6. LIF Applications

• Engine applications
  – Tracer, species detection, visualization

• Gasturbine applications
  – Fuel detection, gasphase/liquidphase detection, visualization

• Furnace/bio applications,
  – Pyrolysis
  – Biomass experiments
Practical applications of laser diagnostics: Special challenges

- High pressure
- Limited optical access
- Sooty environment
  - Laser-induced break-down
  - Laser-induced incandescence
  - Mie scattering
- Practical fuels
  - Extinction, trapping
  - Laser-induced background fluorescence (e.g. from large HC)
  - Photolytic effects, e.g. laser-induced C2 emission
- Window scattering/damages/fouling
General applications
Fuel visualization (1)

Two alternatives:

1. Use "real" fuel
   - Closer to real IC engine/GT conditions
   - Generally strong signal
   - What are we detecting?, temp. dependence, pressure dependence, quenching dependence,,,,?

2. Use one/two component fuel with added fluorescent tracer (e.g iso-octane + three pentanone)
   - Known (measurable) fluorescing characteristics
   - Possibility to quantify the air/fuel ratio
   - Further from real conditions
Fuel visualization (2)

Prerequisite on a fluorescing fuel additive:

- Likely to follow the fuel
- Similar vaporization characteristics as the fuel
- High signal strength
- Minimized influence on combustion properties
- Low absorption of the exciting laser beam
- Signal linearly dependent on concentration
- Signal linearly dependent on laser intensity
- Absorption & emission spectrally separated
- Weak signal dependence on pressure/temp
- No abnormal LIF quenching by oxygen
Fuel visualization

**Diesel fuel**

**Tracer: 3 pentanone (seeded to iso-octane)**
Tracer for measurements of liquid-gasphase visualization

- **Exciplex measurements**
  - add two species, M (fluorescing) and G (exciplex forming)
  - $M^*$ identifies the gas; $M^* + G = E$ identifies the liquid phase

- **Balance of $[M]$ and $[G]$**
  - E.g; TMPD/naphtalene and triethylene /benzene
  - Problem; Quenching of oxygen!
Tracer temperature dependence
LIF visualization

a) Engine environments
Engine types

SI-engine
- Inlet
- Exhaust
- Air + Fuel

GDI-engine
- Intake
- Air

HCCI-engine
- Intake
- Air + Fuel

Combustion

Compression
HCCI
Homogeneous Charge Compression Ignition engine

Compression  Auto-ignition  Combustion

+ High efficiency, low NO\textsubscript{x}
- ignition control, hydrocarbons

**Auto-ignition**
- homogeneous combustion?
- multiple ignition spots?
- temporal distribution of ignition?
- flame fronts?
Engine optical access

- Spark plug
- Quartz liner
- Pentroof window
- Lightsheet positions
  - +7 mm
  - +5
  - +3.5
  - -9
  - -19
- Window to the piston
- Piston
- Mirror
- Camera
Twelve fuel/air calibrated single shot registrations in an engine using 2D LIF with 3-pentanone seeded to iso-octane. This shows the cyclic variations in the engine.
In-situ engine measurements with limited optical access

Endoscopic LIF Detection System for in-situ DISI engine visualization

- A standard Karl Stortz endoscope was inserted in the sparkplug hole.

- The endoscope was coupled to an image intensified CCD camera by a single 25 mm positive lens.
Fuel visualization through endoscope: Comparison between LIF and CFD
Two-photon LIF from CO

Energy level diagram

Spectrum
CO images at different crank angle degrees in a SI engine
Simultaneous detection of formaldehyde and OH

- **Formaldehyde**
  - *Excitation at 355nm*
  - *Detection: >400nm*

- **OH**
  - *Excitation at 283nm*
  - *Detection at 308 nm*

Delay between the two lasers: 500ns

(0.004 CAD @ 1200 rpm)
Experimental setup
Formaldehyde and OH distributions in a DI HCCI engine
Simultaneous visualization of fuel(toluene) and formaldehyde

Nd:YAG lasers; 266 nm and 355 nm
- Sheet forming optics
- 2 x ICCD-cameras, gate: 40 ns
- Beam splitter (HR 260-320 nm)
- Filter: Toluene: N.N.-Dimethylformamide LP, UG 5 LP
  Formaldehyde: GG385, SP 500 nm
Simultaneous visualization of fuel and formaldehyde

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<th>Toluene / Fuel</th>
<th>Formaldehyde</th>
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**Fuel:** 45% n-heptane, 45% iso-octane, 10% toluene

**SOI:** -35 CAD
High speed LIF system

Ordinary Nd:YAG laser

Nd:YAG laser cluster

Beam splitter optics

Optional image intensifier

Iris

Mass storage

Lens mount

CCD 1-6

MCP 1-8

Mirror
Fuel Tracer PLIF in an SI-engine (single-cycle-resolved)

- Fuel: iso-octane
- Tracer: 6% 3-pentanone

TIMING:
- 7 ATDC
- 7.75 ATDC
- 8.5 ATDC
- 9.25 ATDC
- 10 ATDC
- 10.75 ATDC
- 11.5 ATDC
- 12.25 ATDC
High-speed fuel tracer PLIF in an HCCI engine

- Gradual consumption of fuel
- Multiple ignition kernels
- Sharp gradients at the end of combustion
Fuel Tracer PLIF in a DISI-engine
(single-cycle-resolved)

- SOI 64 CAD BTDC

Between exposures:
55 BTDC  54 BTDC  45 BTDC  44 BTDC  35 BTDC  34 BTDC  25 BTDC  24 BTDC
OH PLIF in a SI engine
(resolved single-cycle)

\[ \Delta t = 100 \, \mu s \]
High speed visualization: Misfires in DI Engines

What is different in a misfiring or partially burning cycle?

Quantifying the flow and mixture conditions at spark location and time shows:

- Bad cycles exhibit low velocities and stoichiometric to lean mixtures
- The flame kernel cannot catch up with the ignitable fuel cloud in the piston bowl

Courtesy: Univ. Michigan

B. Peterson, David Reuss, V. Sick, 33rd Symposium (Intl.) on Combustion
B. Peterson, V. Sick, “Simultaneous flow field and fuel concentration imaging at 4.8 kHz in an operating engine,” Applied Physics B, 2009
3-D fuel tracer PLIF

- Information on “flame” topology
- Rapid slicing of the measurement volume
- 3D data reconstructed from the eight resulting 2D-measurements
+6 CAD 3-D fuel tracer PLIF in an engine

Sheet spacing: 0.5 mm

Iso-concentration surface

Isolated fuel islands
Experimental set-up: TLAF

- YAG 1
  - 355
  - 451
- YAG 2
  - 532
  - 667
- Mixing crystal
- Delay line
- $\lambda/2$ plate
- Polarizer
- Signal beamsplitter
- Cylindrical telescope
- Photo diode
- Filters
- Boxcar int.
- CCD 1 ($F_{2o}$)
- CCD 2 ($F_{21}$)
- Engine
- CCD control
  - PC$_1$
  - PC$_2$
Single shot T-distributions in an engine
LIF visualization

a) Gasturbine environments
Experimental set-up at ABB-STAL

ABB double cone burner
Four single-shot PLIF images of air/fuel inhomogeneities
"Swirling" burners at VAC
Experimental set-up
Average OH images at different spatial locations from the burners
Experimental arrangements for Jet-A studies
LIF spectra from JET-A at different $T$
Experimental set-up: simultaneous Mie scattering/LIF
Two-line atomic fluorescence applied in the VAC burner
LIF species visualization

c) Furnace/Biomass environments
Pyrolysis experiments I
Excitation at 266 nm

Laser-induced fluorescence spectra detected with excitation wavelength 266 nm at 500 °C (a) and 800 °C (b)
Pyrolysis experiments II
Excitation with 355 nm
2D LIF imaging of pyrolysis products from wood particles

$t=80\ s$

$t=120\ s$

$t=180\ s$
LIF experiments in a laboratory wood-particle fuelled burner
LIF spectra: exc 282 nm

Fuel: propane

Fuel: biopowder
Furnace applications - LIF