Capri, September 14-18, 2008

30th IEA / Collaborative Task – Hydrogen

Knock Visualization and chemilminescence analysis in a hydrogen spark-ignition engine

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Hydrogen

(www.jhfc.jp)

Fuel cell

Compression ignition

High Self-ignition temperature

➔ Need ignition source

Glow plug/ Pilot diesel fuel

(www.nikkeibp.co.jp/.../shimizu/07622_hydrogen/)

Spark ignition

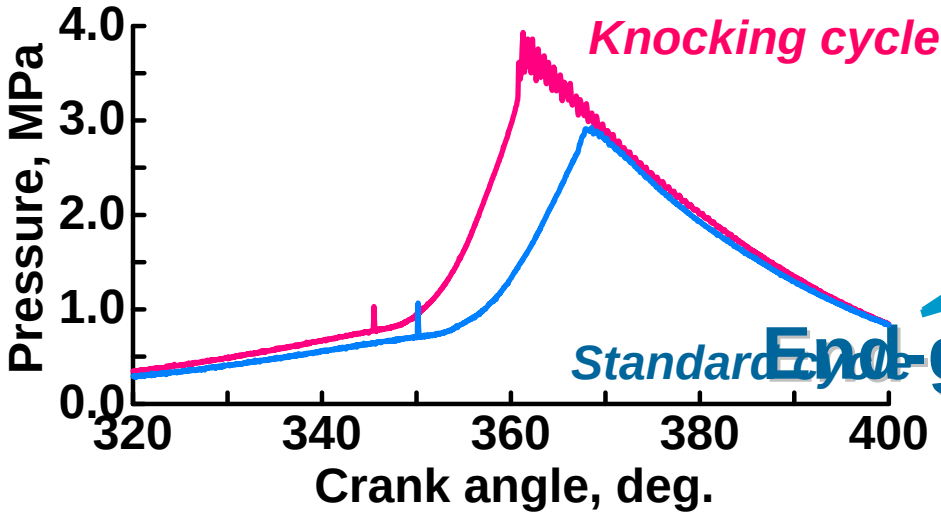
- **Port injection ➔ Direct injection**
- **Lean combustion ➔ Low NOx**
- **Boosting system ➔ Higher IMEP**
- **Lower NOx/ Knocking**

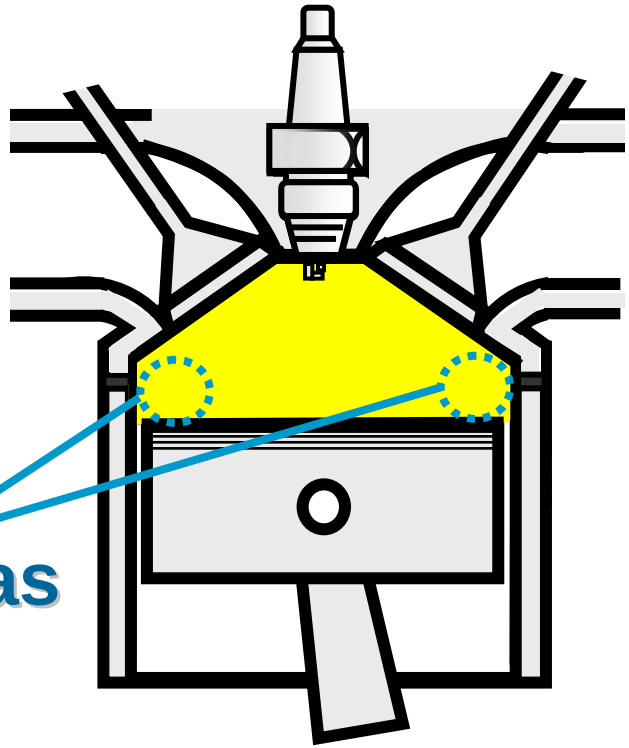
Requirements of spark-ignition (SI) engine

- Lower fuel consumption
- Reduced emission of pollutants.

Higher thermal efficiencies

Engine knocking due to higher compression ratio





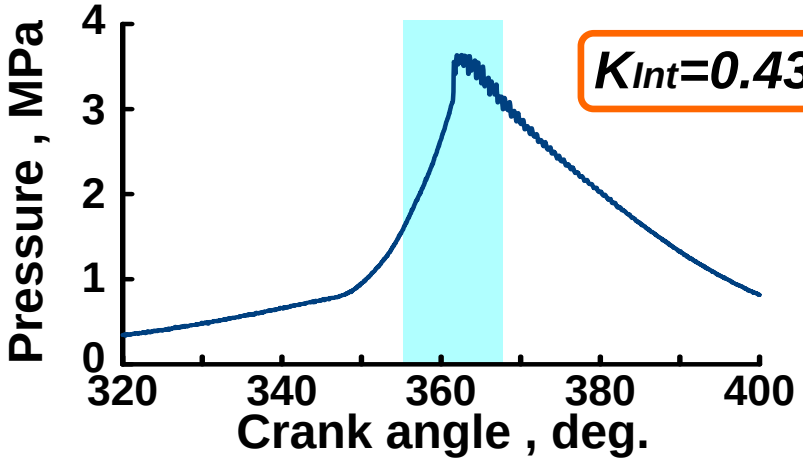
Background

Knocking research

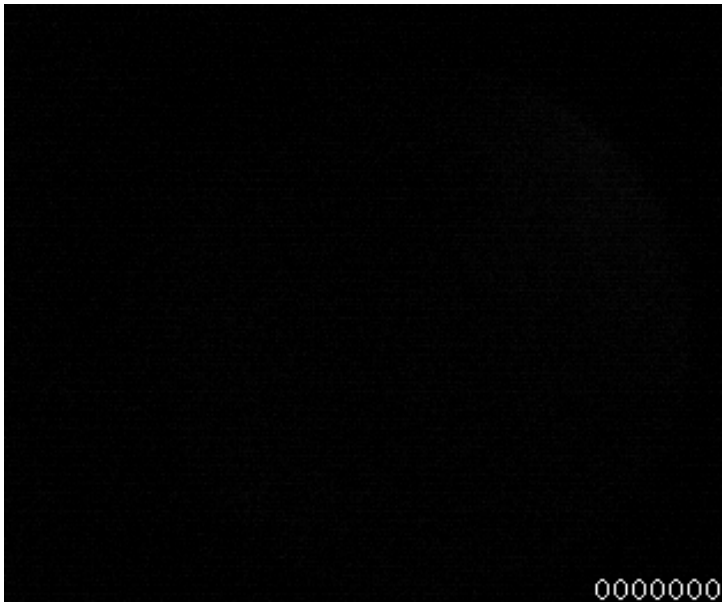
- Visualization of auto-ignition kernel
- Spectroscopic measurement
- Ion current measurement
- Numerical simulation

Fuel : n-Butane , ϕ = 1.0

P_0 = 60kPa , T_0 = 323K , θ_{IT} = 345deg.



K_{Int}=0.434MPa



Knocking image (n-Butane)~ Previous study

Hydrogen vs. Hydrocarbon Fuel

Questions?

What happened in end-gas region before knocking? => Auto-ignition process

Low temp. chemical reaction (HC)

? (H_2)

Auto-ignition process

H_2-O_2

H_2-Air

Chemical reaction

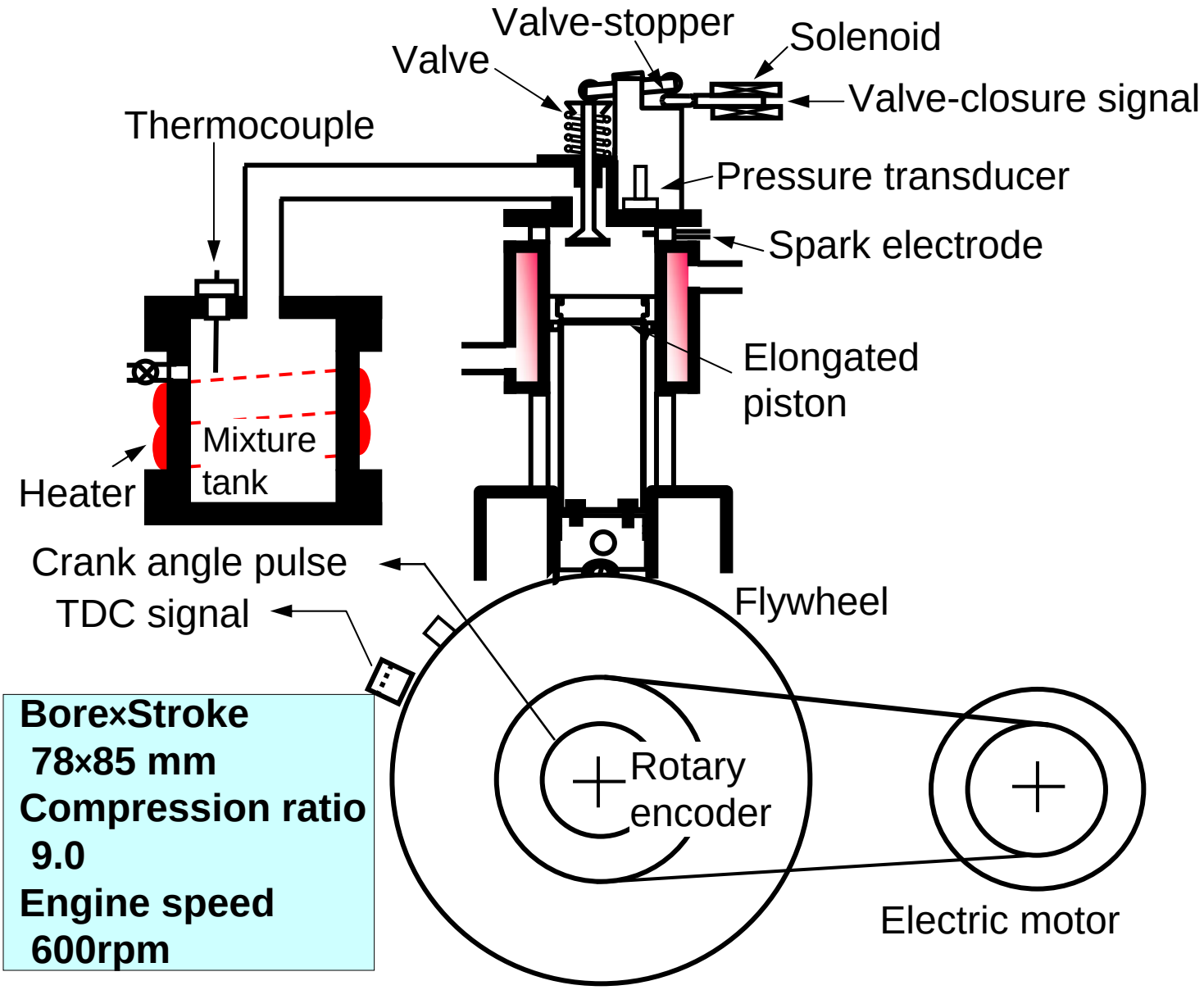
$O_2+H=OH+O$

$H_2+O=H_2O+H$

$O_2+OH=HO_2+O$

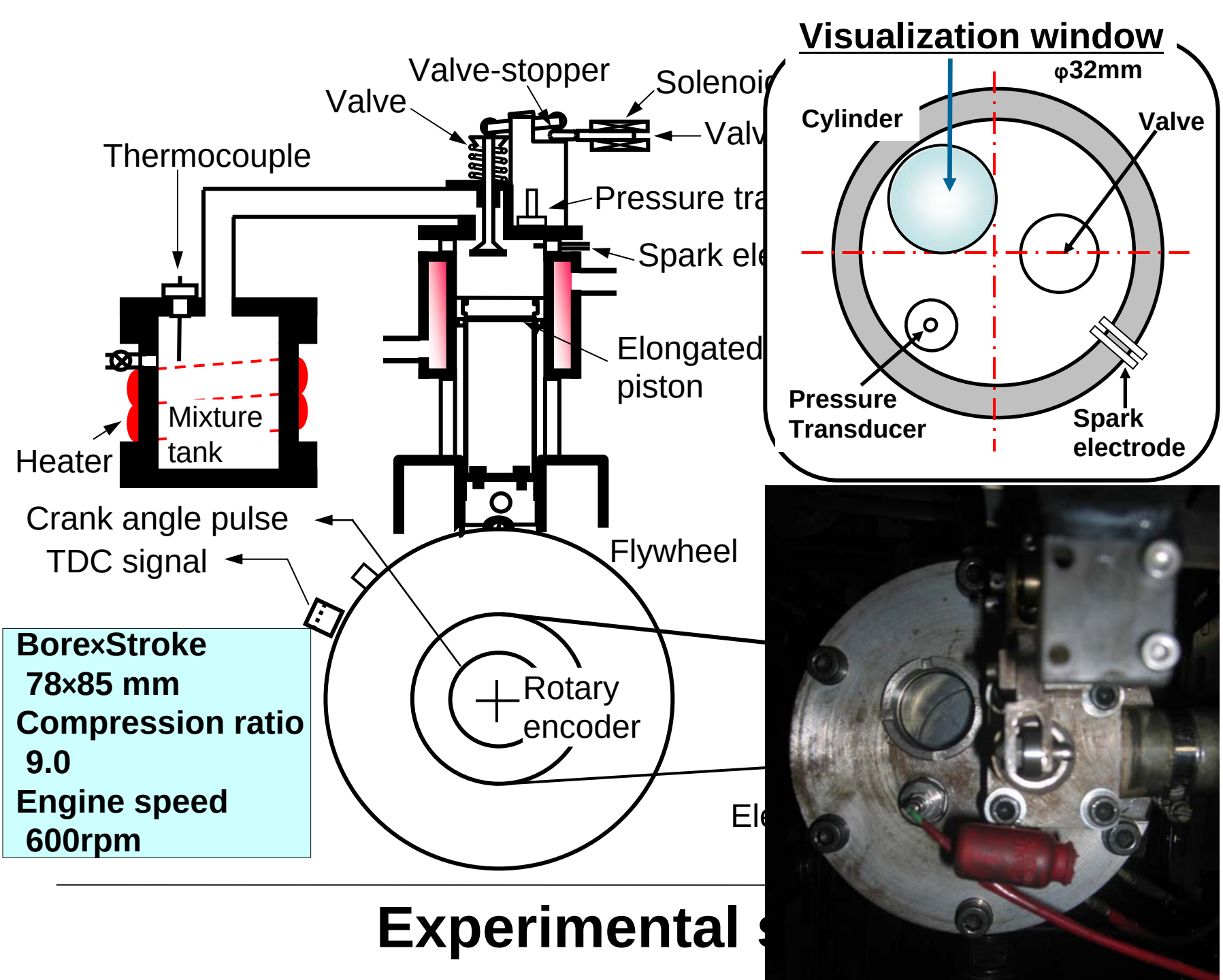
⋮

Effects of pressure wave on combustion



Bore×Stroke
78×85 mm
Compression ratio
9.0
Engine speed
600rpm

Experimental set-up

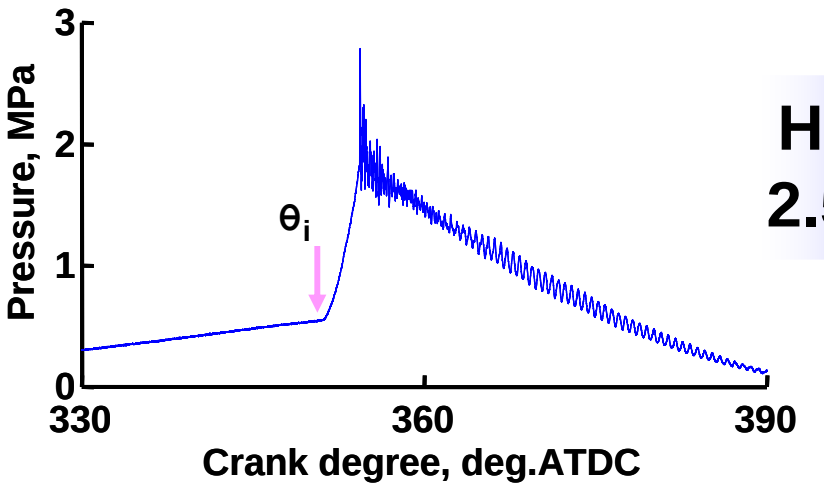


Experimental s

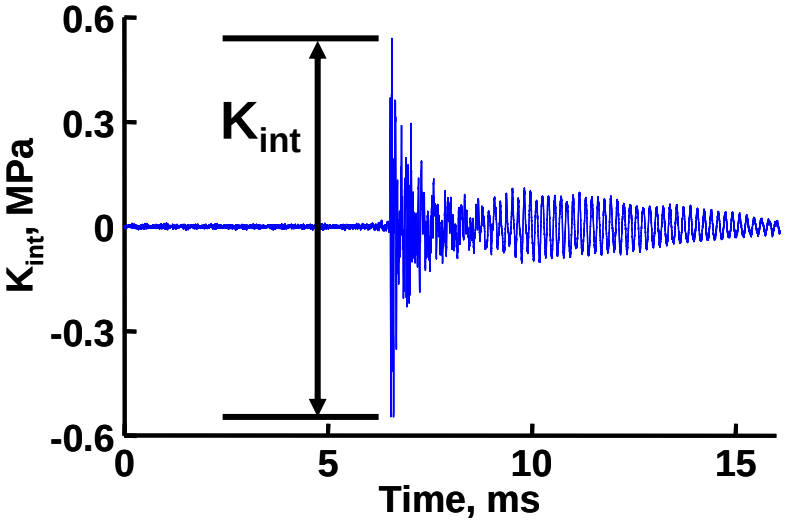
Experimental condition

Fuel mixture	H_2-O_2-Ar H_2-Air
Equivalence ratio, φ	1.0
Initial pressure, P_0	40kPa
Initial temperature, T_0	323K

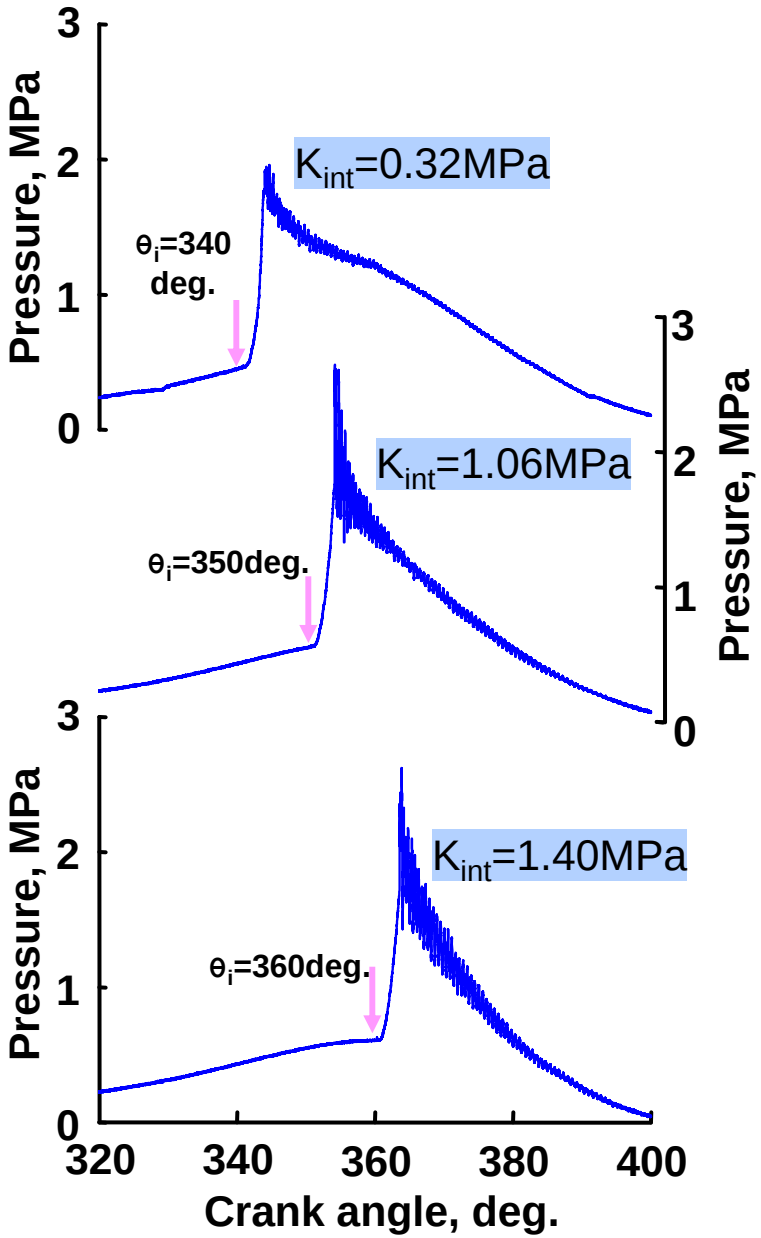
Knock intensity: K_{int}

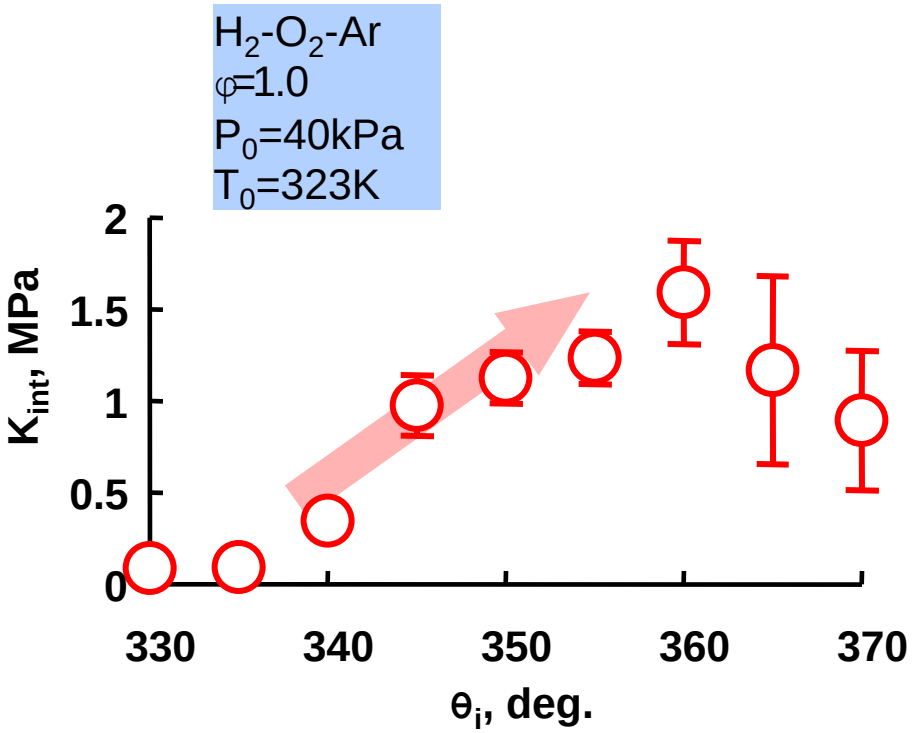


H.P.F.
2.5kHz



Experimental condition and knock intensity





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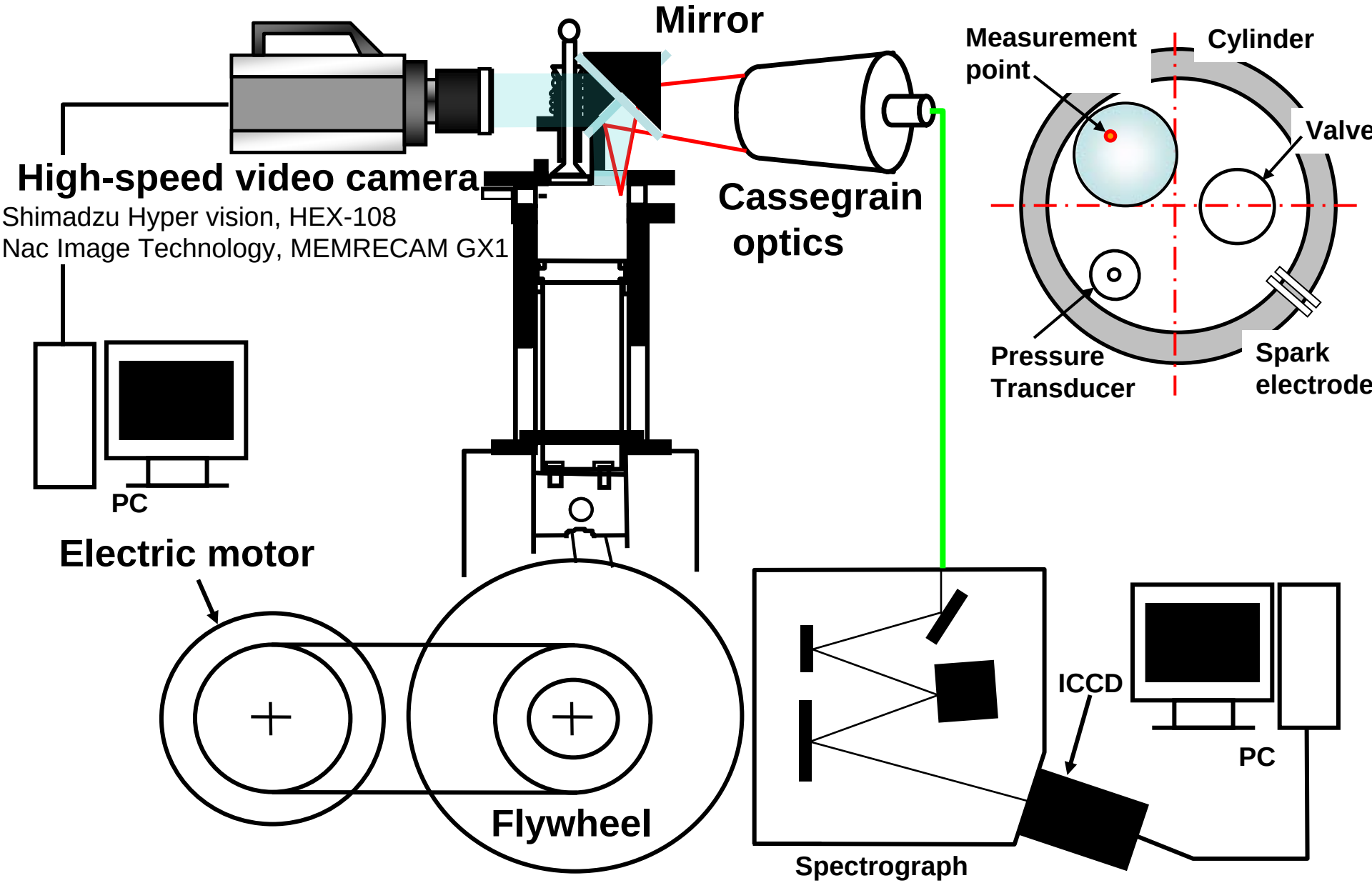
Effect of ignition timing on knock intensity



Experimental methods

-Visualization of knocking cycles with high speed color camera

-Visualization of pressure wave with high speed camera

-Spectral analysis of propagating flame and burned gas

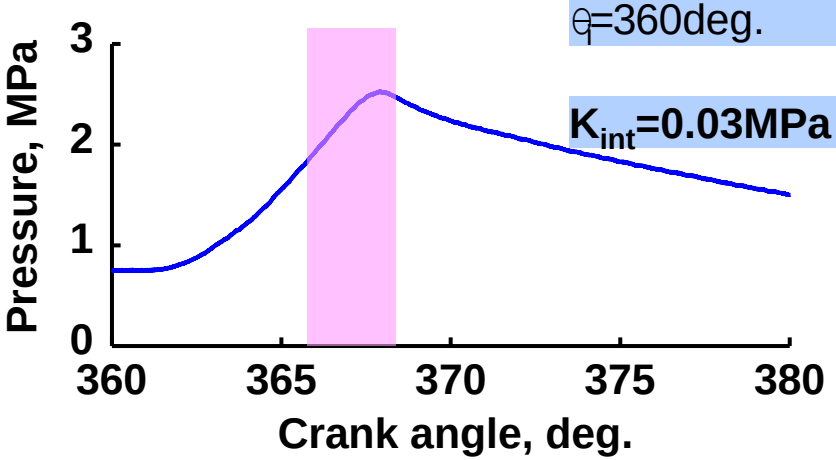
Contents

Normal cycle

Rec. speed=60,000fps

H_2-Air φ=1.0
P_0=60kPa
T_0=323K
φ=360deg.

K_{int}=0.03MPa

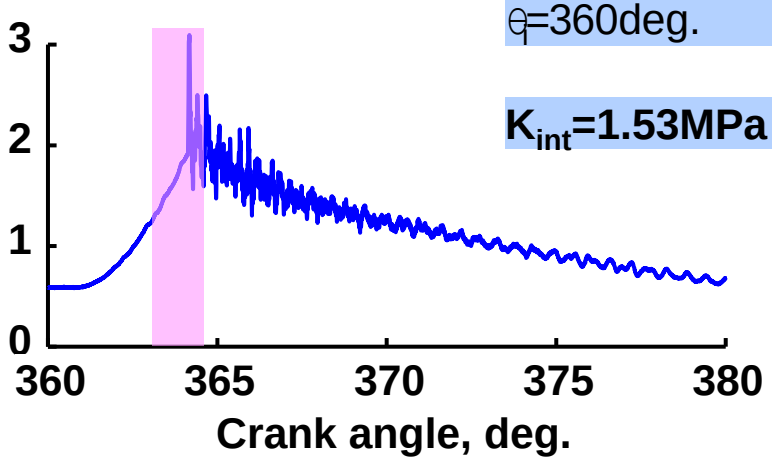


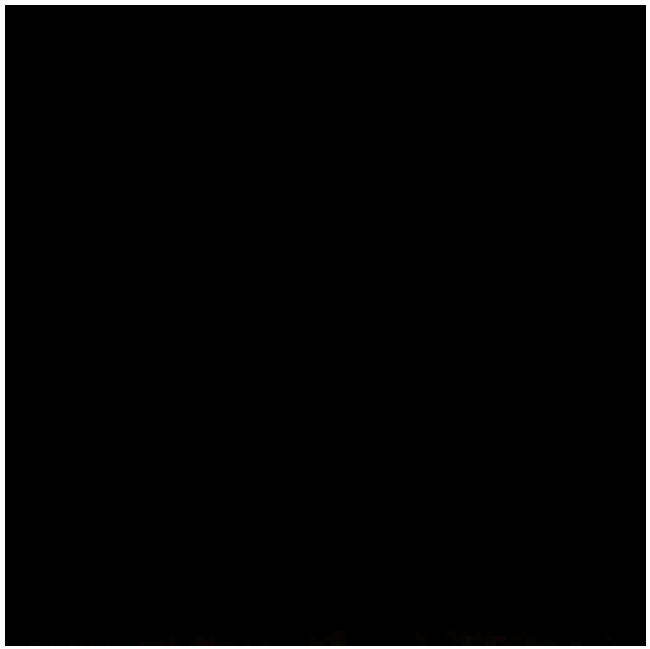
Knocking cycle

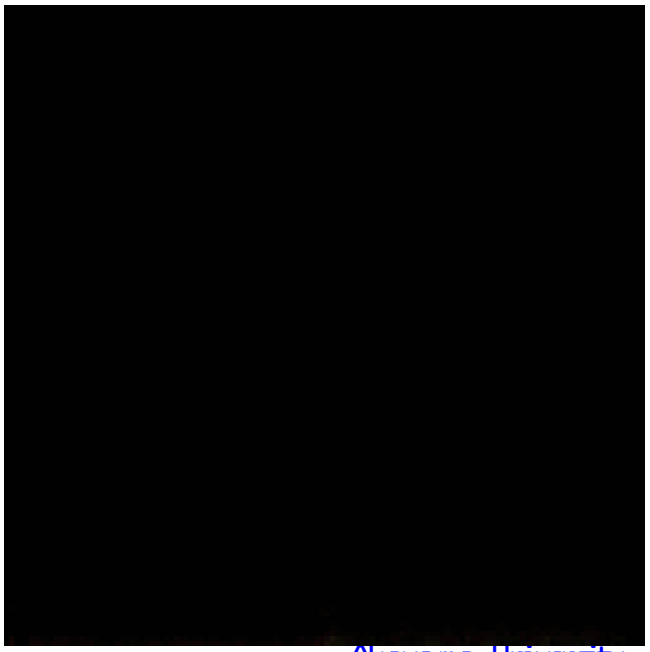
Rec. speed=60,000fps

H_2-O_2-Ar φ=1.0
P_0=40kPa
T_0=323K
φ=360deg.

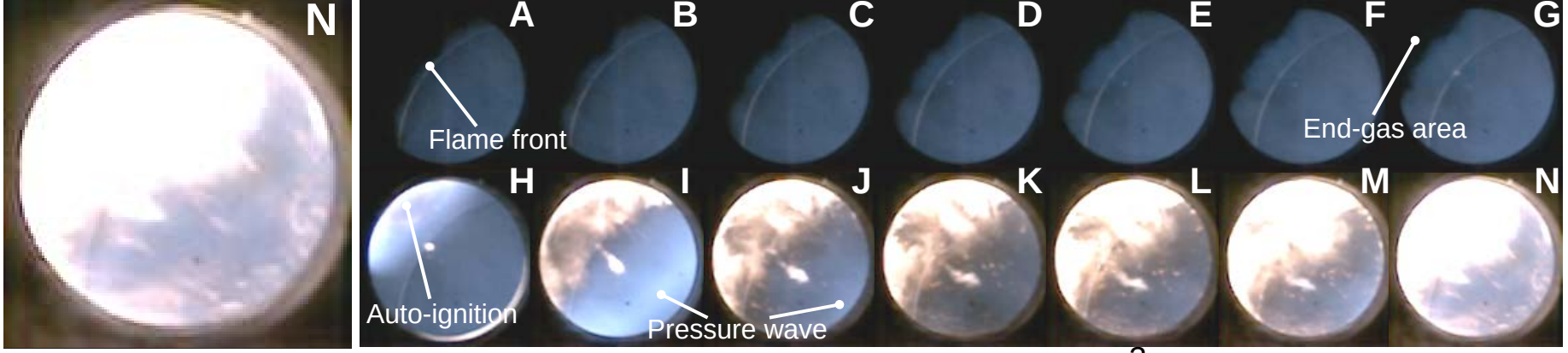
K_{int}=1.53MPa







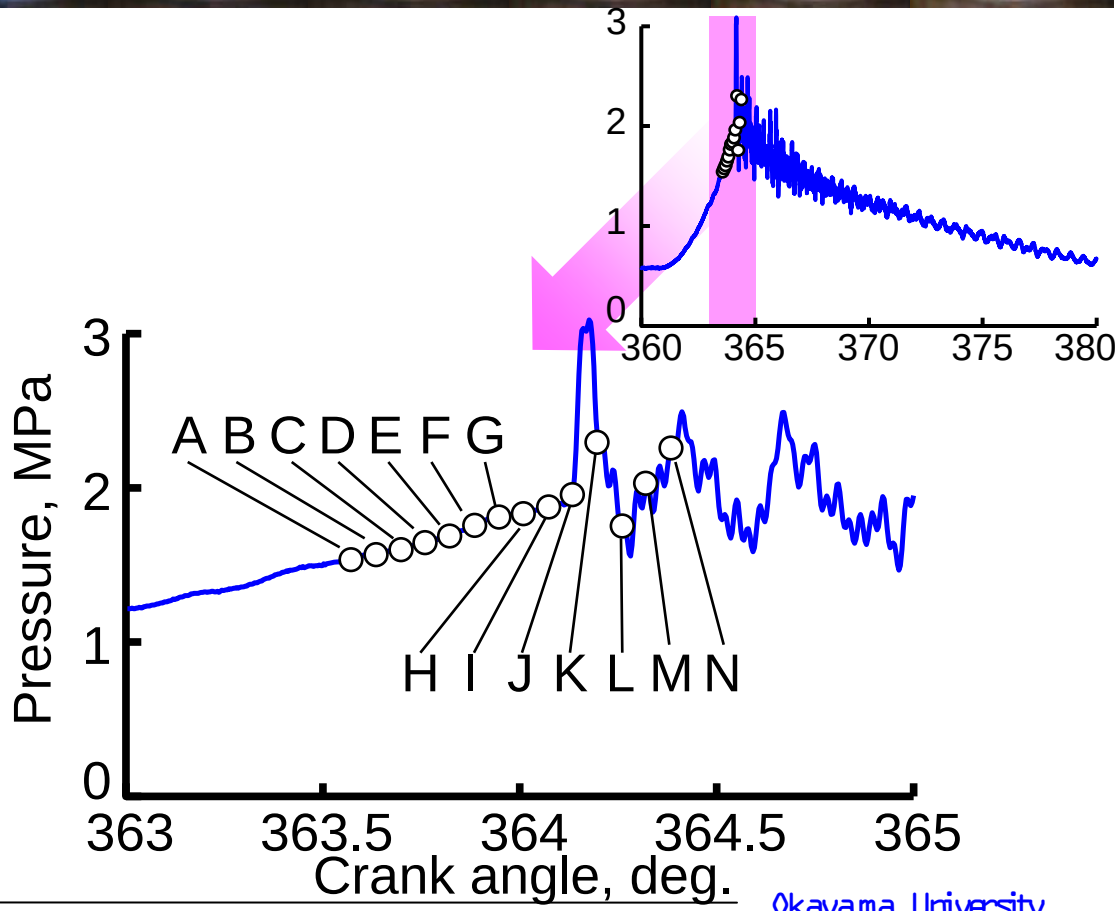
Compared normal cycle with knocking cycle

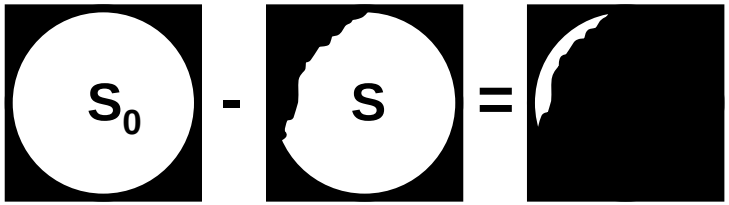


Knocking cycle

H_2-O_2-Ar
ϕ=1.0
P_0=40kPa
T_0=323K
θ_{IT}=360deg.
K_{INT}=1.53MPa

Rec. speed=60,000fps
Exposure time=5μs





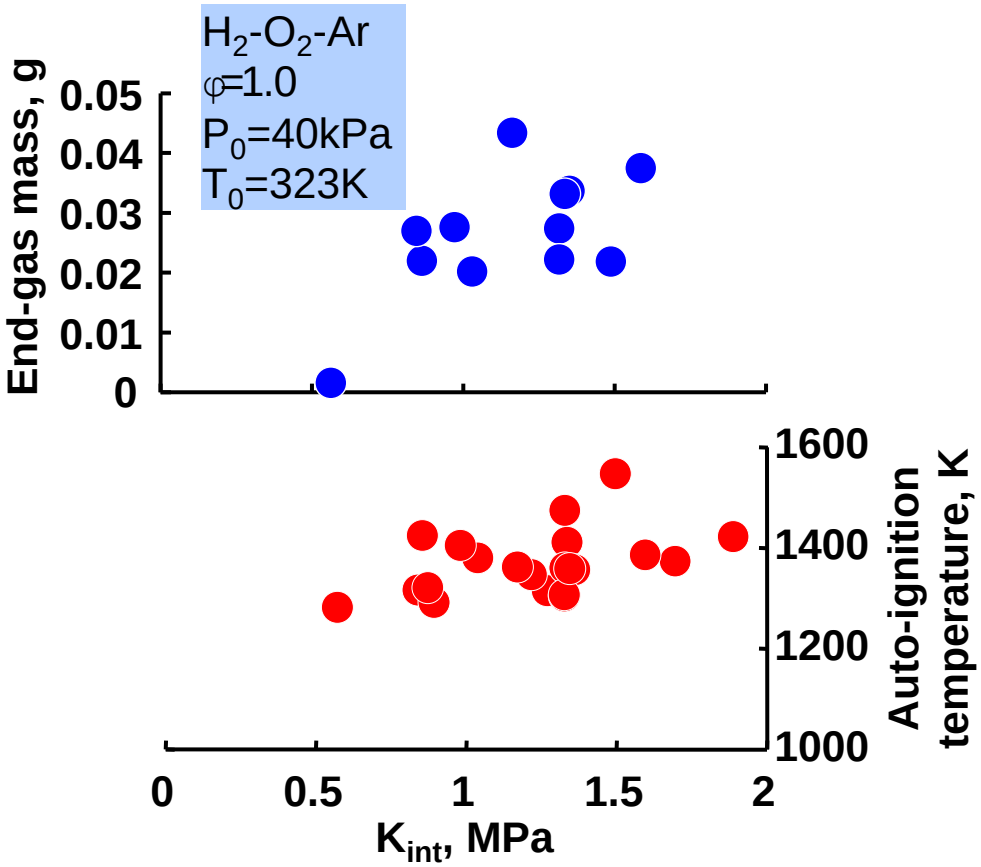
$$\text{End-gas mass} = \rho \times (S_0 - S) \times H$$

End-gas volume

S_0 Visualization area

S Flame area at just before auto-ignition

H Height of combustion chamber at just before auto-ignition



Effects of end-gas mass and auto-ignition temperature on knock intensity

-Visualization of knocking cycles with high speed color camera

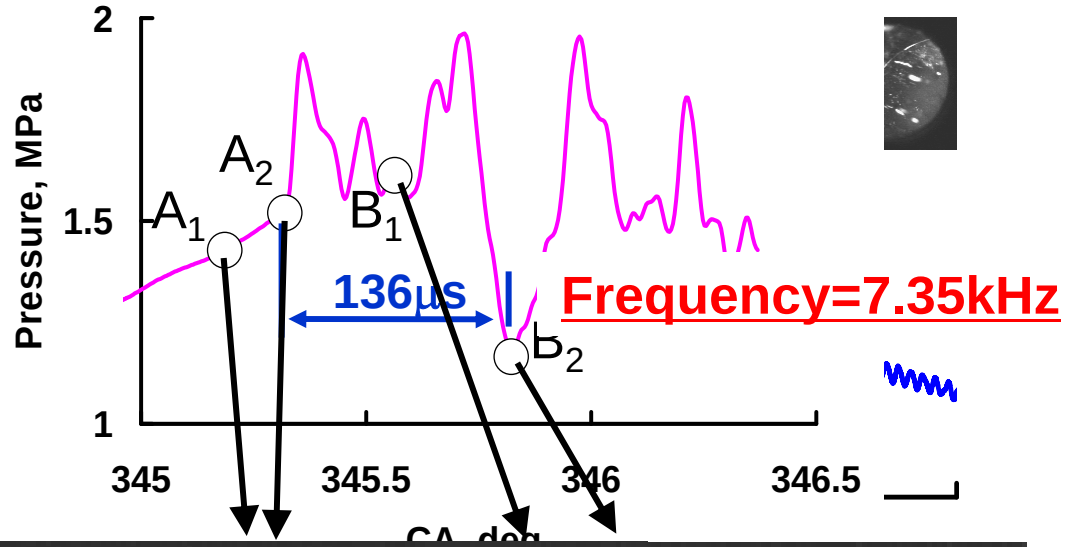
-Visualization of pressure wave with high speed camera

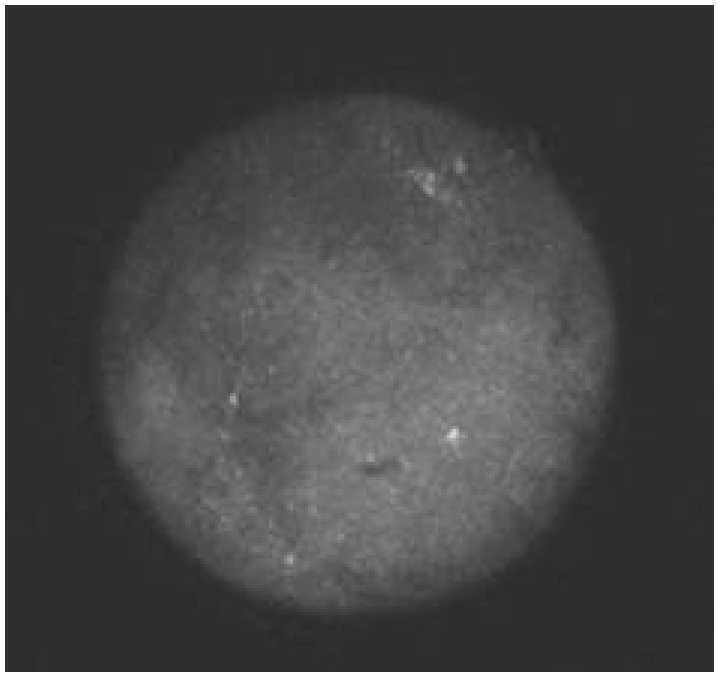
-Spectral analysis of propagating flame and burned gas

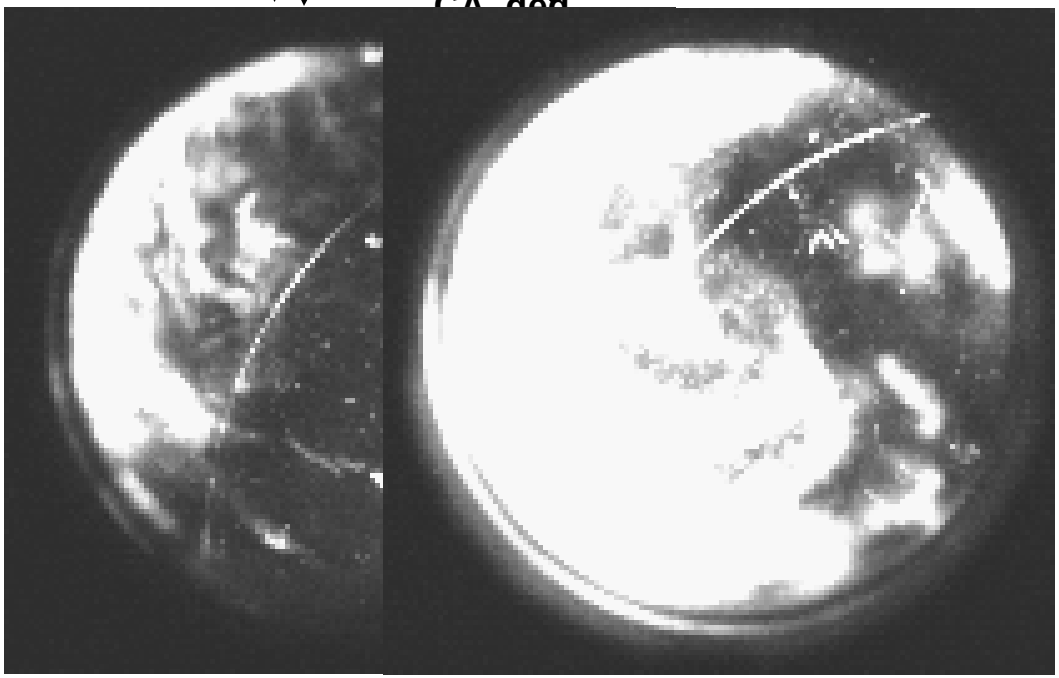
Contents

Knocking cycle

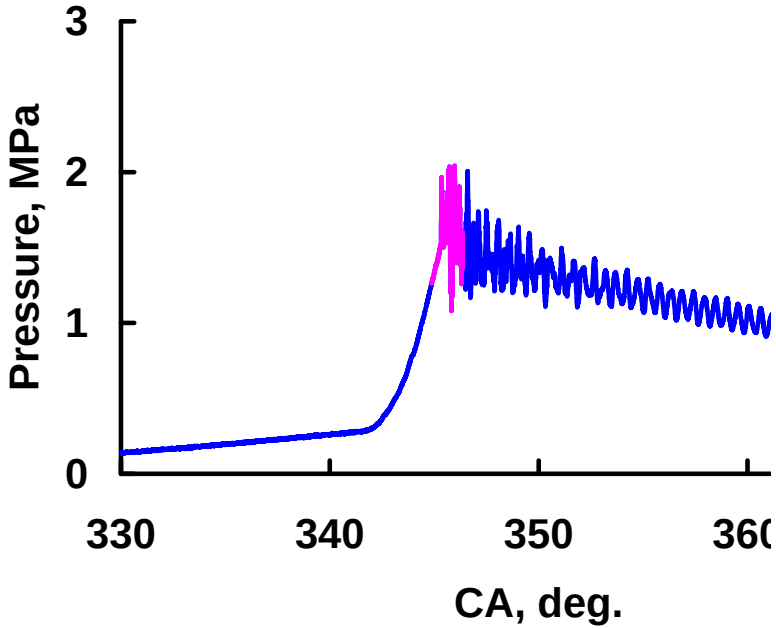
H_2-O_2-Ar φ=1.0
θ=340deg. Rec. speed=250,000fps
Exposure time=2μs
K_{int}=0.99MPa

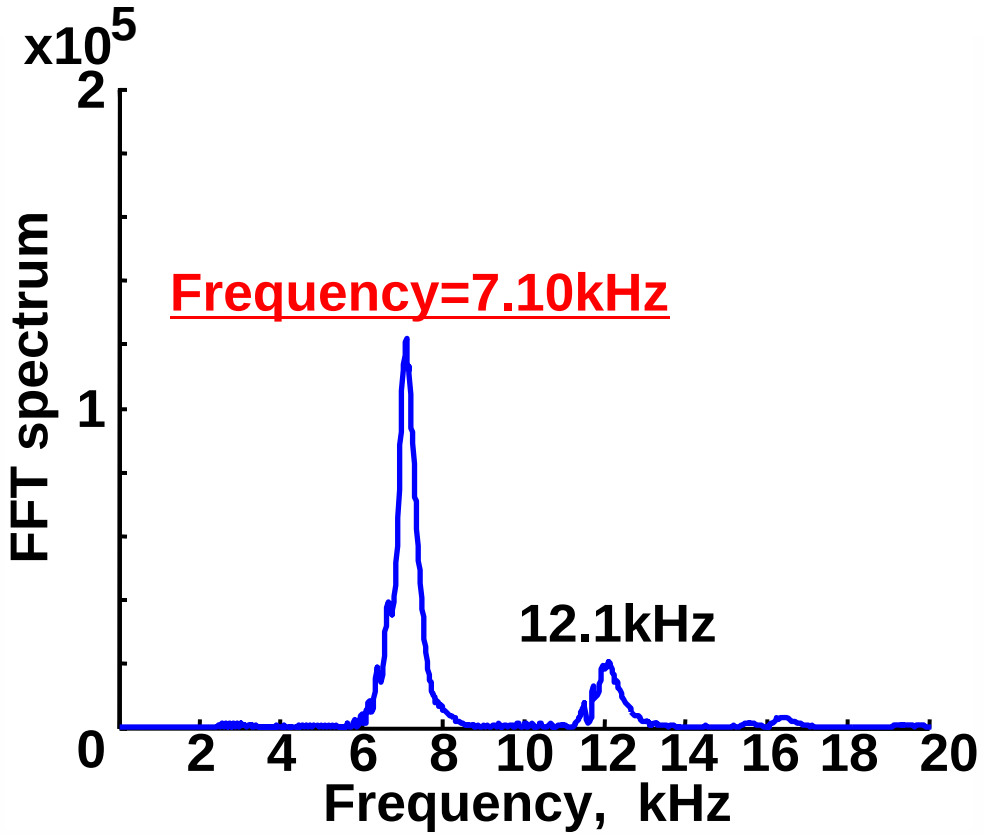






Visualization of pressure wave and estimation of the frequency





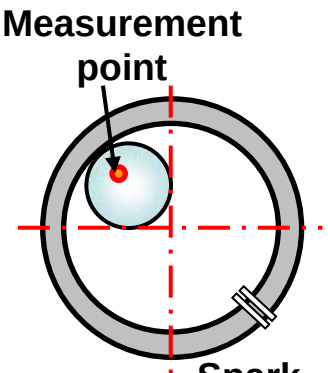
Estimation of knock frequency by pressure

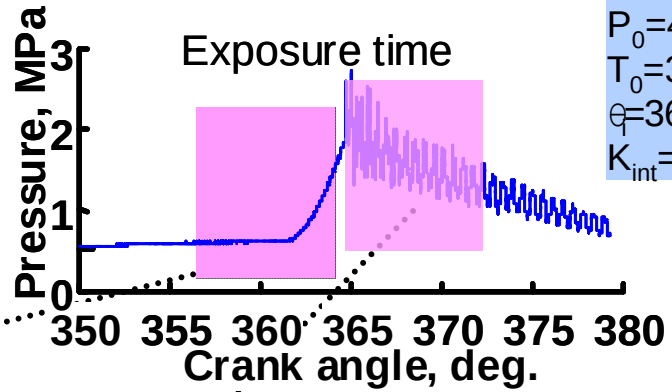
-Visualization of knocking cycles with high speed color camera

-Visualization of pressure wave with high speed camera

-Spectral analysis of propagating flame and burned gas

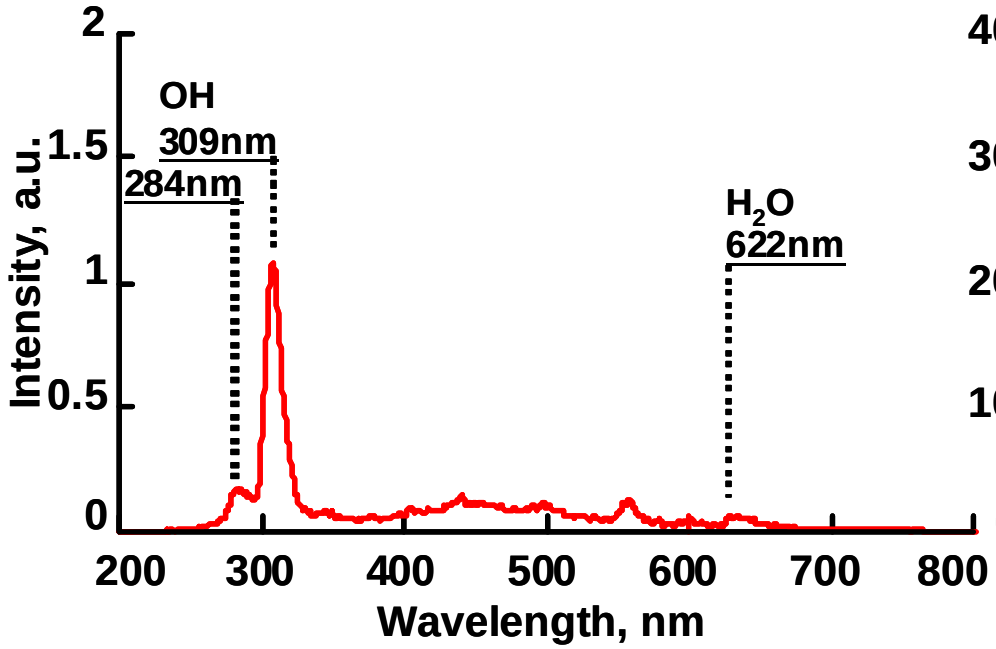
Contents



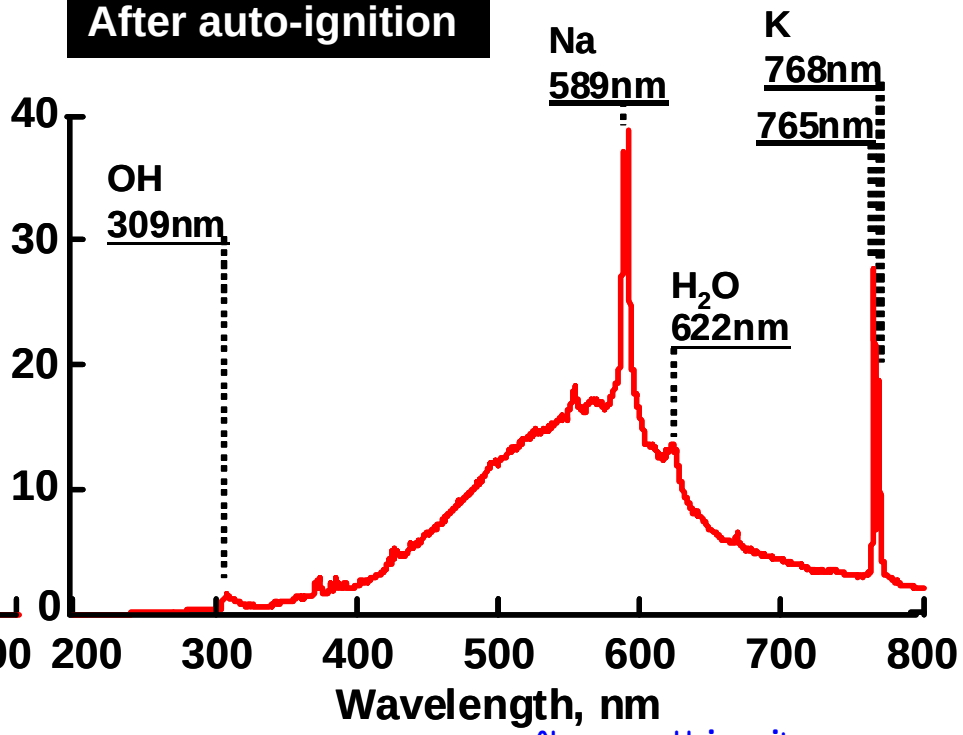


H_2-O_2-Ar
φ=1.0
P_0=40kPa
T_0=323K
θ=360deg.
K_{int}=1.25MPa

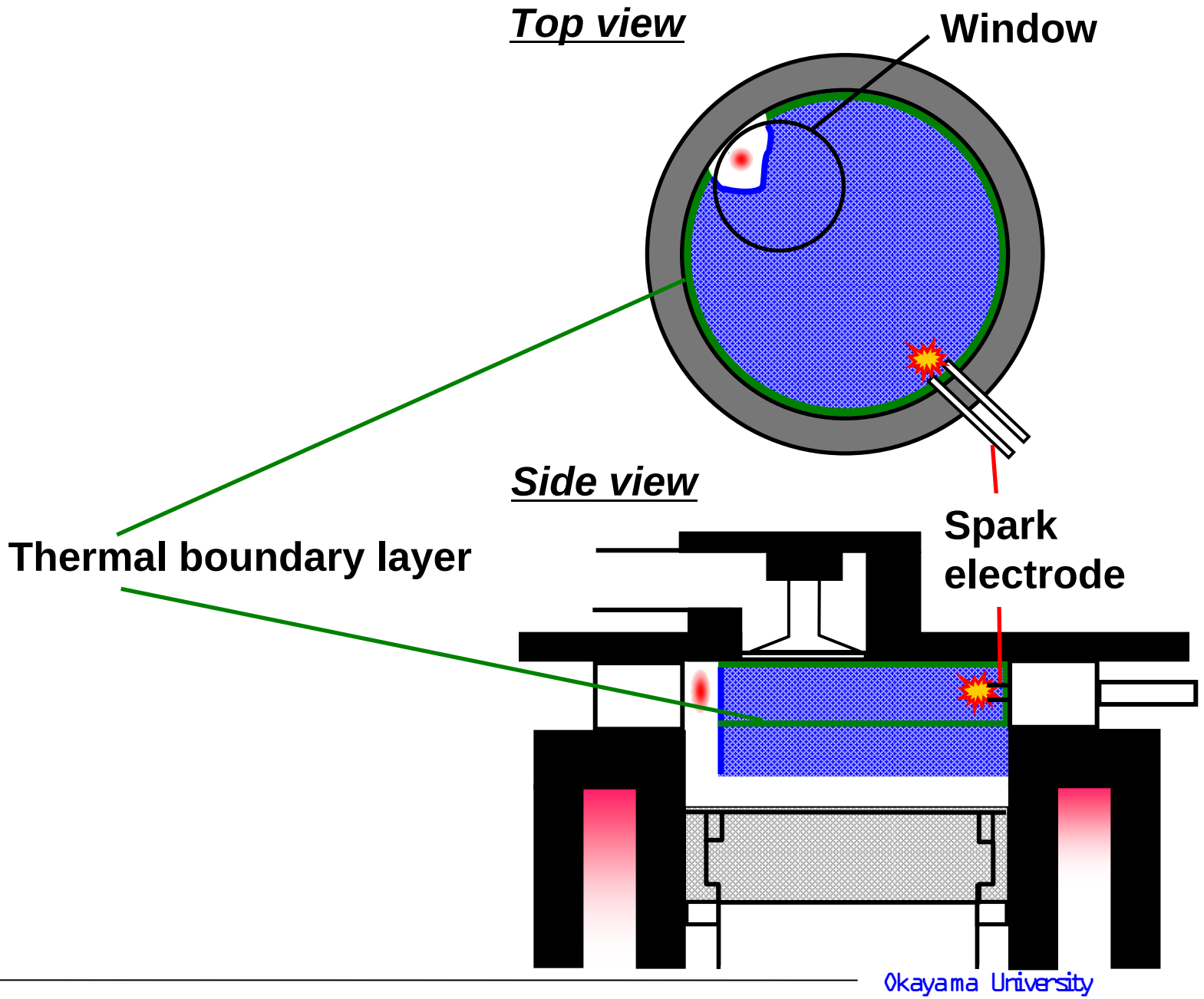
Before auto-ignition



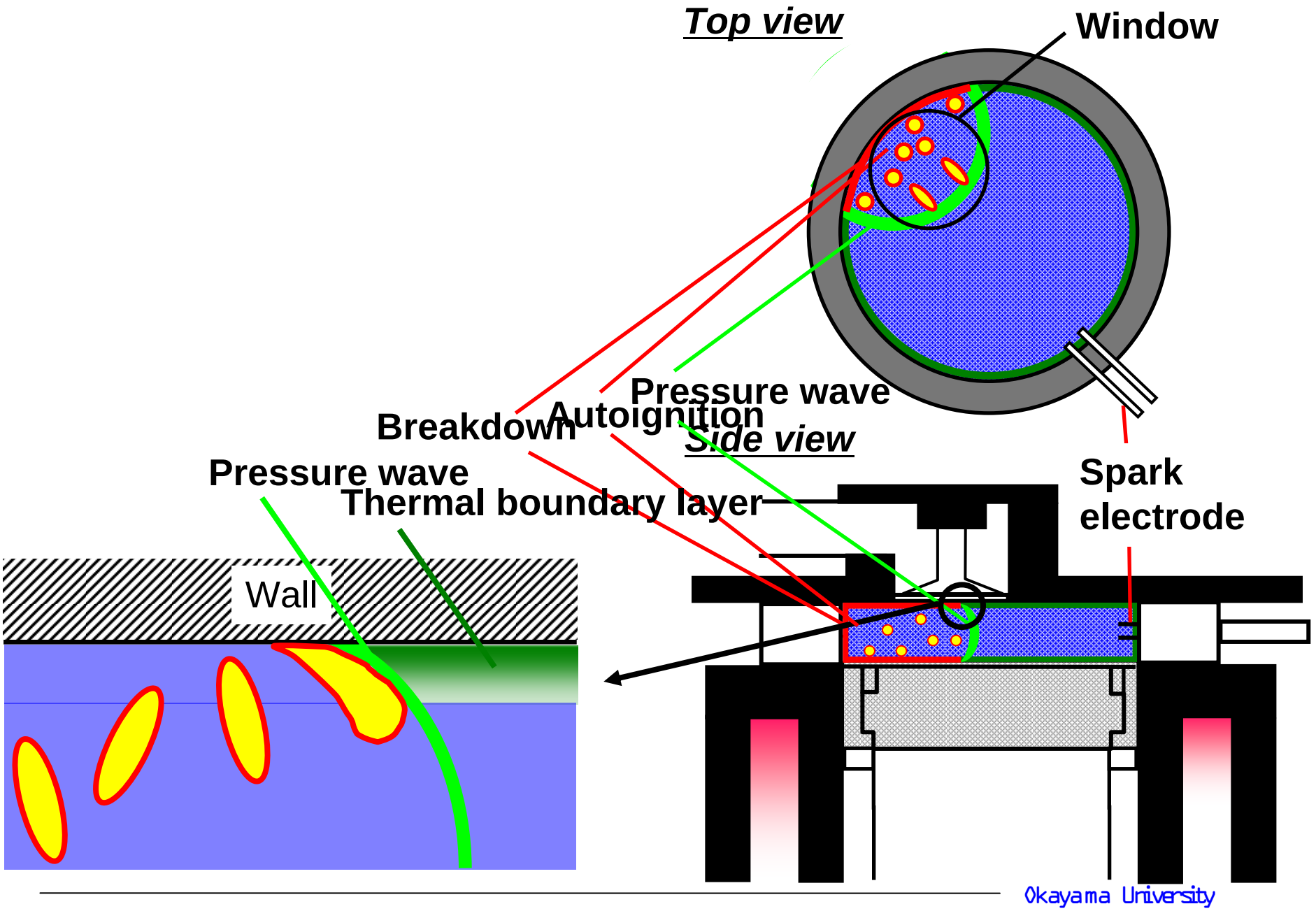
After auto-ignition



Emission spectrum before and after auto-ignition



Breakdown of thermal boundary layer



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Breakdown of thermal boundary layer

Autoignition of the end gas caused by flame propagation and intense oscillations due to shockwaves during knocking in a hydrogen spark-ignition engine were visualized using high-speed color and monochrome cameras. Emissions from the chemical luminescence of the regular propagating flame and burned gas region were detected to analyze the chemical reactions that occurred during engine knocking. The results obtained in this work can be summarized as follows.

(1) Autoignition in an end-gas region that was compressed by the propagating flame front could be visualized using a high-speed video camera. During knocking, a strong luminous flame was found due to the combustion of the lubricating oil grease.

Conclusions

(2) The large amount of unburned mixture generated strong pressure waves caused by the autoignited kernel explosion. Visualized images of a regular propagating flame front confirmed that the knock intensity was strongly related to the mass fraction of the unburned mixture.

(3) Strong pressure wave oscillations induced by the initial autoignition inside the end-gas region could be visualized using a high-speed video camera with a speed of 250,000 frames/s. The autoignition and pressure waves caused the thermal boundary layer to break down near the cylinder wall and piston head, which may result in damage to the cylinder wall and piston head during engine knocking.

Conclusions