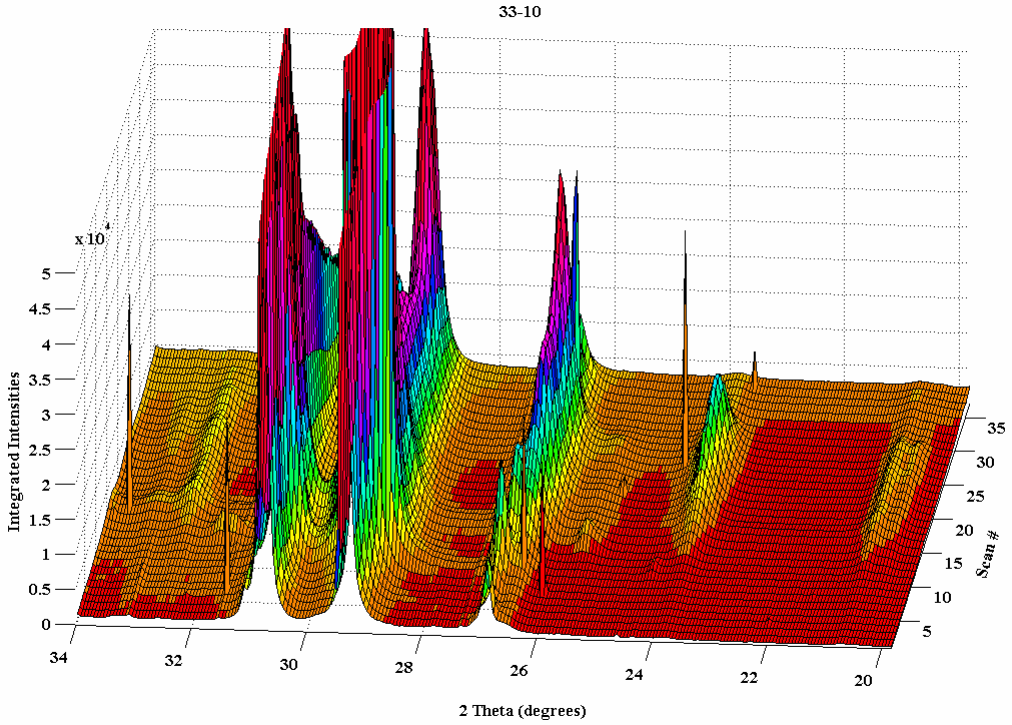
23-15


x 10⁴
Integrated Intensities
0
1
2
3
4
5
34
33
32
31
30
29
28
27
26
25
24
23
22
21
20
2-Theta (degrees)
Distance from Metal/Oxide Interface (microns)
0
5
10
15
20
25
30

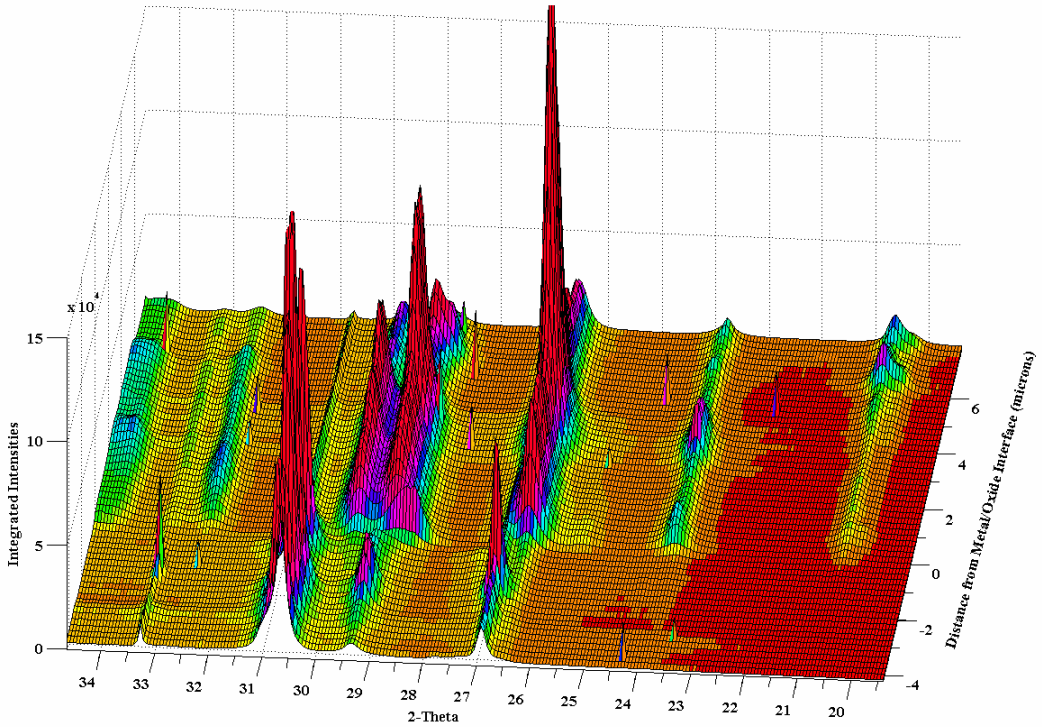
24-2


x 10^4
Integrated Intensities
Distance from Metal/Oxide Interface (microns)
2-Theta (degrees)

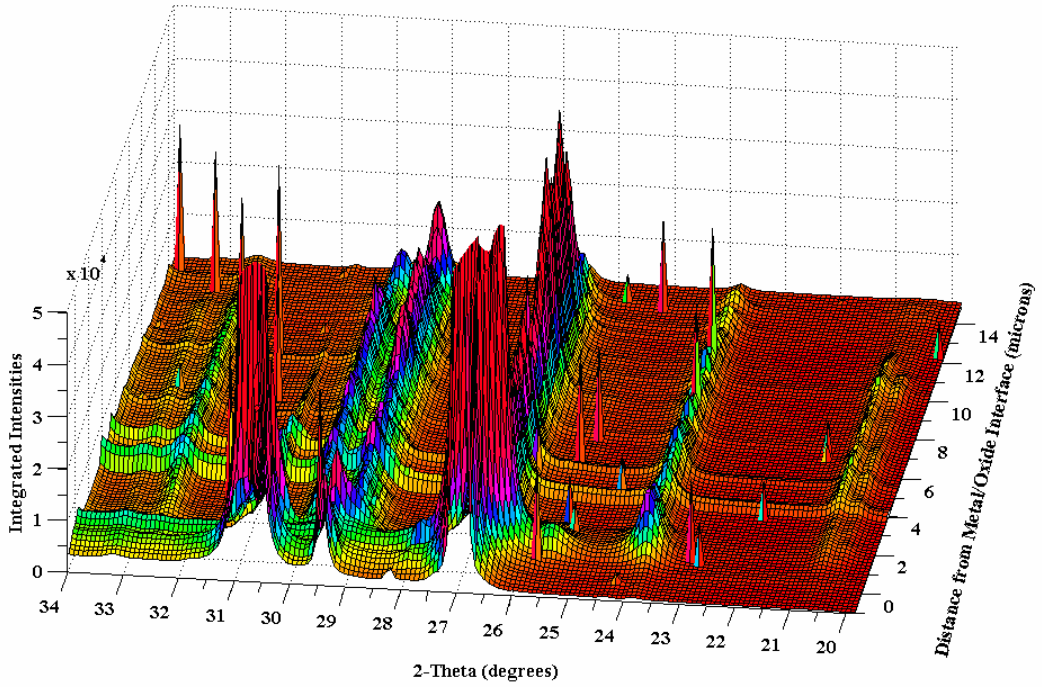
33-10


33-10
x 10^4
Integrated Intensities
Scan #
2 Theta (degrees)

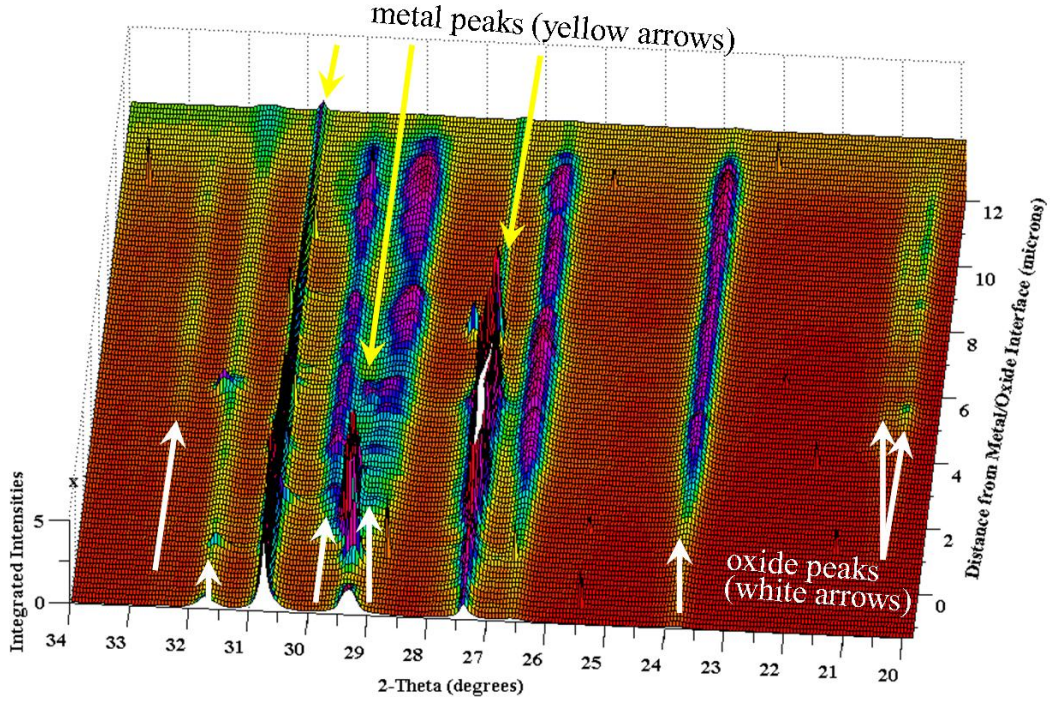
33-1L-2


x 10^4
Integrated Intensities
2-Theta
Distance from Metal/Oxide Interface (microns)

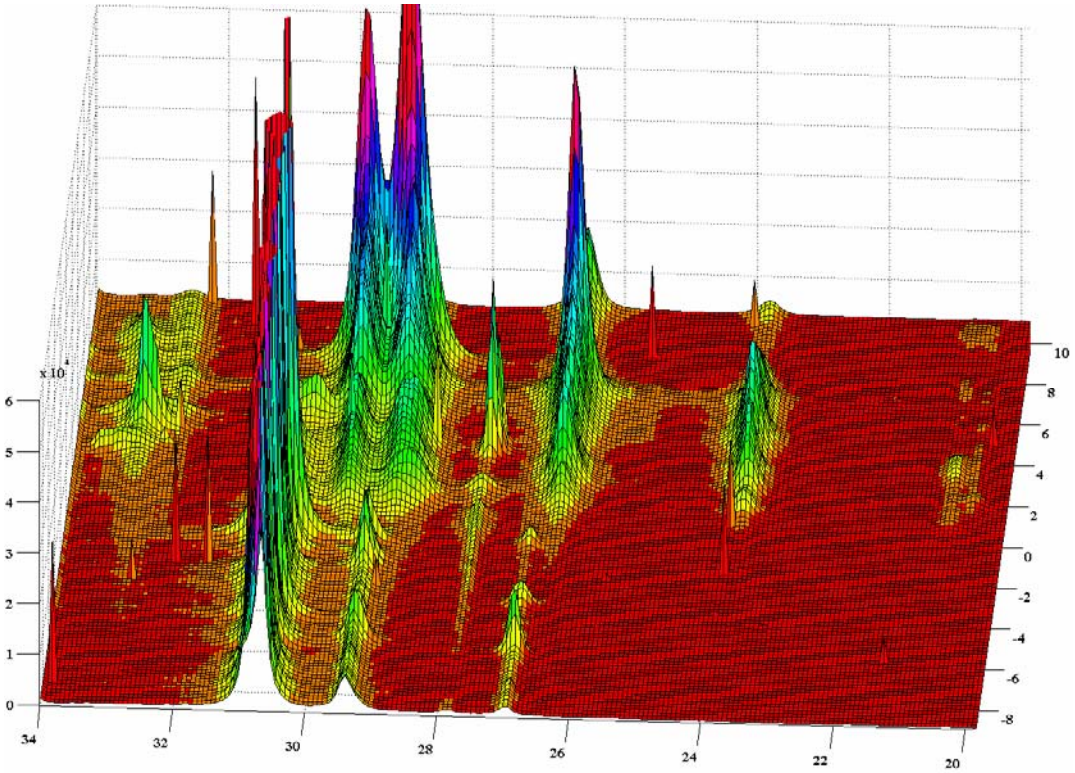
34-3


x 10^4
Integrated Intensities
2-Theta (degrees)
Distance from Metal/Oxide Interface (microns)

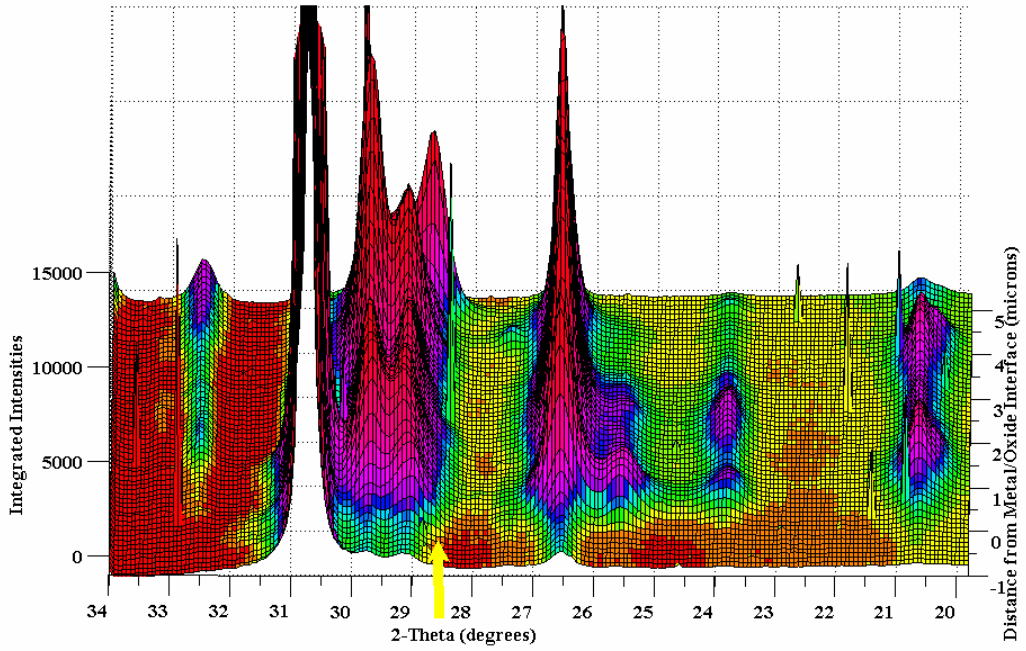
41-9


metal peaks (yellow arrows)
oxide peaks
(white arrows)
Integrated Intensities
2-Theta (degrees)
Distance from Metal/Oxide Interface (microns)

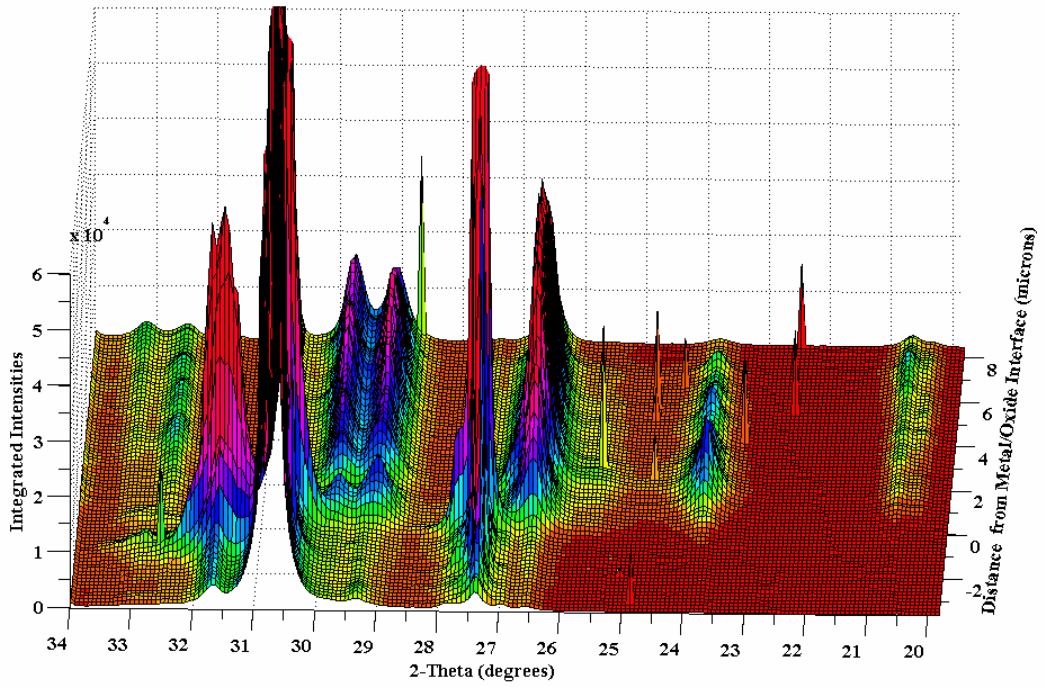
42-10



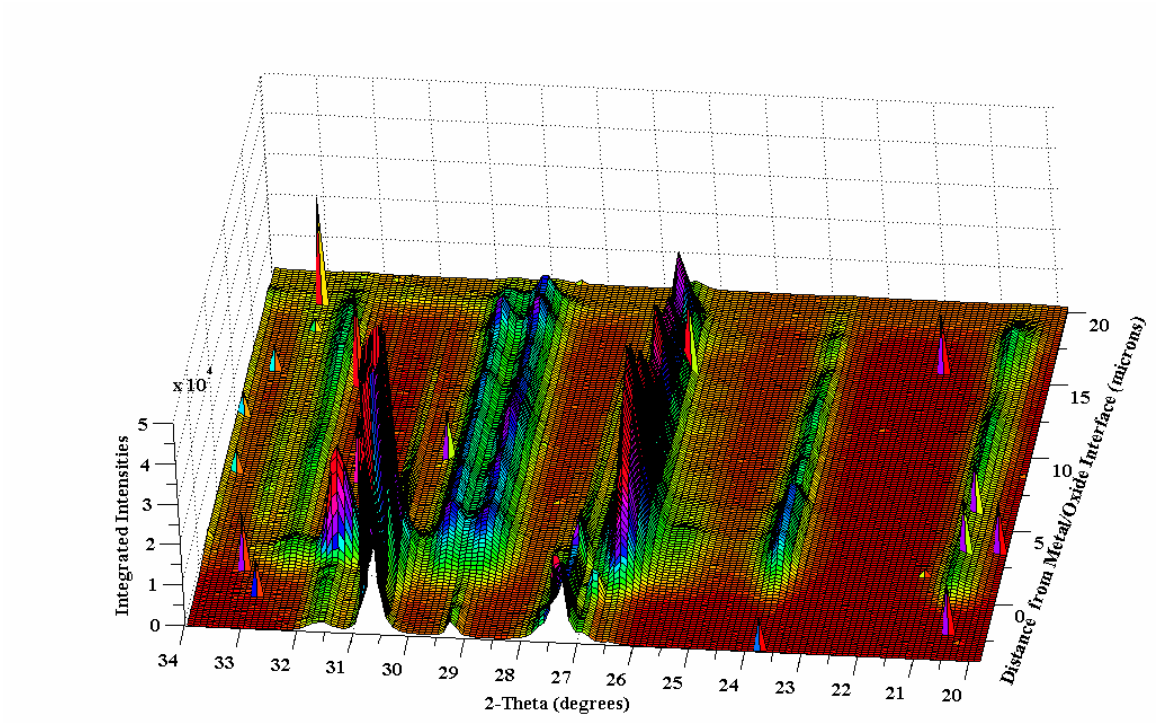
43-10


Integrated Intensities
15000
10000
5000
0
34
33
32
31
30
29
28
27
26
25
24
23
22
21
20
2-Theta (degrees)
Distance from Metal/Oxide Interface (microns)
5
4
3
2
1
0
-1

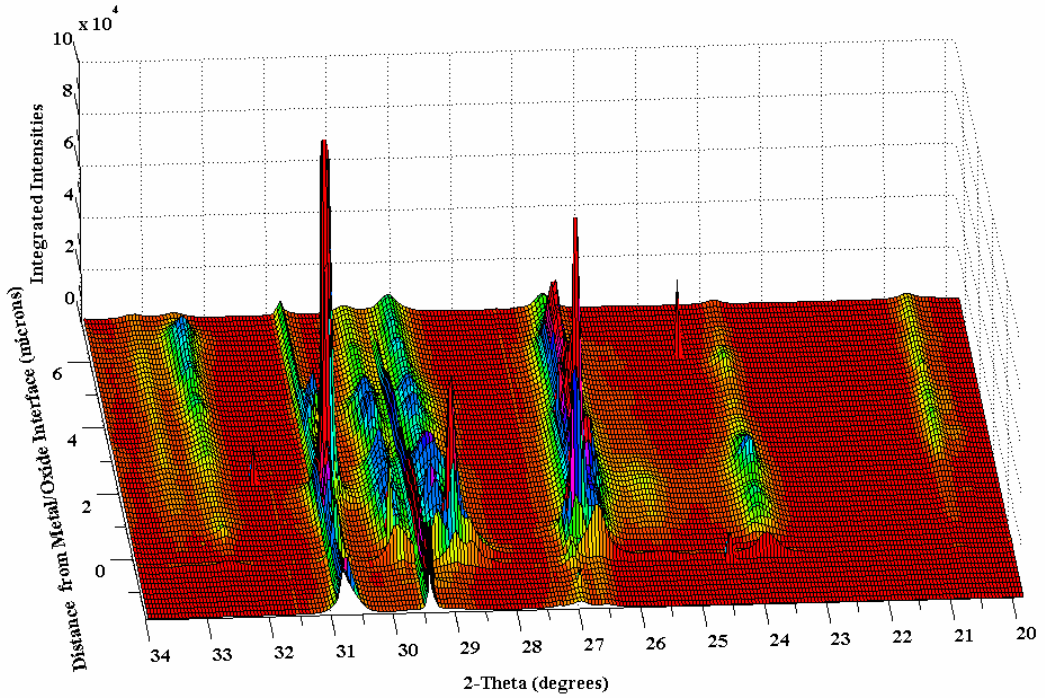
Zr-0.2Sn


x 10^4
Integrated Intensities
6
5
4
3
2
1
0
34
33
32
31
30
29
28
27
26
25
24
23
22
21
20
2-Theta (degrees)
Distance from Metal/Oxide Interface (microns)
8
6
4
2
0
-2

Zr-1.2Sn

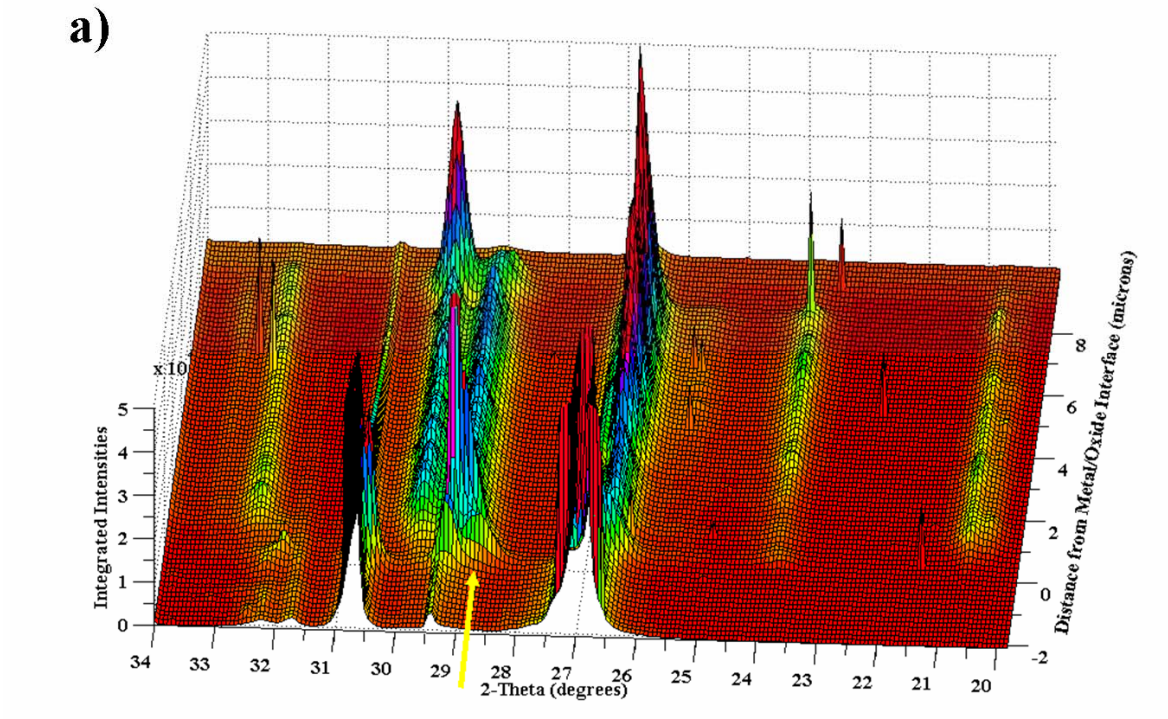


Zr-0.2Nb

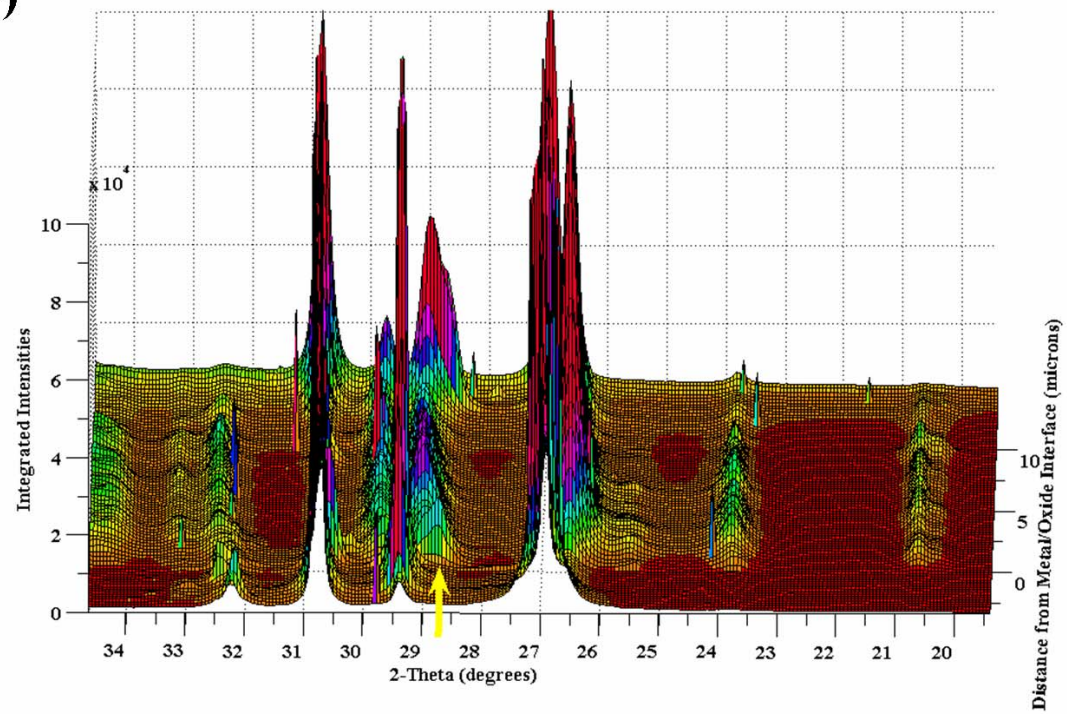


Zr-1.5Nb rolling and transverse directions

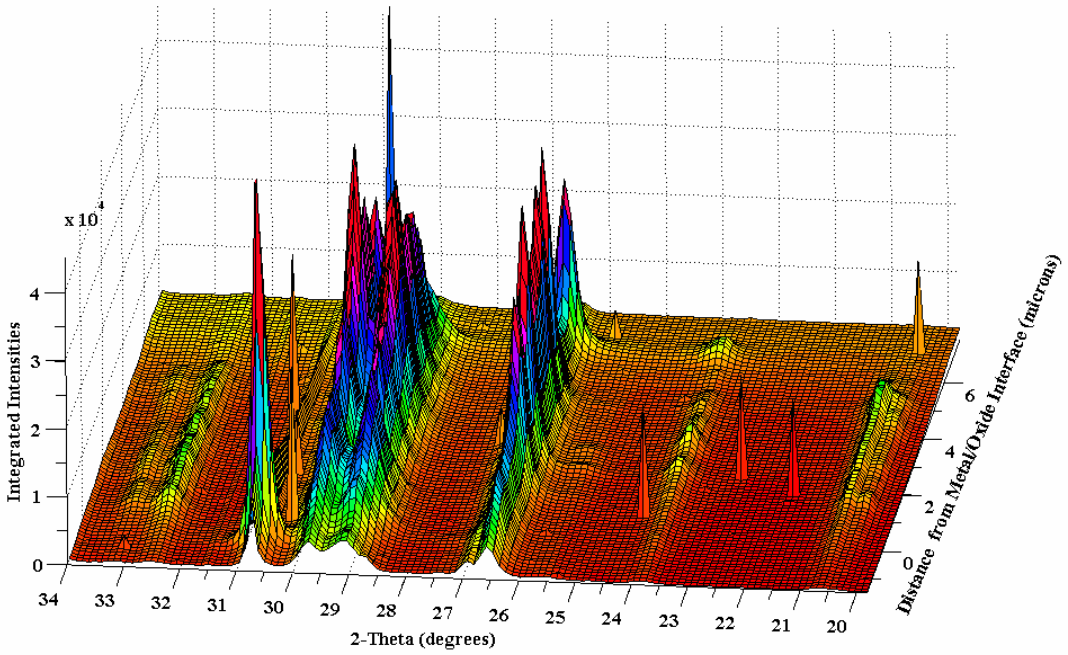
a)



b)



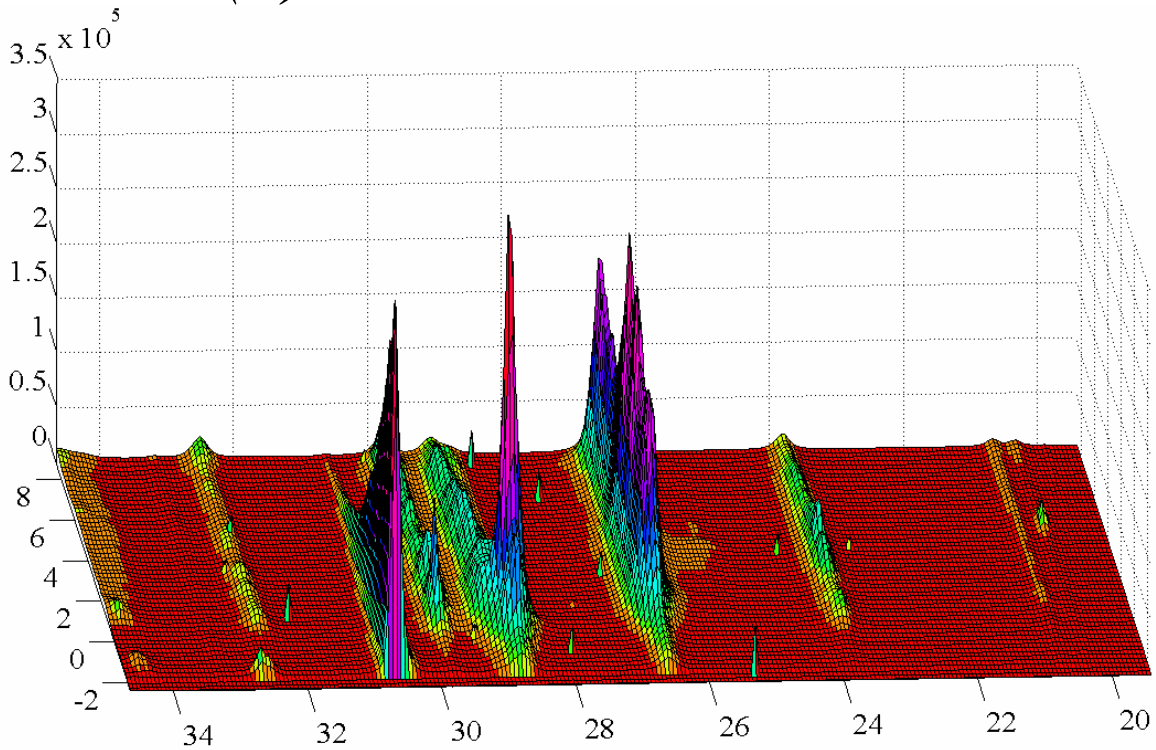
Zr-0.4Nb-0.4Sn


x 10^4
Integrated Intensities
0
1
2
3
4
34
33
32
31
30
29
28
27
26
25
24
23
22
21
20
2-Theta (degrees)
0
2
4
6
Distance from Metal/Oxide Interface (microns)

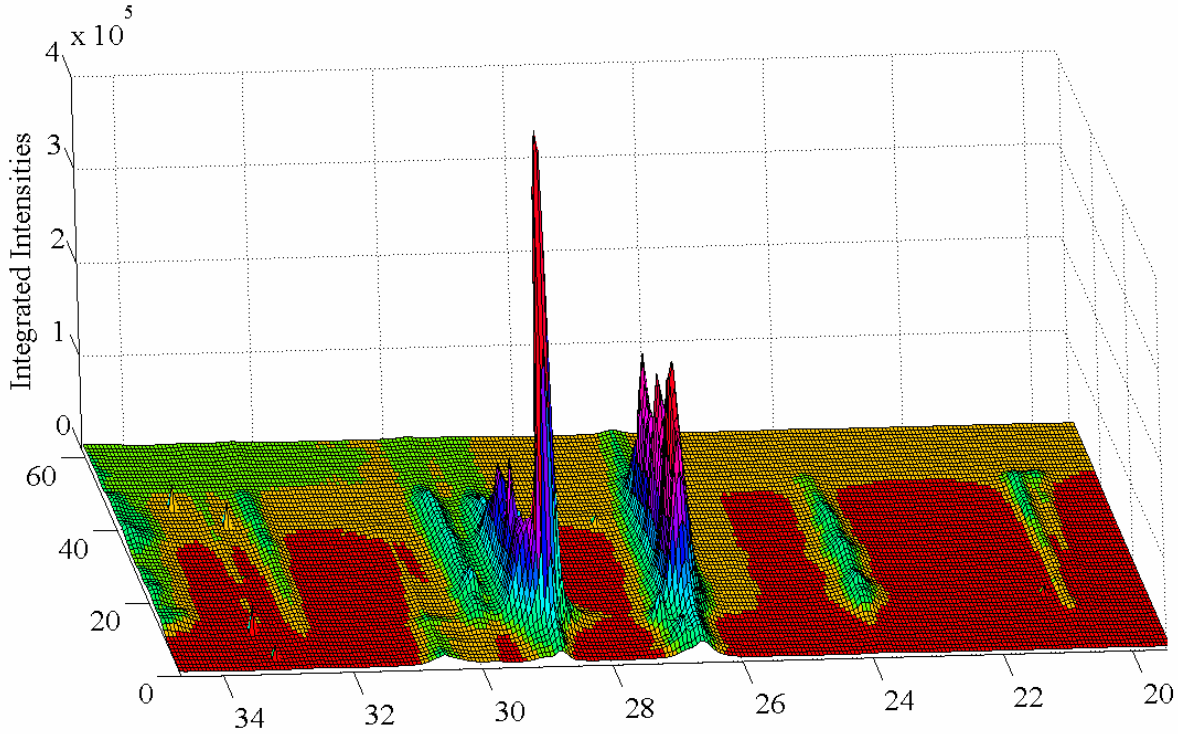
Alloys Examined with Microbeam Synchrotron Radiation - high temperature and commercial alloys

Alloys Examined	*Sample designation*	*Exposure time (days)*	*environment*	*Weight Gain (mg/dm2)*	*Oxide thickness (µm)*
Zr-0.2Fe-0.1Cr (H)	12	60	500°C at 3500 psi SCW	130.3	8.80
Zr-0.4Fe-0.2Cr (L)	13	60	500°C at 3500 psi SCW	118.1	7.98
Zr-0.4Fe-0.2Cr (H)	14	60	500°C at 3500 psi SCW	146.1	9.87
Zr-0.5Cr-0.2Fe	22	60	500°C at 3500 psi SCW	125.2	8.46
Zr-1.0Cr-0.2Fe	24	60	500°C at 3500 psi SCW	168.1	11.36
Zr-0.4Nb	SC22-4	300	500°C at 3500 psi SCW	1718.5	114.6
Zr-1.5Nb	SC42-6	252	500°C at 3500 psi SCW	1466.12	97.7
Zr-0.2Fe-0.1Cr (L)	11-17	3.75 d	500°C at 1500 psi steam	Not measured	Not measured
Zr-0.4Fe-0.2Cr (H)	14-18T-2	n/a	500°C at 1500 psi steam	n/a	8.0
Zr-0.5Cr	21-18	6 hrs	500°C at 1500 psi steam	724	48.27
Zr-1Cr-0.2Fe	24-17	17.3	500°C at 1500 psi steam	75.6	5.04
Zr-1.5Nb	ST42-2 (2 samples)	30	500°C at 1500 psi steam	332.86	22.2
Zr-2.5Nb tube (commercial)	C36 other direction	784	360°C water	190.5	12.7
ZIRLO tube (commercial)	E26 other direction	784	360°C water	272.2	18.15
ZIRLO sheet (commercial)	T-349 other direction	665	360°C water	245.4	16.4

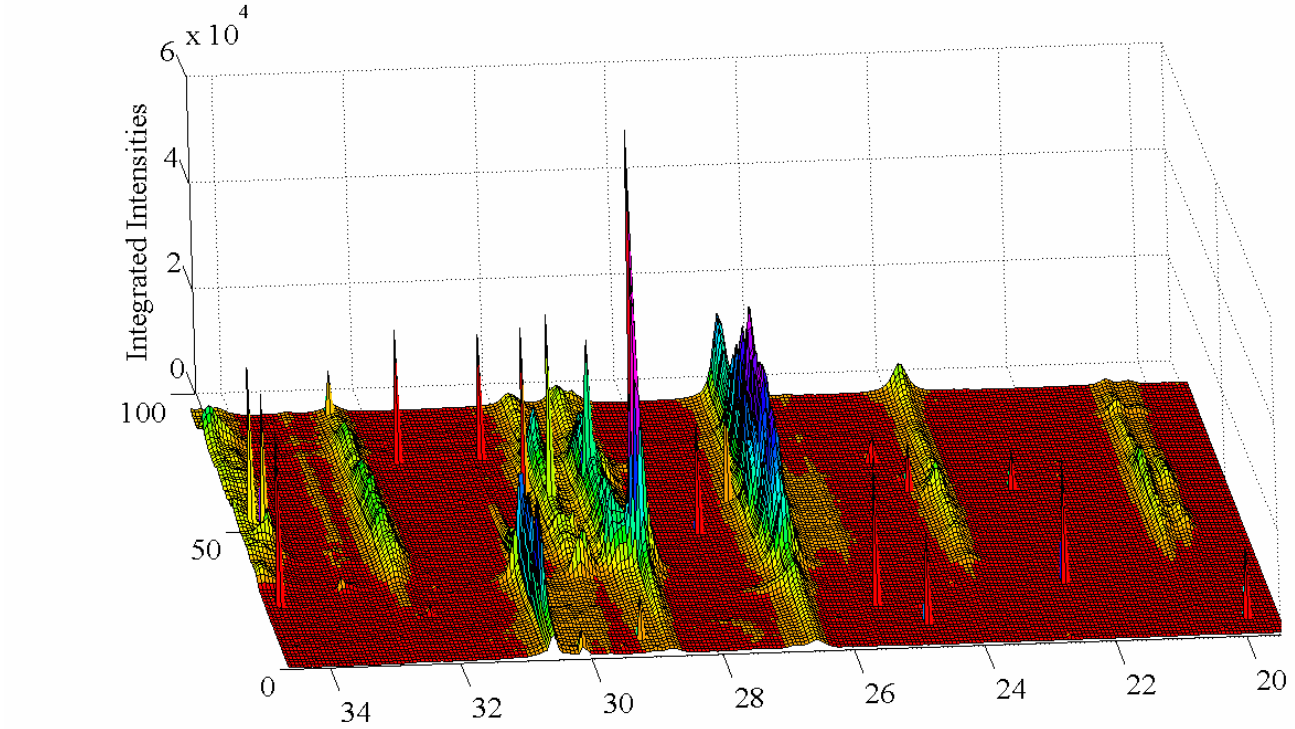
Zr-0.2Fe-0.1Cr (H) - SCW



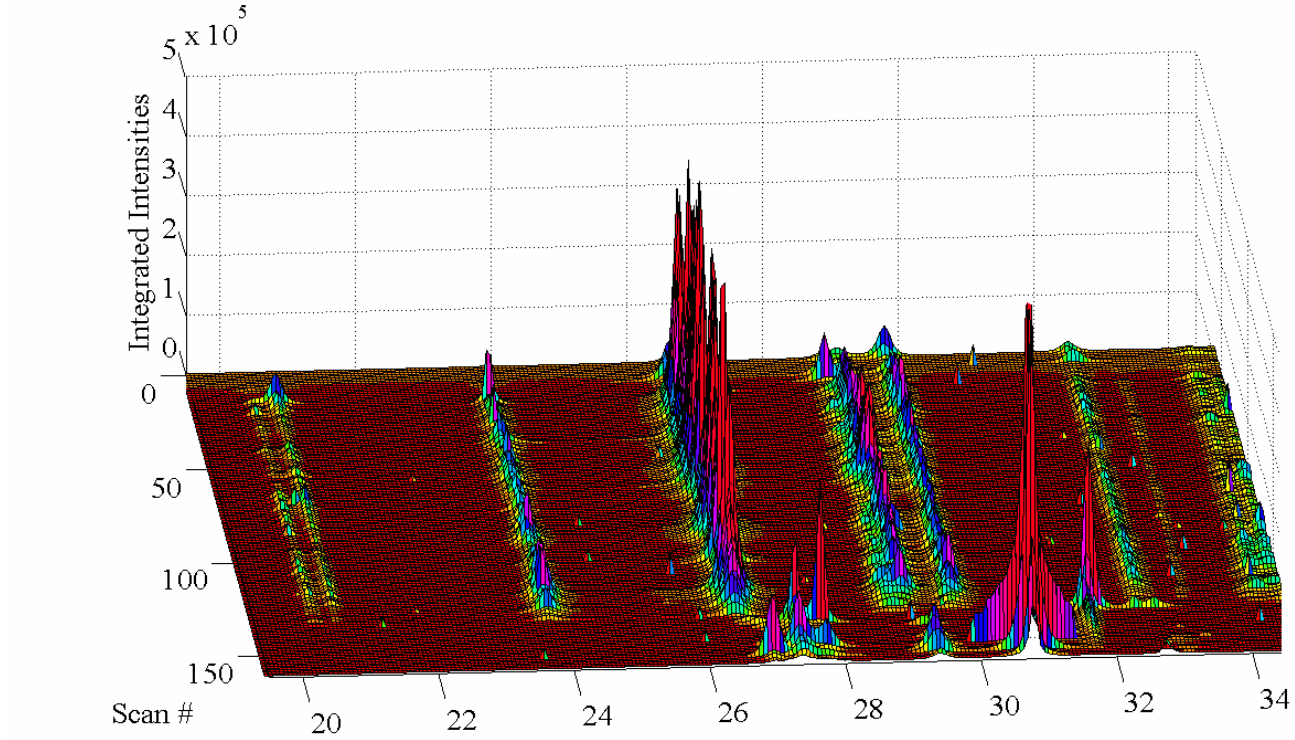
Zr-0.4Fe-0.2Cr (L) - SCW



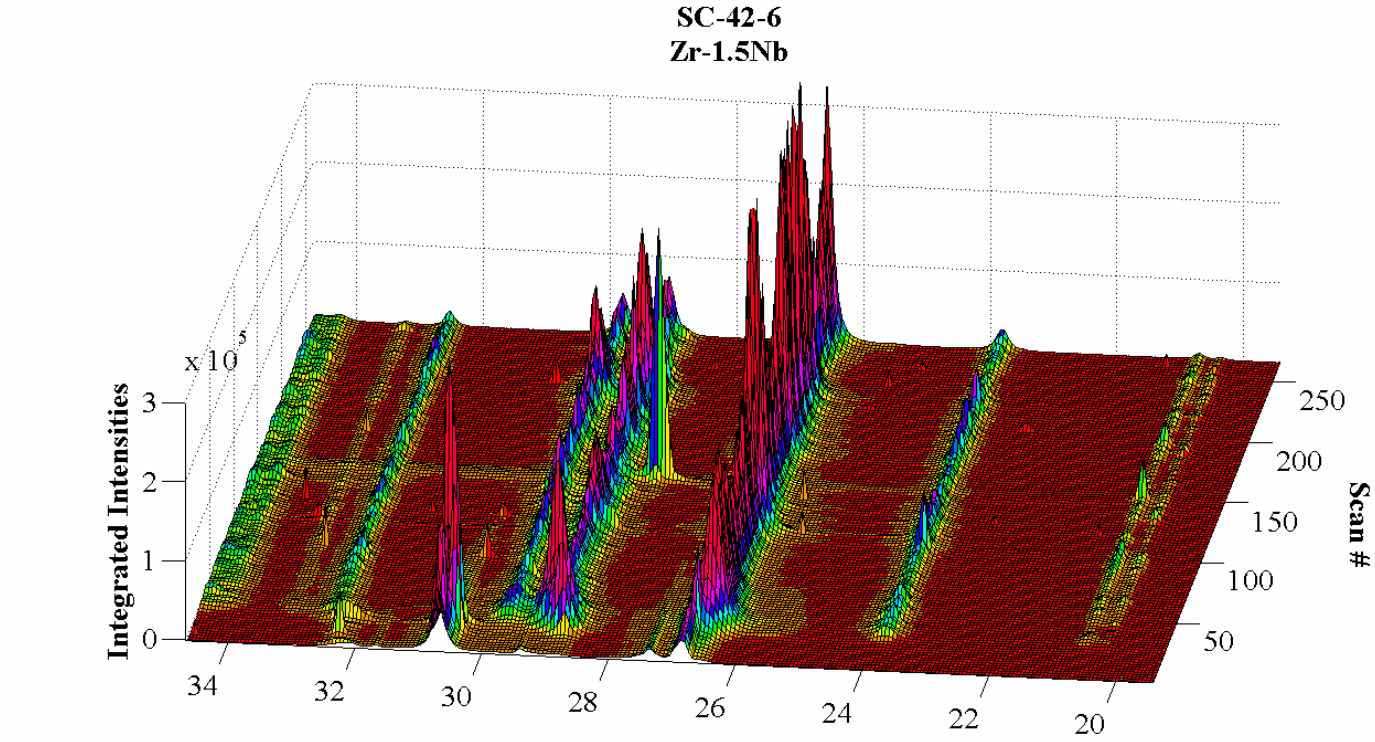
Zr-0.4Fe-0.2Cr (H) - SCW



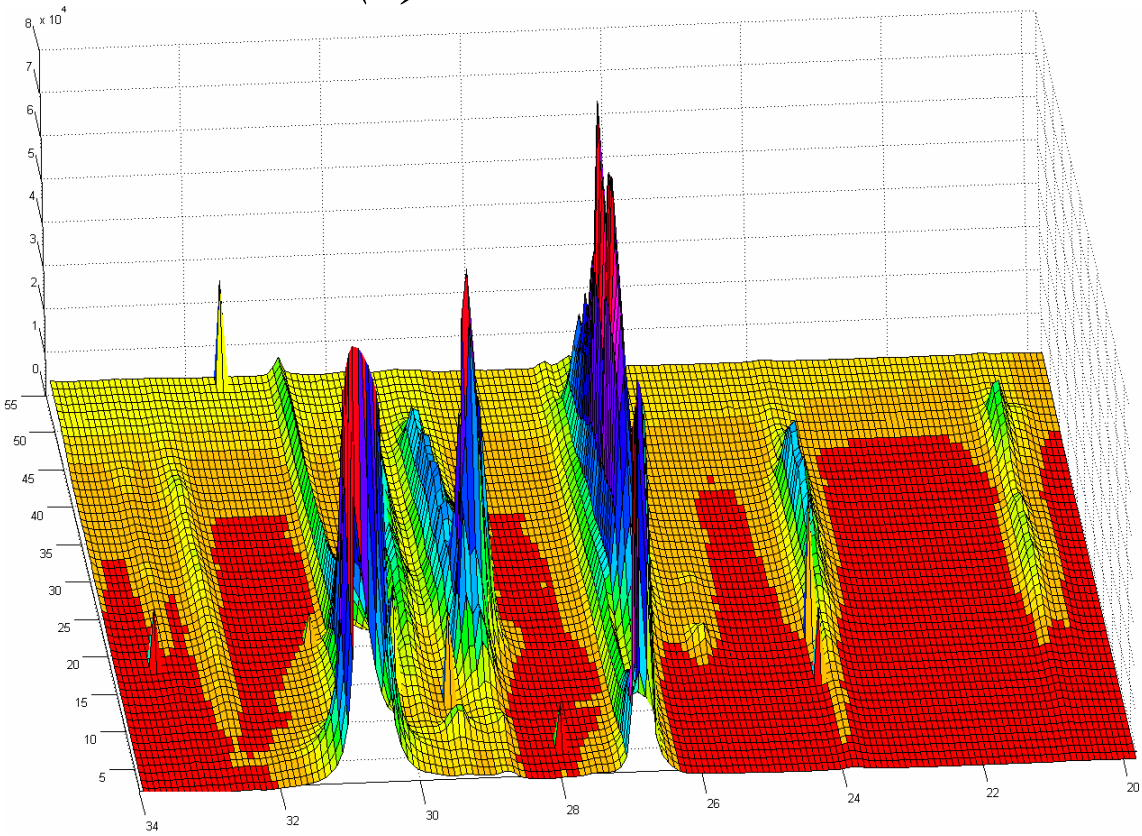
Zr-0.4Nb- SCW



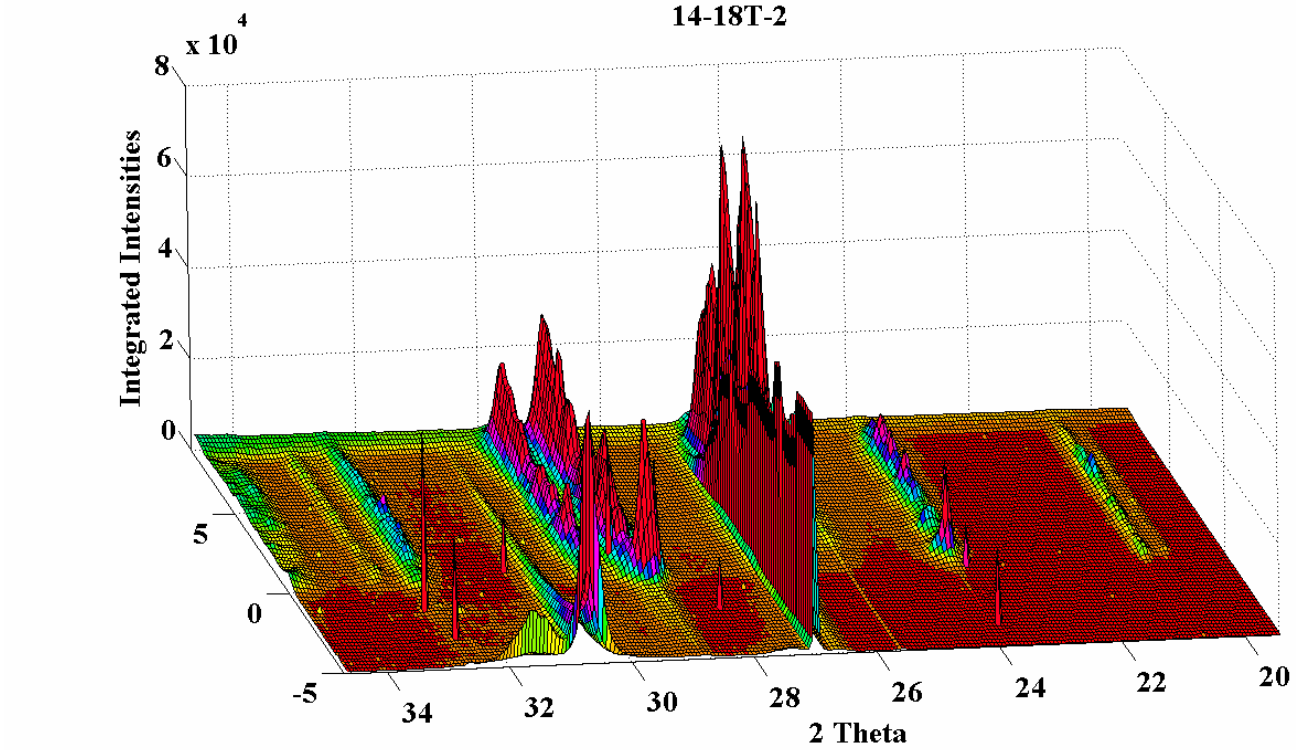
Zr-1.5Nb- SCW



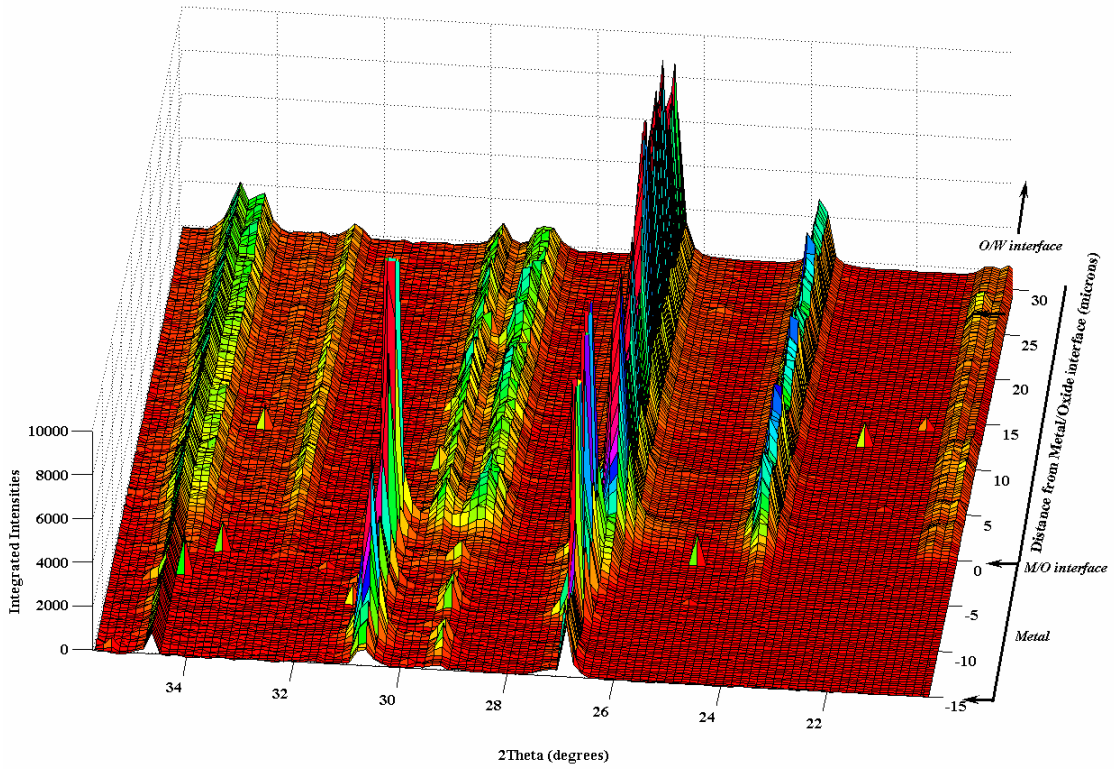
Zr-0.2Fe-0.1Cr (L) – 500°C Steam



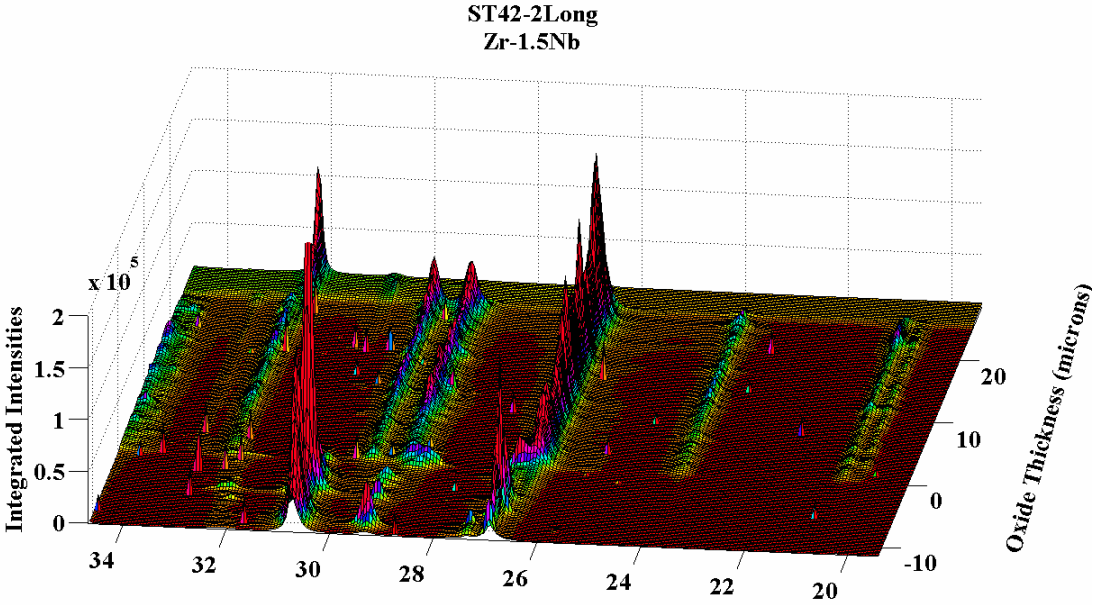
Zr-0.4Fe-0.2Cr (H) - 500°C Steam

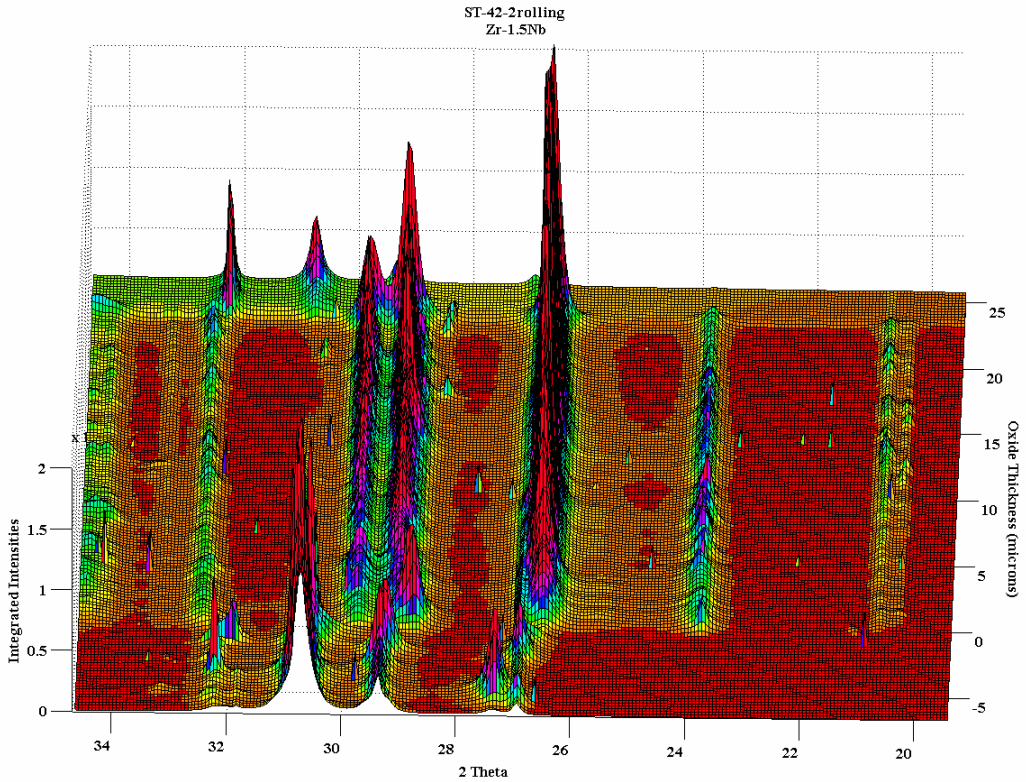


Zr-0.5Cr - 500°C Steam

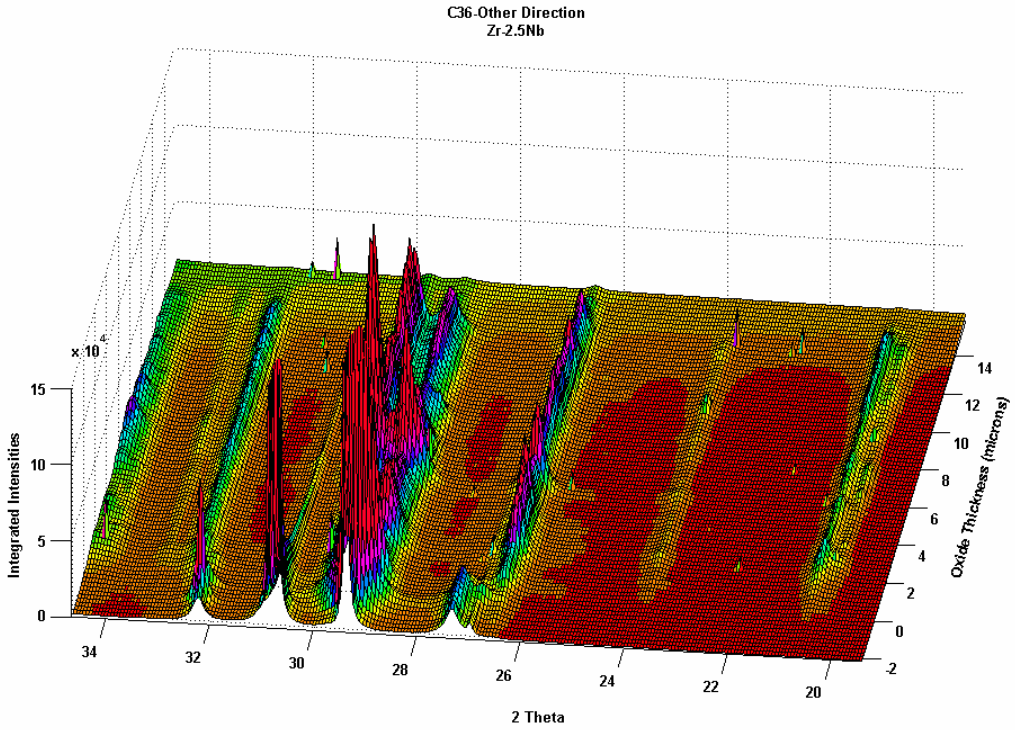


Zr-1.5Nb - 500°C Steam

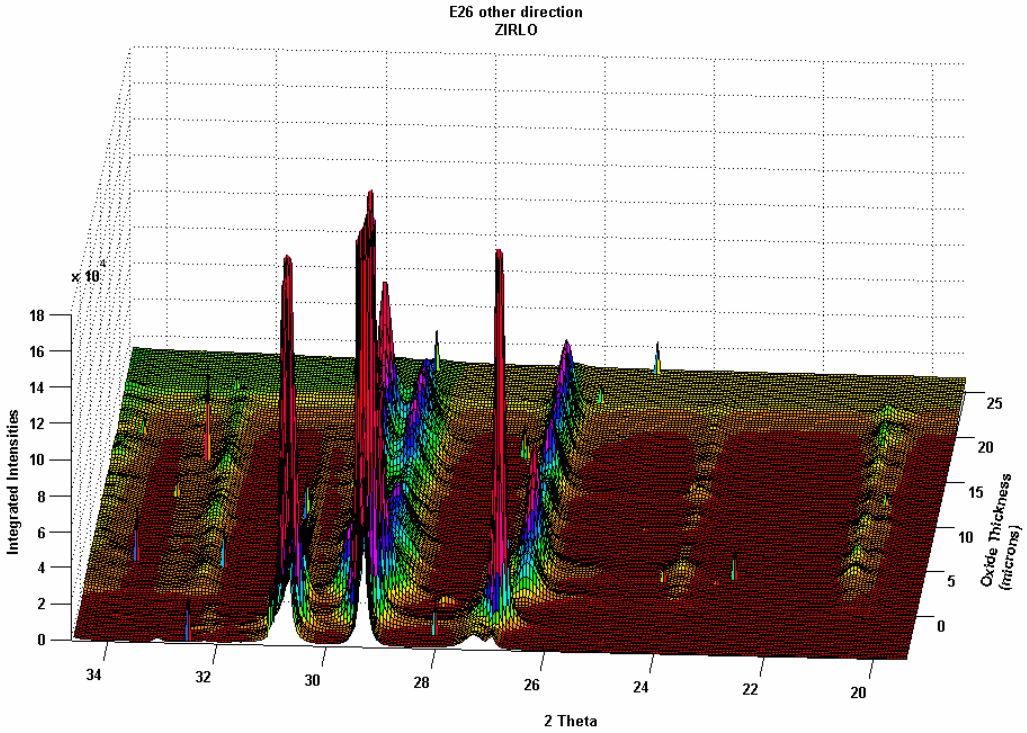
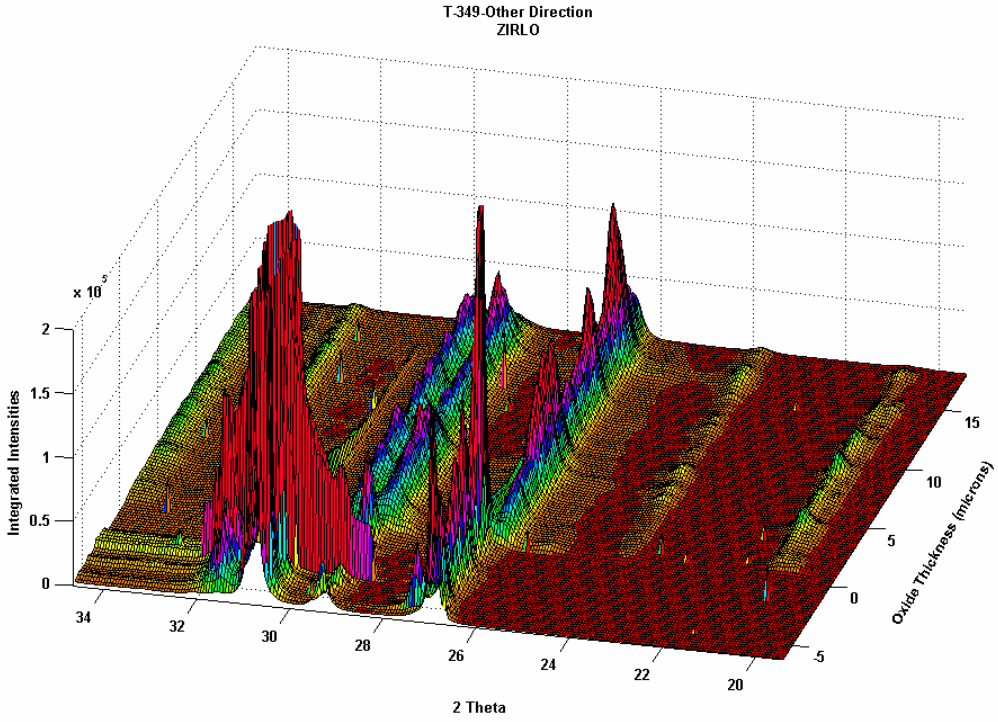




Zr-2.5Nb tube (commercial) - 500°C Steam



ZIRLO tube (commercial) - 500°C Steam



ZIRLO sheet (commercial) - 500°C Steam