Electronic Supplementary Material (ESI) for Journal of Analytical Atomic Spectrometry.

Twelve different types of data normalization for the proposition of classification, univariate and multivariate regression models for the direct analyses of alloys by Laser-induced breakdown spectroscopy (LIBS)

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Supplementary Material

Table 1S

Pictorial description of the twelve normalization modes used in this study

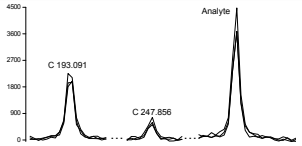
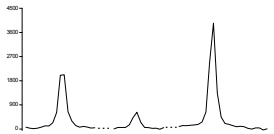
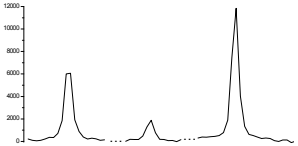
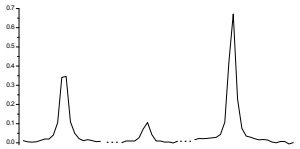
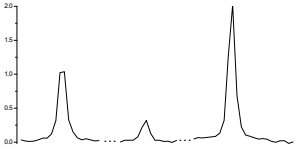
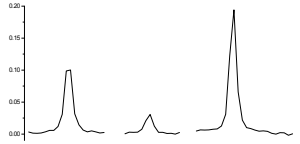
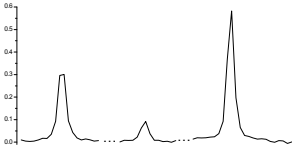
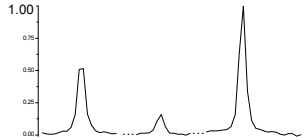
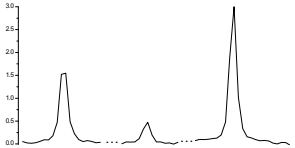
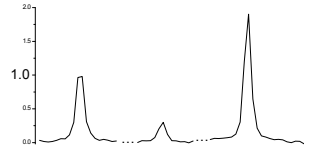
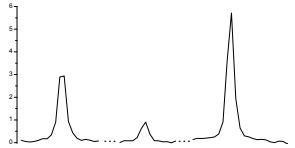
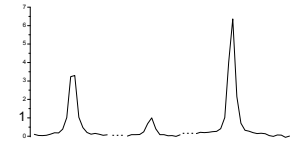
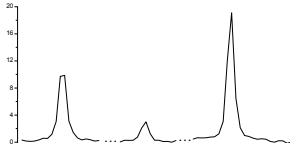
Identification	Normalization mode	Graphical description	Identification	Normalization mode	Graphical description
None	Original data composed of carbon lines and a hypothetical analyte		-	-	-
1	Average		7	Sum	
2	Normalized by the individual norm and averaged over n pulses (the final norm of each spectrum is 1)		8	Normalized by the individual norm and sum over n pulses	
3	Normalized by the individual area and averaged over n pulses		9	Normalized by the individual area and sum over n pulses	
4	Normalized by the individual maximum and averaged over n pulses (the signal of the highest emission line is 1)		10	Normalized by the individual maximum and sum over n pulses	
5	Normalized by the individual C I 193.091 nm intensity and averaged over n pulses (the signal of C I 193.091 is 1)		11	Normalized by the individual C I 193.091 nm intensity and sum over n pulses	
6	Normalized by the individual C I 247.856 nm intensity and averaged over n pulses (the signal of C I 247.856 is 1)		12	Normalized by the individual C I 247.856 nm intensity and sum over n pulses	

Table 2S: Anova tables for models calculated using signal area

Sample name and emission line	Parameter	Sum of Square (SS)	Degree of Freedom (DF)	Mean of Square (MS)	F test
Aluminum alloy (Al I 394.400 nm)	Regression (R)	4.983×10^{8}	3	1.661×10^{8}	Test F1: Test F1: MSR/MSres = 32.61
	Residue (res)	5.602×10^{7}	11	5.093×10^{6}	F tab (95%, 3, 11) = 3.587
	Total (T)	5.543×10^{8}	14	3.959×10^{7}	
	Pure error (PE)	6.160×10^{5}	2	3.080×10^{5}	Test F2: MSLoF/MSPE = 19.99
	Lack of fit (LoF)	5.541×10^{7}	9	6.157×10^{6}	F tab (95%, 9, 2) = 19.38
	R^2	0.8989	R	0.9481	
	Maximum R^2	0.9989	Maximum R	0.9994	
Co-Cr-Mo alloy (Cr II 283.563 nm)	Regression (R)	1.203×10^{9}	5	2.406×10^{8}	Test F1: MSR/MSres = 72.67
	Residue (res)	2.979×10^{7}	9	3.311×10^{6}	F tab (95%, 5, 9) = 3.481
	Total (T)	1.233×10^{9}	14	8.806×10^{7}	
	Pure error (PE)	1.140×10^{6}	2	5.700×10^{5}	Test F2: MSLoF/MSPE = 7.183
	Lack of fit (LoF)	2.866×10^{7}	7	4.094×10^{6}	F tab (95%, 7, 2) = 19.35
	R^2	0.9758	R	0.9878	
	Maximum R^2	0.9991	Maximum R	0.9995	
Unidentified alloy (Cu I 324.754 nm)	Regression (R)	1.464×10^{7}	4	3.659×10^{6}	Test F1: MSR/MSres = 77.60
	Residue (res)	4.716×10^{5}	10	4.716×10^{4}	F tab (95%, 4, 10) = 3.478
	Total (T)	1.511×10^{7}	14	1.079×10^{6}	
	Pure error (PE)	1.800×10^{4}	2	9.000×10^{3}	Test F2: MSLoF/MSPE = 6.300
	Lack of fit (LoF)	4.536×10^{5}	8	5.670×10^{4}	F tab (95%, 8, 2) = 19.37
	R^2	0.9688	R	0.9843	
	Maximum R^2	0.9988	Maximum R	0.9994	
Steel (Fe II 259.940 nm)	Regression (R)	4.184×10^{10}	4	1.046×10^{10}	Test F1: MSR/MSres = 221.5
	Residue (res)	4.722×10^{8}	10	4.722×10^{7}	F tab (95%, 4, 10) = 3.478
	Total (T)	4.232×10^{10}	14	3.023×10^{9}	
	Pure error (PE)	1.510×10^{7}	2	7.550×10^{6}	Test F2: MSLoF/MSPE = 7.568
	Lack of fit (LoF)	4.571×10^{8}	8	5.714×10^{7}	F tab (95%, 8, 2) = 19.37
	R^2	0.9888	R	0.9944	
	Maximum R^2	0.9996	Maximum R	0.9998	
Stainless steel (Fe II 259.940 nm)	Regression (R)	2.792×10^{9}	3	9.307×10^{8}	Test F1: MSR/MSres = 19.18
	Residue (res)	5.338×10^{8}	11	4.853×10^{7}	F tab (95%, 3, 11) = 3.587
	Total (T)	3.326×10^{9}	14	2.374×10^{8}	
	Pure error (PE)	1.710×10^{7}	2	8.550×10^{6}	Test F2: MSLoF/MSPE = 6.715
	Lack of fit (LoF)	5.167×10^{8}	9	5.741×10^{7}	F tab (95%, 9, 2) = 19.38
	R^2	0.8395	R	0.9162	
	Maximum R^2	0.9949	Maximum R	0.9974	

Table 2S: Continuation

Sample name and emission line	Parameter	Sum of Square (SS)	Degree of Freedom (DF)	Mean of Square (MS)	F test
Stainless steel (Fe II 259.940 nm)	Regression (R)	2.545×10^{9}	5	5.091×10^{8}	Test F1: MSR/MSres = 45.51
	Residue (res)	1.007×10^{8}	9	1.118×10^{7}	F tab (95%, 5, 9) = 3.481
	Total (T)	2.646×10^{9}	14	1.890×10^{8}	
	Pure error (PE)	8.290×10^{6}	2	4.145×10^{6}	Test F2: MSLoF/MSPE = 3.184
	Lack of fit (LoF)	9.240×10^{7}	7	1.320×10^{7}	F tab (95%, 7, 2) = 19.35
	R^2	0.9619	R	0.9808	
	Maximum R^2	0.9969	Maximum R	0.9984	
Stainless steel (Mn II 294.920 nm)	Regression (R)	3.989×10^{7}	4	9.973×10^{6}	Test F1: MSR/MSres = 105.4
	Residue (res)	9.459×10^{5}	10	9.459×10^{4}	F tab (95%, 4, 10) = 3.478
	Total (T)	4.084×10^{7}	14	2.917×10^{6}	
	Pure error (PE)	1.470×10^{4}	2	7.350×10^{3}	Test F2: MSLoF/MSPE = 15.84
	Lack of fit (LoF)	9.312×10^{5}	8	1.164×10^{5}	F tab (95%, 8, 2) = 19.37
	R^2	0.9768	R	0.9884	
	Maximum R^2	0.9996	Maximum R	0.9998	
Hastelloy (Mo I 386.411 nm)	Regression (R)	1.057×10^{6}	1	1.057×10^{6}	Test F1: MSR/MSres = 25.25
	Residue (res)	5.444×10^{5}	13	4.187×10^{4}	F tab (95%, 1, 13) = 4.667
	Total (T)	1.602×10^{6}	14	1.144×10^{5}	
	Pure error (PE)	1.300×10^{5}	8	1.625×10^{4}	Test F2: MSLoF/MSPE = 5.100
	Lack of fit (LoF)	4.144×10^{5}	5	8.288×10^{4}	F tab (95%, 5, 8) = 3.687
	R^2	0.6602	R	0.8125	
	Maximum R^2	0.9188	Maximum R	0.9586	
Hastelloy (Ni I 361.939 nm)	Regression (R)	2.295×10^{6}	1	2.295×10^{6}	Test F1: MSR/MSres = 20.08
	Residue (res)	1.485×10^{6}	13	1.143×10^{5}	F tab (95%, 1, 13) = 4.667
	Total (T)	3.781×10^{6}	14	2.701×10^{5}	
	Pure error (PE)	3.759×10^{5}	8	4.699×10^{4}	Test F2: MSLoF/MSPE = 4.721
	Lack of fit (LoF)	1.109×10^{6}	5	2.219×10^{5}	F tab (95%, 5, 8) = 3.687
	R^2	0.6071	R	0.7792	
	Maximum R^2	0.9006	Maximum R	0.9490	
6Al 4V titanium alloy (V I 437.924 nm)	Regression (R)	3.348×10^{3}	1	3.348×10^{3}	Test F1: MSR/MSres = 5.472
	Residue (res)	7.954×10^{3}	13	6.118×10^{2}	F tab (95%, 1, 13) = 4.667
	Total (T)	1.130×10^{4}	14	8.073×10^{2}	
	Pure error (PE)	4.870×10^{3}	8	6.087×10^{2}	Test F2: MSLoF/MSPE = 1.013
	Lack of fit (LoF)	3.084×10^{3}	5	6.168×10^{2}	F tab (95%, 5, 8) = 3.687
	R^2	0.2963	R	0.5443	
	Maximum R^2	0.5691	Maximum R	0.7544	
Steel - two layers of Cr (Zn I 481.053 nm)	Regression (R)	1.209×10^{11}	3	4.031×10^{10}	Test F1: MSR/MSres = 73.78
	Residue (res)	6.009×10^{9}	11	5.463×10^{8}	F tab (95%, 3, 11) = 3.587
	Total (T)	1.269×10^{11}	14	9.067×10^{9}	
	Pure error (PE)	4.250×10^{8}	2	2.125×10^{8}	Test F2: MSLoF/MSPE = 2.919
	Lack of fit (LoF)	5.584×10^{9}	9	6.204×10^{8}	F tab (95%, 9, 2) = 19.38
	R^2	0.9527	R	0.9760	
	Maximum R^2	0.9967	Maximum R	0.9983	

Table 3S: Anova tables for models calculated using signal height

Sample name and emission line	Parameter	Sum of Square (SS)	Degree of Freedom (DF)	Mean of Square (MS)	F test
Aluminum alloy (Al I 394.400 nm)	Regression (R)	4.486×10^{7}	2	2.243×10^{7}	Test F1: MSR/MSres = 21.97
	Residue (res)	1.225×10^{7}	12	1.021×10^{6}	F tab (95%, 2, 12) = 3.885
	Total (T)	5.711×10^{7}	14	4.079×10^{6}	
	Pure error (PE)	9.530×10^{3}	2	4.765×10^{3}	Test F2: MSLoF/MSPE = 256.9
	Lack of fit (LoF)	1.224×10^{7}	10	1.224×10^{6}	F tab (95%, 10, 2) = 19.39
	R^2	0.7855	R	0.8863	
	Maximum R^2	0.9998	Maximum R	0.9999	
Co-Cr-Mo alloy (Cr II 283.563 nm)	Regression (R)	2.363×10^{8}	4	5.909×10^{7}	Test F1: MSR/MSres = 42.50
	Residue (res)	1.390×10^{7}	10	1.390×10^{6}	F tab (95%, 4, 10) = 3.478
	Total (T)	2.502×10^{8}	14	1.787×10^{7}	
	Pure error (PE)	2.850×10^{5}	2	1.425×10^{5}	Test F2: MSLoF/MSPE = 11.94
	Lack of fit (LoF)	1.362×10^{7}	8	1.702×10^{6}	F tab (95%, 8, 2) = 19.37
	R^2	0.9444	R	0.9718	
	Maximum R^2	0.9989	Maximum R	0.9994	
Unidentified alloy (Cu I 324.754 nm)	Regression (R)	1.941×10^{6}	3	6.469×10^{5}	Test F1: MSR/MSres = 83.48
	Residue (res)	8.525×10^{4}	11	7.750×10^{3}	F tab (95%, 3, 11) = 3.587
	Total (T)	2.026×10^{6}	14	1.447×10^{5}	
	Pure error (PE)	3.800×10^{3}	2	1.900×10^{3}	Test F2: MSLoF/MSPE = 4.763
	Lack of fit (LoF)	8.145×10^{4}	9	9.050×10^{3}	F tab (95%, 9, 2) = 19.38
	R^2	0.9579	R	0.9787	
	Maximum R^2	0.9981	Maximum R	0.9991	
Steel (Fe II 259.940 nm)	Regression (R)	3.235×10^{9}	4	8.087×10^{8}	Test F1: MSR/MSres = 314.9
	Residue (res)	2.568×10^{7}	10	2.568×10^{6}	F tab (95%, 4, 10) = 3.478
	Total (T)	3.261×10^{9}	14	2.329×10^{8}	
	Pure error (PE)	6.190×10^{5}	2	3.095×10^{5}	Test F2: MSLoF/MSPE = 10.12
	Lack of fit (LoF)	2.506×10^{7}	8	3.132×10^{6}	F tab (95%, 8, 2) = 19.37
	R^2	0.9921	R	0.9961	
	Maximum R^2	0.9998	Maximum R	0.9999	
Stainless steel (Fe II 259.940 nm)	Regression (R)	2.809×10^{8}	3	9.363×10^{7}	Test F1: MSR/MSres = 20.06
	Residue (res)	5.134×10^{7}	11	4.667×10^{6}	F tab (95%, 3, 11) = 3.587
	Total (T)	3.322×10^{8}	14	2.373×10^{7}	
	Pure error (PE)	1.790×10^{6}	2	8.950×10^{5}	Test F2: MSLoF/MSPE = 6.151
	Lack of fit (LoF)	4.955×10^{7}	9	5.505×10^{6}	F tab (95%, 9, 2) = 19.38
	R^2	0.8455	R	0.9195	
	Maximum R^2	0.9946	Maximum R	0.9973	

Table 3S: Continuation

Sample name and emission line	Parameter	Sum of Square (SS)	Degree of Freedom (DF)	Mean of Square (MS)	F test
Stainless steel (Fe II 259.940 nm)	Regression (R)	2.907×10^8	6	4.844×10^7	Test F1: MSR/MSres = 63.64
	Residue (res)	6.089×10^6	8	7.612×10^5	F tab (95%, 6, 8) = 3.580
	Total (T)	2.967×10^8	14	2.119×10^7	
	Pure error (PE)	1.030×10^6	2	5.150×10^5	Test F2: MSLoF/MSPE = 1.637
	Lack of fit (LoF)	5.059×10^6	6	8.432×10^5	F tab (95%, 6, 2) = 19.33
	R^2	0.9795	R	0.9897	
	Maximum R^2	0.9965	Maximum R	0.9983	
Stainless steel (Mn II 294.920 nm)	Regression (R)	1.153×10^7	4	2.884×10^6	Test F1: MSR/MSres = 102.7
	Residue (res)	2.808×10^5	10	2.808×10^4	F tab (95%, 4, 10) = 3.478
	Total (T)	1.181×10^7	14	8.439×10^5	
	Pure error (PE)	5.450×10^3	2	2.725×10^3	Test F2: MSLoF/MSPE = 12.63
	Lack of fit (LoF)	2.754×10^5	8	3.442×10^4	F tab (95%, 8, 2) = 19.37
	R^2	0.9762	R	0.9880	
	Maximum R^2	0.9995	Maximum R	0.9998	
Hastelloy (Mo I 386.411 nm)	Regression (R)	2.003×10^5	1	2.003×10^5	Test F1: MSR/MSres = 25.86
	Residue (res)	1.006×10^5	13	7.744×10^3	F tab (95%, 1, 13) = 4.667
	Total (T)	3.010×10^5	14	2.150×10^4	
	Pure error (PE)	3.080×10^4	8	3.850×10^3	Test F2: MSLoF/MSPE = 3.629
	Lack of fit (LoF)	6.987×10^4	5	1.397×10^4	F tab (95%, 5, 8) = 3.687
	R^2	0.6655	R	0.8158	
	Maximum R^2	0.8977	Maximum R	0.9475	
Hastelloy (Ni I 361.939 nm)	Regression (R)	3.977×10^5	1	3.977×10^5	Test F1: MSR/MSres = 18.05
	Residue (res)	2.864×10^5	13	2.203×10^4	F tab (95%, 1, 13) = 4.667
	Total (T)	6.841×10^5	14	4.886×10^4	
	Pure error (PE)	1.939×10^5	8	2.424×10^4	Test F2: MSLoF/MSPE = 0.7630
	Lack of fit (LoF)	9.248×10^4	5	1.849×10^4	F tab (95%, 5, 8) = 3.687
	R^2	0.5813	R	0.7624	
	Maximum R^2	0.7165	Maximum R	0.8465	
6Al 4V titanium alloy (V I 437.924 nm)	Regression (R)	8.601×10^3	1	8.601×10^3	Test F1: MSR/MSres = 9.621
	Residue (res)	1.162×10^4	13	8.939×10^2	F tab (95%, 1, 13) = 4.667
	Total (T)	2.022×10^4	14	1.444×10^3	
	Pure error (PE)	5.727×10^3	10	5.727×10^2	Test F2: MSLoF/MSPE = 3.431
	Lack of fit (LoF)	5.894×10^3	3	1.965×10^3	F tab (95%, 3, 10) = 3.708
	R^2	0.4253	R	0.6522	
	Maximum R^2	0.7168	Maximum R	0.8466	
Steel - two layers of Cr (Zn I 481.053 nm)	Regression (R)	4.129×10^9	3	1.376×10^9	Test F1: MSR/MSres = 63.93
	Residue (res)	2.368×10^8	11	2.153×10^7	F tab (95%, 3, 11) = 3.587
	Total (T)	4.366×10^9	14	3.118×10^8	
	Pure error (PE)	2.740×10^7	2	1.370×10^7	Test F2: MSLoF/MSPE = 1.698
	Lack of fit (LoF)	2.094×10^8	9	2.327×10^7	F tab (95%, 9, 2) = 19.38
	R^2	0.9458	R	0.9725	
	Maximum R^2	0.9937	Maximum R	0.9969	

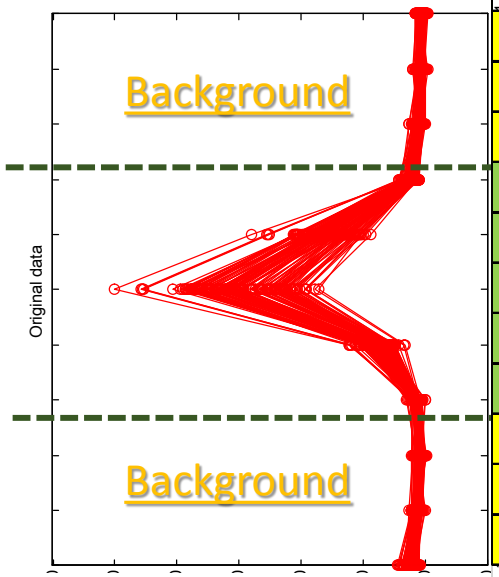
Table 4S

Anova table parameters (Tables 2S and 3S) identification and equations for the models calculated at Table 3.

Parameters	Sum of Squares (SS)	Degree of freedom (D.F.)	Remarks
Regression, SSR	$\sum_{i=1}^{n}(\hat{y}_i - \overline{y})^2$	p-1	p = number of coefficients n = number of experiments m = number of independent experiments $\hat{y}_i$: predicted response (area or height) $\overline{y}$: average of experimental responses (area or height)
residue, SSres	$\sum_{i=1}^{n}(y_i - \hat{y}_i)^2$	n-p	
Total, SST	$\sum_{i=1}^{n}(y_i - \overline{y})^2$	n-1	
Pure Error, SSPE	$\sum_{i=1}^{m}\sum_{j=1}^{n_i}(y_{ij} - \overline{y}_i)^2$	n-m	
Lack of Fit, SSLoF	$\sum_{i=1}^{m}\sum_{j=1}^{n_i}(\hat{y}_i - \overline{y}_i)^2$	m-p	
R^2	$\frac{SSR}{SST}$		
Maximum R^2	$\frac{SST - SSPE}{SST}$		

Fig. 1S

Pictorial description used for standard deviation calculation of the signal background.



	Replicates (n = 105)									
Emission lines	1	2	3	4		102	103	104	105	Variance
11	147	204	423	345	...	99	180	141	160	6177
10	101	199	186	203	...	146	122	45	38	2637
9	7	107	121	151	...	21	50	35	4	2345
8	86	181	172	287	...	68	72	143	57	Signal
7	621	709	985	966	...	311	477	563	543	
6	2155	3065	3216	3727	...	1718	2170	2354	2773	
5	1086	1608	1839	2076	...	1029	948	1345	1383	
4	189	210	315	242	...	95	159	85	147	
3	45	123	264	188	...	74	113	130	109	2627
2	90	199	103	125	...	40	47	-33	51	2344
1	67	129	6	18	...	-25	0	86	15	2309

$$SD = \sqrt{\mathrm{var}_1 + \mathrm{var}_2 + \mathrm{var}_n}$$

$$SD = \sqrt{18439} = 136$$

Sum of the variances

18439

Standard deviation

136

Fig. 2Sa Emission spectra for some samples and selected emission lines: steel with C and Fe lines (a), stainless steel with C and Fe lines (b), stainless steel with Mn lines (c), steel – two layers of Cr with Zn lines (d), aluminum alloy with Al lines (e), unidentified sample with Cu lines (f), Co-Cr-Mo alloy sample with Co and Cr lines (g), 6Al 4V titanium alloy with Ti and V lines (h), and hastelloy sample with Ni and Mo lines (i).

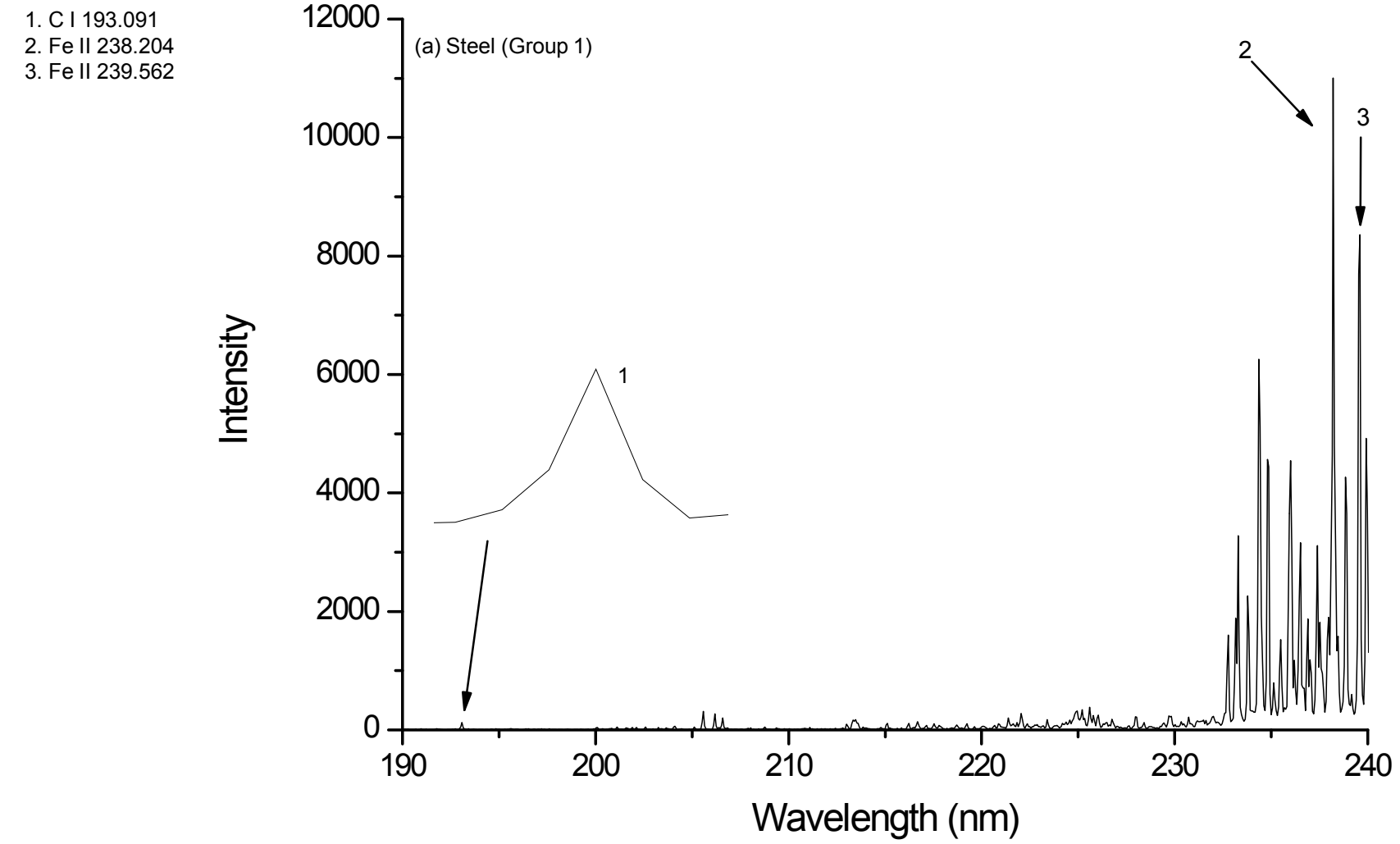


Fig. 2Sb

4. C I 247.856
5. Fe I 248.327
6. Fe II 259.940
7. Fe II 273.955
8. Fe II 274.648
9. Fe II 274.948
10. Fe II 275.573

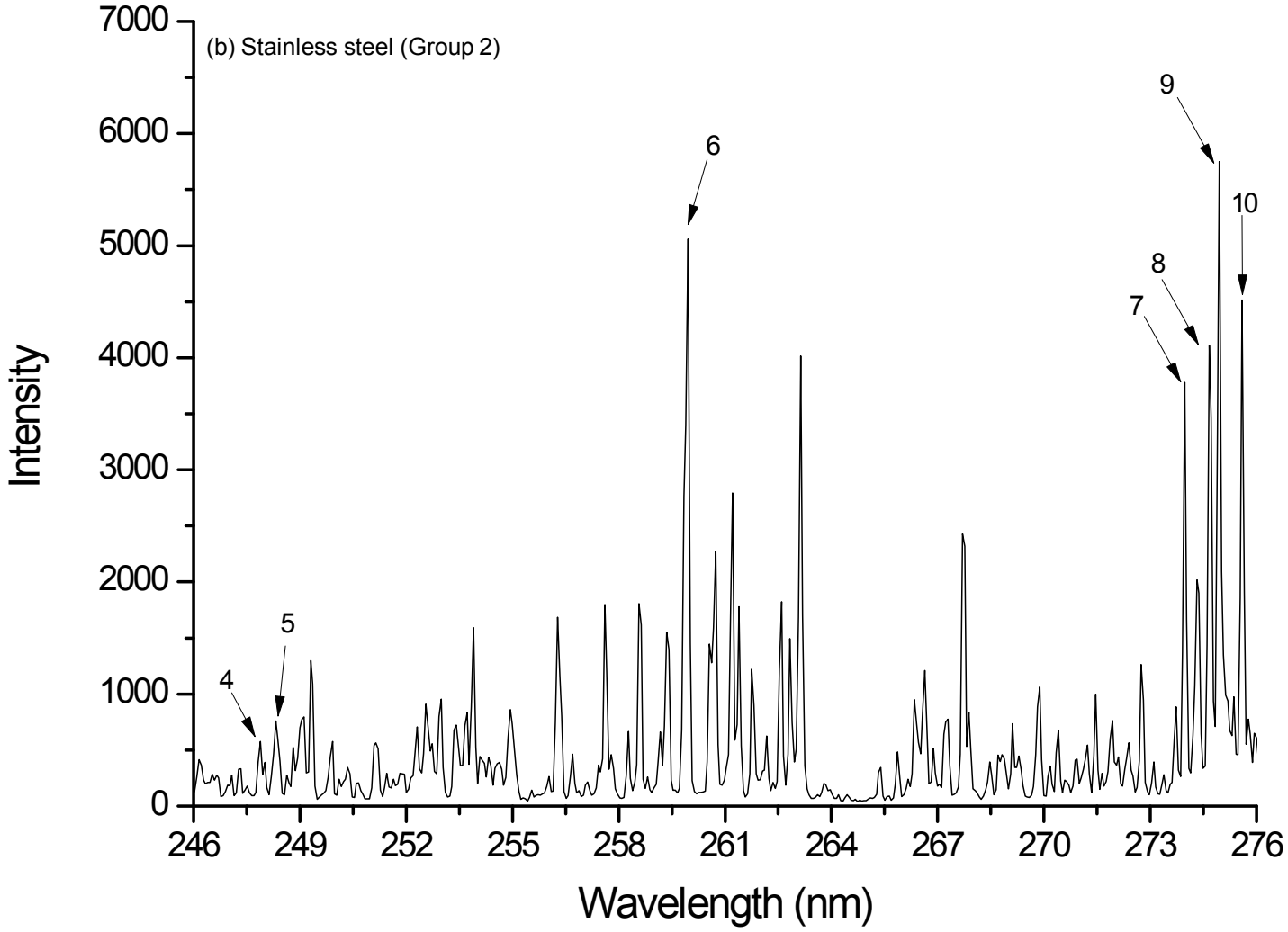


Fig. 2Sc

11. Mn II 257.610
12. Mn II 259.373
13. Mn II 294.920

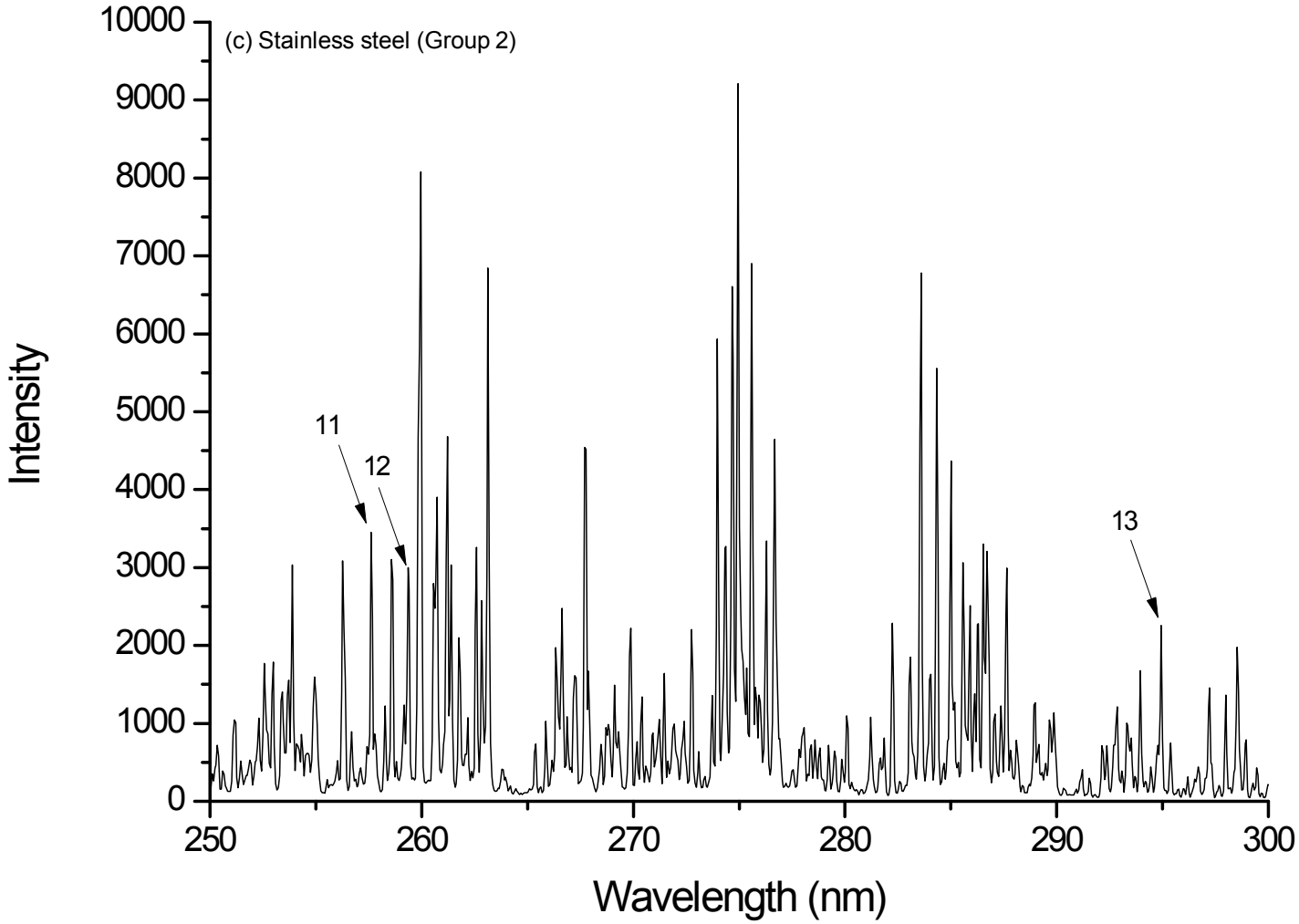


Fig. 2Sd

14. Zn II 255.795
15. Zn I 328.233
16. Zn I 330.258
17. Zn I 334.502
18. Zn I 468.014
19. Zn I 472.215
20. Zn I 481.053

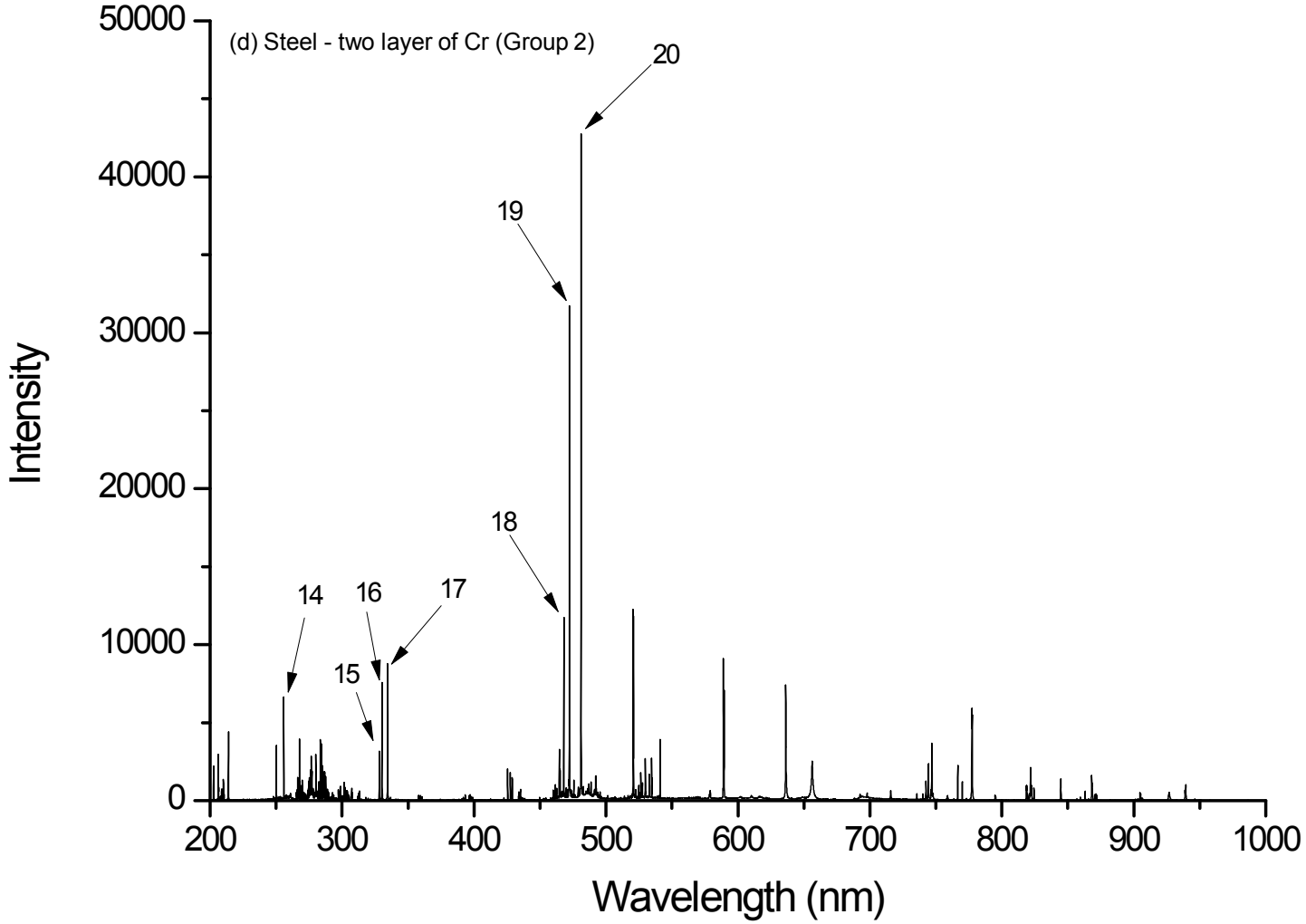


Fig. 2Se

21. Al I 308.215
22. Al I 309.271
23. Al I 394.400
24. Al I 396.152

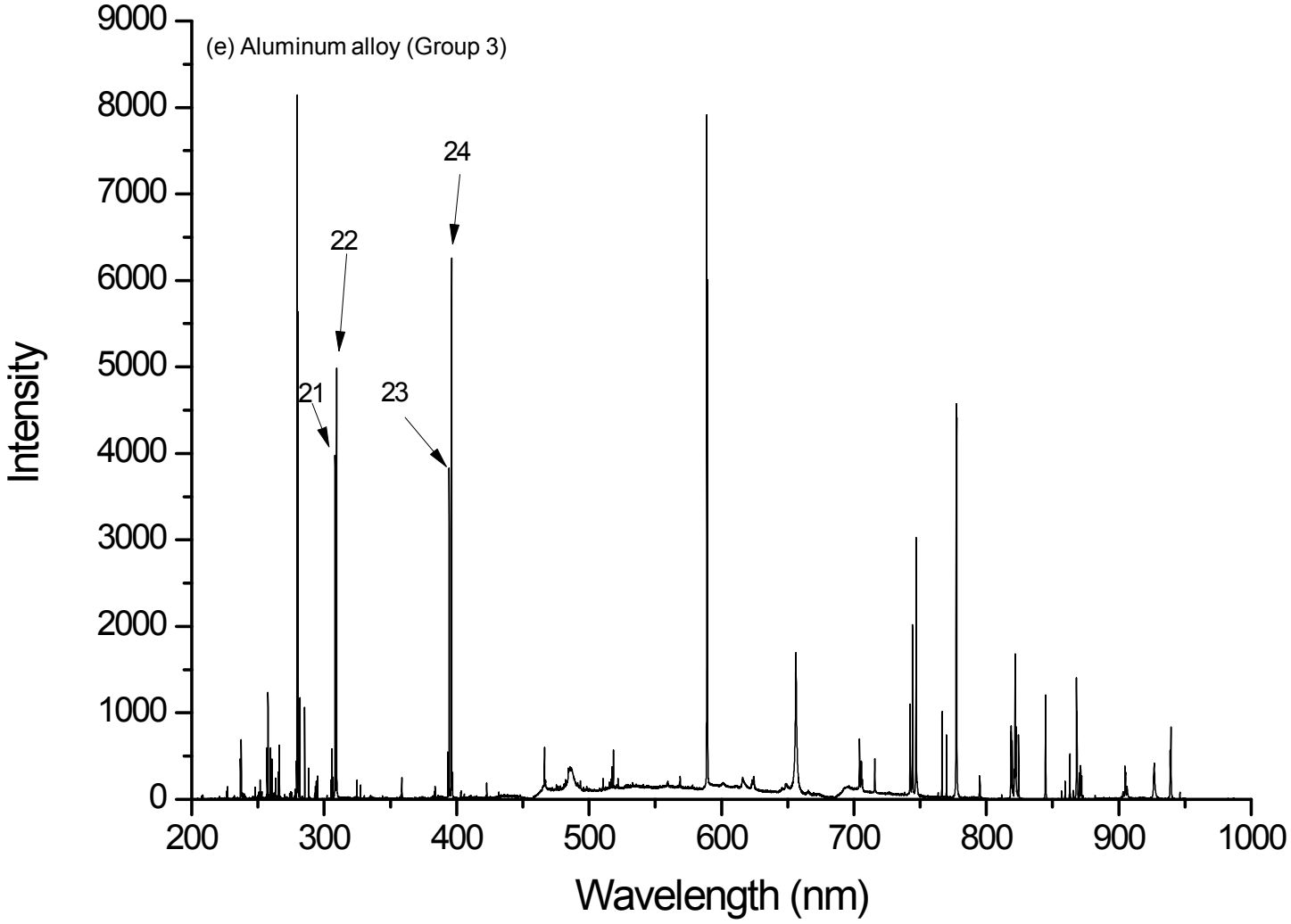


Fig. 2Sf

25. Cu II 224.700
26. Cu I 324.754
27. Cu I 327.396
28. Cu I 510.554
29. Cu I 515.324
30. Cu I 521.820
31. Cu I 578.213

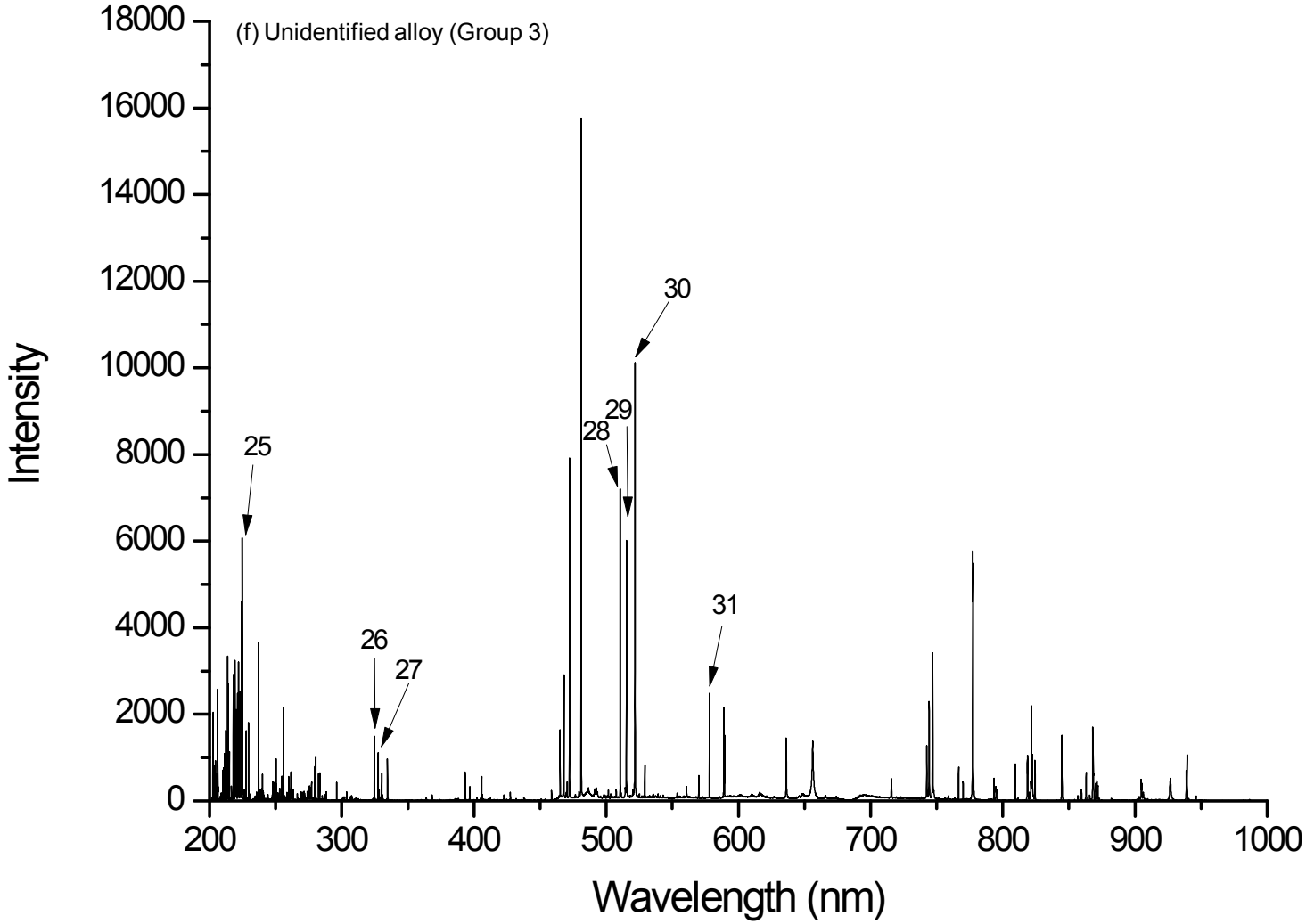


Fig. 2Sg

32. Co II 228.615
33. Co II 230.785
34. Co II 237.862
35. Cr II 267.716
36. Cr II 283.563
37. Cr II 284.325
38. Cr II 284.984
39. Cr I 357.869
40. Cr I 359.349
41. Cr I 425.435
42. Cr I 427.480

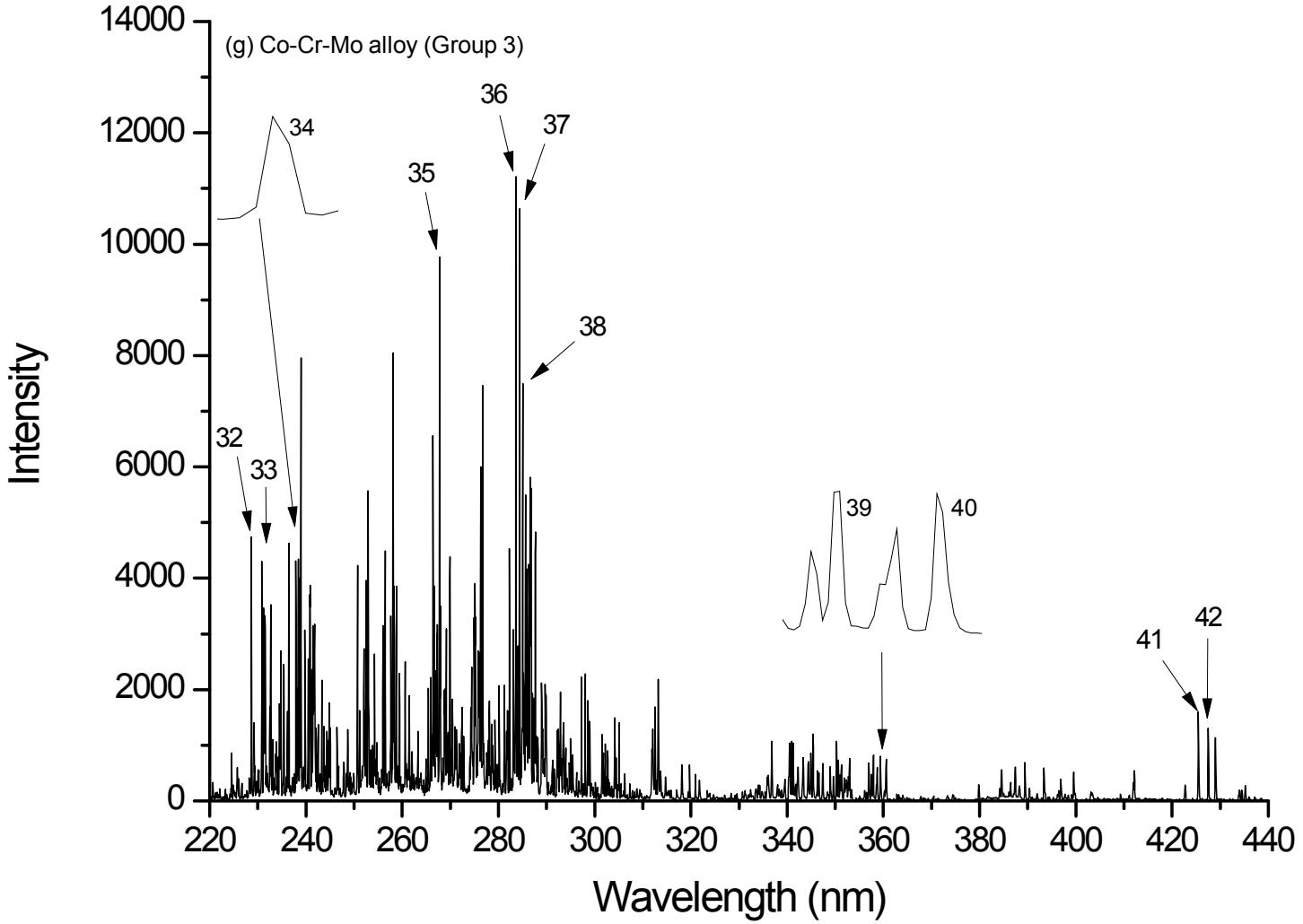


Fig. 2Sh

43. Ti II 307.864
44. Ti II 308.802
45. Ti I 334.188
46. Ti II 334.941
47. Ti II 368.520
48. V I 411.178
49. Ti I 430.109
50. V I 437.924
51. V I 440.820
52. Ti I 498.173

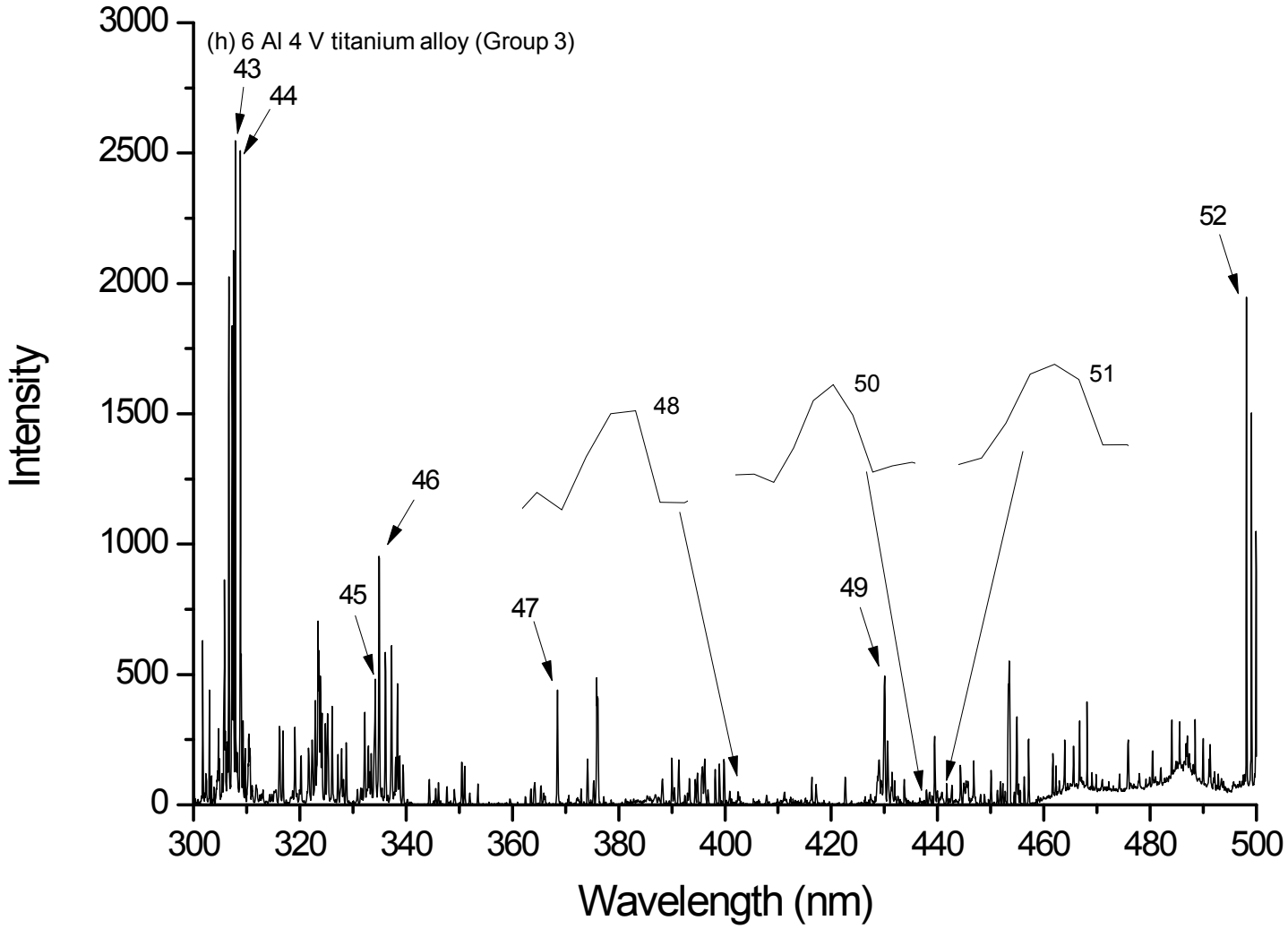


Fig. 2Si

53. Ni I 356.637
54. Ni I 361.939
55. Mo I 386.411
56. Mo I 379.825
57. Mo I 550.649

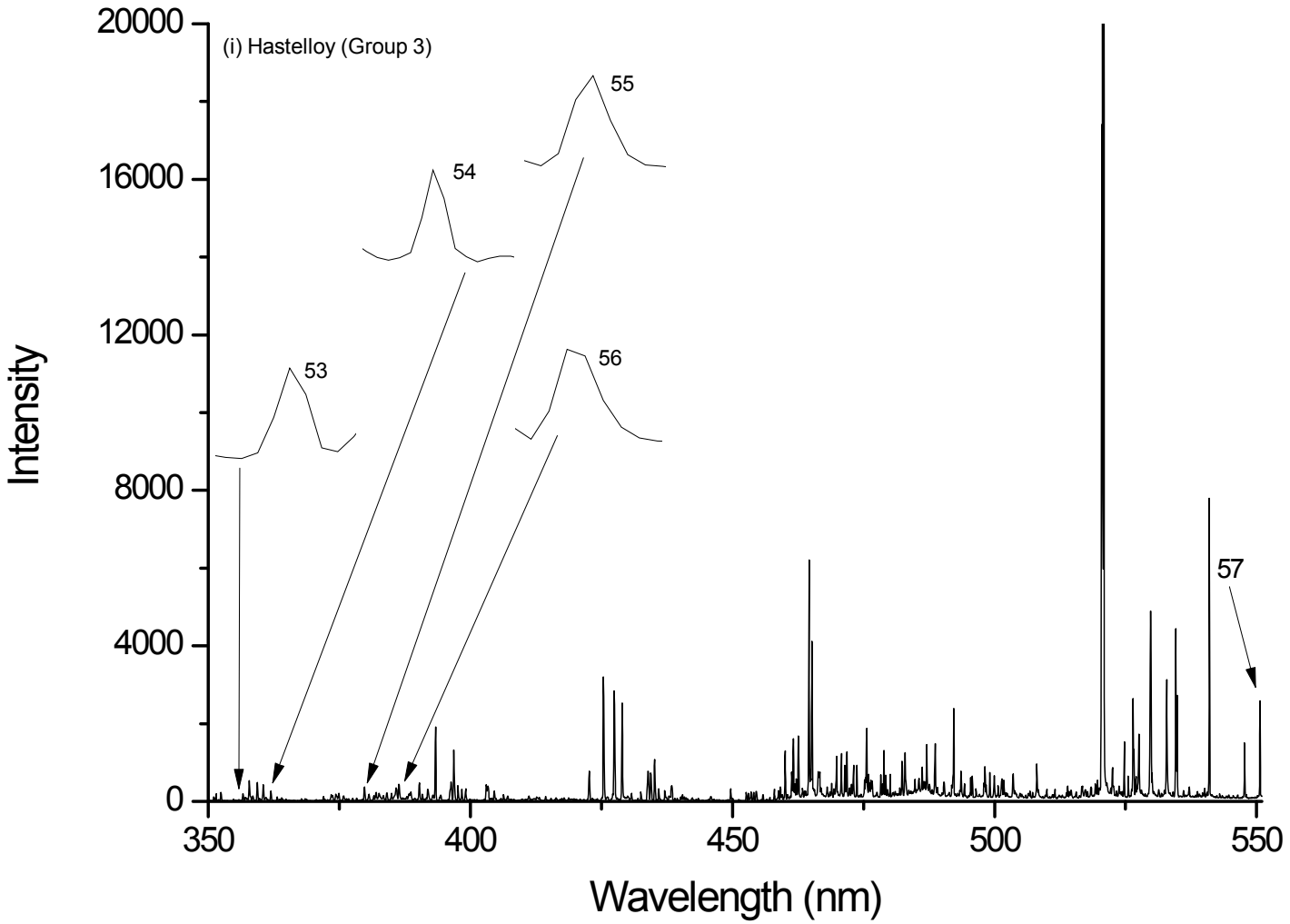
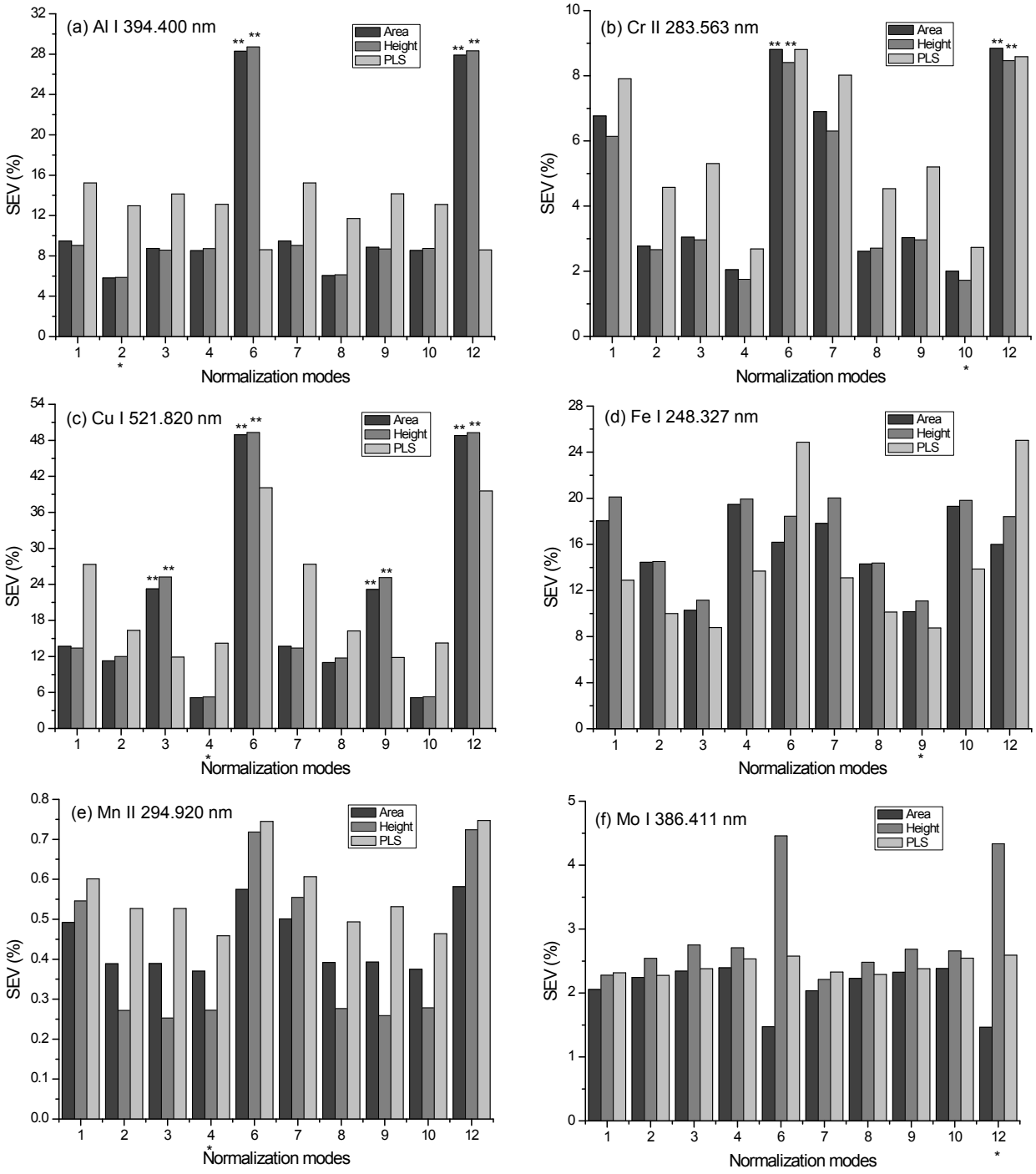
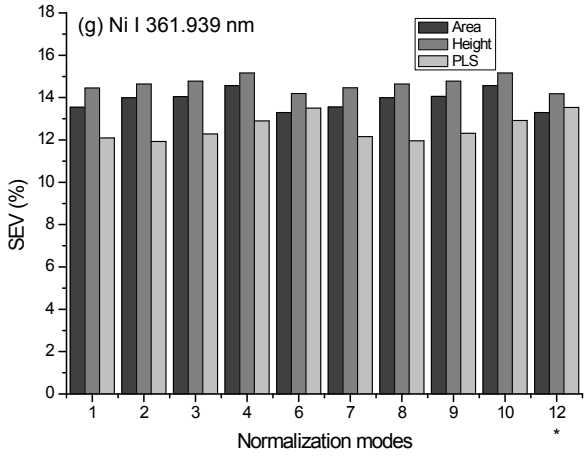
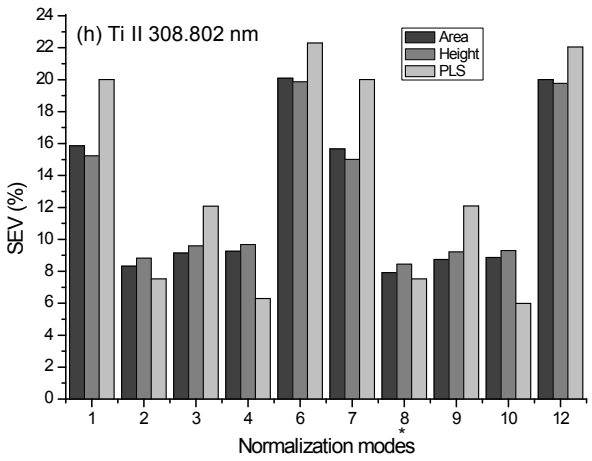


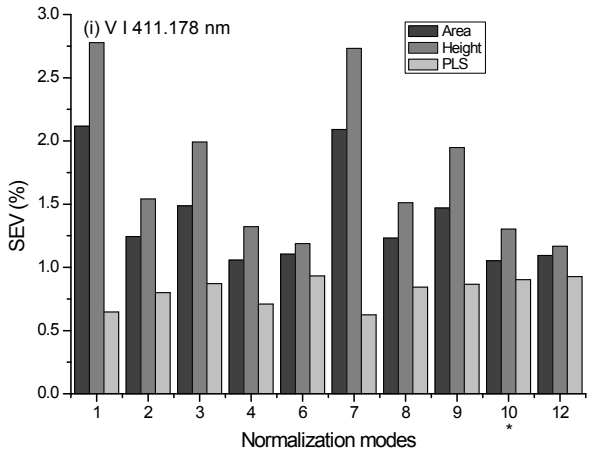
Fig. 3S

Standard error of validation for (a) Al, (b) Cr, (c) Cu, (d) Fe, (e) Mn, (f) Mo, (g) Ni, (h) Ti, (i) V and (j) Zn (SEC was used) using univariate and multivariate models applying the normalization modes proposed. An asterisk represents the mode selected and type of the signal. Normalization modes with two asterisks presented significant difference with the selected one with 95% of confidence level.




(g) Ni I 361.939 nm
Area
Height
PLS
SEV (%)
Normalization modes
1
2
3
4
6
7
8
9
10
12
*


(h) Ti II 308.802 nm
Area
Height
PLS
SEV (%)
Normalization modes
1
2
3
4
6
7
8
*
9
10
12


(i) V I 411.178 nm
Area
Height
PLS
SEV (%)
Normalization modes
1
2
3
4
6
7
8
9
10
*
12

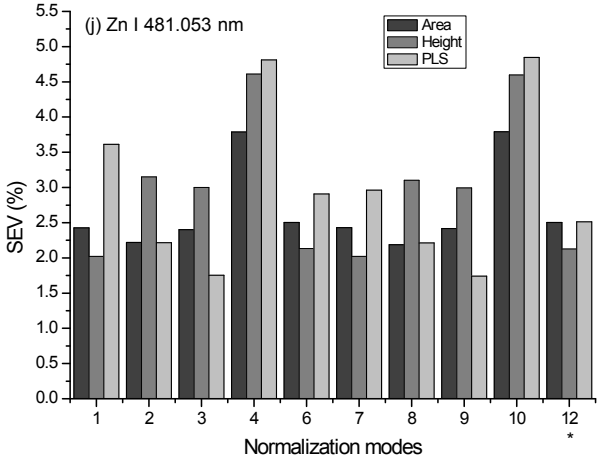
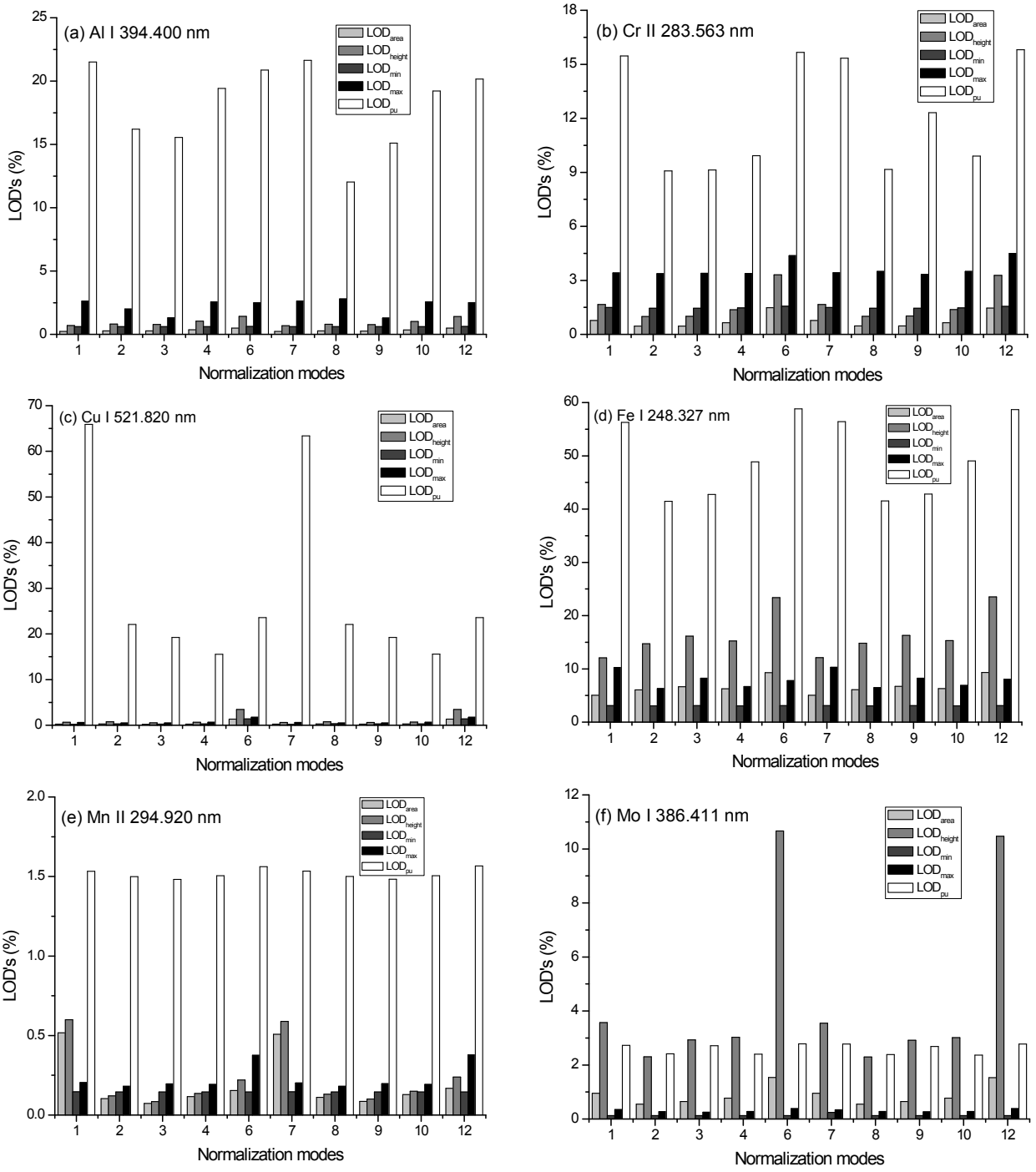
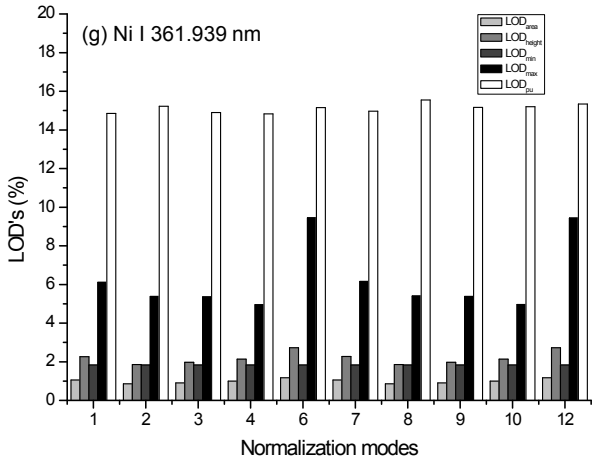
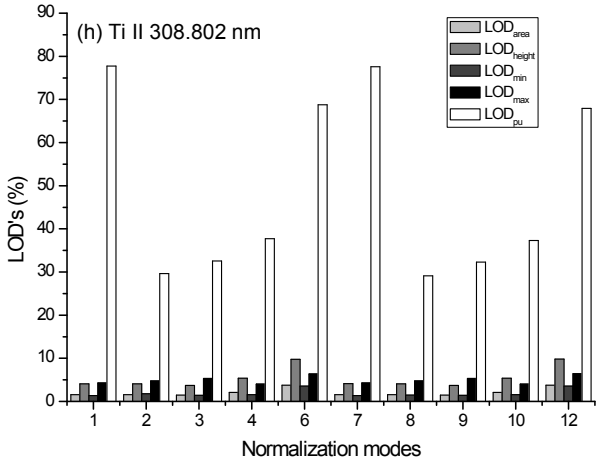

(j) Zn I 481.053 nm
Area
Height
PLS
SEV (%)
Normalization modes
1
2
3
4
6
7
8
9
10
12
*

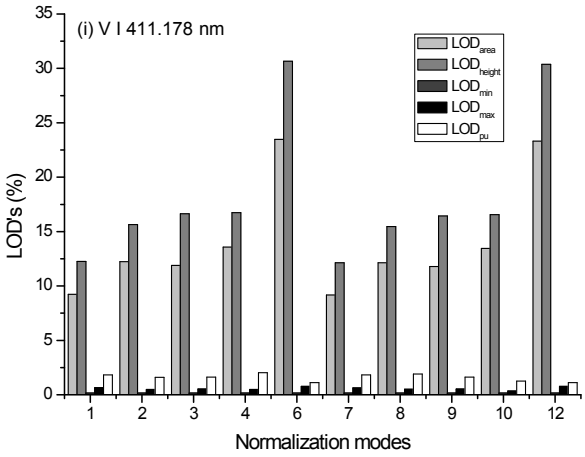
Fig. 4S

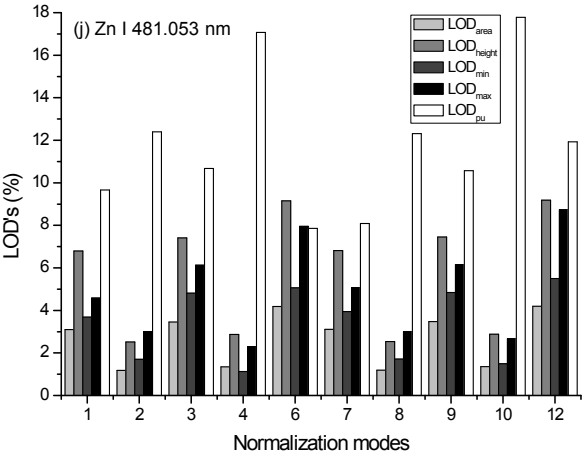
LOD's values for all normalization modes of area and height signal and LOD_{min}, LOD_{max} and LOD_{pu} for PLS (multivariate): (a) Al, (b) Cr, (c) Cu, (d) Fe, (e) Mn, (f) Mo, (g) Ni, (h) Ti, (i) V and (j) Zn.




(g) Ni I 361.939 nm
LOD's (%)
Normalization modes
LOD_area
LOD_height
LOD_min
LOD_max
LOD_pu


(h) Ti II 308.802 nm
LOD's (%)
Normalization modes
LOD_area
LOD_height
LOD_min
LOD_max
LOD_pu


(i) V I 411.178 nm
LOD's (%)
Normalization modes
LOD_area
LOD_height
LOD_min
LOD_max
LOD_pu


(j) Zn I 481.053 nm
LOD's (%)
Normalization modes
LOD_area
LOD_height
LOD_min
LOD_max
LOD_pu