Investigation of the effect of observation window on the sensitivity enhancement in the multi-pass cell outside the expansion wave tube chamber

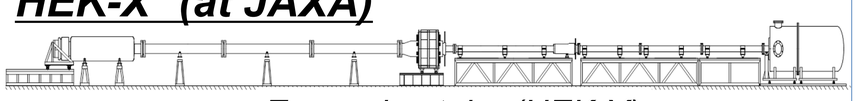
Ryuji Kobayashi, Hiroaki Sakai, Makoto Matsui (Shizuoka University)

1. Background

Reproduce re-entry condition at ground

- Shock tunnel
- Arc-Heated wind Tunnel
- **Expansion tube** → Produces a **high-speed**, **low-temperature** flow and molecules of oxygen and nitrogen do **not diverge**.

HEK-X (at JAXA)



Expansion tube (HEK-X)

HEK-X is one of **the biggest expansion-tube**

→ Expects operations for the next mission

Measuring flow condition is needed for operating

- Temperature
- Density
- Flow speed

→ Laser Absorption Spectr-oscopy (LAS) is able to measure these value with high time resolution.

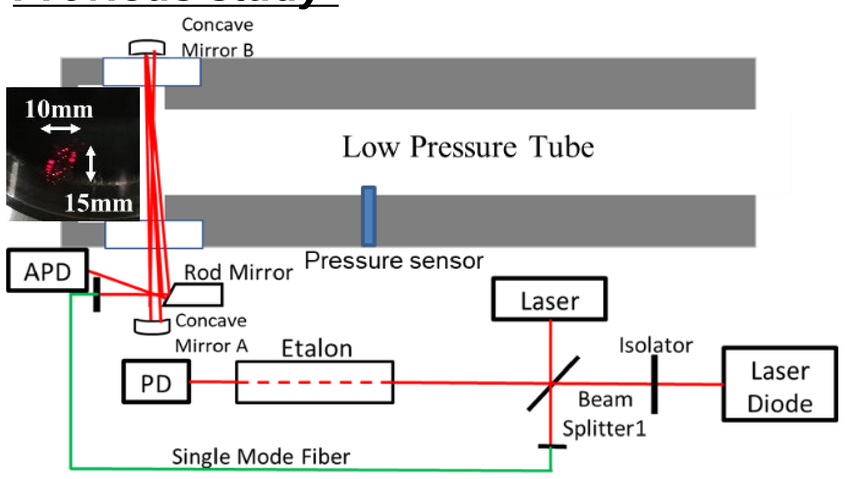
However, the sensitivity of the LAS targeting oxygen molecules was not enough…

High Sensitization Methods of LAS

	WMS	ICOS	Multi-pass
Sensitivity	<100	10^3-10^4	**10-100**
Time resolution	> ms	> s	**< 10us**
Spatial resolution	○	△	△

→ Multi-pass is adopted since it is a **high time resolution**

Previous study[1]



Multi-pass LAS for ISAS expansion tube

- The sensitivity was increased by **44 times**
- Estimated test time was **30~80 us**
- The translational temperature of the oxygen molecules was **3000 ~ 5000 K**

However, the observation windows were moved by the shock wave, so it was not possible to measure with higher sensitivity.

1.Ryuji. K, et.al., Journal of IAPS, Vol.29, No.1

2. Objective

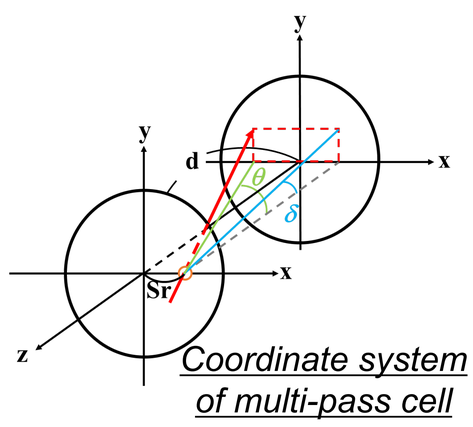
The sensitivity enhancement of multi-pass cells in the inclination of interior cell window was investigated

- **By calculation using the ray-tracing method considering the laser spread**
- **By experiments to reproduce the calculation results using LAS**

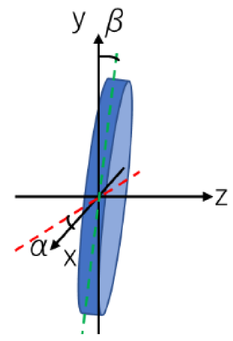
3. Calculations Conditions

Ray-tracing method

- Obtain the trajectory of a reflected ray
- No near-axis approximation
- Consider the spread of the ray
- **Tolerance is defined as the interval in which sensitivity does not change**



Coordinate system of multi-pass cell



Coordinate system of window

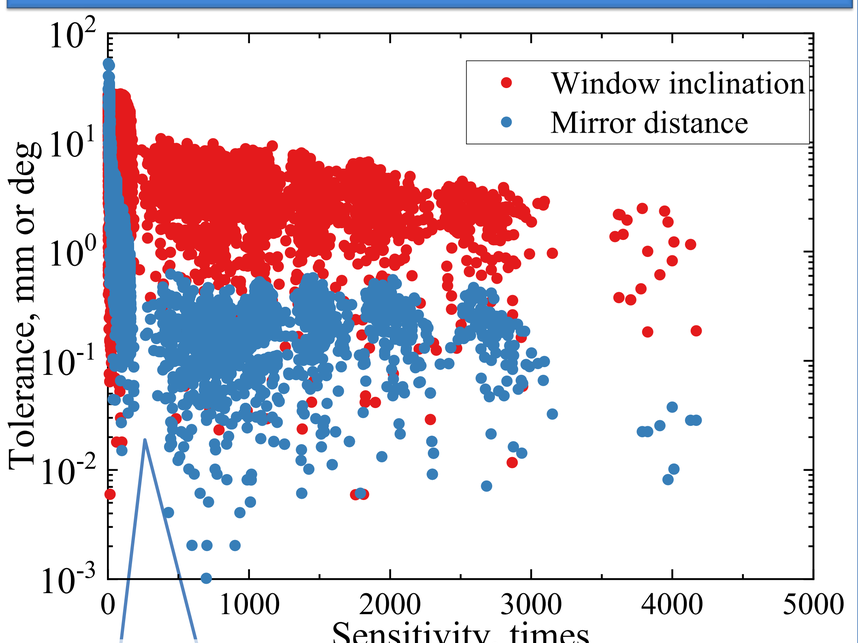
Calculation parameter

Parameters	Symbol	Conditions
Concave mirror size	*Ms*	50.0 mm
Concave mirror focus length	*f*	200 mm
Mirror distance	*d*	350 ~ 400 mm
Initial position	*Sr*	0 ~ *Ms*/2
Initial angle of x-axis	θ	$-\tan^{-1}\frac{0.5M_s+S_r}{d}$ ~ $\tan^{-1}\frac{0.5M_s-S_r}{d}$
Initial angle of y-axis	δ	0 ~ $\tan^{-1}\frac{S_r}{d}$
Entrance and exit hole		2.0 mm
Beam diameter		1.0 mm
Window distance		170 mm
Refractive index		1.513
Window thickness		4.0 mm

Judgment conditions for sensitivity

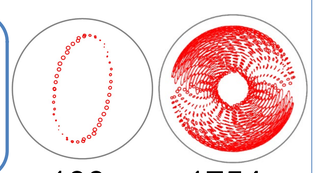
- Beam diameter is within *Ms* range
- Calculation ends when the beam overlaps the entrance hole → **sensitivity calculation**

4. Calculation Results



The relationship between sensitivity and tolerance in observation windows inclination and mirror distance

The pattern of the multi-pass cell changes **from a single circle to an exotic pattern.**



100x 1754x

Tolerance of mirror distance → More 10 times → **Tolerance of observation windows inclination**

4. Experimental system

Lambert-Baer law

$$I_\nu(x) = I_0 \exp(-k_\nu x)$$

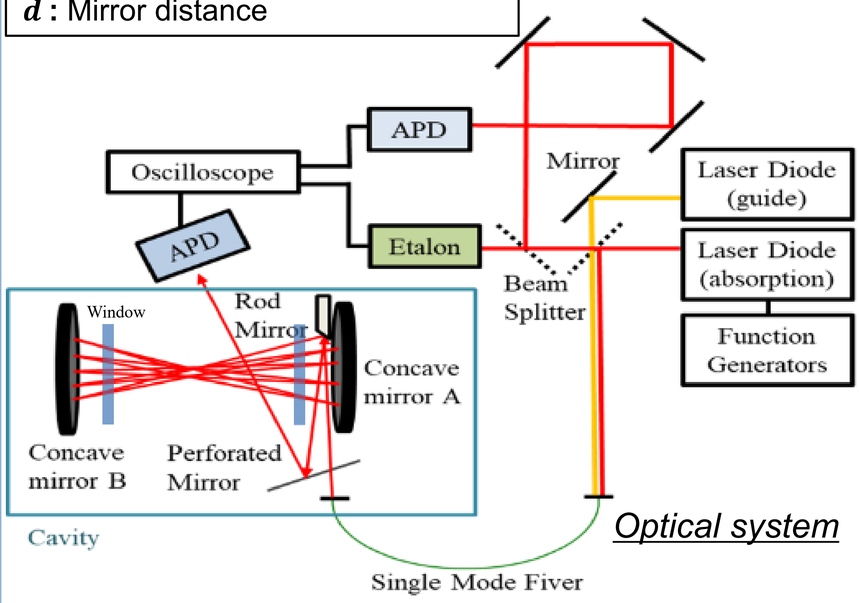
$$x \propto \ln\left(\frac{I_\nu(x)}{I_0}\right) = a$$

$I_\nu(x)$: Through light intensity
ν: Laser frequency
x: Light path length
I_0 : Laser intensity
k_ν : Absorption coefficient
a : Absorbance

Calculation of sensitivity

$$sensitivity = \frac{a_{multi}}{a_{single}} \times \frac{3.5}{d}$$

a_{single} : Absorbance of 3.5 m(single)
a_{multi} : Absorbance of Multi-pass
d : Mirror distance

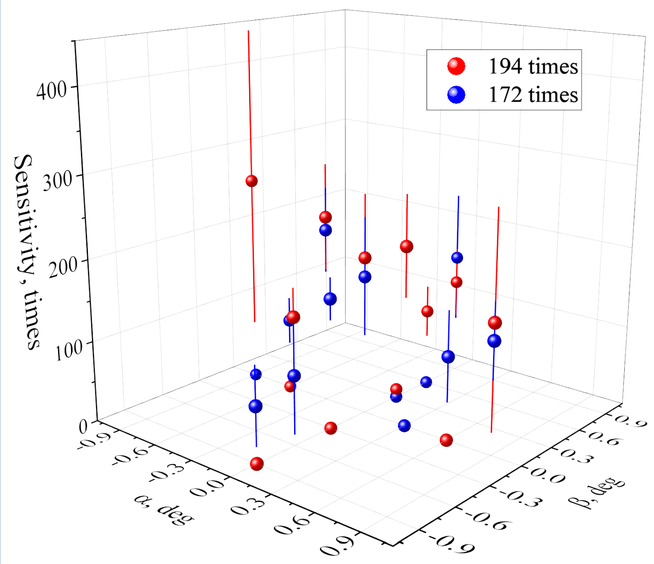


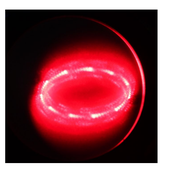
Optical system

Experimental conditions

- Laser frequency : **762.31 nm**
- Sweep frequency and width : **100 Hz, 35 GHz**
- Concave mirror size and reflectance : **48.3 mm, 99.96 %**
- Exclude patterns that are affected by overlap

6. Experimental Results





194 times

172 times

The relationship between sensitivity and tolerance in observation windows inclination (sensitivity 0 is overlap)

- It was **not possible** to create multi-pass cell (exotic pattern) of **over 200 times.**
- If the window is tilted just 0.3° , overlap will take and sensitivity will change.
- The tolerance for window inclination is stricter than calculated, **because of the effects of overlap.**

It is better not to use observation windows when the sensitivity is over 100 times.

7. Summary

- Tolerance of observed window inclination is 10 times more than tolerance of mirror distance.
- However, in experimental results, the effect of overlap makes it more stricter than calculated.