General procedure for the qualitative analysis of LIBS spectra

Introduction

Laser Induced Breakdown Spectroscopy (LIBS) is an analytical technique that allows the elemental composition of, in principle, any kind of sample (solid, liquid or gas) to be obtained in a few seconds without any or with only minimal sample preparation. A LIBS spectrum is obtained within seconds by delivering several laser shots (typically 1-50) to the sample and collecting light emitted from the resulting sample plasma. The spectrum acquired contains all the analytical information required for the identification of the analysed material. Due to the large number of peaks present in most sample spectra, identification of relevant peaks can be laborious. However, following several rules summarised in this document, a relatively inexperienced user will be able to rapidly identify the peaks of a LIBS spectrum. As more experience is gained and the task becomes more customary, users will be able to recognise significant peaks (or groups of peaks) in the spectrum straightaway.

General considerations

The LIBS spectrum characteristics (i.e. the number of detected peaks, absolute and relative intensities between different atomic emission lines, continuum, etc.) for a given sample change depending on a large number of factors including the laser pulse energy and duration, focussing conditions, detection system employed, time acquisition parameters (integration and delay time), etc. These factors should be taken into account when comparing spectra obtained with different LIBS systems and/or utilising different experimental conditions. Similar but not identical spectra should be expected when analysing the same sample under different experimental conditions.

The following considerations should be taken into account when interpreting a LIBS spectrum:

- Under the typical power densities employed in a LIBS experiment (some tenths of GW/cm^2), a spectrum would typically display neutral (I) and single ionised (II) emission lines. Higher ionisation states are not to be expected.
- The number of emission lines/peaks detected in the spectrum depends on the plasma “brightness”, which is affected by the laser pulse energy, focussing conditions, etc. The spectrum of a bright/hot plasma will display more emission lines with higher intensity, than a spectrum obtained from a less bright/cooler plasma (when analysing the same sample).
- The number of emission lines displayed on the spectra can vary depending on the sample composition. The spectrum of some pure element samples, such as Fe, Ti, Zr, Ni or Cr, can display hundreds of peaks, while the spectrum of others, such as Si, Al or Zn display relatively few emission lines.
- Acquisition time parameters: The number and intensity of emission lines displayed in a LIBS spectrum depend on the acquisition time parameters (i.e. integration and delay time). In LIBS analysis it is common to use a delay time between plasma generation and detection in order to avoid the strong continuum and broader atomic emission lines present in the early phase of the plasma lifetime. However, the use of a long delay could hinder the detection of ionic emission lines since the lifetime of ionic lines is shorter than that of neutral lines. Thus the optimum delay time should be investigated and chosen carefully according to the experimental conditions applied each time.
- Spectral interferences: Depending on the resolution of the spectrometer a peak in a LIBS spectrum may be the result of the contribution of two or more different emission lines from the same or different elements.
- Concentration of the element: The concentration of a given element in the analysed sample will define the number and intensity of emission lines detected in the spectrum. If the element is a trace element in the sample probably only the strongest emission lines will be detected. It should be noted that if the concentration of an element is doubled in a sample the intensity of the corresponding

emission lines will not necessarily double. Moreover, the same concentration of an element in two different matrices will not necessarily yield the same emission line intensities (*for quantitative LIBS analysis please check the corresponding tutorial: General procedure for quantitative analysis with LIBS*).

- Efficiency of the collection optics/spectrometer/detection system: The efficiency of the plasma collection system "modulates" the detected spectrum. For example, if BK7 optics are employed, the emission lines in the ultraviolet range will be blocked and therefore will not be seen in the acquired spectrum.

Databases and software

The following databases provide access to spectroscopic data and they are usually employed for the identification of emission lines:

- http://physics.nist.gov/PhysRefData/ASD/lines_form.html
- https://www.cfa.harvard.edu/amp/ampdata/kurucz23/sekur.html
- http://vald.astro.uu.se

Also specific software such as LIBSoft (Applied Photonics Limited) or Plasus SpecLine (http://www.plasus.de/index.php?page=software_specline&lang=en) provides several tools for the identification of atomic emission lines in LIBS spectra.

These software/databases provide information such as emission line wavelength, ionisation state or relative intensity of a line. In order to find the strongest emission lines, the relative intensity information can be advised. It should though be highlighted that relative intensities can be compared only among emission lines of the same element for the same ionisation state. Therefore, it is meaningless to compare the relative intensity of an Al line with a Cu line or even an Al neutral line with an Al ionic line. Furthermore, since the intensity of the emission lines depends on the plasma properties, which in turn depends on the laser energy, focussing conditions, etc, and the spectral response of the LIBS system used, the relative intensities provided by these databases will not match exactly the ones found in an experimental LIBS spectrum and therefore they should be used only as an indication of what to expect.

Spectrum analysis

General considerations

Before beginning the identification of the peaks of a LIBS spectrum, the user should be aware that not all the elements detected in a LIBS spectrum are necessarily a constituent of the analysed sample; the following tips should be taken into account when a LIBS qualitative analysis is carried out:

- Alkali metals and alkaline earth metals such as Mg, Ca, Na, Ba, K, Li or Sr are very easily detected by LIBS and are usually present in the sample due to surface contamination. If the sample surface is not cleaned before the analysis (by means of conditioning laser shots or another method) it is quite possible that emission lines of these elements will appear in the spectrum. The user should clean the sample surface properly to make sure that the detected elements are indeed a constituent of the sample.
- If the LIBS analysis is carried out in air, emission lines of O (777.194, 777.417 and 777.539 nm), N (742.364, 744.229 and 746.831 nm) and H (656.279 nm) among others could be detected in the spectrum due to the interaction between the generated plasma and the surrounding atmosphere. If the analysis is performed using a buffer gas it is expected that emission lines from this gas will appear in the spectra.

Identification methodology

It should be noted, that the following methodology provides general guidelines to help users in the identification of LIBS spectra and it is not intended to be the only way to carry out the identification of the peaks in a LIBS spectrum.

Whether the user uses an internet database or other software, the identification of an unknown line is usually carried out using this methodology:

1st: A search for possible emission lines in a specified interval either side of the wavelength of the spectrum peak to be identified.

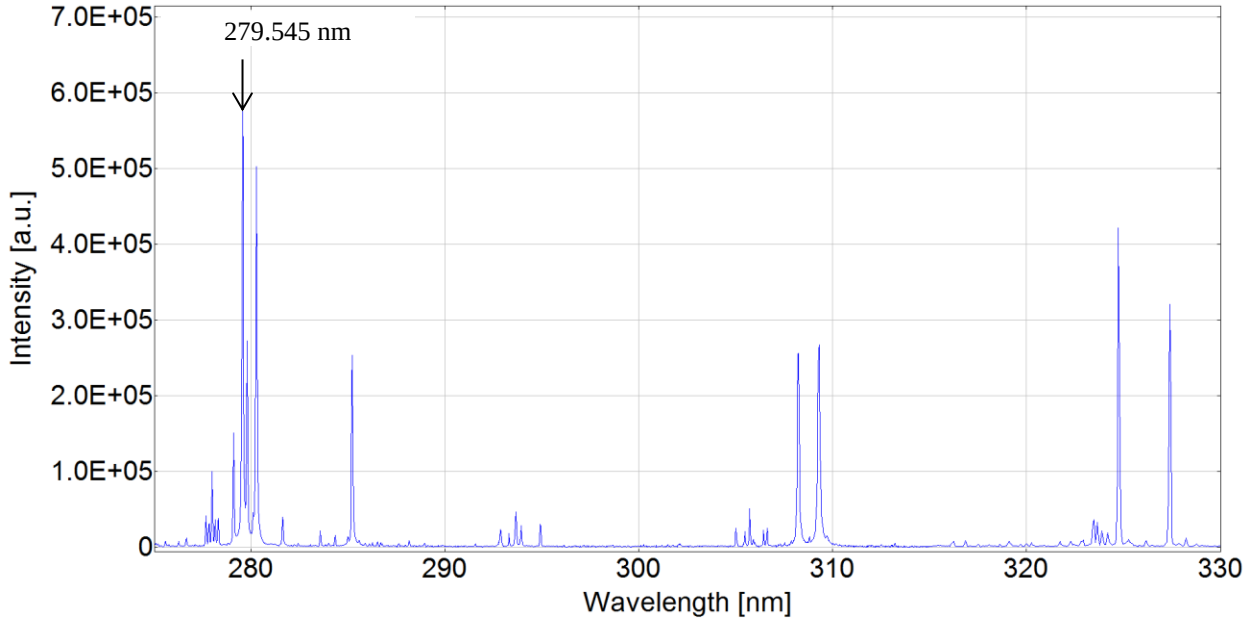
The interval depends on the resolution and the wavelength calibration precision of the LIBS system used. The result of the search provides a list of possible emission lines/elements. It is the task for the user, taking into account the nature of the analysed sample, to decide which of the possible emission lines/elements are reasonable.

2nd: Confirm the presence of an element. The fact that an element is listed in the results of a search does not mean that this element is part of the sample. To confirm the presence of an element in the sample, the strongest emission lines of this element should be also detected in the spectrum. In addition to the emission line wavelength the spectroscopic databases include information about the relative strength/intensity of a given line. Tables 1 and 2 included in Appendix 1 of this document also list the strongest emission lines of each element and can be used in this step.

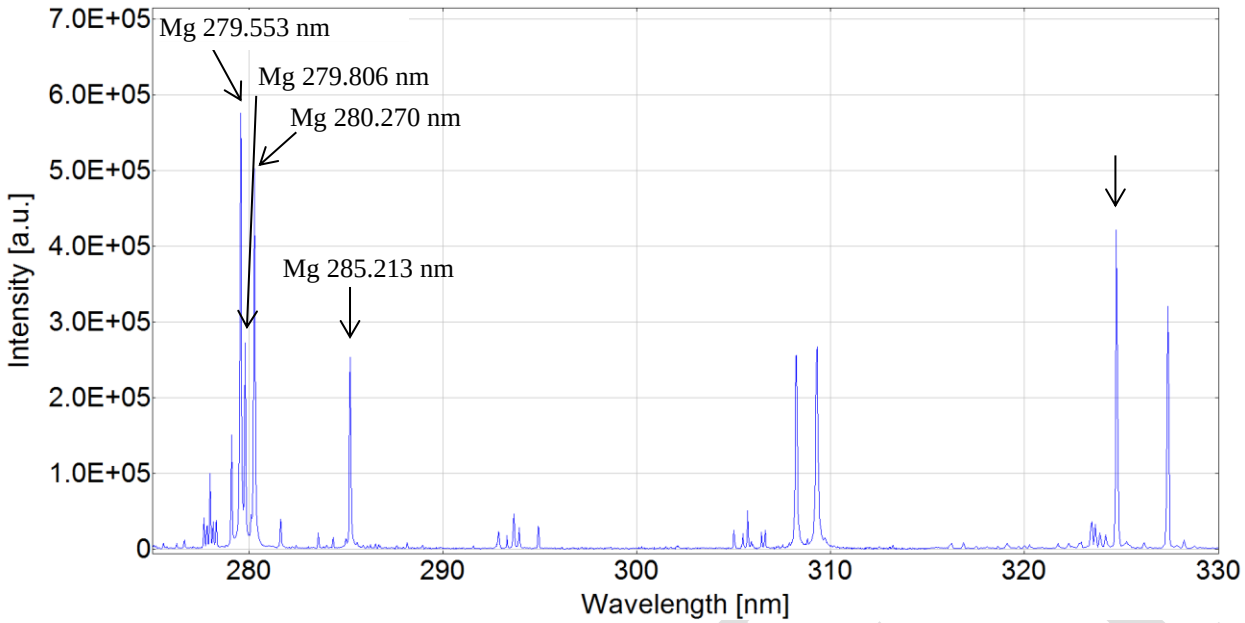
Example of identification of the peaks in a LIBS spectrum

In the following example the identification of the peaks of a LIBS spectrum acquired by analysing an unknown metal is carried out.

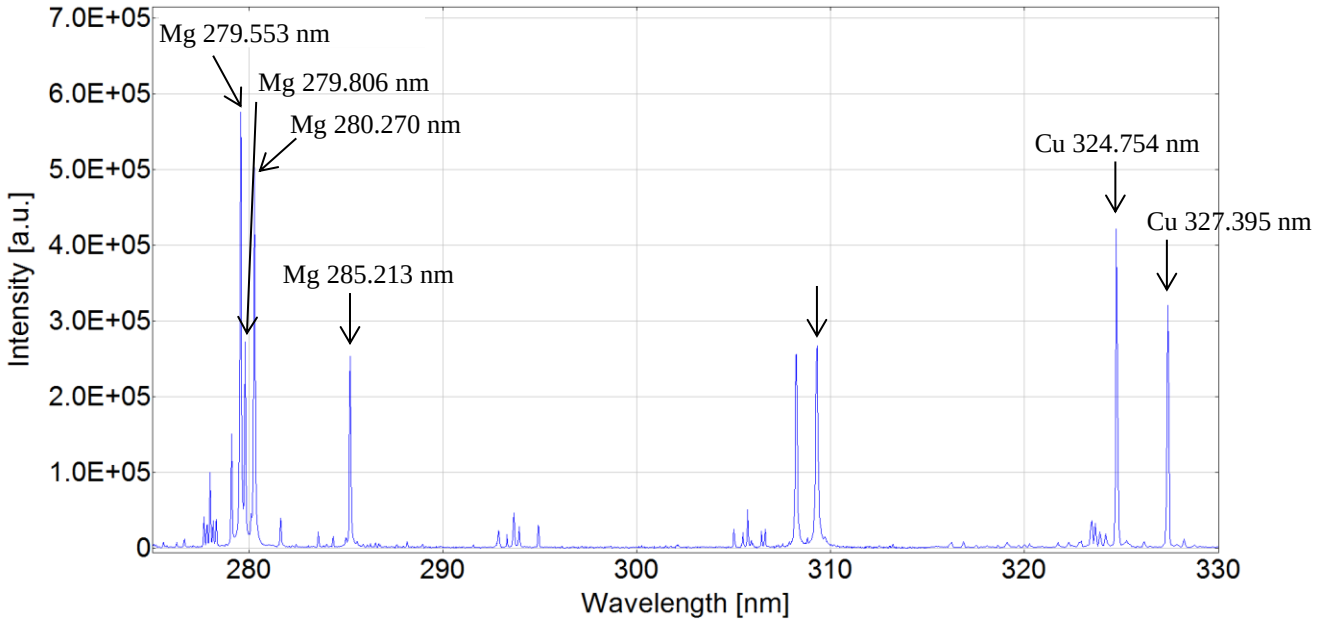
The most intense peak in the spectrum is at 279.545 nm. A search in the NIST website using an interval of 0.02 nm yields the following possible elements: Cr, Fe, Ar, Yb, Ti, Mn, Mg, Ne, Co and Tc.



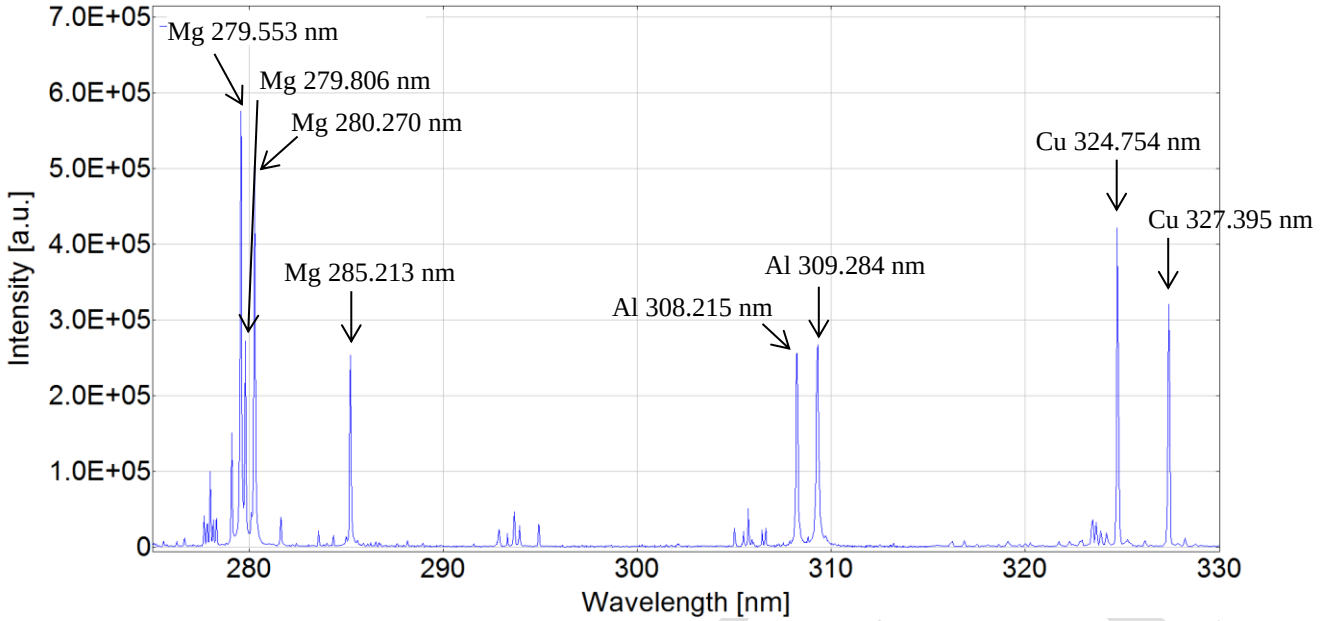
Magnesium is one of the listed elements and as was mentioned before, this element is easily detected by LIBS. To confirm the presence of Mg the strongest lines of this element should be also detected in the spectrum. According to Table 1 in Appendix 1 the strongest lines of Mg (within the interval range of this spectrum) are 279.553, 279.800, 280.270 and 285.213 nm. All of them are present in the spectrum (see figure below) confirming the presence of Mg in the spectrum.



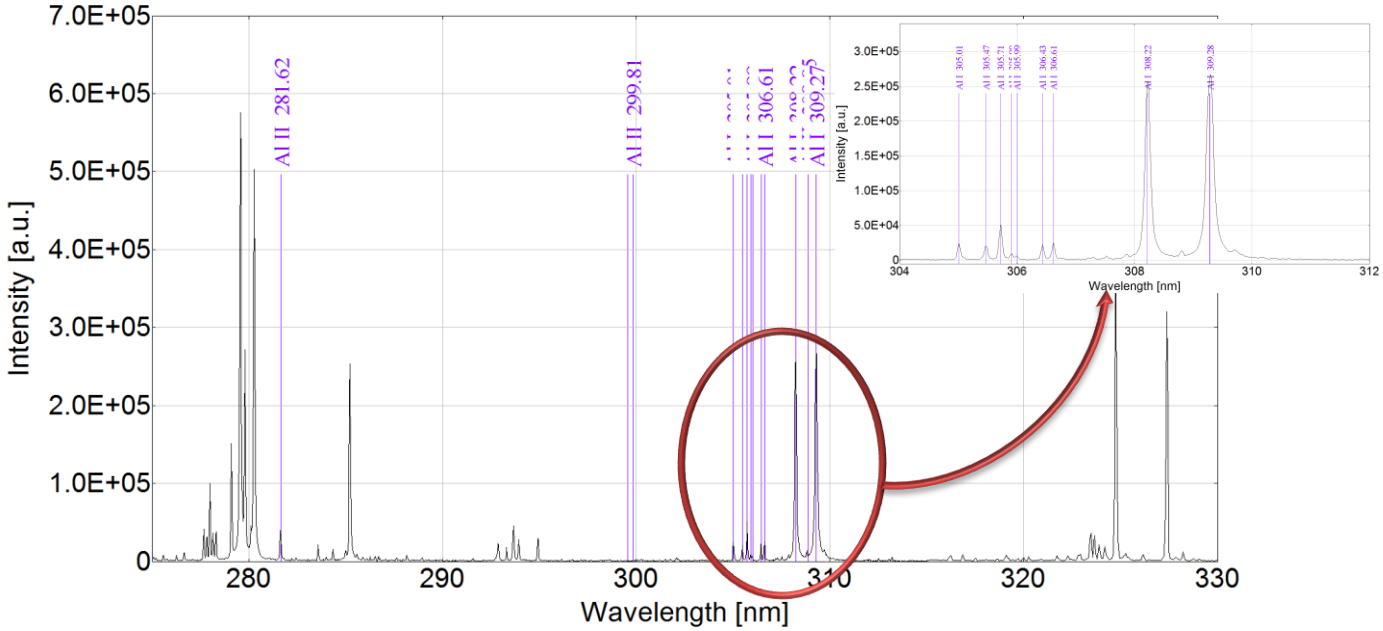
The next most intense peak of the spectrum is at 324.723 nm (See figure above). A search in the NIST database yields these elements: Bk, Cr, Fe, Eu, Na, W, Tm, Nb, Ar, Cu, Pu and Mo. Elements such as Bk, Eu, Tm or Pu can be usually discarded (unless the nature of the sample dictates the contrary). Using Table 1 in Appendix 1 the Cu emission line at 324.754 nm appears to be a good match. To confirm the presence of this element further strong emission lines for Cu should also be detected. According to the table Cu should display another strong line in this spectral window at 327.396 nm. This line can be also detected confirming the presence of copper (See figure below).



The next most intense peak is at 309.302 nm and a search in the NIST database yields the following elements: Cr, Al, Sc, Ne, Nd, Mn, Mg, U, W, Na, V and Fr. Again elements such as U and Fr can be discarded. Among the other elements Al is the one that features a strong emission line at this wavelength. Furthermore, the presence of another strong Al emission line at 308.215 nm in the spectrum confirms this element's presence. (See figure below)



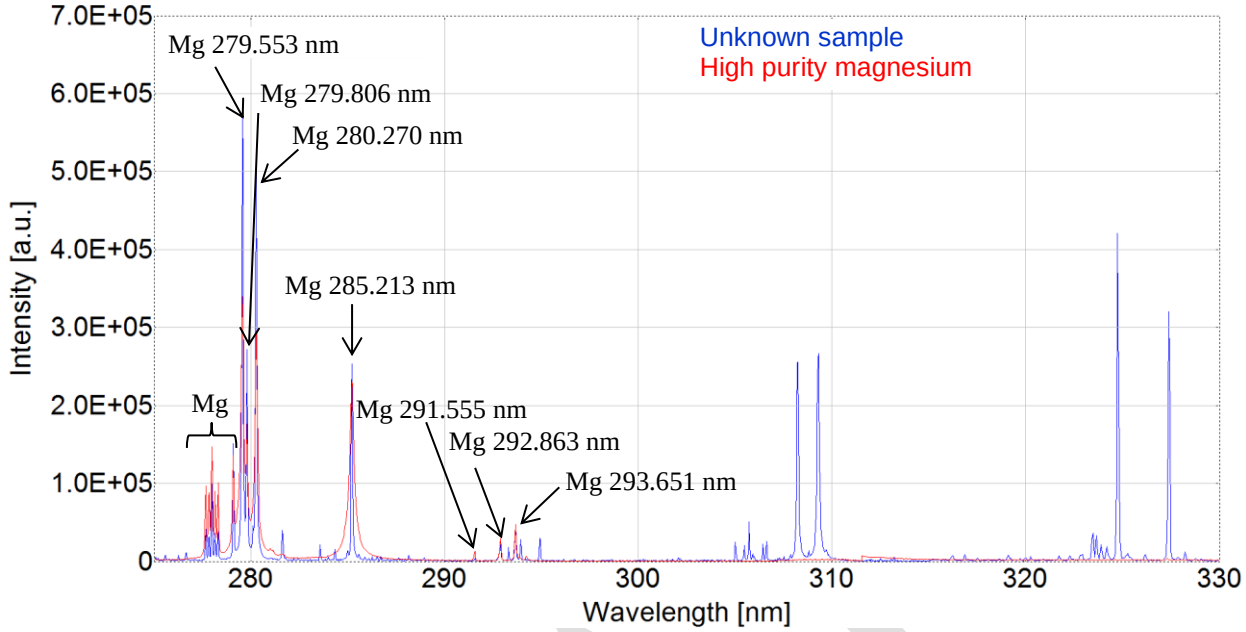
Once the most intense peaks are identified and the presence of some elements has been confirmed, the user can employ this information during the identification of weaker peaks. In this example Mg, Al and Cu were identified, so it is quite possible that other emission lines of these elements are also present in the spectrum. LIBSoft and Plasus SpecLine software feature a tool that allows plotting the position of emission lines over an experimental spectrum. In the figure below, this capability was employed and the positions of neutral and ionic aluminium emission lines were plotted over the experimental spectrum allowing the identification of other aluminium emission lines in the spectrum.



It must be noted that the user should not expect the presence in a LIBS spectrum of every single emission line listed in an atomic emission database and normally only the most intense lines of each element will be detected. The relative intensity information of the emission lines, included in databases, should be used as an indicator to decide which emission lines are going to be detected. In this example (see figure above), although two weak aluminium lines at ~299 nm are not detected in the spectrum, the presence of aluminium in the sample is clearly confirmed because a large number of aluminium emission lines has been detected.

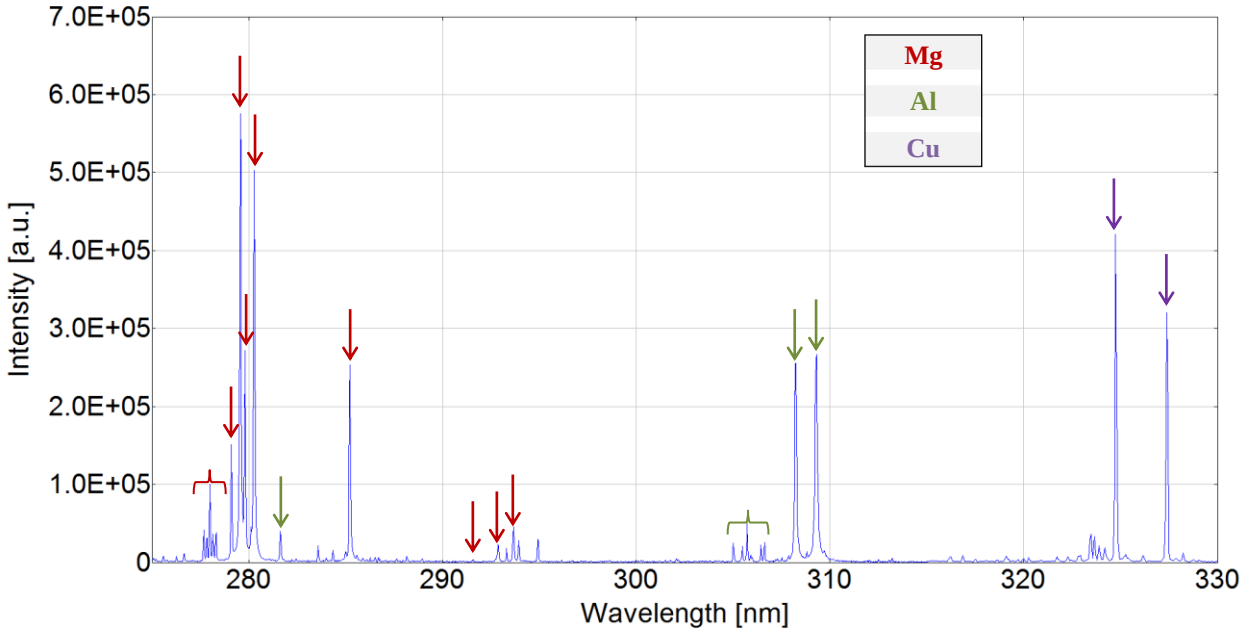
Another really helpful method for the identification/confirmation of the elements present in the analysed material is the comparison of its spectrum with that of a known composition sample, e.g. high purity

material, analysed preferably under the same experimental conditions with the same LIBS equipment. For the sample examined in this case study and in order to confirm the presence of magnesium, a high purity magnesium sample was analysed. In the following figure the spectrum of the unknown sample and the one of the high purity magnesium have been superimposed.



Apart from the already identified magnesium lines (279.553, 279.800, 280.270 and 285.213 nm), a group of lines between 277-279 nm as well as the peaks at 291.555, 292.863 and 293.651 nm can be clearly attributed to magnesium. Variations in the relative intensities of the magnesium lines between the two samples, are expected but this should not affect the reliable identification of the spectrum peaks.

The following graph shows the results of the qualitative analysis of the unknown sample chosen in this example.



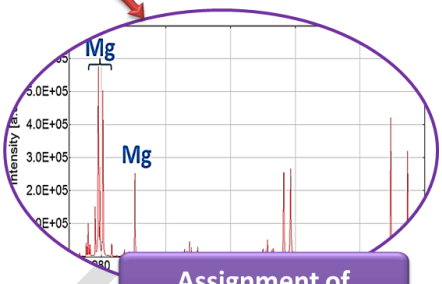
If a more exhaustive assignment of the spectrum peaks is needed (that will depend on the nature of the application), then the unknown peaks left should be also identified following the methodology previously described.

Procedure summary

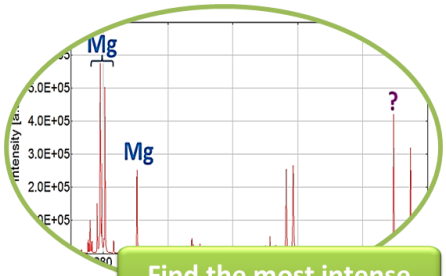
Find the most intense peak in the spectrum

Selection of the most suitable element

Possible element	Presence of the strongest emission lines
Mg	✓
Cr	×
Mn	×
W	×



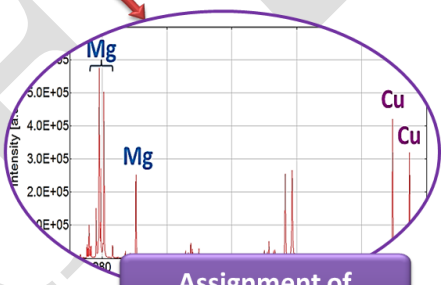
Assignment of emission lines



Find the most intense peak left in the spectrum

Selection of the most suitable element

Possible element	Presence of the strongest emission lines
Cu	✓
Fe	×
Nb	×
Mo	×



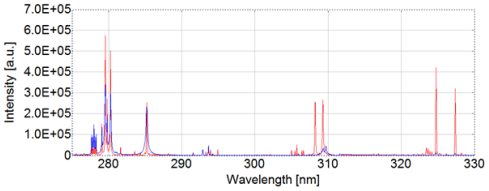
Assignment of emission lines

Qualitative analysis results

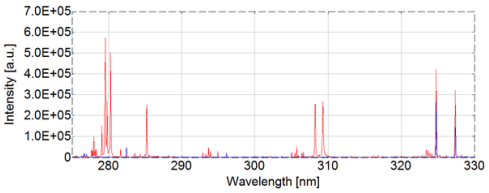
Possible element	Presence of the strongest emission lines
Mg	✓
Cu	✓
Al	✓

Overlay experimental high purity spectra to confirm element detection (when available)

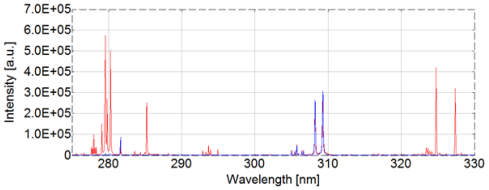
Mg



Cu



Al



Appendix 1 Table 1 and Table 2 list the strongest lines usually detected by LIBS for each element. These tables try to gather information from published papers but also the experience acquired by Applied Photonics researchers throughout the years. This list is not intended as a substitute for spectroscopic databases or specified software but as a complement to them.

Table 1. List of the strongest lines (nm) usually detected by LIBS for common analysed elements.

Ag	243.778 I	**Al**	256.798 I	**Ar**	750.387 I	**As**	189.042 I	**Au**	242.795 I
	247.379 II		257.509 I		751.465 I		193.759 I		267.595 I
	328.068 I		**308.215 I**		763.511 I		197.262 I		274.825 I
	338.289 I		**309.271 I**		772.376 I		228.812 I		312.278 I
	520.908 I		**309.284 I**		772.421 I		234.984 I		523.026 I
	546.550 I		**394.401 I**		810.369 I		278.022 I		583.737 I
			396.152 I		811.531 I		286.044 I		627.817 I
									751.073 I
Ba	230.425 II	**Be**	234.861 I	**Br**	826.496 I	**C**	193.091 I	**Ca**	315.887 II
	233.527 II		249.458 I		827.244 I		247.856 I		317.933 II
	389.178 II		265.069 I				512.93 (C_2)		318.128 II
	455.403 II		**313.042 II**				516.52 (C_2)		**393.366 II**
	493.408 II		**313.107 II**				558.55 (C_2)		**396.847 II**
			332.108 I				563.55 (C_2)		**422.673 I**
			332.134 I				418.89 (CN)		643.907 I
							421.60 (CN)		646.257 I
Cd	226.502 II	**Cl**	478.132 II	**Co**	340.512 I	**Cr**	267.716 II	**Cu**	**324.754 I**
	228.802 I		837.594 I		345.350 I		286.257 II		**327.396 I**
	346.620 I				350.228 I		357.870 I		465.112 I
	361.051 I				350.632 I		**425.435 I**		510.554 I
	361.287 I				352.981 I		**427.481 I**		515.323 I
	467.815 I				356.938 I		**428.973 I**		521.820 I
	479.991 I				358.719 I		520.450 I		
					399.531 I		520.602 I		
							520.841 I		
F	623.965 I	**Fe**	238.204 II	**H**	656.279 I	**He**	388.865 I	**Hg**	253.652 I
	634.851 I		239.562 II				447.148 I		365.016 I
	641.365 I		240.488 II				587.562 I		404.656 I
	685.603 I		259.939 II				667.815 I		435.833 I
			404.581 I						546.075 I
			406.359 I						576.961 I
			430.790 I						579.067 I
			432.576 I						
			438.354 I						
			440.475 I						
K	766.490 I	**Li**	323.266 I	**Mg**	**279.553 II**	**Mn**	353.212 I	**Mo**	313.259 I
	769.896 I		413.256 I		279.800 II		354.780 I		317.035 I
			413.262 I		280.270 II		**403.076 I**		379.825 I
			427.307 I		**285.213 I**		**403.307 I**		386.411 I
			427.313 I		382.935 I		**403.449 I**		**550.649 I**
			497.166 I		383.230 I		**403.573 I**		**553.305 I**
			497.175 I		383.829 I		**404.136 I**		**557.044 I**
			610.354 I		516.732 I		404.876 I		
			670.776 I		517.268 I				
			670.791 I		518.360 I				

N	**742.364**	**I**	**Na**	**3**30.237	I	**Nb**	309.418	II	**Ni**	231.604	II	**O**	**777.194**	**I**
	744.229	**I**		330.298	I		316.340	II		341.476	I		**777.417**	**I**
	746.831	**I**		568.263	I		319.490	II		351.505	I		**777.539**	**I**
	818.487	I		568.820	**I**		405.894	I		352.454	I		844.636	I
	821.634	I		**588.995**	**I**		407.973	I		361.939	I			
	822.314	I		**589.592**	**I**		410.092	I		471.442	I			
	862.924	I		818.326	I		412.381	I		508.052	I			
	868.028	I		819.482	I									
	868.340	I												
P	177.495	I	**Pb**	280.199	I	**Pd**	223.160	II	**Pt**	208.459	I	**S**	180.731	I
	178.284	I		283.305	I		276.309	I		214.423	I		182.624	I
	213.618	I		357.273	I		340.457	I		224.552	II		545.383	II
	214.915	I		363.957	I		342.122	I		320.404	I		547.362	II
	253.398	I		367.149	I		355.308	I		340.813	I		869.471	I
	253.560	I		368.346	I		360.955	I		364.317	I		921.286	I
				373.993	I		363.469	I		505.948	I		922.809	I
				405.781	I								923.754	I
Sb	252.852	I	**Si**	250.690	I	**Sn**	266.124	I	**Sr**	407.771	II	**Ti**	323.451	II
	259.805	I		251.611	I		286.332	I		421.552	II		323.657	II
				252.411	I		303.412	I		460.733	I		323.904	II
				252.851	I		317.504	I					**334.187**	**II**
				263.128	I		326.233	I					**334.903**	**II**
				288.158	**I**		452.473	I					**334.940**	**II**
				390.552	I		563.170	I					**336.121**	**II**
													337.279	**II**
													375.929	II
													376.132	II
													498.173	I
													499.107	I
													499.950	I
V	292.402	II	**W**	294.699	I	**Zn**	202.548	II	**Zr**	343.823	II			
	309.311	II		400.875	I		206.200	II		349.621	II			
	310.230	II		407.436	I		213.856	I		360.119	I			
	311.071	II		426.938	I		328.233	I		414.920	II			
	411.178	I		429.461	I		330.258	I		422.776	I			
	411.518	I		459.994	I		330.294	I		471.008	I			
	412.807	I		460.989	I		334.502	I						
	437.924	I					334.557	I						
	438.472	I					472.215	I						
	438.997	I					481.053	I						

	Atmospheric elements.
	Alkali Metals and Alkaline Earth Metals elements, very easily detected by LIBS. Emission lines from these elements tend to appear in the LIBS spectrum when the sample surface is not cleaned properly.

Table 2. List of the strongest lines (nm) usually detected by LIBS for uncommon elements.

B	249.677 I 249.772 I 345.130 II 447.210 II 447.285 II	**Bi**	211.022 I 213.360 I 223.060 I 293.830 I 302.462 I 306.770 I	**Ce**	413.380 II 413.765 II 422.260 II 424.868 II 453.975 II 456.236 II 457.228 II	**Cs**	455.528 I 459.317 I 672.446 II 697.330 I 852.113 I 894.347 I	**Dy**	353.170 II
Er	349.910 II	**Eu**	381.967 II 390.710 II 459.403 I 462.722 I 466.188 I	**Ga**	245.008 I 265.987 I 271.966 I 403.297 I 417.204 I	**Gd**	336.223 II 364.619 II 366.460 II 367.120 II	**Ge**	303.907 II
Hf	232.247 II 232.325 II 232.489 II 234.744 II 310.912 II 313.472 II 319.419 II 356.166 II 364.436 II	**Ho**	345.600 II	**I**	258.279 II 516.120 II 546.462 II 562.569 II 595.025 II	**In**	271.026 I 275.388 I 293.263 I 325.608 I 410.176 I 451.130 I	**Ir**	357.372 I 362.867 I 380.012 I 397.631 I 439.947 I
Kr	810.437 I	**La**	379.083 II 394.910 II 408.672 II 412.323 II 433.374 II	**Lu**	291.139 II	**Nd**	387.955 II 388.078 II 401.225 II 430.358 II 490.184 I 492.453 I	**Os**	To be added shortly
Pr	417.939 II	**Pu**	440.489 I 453.615 II 648.885 I 660.895 I 688.771 I	**Rb**	780.027 I	**Re**	296.227 I 346.046 I 346.473 I	**Rh**	339.682 I 343.488 I 369.236 I 385.652 I
Ru	245.657 II 358.962 I 359.302 I 359.618 I 359.976 I 366.135 I 372.693 I 372.803 I	**Sc**	361.383 II 431.408 II 498.345 I	**Se**	484.50 II 522.75 II 530.54 II 891.886 I	**Sm**	356.827 II 471.610 I	**Ta**	271.467 I 331.116 I
Tb	384.873 II	**Tc**	423.819 I 426.227 I 429.706 I	**Te**	214.281 I 238.328 I 238.579 I	**Th**	339.204 II	**Tl**	276.787 I 535.046 I
Tm	388.313 I	**U**	358.488 I 367.007 I 409.013 II 436.205 I 591.539 I	**Xe**	529.222 II	**Y**	317.941 II 371.030 II 410.236 I	**Yb**	369.419 II 398.799 I

Appendix 2 Table 3 includes the strongest emission lines included in Table 1 and 2 sorted by wavelength.

Table 3. Strongest emission lines by LIBS sorted by wavelength

P I	177.495	Fe II	240.488	Mg II	279.553	Ca II	317.933	Ni I	341.476
P I	178.284	Au I	242.795	Mg II	279.800	Y II	317.941	Pd I	342.122
S I	180.731	Ag I	243.778	Pb I	280.199	Ca II	318.128	Rh I	343.488
S I	182.624	Ga I	245.008	Mg II	280.270	Hf II	319.419	Zr II	343.823
As I	189.042	Ru II	245.657	Pb I	283.305	Nb II	319.490	B II	345.130
C I	193.091	Ag II	247.379	Mg I	285.213	Pt I	320.404	Co I	345.350
As I	193.759	C I	247.856	As I	286.044	Li I	323.266	Ho II	345.600
As I	197.262	Be I	249.458	Cr II	286.257	Ti II	323.451	Re I	346.046
Zn II	202.548	B I	249.677	Sn I	286.332	Ti II	323.657	Re I	346.473
Zn II	206.200	B I	249.772	Si I	288.158	Ti II	323.904	Cd I	346.620
Pt I	208.459	Si I	250.690	Lu II	291.139	Cu I	324.754	Zr II	349.621
Bi I	211.022	Si I	251.611	V II	292.402	In I	325.608	Er II	349.910
Bi I	213.360	Si I	252.411	In I	293.263	Sn I	326.233	Co I	350.228
P I	213.618	Si I	252.851	Bi I	293.830	Cu I	327.396	Co I	350.632
Zn I	213.856	Sb I	252.852	W I	294.699	Ag I	328.068	Ni I	351.505
Te I	214.281	P I	253.398	Re I	296.227	Zn I	328.233	Ni I	352.454
Pt I	214.423	P I	253.560	Bi I	302.462	Zn I	330.258	Co I	352.981
P I	214.915	Hg I	253.652	Sn I	303.412	Na I	330.237	Dy II	353.170
Bi I	223.060	Al I	256.798	Ge II	303.907	Zn I	330.294	Mn I	353.212
Pd II	223.160	Al I	257.509	Bi I	306.770	Na I	330.298	Mn I	354.780
Pt II	224.552	I II	258.279	Al I	308.215	Ta I	331.116	Pd I	355.308
Cd II	226.502	Sb I	259.805	Al I	309.271	Be I	332.108	Hf II	356.166
Cd I	228.802	Fe II	259.939	Al I	309.284	Be I	332.134	Sm II	356.827
As I	228.812	Si I	263.128	V II	309.311	Ti II	334.187	Co I	356.938
Ba II	230.425	Be I	265.069	Nb II	309.418	Zn I	334.502	Pb I	357.273
Ni II	231.604	Ga I	265.987	V II	310.230	Zn I	334.557	Ir I	357.372
Hf II	232.247	Sn I	266.124	Hf II	310.912	Ti II	334.903	Cr I	357.870
Hf II	232.325	Au I	267.595	V II	311.071	Ti II	334.940	U I	358.488
Hf II	232.489	Cr II	267.716	Au I	312.278	Ti II	336.121	Co I	358.719
Ba II	233.527	In I	271.026	Be II	313.042	Gd II	336.223	Ru I	358.962
Hf II	234.744	Ta I	271.467	Be II	313.107	Ti II	337.279	Ru I	359.302
Be I	234.861	Ga I	271.966	Mo I	313.259	Ag I	338.289	Ru I	359.618
As I	234.984	Au I	274.825	Hf II	313.472	Th II	339.204	Ru I	359.976
Fe II	238.204	In I	275.388	Ca II	315.887	Rh I	339.682	Zr I	360.119
Te I	238.328	Pd I	276.309	Nb II	316.340	Pd I	340.457	Pd I	360.955
Te I	238.579	Tl I	276.787	Mo I	317.035	Co I	340.512	Cd I	361.051
Fe II	239.562	As I	278.022	Sn I	317.504	Pt I	340.813	Cd I	361.287

Sc II	361.383	Eu II	390.710	Ce II	413.765	Sn I	452.473	C_2	516.52
Ni I	361.939	Ca II	393.366	Zr II	414.920	Pu II	453.615	Mg I	517.268
Ir I	362.867	Al I	394.401	Ga I	417.204	Ce II	453.975	Mg I	516.732
Pd I	363.469	La II	394.910	Pr II	417.939	Ba II	455.403	Mg I	518.360
Pb I	363.957	Al I	396.152	CN	418.89	Cs I	455.528	Cr I	520.450
Pt I	364.317	Ca II	396.847	Sr II	421.552	Ce II	456.236	Cr I	520.602
Hf II	364.436	Ir I	397.631	CN	421.60	Ce II	457.228	Cr I	520.841
Gd II	364.619	Yb I	398.799	Ce II	422.260	Cs I	459.317	Ag I	520.908
Hg I	365.016	Co I	399.531	Ca I	422.673	Eu I	459.403	Cu I	521.820
Ru I	366.135	W I	400.875	Zr I	422.776	W I	459.994	Se II	522.75
Gd II	366.460	Nd II	401.225	Tc I	423.819	Sr I	460.733	Au I	523.026
U I	367.007	Mn I	403.076	Ce II	424.868	W I	460.989	Xe II	529.222
Gd II	367.120	Ga I	403.297	Cr I	425.435	Eu I	462.722	Se II	530.54
Pb I	367.149	Mn I	403.307	Tc I	426.227	Cu I	465.112	Tl I	535.046
Pb I	368.346	Mn I	403.449	W I	426.938	Eu I	466.188	S II	545.383
Rh I	369.236	Mn I	403.573	Li I	427.307	Cd I	467.815	Hg I	546.075
Yb II	369.419	Mn I	404.136	Li I	427.313	Zr I	471.008	I II	546.462
Y II	371.030	Fe I	404.581	Cr I	427.481	Ni I	471.442	Ag I	546.550
Ru I	372.693	Hg I	404.656	Cr I	428.973	Sm I	471.610	S II	547.362
Ru I	372.803	Mn I	404.876	W I	429.461	Zn I	472.215	Mo I	550.649
Pb I	373.993	Pb I	405.781	Tc I	429.706	Cl II	478.132	Mo I	553.305
Ti II	375.929	Nb I	405.894	Nd II	430.358	Cd I	479.991	Mo I	557.044
Ti II	376.132	Fe I	406.359	Fe I	430.790	Zn I	481.053	C_2	558.55
La II	379.083	W I	407.436	Sc II	431.408	Se II	484.50	I II	562.569
Mo I	379.825	Sr II	407.771	Fe I	432.576	Nd I	490.184	Sn I	563.170
Ir I	380.012	Nb I	407.973	La II	433.374	Nd I	492.453	C_2	563.55
Eu II	381.967	La II	408.672	Hg I	435.833	Ba II	493.408	Na I	568.263
Mg I	382.935	U II	409.013	U I	436.205	Li I	497.166	Na I	568.820
Mg I	383.230	Nb I	410.092	V I	437.924	Li I	497.175	Hg I	576.961
Mg I	383.829	In I	410.176	Fe I	438.354	Ti I	498.173	Hg I	579.067
Tb II	384.873	Y I	410.236	V I	438.472	Sc I	498.345	Au I	583.737
Rh I	385.652	V I	411.178	V I	438.997	Ti I	499.107	He I	587.562
Mo I	386.411	V I	411.518	Ir I	439.947	Ti I	499.950	Na I	588.995
Nd II	387.955	La II	412.323	Fe I	440.475	Pt I	505.948	Na I	589.592
Nd II	388.078	Nb I	412.381	Pu I	440.489	Ni I	508.052	U I	591.539
Tm I	388.313	V I	412.807	He I	447.148	Cu I	510.554	I II	595.025
He I	388.865	Li I	413.256	B II	447.210	C_2	512.93	Li I	610.354
Ba II	389.178	Li I	413.262	B II	447.285	Cu I	515.323	F I	623.965
Si I	390.552	Ce II	413.380	In I	451.130	I II	516.120	Au I	627.817

Applied Photonics Limited Unit 8 Carleton Business Park, Skipton, North Yorkshire BD23 2DE United Kingdom
Telephone: +44 (0)1756 708900 **Facsimile:** +44 (0)1756 708909 **Email:** mail@appliedphotonics.co.uk
Website: www.appliedphotonics.co.uk

F I	634.851	Br I	826.496		
F I	641.365	Br I	827.244		
Ca I	643.907	Cl I	837.594		
Ca I	646.257	O I	844.636		
Pu I	648.885	Cs I	852.113		
H I	656.279	N I	862.924		
Pu I	660.895	N I	868.028		
He I	667.815	N I	868.340		
Li I	670.776	S I	869.471		
Li I	670.791	Se I	891.886		
Cs II	672.446	Cs I	894.347		
F I	685.603	S I	921.286		
Pu I	688.771	S I	922.809		
Cs I	697.330	S I	923.754		
N I	742.364				
N I	744.229				
N I	746.831				
Ar I	750.387				
Au I	751.073				
Ar I	751.465				
Ar I	763.511				
K I	766.490				
K I	769.896				
Ar I	772.376				
Ar I	772.421				
O I	777.194				
O I	777.417				
O I	777.539				
Rb I	780.027				
Ar I	810.369				
Kr I	810.437				
Ar I	811.531				
Na I	818.326				
N I	818.487				
Na I	819.482				
N I	821.634				
N I	822.314				

Applied Photonics Limited Unit 8 Carleton Business Park, Skipton, North Yorkshire BD23 2DE United Kingdom
Telephone: +44 (0)1756 708900 **Facsimile:** +44 (0)1756 708909 **Email:** mail@appliedphotonics.co.uk
Website: www.appliedphotonics.co.uk