General Technical Specifications for the Applied Photonics Ltd range of Modular LIBS products

Applied Photonics Ltd (APL) offer a range of modular LIBS products which are unique in design. The modular design allows great versatility in how a LIBS system may be configured – this being very important for LIBS since the range of applications is so diverse. The following bullet points list some of the major advantages offered by APL's modular design:

- A variety of lasers and spectrometers may be used with many of our LIBS products, increasing further the versatility for the user.
- For many of our LIBS products, the user may use their own laser and/or their own spectrometer(s) – the user is not restricted to using lasers and/or spectrometers supplied by us.
- The LIBS system may be used with a sample chamber (meeting Class 1 Laser Product standards) or without a sample chamber (Class 4 Laser Product standards) – this allows the user to conduct analysis of samples which are either too large or impractical to fit inside a sample chamber.
- We offer a range of modular sample chambers of varying size and complexity including chambers with manual or computer-controlled motorised translation stages. This allows the user to choose a sample chamber which best meets their application and budget requirements.
- The modular design allows the user to have more than one sample chamber – switching between sample chambers is easy to do due to the design of the hardware.

In addition to our standard range of modular sample chambers which are designed primarily for analysing solid samples, we offer specialised sample chambers which are suitable for direct analysis of liquids and gases. In addition to a wide range of regular, non-hazardous materials, our LIBS products have been used to analyse more challenging materials including radioactive materials, toxic gas mixtures, and acid / alkaline solutions.

APL has supplied LIBS products and services to more than 50 countries around the world. Our customers include US Department of Energy, US Department of Defense, NASA, UK Ministry of Defence, various national laboratories, blue-chip corporations, university research groups, small companies and many more. APL is one of the longest established companies specialising in LIBS, with a track record of achievement spanning the last 22+ years.

In addition to the supply of LIBS products, APL has conducted a number of highly-specialised applications of LIBS including providing a radioactive materials characterisation service to the nuclear industry, custom-designed LIBS systems including a 150 metre range Stand-Off LIBS system, and a wide range of field trials including industrial, scientific and security applications. APL was the first company to use LIBS inside a nuclear reactor, was the first company to analyse radioactive materials through a lead-glass shield window, and developed the first commercially-available submersible LIBS probe which has been tested to a depth of 30+ metres in the sea.

APL employs 10 people including four with PhDs. Together with our dedicated team, we have well equipped laboratory and machineshop in-house facilities which enable us to remain at the leading edge of the development, design and supply of LIBS products and services.

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Lasers

We use the following lasers with our LIBS products:

1. Litron lasers (United Kingdom) – several 1064 nm lasers such as Nano LG 300-10, Nano LG 225-10, Nano SG 150-10 / Nano SG 120-20 and 266 nm lasers such as LG 225-10 (266 nm).
2. Lumibird – formerly Quantel - lasers (France and USA) – Big Sky Series (CFR Ultra, CFR 200, etc), Brilliant and Brilliant B, Q-Smart 450 and 850, Viron (1064 nm) and others.
3. EKSPLA lasers (Lithuania) – various models of Q-switched Nd:YAG laser
4. Innolas lasers (Germany) – SpitLite Compact 200 and 400 including double-pulse (single-cavity) models
5. APL lasers – compact, low-cost lasers designed and manufactured by us including 50 mJ 1 Hz 1064 nm laser as used in our portable LIBSCAN 25+ and LIBSCAN EDU-50 products, and a 150 mJ, 10 Hz 1064 nm laser.
6. Other lasers including lasers already owned by the customer (APL can in many cases supply an adaptor platform which allows the laser to be fitted to one of our LIBS modules) – contact us for details

Spectrometers

We use the following spectrometers with our LIBS products:

1. Avantes (Netherlands) – AvaSpec EVO 4096 externally triggered compact spectrometer modules – used in our SpectroModule-6 and SpectroModule-8 (six-channel and eight-channel respectively) LIBS spectrometers with wavelength ranges of 190 – 910 nm (6-channel) and 182 – 1016 nm (8-channel). These spectrometers are compact, relatively low cost, very rugged, easy to use and offer good wavelength resolution (up to approx. 6,000 resolving power). Detector delay, relative the laser q-switch trigger, of 0.9 µs to more than 100 µs and integration time of 9 µs to 40 seconds, both are user-adjustable via our LIBSoft software. Excellent spectrometers for general purpose LIBS applications.
2. Catalina Scientific (USA) – EMU 120/65 high-performance echelle spectrograph with EMCCD camera. Broad-band, high-throughput (up to f/3) with user-switchable dispersion cassettes which allow resolving power of up to approx. 65,000 to be achieved. Suitable for more demanding applications of LIBS including isotope measurements.
3. Other spectrometers including spectrometers already owned by the customer – contact us for details

LIBSoft Software

LIBSoft is a proprietary software application written to control all aspects of the acquisition of spectra using the full range of Applied Photonics Limited LIBS systems. It provides control of all hardware components including the laser and spectrometer as well as a computer-controlled sample chamber if connected and the optional imaging kit. In addition to the acquisition and display of spectra, LIBSoft also provides spectrum analysis and comparison, peak identification and spectral fingerprinting functionality together with the ability to produce quantitative calibration curves from acquired spectra.

LIBSoft supports lasers from a range of manufacturers including Quantel (Ultra, CFR 200 and Q-Smart), Litron (Nano), Innolas (Spitlight single or double pulse) and Ekspla. Spectrometers supported include APL's own range of multi-channel SpectroModule devices, Avantes AvaSpec and Catalina Scientific EMU-65 (coupled to either Andor iXon or Raptor Photonics Falcon Blue cameras). LIBSoft supports APL's own range of computer-controlled sample chambers including the 3-axis XYZ-750.

LIBSoft can display live video images of the sample under analysis from APL's own optional imaging kit providing a resizable image display with zoom/expand functionality and crosshair marking of the target site. Still images from the live video can be acquired and saved to disk as JPEG files for inclusion in external reports and other documents.

Safety

All of our LIBS products meet the international standards on laser and electrical safety including BS EN 60825 and ANSI Z136.1. We provide comprehensive User's Manuals with our LIBS equipment, in addition to the User's Manuals provided by the laser manufacturer and the spectrometer manufacturer.

Key features of our LIBS products and services

- Designed by experts with more than 25 years' experience in LIBS
- We have supplied our LIBS products to customers in 50 countries around the world
- Unique modular design provides a high degree of versatility
- Modular design allows for easy upgrading in the future
- Wide range of configurations and options - suitable for R&D use and industrial use
- The use of high-quality components and devices, in particular the optics, lasers and the spectrometers.
- Comprehensive laser safety interlock features, meeting Class 1 laser product standards when used with any of our range of modular sample chambers.
- Most of our LIBS products can be used without a sample chamber as Class 4 laser products. This allows for the analysis of samples which may not be suitable for placing inside a sample chamber. Our laser safety interlock circuit includes a key-activated switch which overrides the sample chamber interlock when a sample chamber is not used, and a warning light alerts the user that the LIBS system is in Class 4 mode.
- Custom-designed LIBS systems and components
- Considerable field experience of LIBS including hazardous environments
- Competitive pricing
- Comprehensive User's Manuals.
- High-level of customer support including training and advice on how to get the best from our LIBS products
- On-going technical support to assist the customer with their application development.

What to look for in a LIBS product

1. The spectrometer should ideally be capable of external triggering (i.e. can be triggered directly from the laser q-switch using the laser as the master trigger generator) and should have at least a 16-bit A/D converter. Some spectrometers require the laser to be pre-triggered using a separate pulse / delay generator - our advice is to avoid these unless your application demands it. The detector electronics should use a 16-bit A/D converter rather than a 14-bit as used by some spectrometer manufacturers. The spectrometer should be capable of providing a variable delay between the laser pulse and the start of integration – ideally the delay time should be adjustable between approx. 1 and 100 microseconds. The integration time should also be adjustable by the user, ideally from approx. 10 microseconds to at least 100 microseconds.
2. The laser should be from a reputable manufacturer and should have an output stability (shot-to-shot) of better than 2% (active Q-switched lasers) and better than 10% (passive Q-switched lasers). The output beam divergence of the laser source should ideally be less than approx. 1.5 mrad (half-angle divergence) unless fibre-optic transmission of the laser beam is required. The laser output energy and pulse repetition rate should be user-adjustable via the LIBS system software. For the vast majority of laboratory bench-top LIBS applications, a multi-mode Q-switched Nd:YAG laser operating at 1064 nm and producing a pulse energy of around 100 to 200 mJ is sufficient. Certain applications require alternative laser wavelengths, for example LIBS analysis of optically transparent materials such as sapphire require a 266 nm laser. Certain other applications such as Stand-Off LIBS may require much higher pulse energies, but these are special applications.
3. The plasma light collection optics should be of a high-efficiency design. Some suppliers of LIBS equipment use a flexible fibre-bundle (with or without a lens) which the user positions close to the LIBS plasma. This should be avoided as not only does it not provide high collection efficiency, the field of view will depend on how the user positions the fibre-bundle and so is not highly repeatable. Our multi-channel collection optics are designed to maximise collection efficiency and to allow for highly repeatable measurements.
4. The laser beam focussing optics should use a good quality beam expander which is able to produce a minimum spot size of approaching 30 microns or less. Be wary of claims of sub 10 micron spot size – a spot size of 10 microns is rarely necessary for LIBS or achievable using the type of lasers most often used with LIBS. Our beam expanders are

designed by us and use a three-lens design modelled using Zemax optical CAD software. One way of telling if the spot size is sufficiently small is to ask if the LIBS system is able to produce an air plasma with less than about 20 mJ (at 1064 nm). The air plasma should be highly localised in space – if it is not then this can indicate either a poor optical design or that the laser produces a low quality beam profile and/or has high divergence. If significantly more than 20 mJ (at 1064 nm) is needed to produce an air plasma, this indicates that the minimum spot size achievable with the LIBS equipment is relatively large.

5. Does the LIBS product utilise a modular, user-configurable design? If it does not, then this will limit the versatility. Some LIBS products consist of a single large "box" which contains all the hardware and also the sample chamber. These are, by design, very limited in versatility – for example there is no option to use alternative (e.g. larger) sample chambers, or to analyse samples which are not suitable for placing inside a sample chamber.

6. The motorised translation stages of the sample chamber should be of a highly rigid mechanical design so as to minimise flexure when a heavy sample is loaded onto the sample stage. Many manufacturers quote unnecessarily high levels of linear resolution (e.g. 1 micron) but conveniently forget to mention the degree of flexure of the sample stage, which can in some cases be many 100s of microns with only a modest weight applied. Our sample chambers use XYZ translation stages designed and manufactured by us so that we can ensure they are suitable and "fit for purpose".

7. Be wary of claims of ppm detection limits and quantitative analysis of materials unless the LIBS equipment supplier can back their claims with hard evidence. Compared with certain traditional laboratory analysis techniques such as ICP-AES or ICP-MS, LIBS is not particularly sensitive with detection limits for most element / matrix combinations in the 10s to 100s of ppm at best. Quantitative measurements require calibration using matrix-matched calibration samples – such samples are not readily available for many materials. We at APL are not big fans of the so-called "calibration-free" technique applied to LIBS, believing that it is at best a subject of interest to researchers but has limited utility in "real world" applications.

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