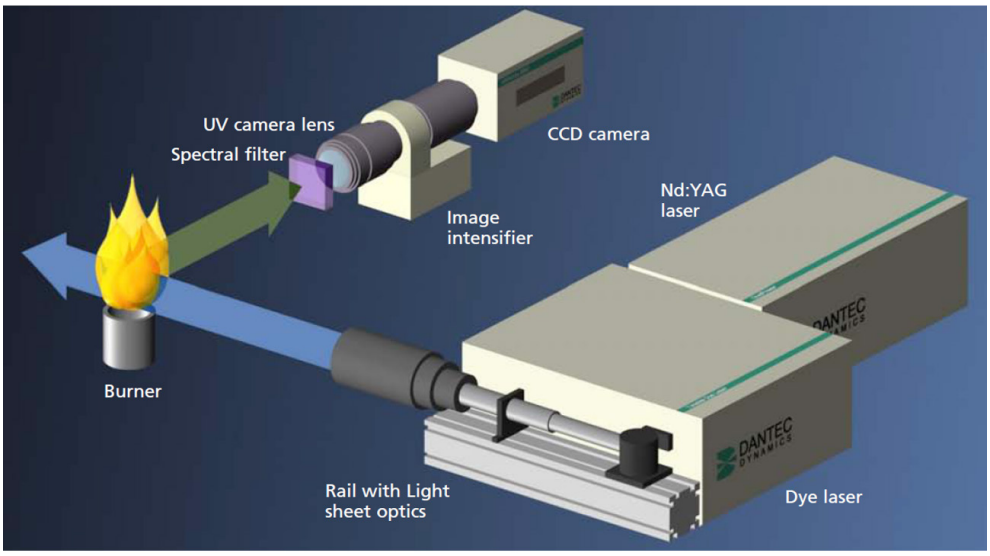
SOLUTION SHEET

LIF Systems for Combustion Diagnostics

Complete, modern and modular solutions for planar LIF measurements



The complete solution for LIF measurements in combustion research

Designed as a complete, modern and modular imaging system for data acquisition and analysis, our Combustion LIF system it is a unique tool for experimental diagnostics of combustion by means of planar Laser-induced Fluorescence (LIF).

By handling measurements of combustion radicals, pollutants, fuel tracers etc., the system is suitable for studies of a vast number of phenomena, such as fuel injections, ignition phenomena and flame fronts, ultimately improving the understanding of combustion processes.

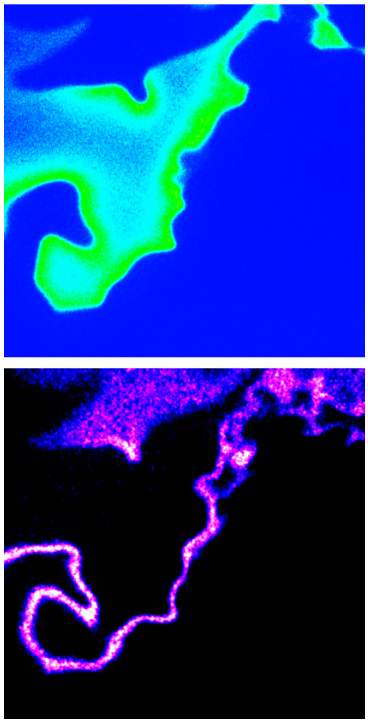
Key benefits

- Non-intrusive imaging technique for measurements of several combustion species
- Compact and integrated tunable pump and dye laser systems with improved laser safety and excellent beam quality
- Wide range of high-sensitivity cameras and image intensifiers
- Advanced synchronization with temporal precision down to sub-nanoseconds
- Complete software platform for system set-up, data acquisition, data analysis and visualization of results
- Dedicated software modules for LIF of combustion radicals and LIF of fuel tracers
- Fully compatible also with Dantec Dynamics' PIV systems, for combined multi-parameter measurements

Flexible planar LIF system for measurements of combustion species

Dantec Dynamics' combustion LIF system utilizes a non-intrusive (optical), two-dimensional measurement method based on the laser-induced fluorescence emissions of molecular species. The system enables the user to select between number of species to study, ranging from flame radicals such as OH and CH, and pollutants such as NO and CO, produced during combustion, to larger combustion species or tracers seeded into the process such as Formaldehyde and Acetone. This makes the system very versatile, and well suited for combustion research. The beam from a sophisticated tunable laser source is shaped into a light-sheet illuminating a thin planar section of the combustion process and exciting the selected species. The subsequent fluorescence is recorded by an intensified camera, creating a map of the species distribution in the illuminated plane. Through user-friendly hardware and software the user quickly gains full confidence to operate the system. As the backbone of our systems, we have developed the most comprehensive imaging software for optical diagnostics – DynamicStudio. From here you can easily control the measurement system as well as perform advanced image data analysis, to extract valuable information for a better understanding of the studied combustion process.

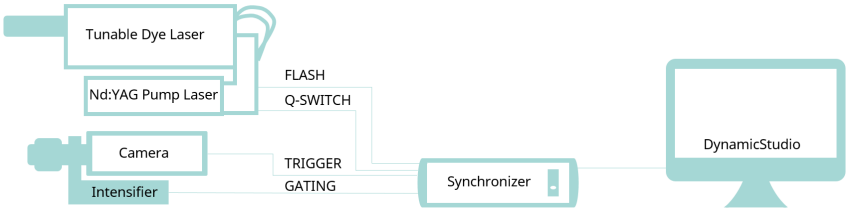
Naturally, velocity information from a PIV system can be integrated for further advanced analyses combining combustion chemistry and fluid mechanics.



Simultaneous dual-species PLIF by two synchronized systems, showing the flame front and postflame gases (OH, top) and the pre-heat layer (CH2O, bottom) in a turbulent lab flame.

The Combustion LIF system solutions in brief

The system consists of a Nd:YAG pumped, state-of-the-art tunable dye laser with light-sheet optics, a camera equipped with an image intensifier for imaging UV fluorescence, advanced electronics for hardware synchronization and software for straightforward data acquisition and analysis.



Overview of the different components, timing and data flow.

Laser light sources

The Nd:YAG laser, optimized for 10 Hz repetition rate, is equipped with a temperature stabilized 2nd harmonic generator, providing 430 mJ at 532 nm. Optionally it can also include a 3rd or 4th harmonic for applications such as tracer LIF or Formaldehyde (HCHO) LIF. All Nd:YAG harmonics come with intelligent auto-tuning to maintain optimum phase matching and thus maximum output energy, clearly improving the user experience. The air/water heat exchanger for this laser does not require external water-cooling.
Two modular tunable dye laser models are available; a compact system (the most compact on the market) and an advanced system with a larger footprint but with unique features to benefit the user.

The compact system is an advantage when lab space and/or economy is of importance, however it uses both 532 nm and 355 nm from the Nd:YAG laser for pumping, depending on what species/wavelength range is required.

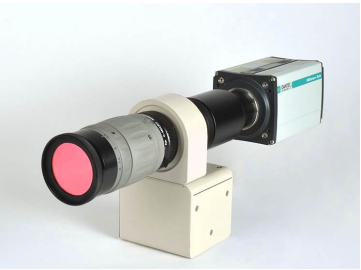
The advanced system can reach all species by using 532 nm pumping only. This makes it easier for the user as there is no need to switch pump laser output when switching to a different dye laser wavelength. As only 532 nm pumping is required, this also facilitates the use of more stable long-lived laser dyes, instead of the use of the more short-lived dyes normally associated with 355 nm pumping. For the user this means no need for frequent replacement of the dye, and more time to focus on the research.

The two dye laser models have several features in common. They enable operation across a very wide range of wavelengths, direct tuning from 420 to 740 nm with 2400 l/mm grating. (Can optionally be expanded to 900 nm, with an additional 1800 l/mm grating.) The lasers feature:

- Linewidth 0.06 cm-1 at 570 nm providing more efficient excitation of narrow absorption lines, and thus increased signal-to-noise ratio
- Main amplifier with Bethune cell providing superior circular beam quality and thus improved image quality
- Digital wavelength selection making it easy for the user to control from a computer
- Automated crystal phase matching even through wavelength scanning and thus no need for the user to do manual adjustments

UV / visible parallel light sheet optics

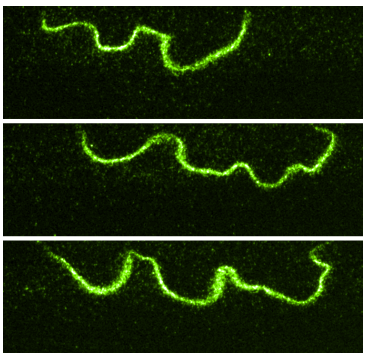
The laser comes with UV extension. To gain the highest energy level outputs possible, the dye laser is equipped with dedicated, modular crystals optimized for UV light. The crystal to produce the wavelengths for OH excitation is included, and crystals for species such as CH, NO and CO can be added at any time. The output is fine-tuned by scanning the wavelength from the software, and the crystal phase matching follows automatically to maintain optimum energy throughout the scan. The pump and dye lasers are fitted together, virtually forming a single laser unit which makes it easier for the user and ensures the best possible stability for maintaining alignment.



HiSense Zyla camera, image intensifier and UV front lens

Dantec Dynamics' optical devices used to form parallel UV light sheets are included with the system. Light sheet dimensions are approx. 50 mm x 0.1 mm (when used with a beam waist adjuster) with a working distance of 600 mm.

To ensure a secure working environment, UV and visible light - from the Nd:YAG laser to the location at which the light sheet is formed - is all shielded. Laser alignment goggles and protective goggles are also available for your safety.



LIF imaging of CH showing the thin flame front at the base of a turbulent gas flame.

Cameras, Image Intensifiers and Lenses

The cameras and the image intensifiers are separate units, thereby allowing existing hardware systems to be upgraded to combustion applications. This solution is ideal for laboratories dealing with multiple applications such as PIV, LIF in liquid and gaseous phases including combustion processes, microscopy and spectroscopy. Typically a camera from our HiSense family is selected, featuring high sensitivity and low noise levels.

The image intensifier units are designed for UV, visible and near-IR applications using a broadband Multialkali or S20 photocathode in order to cover a wide range of LIF applications of different species. The units offer full control over gain and gate time options ranging from continuous to ultra-fast, with a minimum gate time of down to 3 ns, depending on the model. Relay optics used to adapt the camera to the image intensifier unit is also included. (Please refer to the related Data Sheets for further information about these cameras and image intensifiers)

Two camera lenses (f=78 mm and f=100 mm) with optimized transmission for UV light are available together with an adapter ring for fitting interference filters to the selected lens. Interference filters are available for measurements of tracers and combustion species.

Synchronizer

Synchronization between laser pulses, cameras and image intensifiers is mastered by the High Performance Synchronizer, fully controlled via the DynamicStudio software. The synchronizer is a multi-channel delay and signal generator with <= 1ns resolution. The 32 output channels are programmed independently; thereby offering comprehensive synchronization and triggering facilities for highly demanding processes. It also features four input channels for synchronization with external devices or events.

The High Performance Synchronizer dedicated for LIF applications.

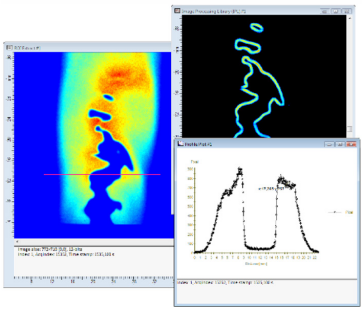
User-friendly imaging software platform - Straightforward data analysis

The image acquisition system is based on DynamicStudio, a comprehensive and user-friendly software platform for imaging applications. It features an advanced plug-and-play based distributed system, making it easy for the user to get full control over the hardware for image acquisition. Data acquisition as well as analysis is supported within the same software, so there is no need to export the data for continuing with the analysis.

With easy access to numerous numerical methods and quick and accurate calibration and processing methods, users will experience the benefits of working with a truly integrated solution.

Numerical methods available with the software:

- Calibration (Tracers)
- Processing (Tracers)
- Statistics on LIF images and scalar maps
- Re-sampling
- Reynolds flux



OH distribution in a Bunsen type flame, including a cross-section intensity plot and the result of gradient detection showing the main reaction zone.

The software features many automated options such as laser pulse energy correction (on each individual LIF image), hardware calibration and processing routines etc.

DynamicStudio also features an Image Processing Library (IPL), which is a comprehensive “catalogue” of numerical methods, offering quick access to image quality enhancement, image filtering and other more advanced numerical processing to work with LIF images. Processing is fully automated and includes macro-analysis capability (i.e. sequence of processing methods).

Boosting analysis capabilities with analysis sequences and MatLab® Link

The data analysis is further strengthened by the possibility of defining analysis sequences and performing batch processing, which significantly speeds up the way of working with large data sets. And with the MatLab Link in DynamicStudio, you can tailor your analysis by calling up your personally designed MatLab scripts directly from DynamicStudio, allowing you to process the data directly in the database without the need of first exporting the data.

Simultaneous control of multiple systems

The modular design of the systems allows the user to control several different systems at the same time from one master computer. In this way, a Combustion LIF system can be combined with a PIV system for simultaneous combustion species measurements and flow velocity measurements. Or two LIF systems can be combined to measure two species simultaneously. With data from all systems collected in one database, perfectly synchronized (time-stamped) correlated analyses and visualizations are made easy.

Additional options

Pulse energy monitor

A proven method of reaching higher accuracy is to measure the laser pulse-to-pulse fluctuations by means of a Pulse Energy Monitor and subsequently compensate for this during LIF image analysis. The Pulse Energy Monitor can be mounted between the laser output and the light-sheet optics. The photo sensor is sensitive to UV (down to 200 nm), visible and IR (up to 1100 nm) laser light and can monitor laser pulses with a repetition rate of up to 1 kHz. For recording the output signal from the pulse energy monitor an analog input solution is also required.

Technical specifications

Pump laser	Second harmonic	Third harmonic	Fourth harmonic
Wavelength (nm)	532	355 (optional)	266 (optional)
Pulse energy (mJ)	430	230	100
Pulse duration (ns)		~5	
Repetition rate (Hz)		10	

Tunable dye lasers	Tunable dye laser 1: Compact model	Tunable dye laser 2: Advanced & user-friendly
Fundamental tuning range, 2400 l/mm grating	420-740 nm	
Linewidth	< 0.06 cm^{-1} at 570 nm	
Enhanced tuning added 1800 l/mm grating option	420-900 nm	
UV extension unit	Frequency doubling	Frequency doubling/tripling
Required pump beams	532 nm & 355 nm	532 nm only
Crystals for species typically included	OH, CH, NO and CO (typically 220-266 nm & 275-400 nm)	

Camera	HiSense Zyla
Speed (fps)	49
Resolution (MP)	5.5
Sensor resolution (pixels)	2560 x 2160
Pixel size (µm)	6.5

Image intensifiers	H Series 18 mm	L Series 18 mm
Minimum gate time	3 ns	
Photocathode diameter	18 mm	
Photo cathode material	Multialkali	S20
Phosphor screen	P43	

Software	
DynamicStudio	Base package
	Combustion LIF Add-on for DynamicStudio
	Liquid and Gas LIF Add-on for DynamicStudio

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