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A Dynamic Optical Measurement System for Cryogenic Fluids Using Laser Interferometry

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Introduction

Question: How to observe the fluid behavior?

Concentration measurement	Advantages	Disadvantages	Accuracy
Capacitance method	Simple installation, real-time monitoring	Can't provide two-dimensional concentration distribution	$\sim 10^{-4}$

No effective way for two-dimensional real-time monitoring

Introduction

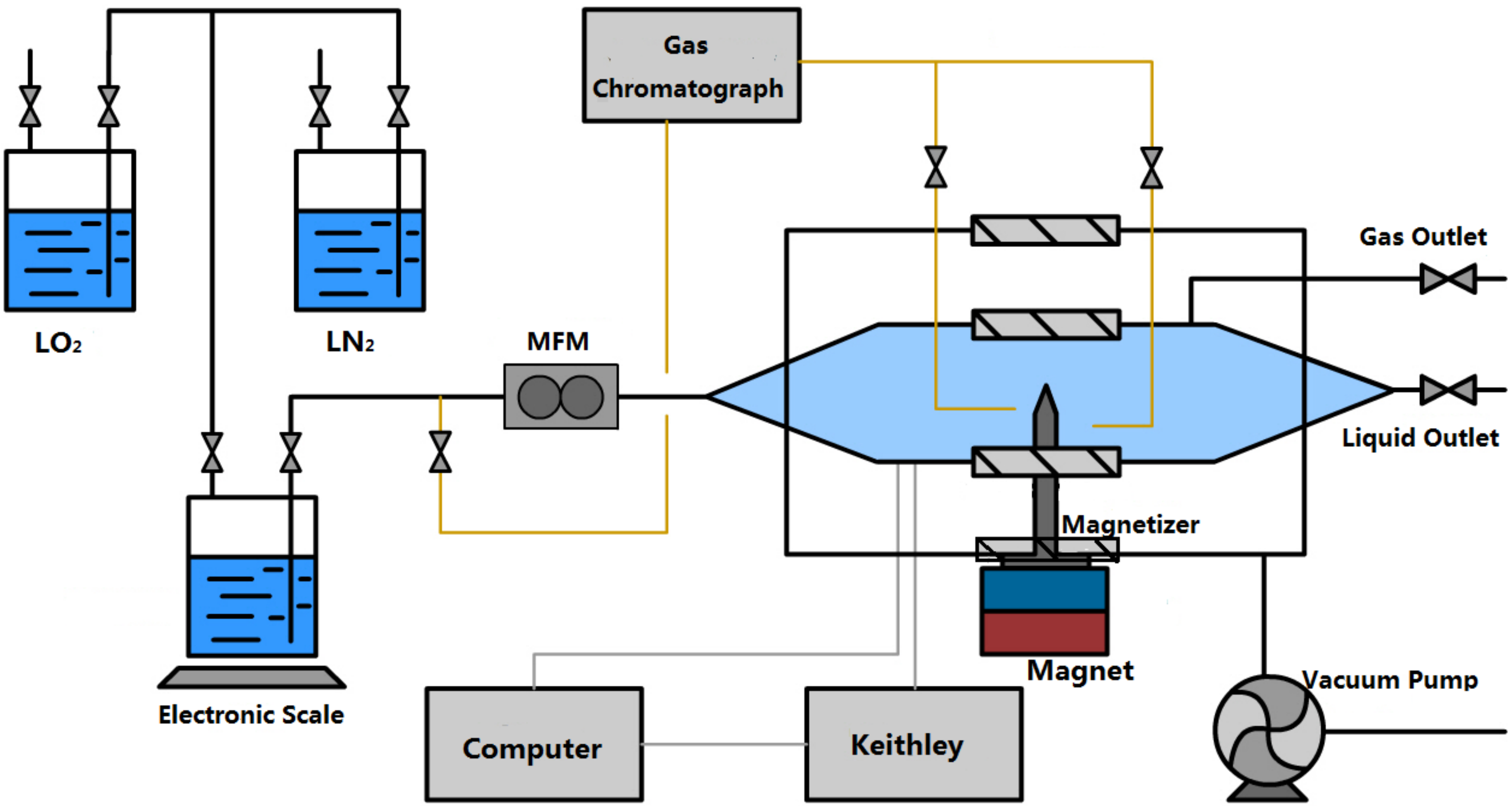
Laser interferometry *when coherent lights meet*

- Principle : fluid → refractive index → optical path difference → interference pattern
- Application: accurate scale measurement, gas/liquid concentration measurement (T≈300K)
- Advantage: undisturbed, accurate, two-dimensional

Question: Why not apply it to the cryogenic fluid?

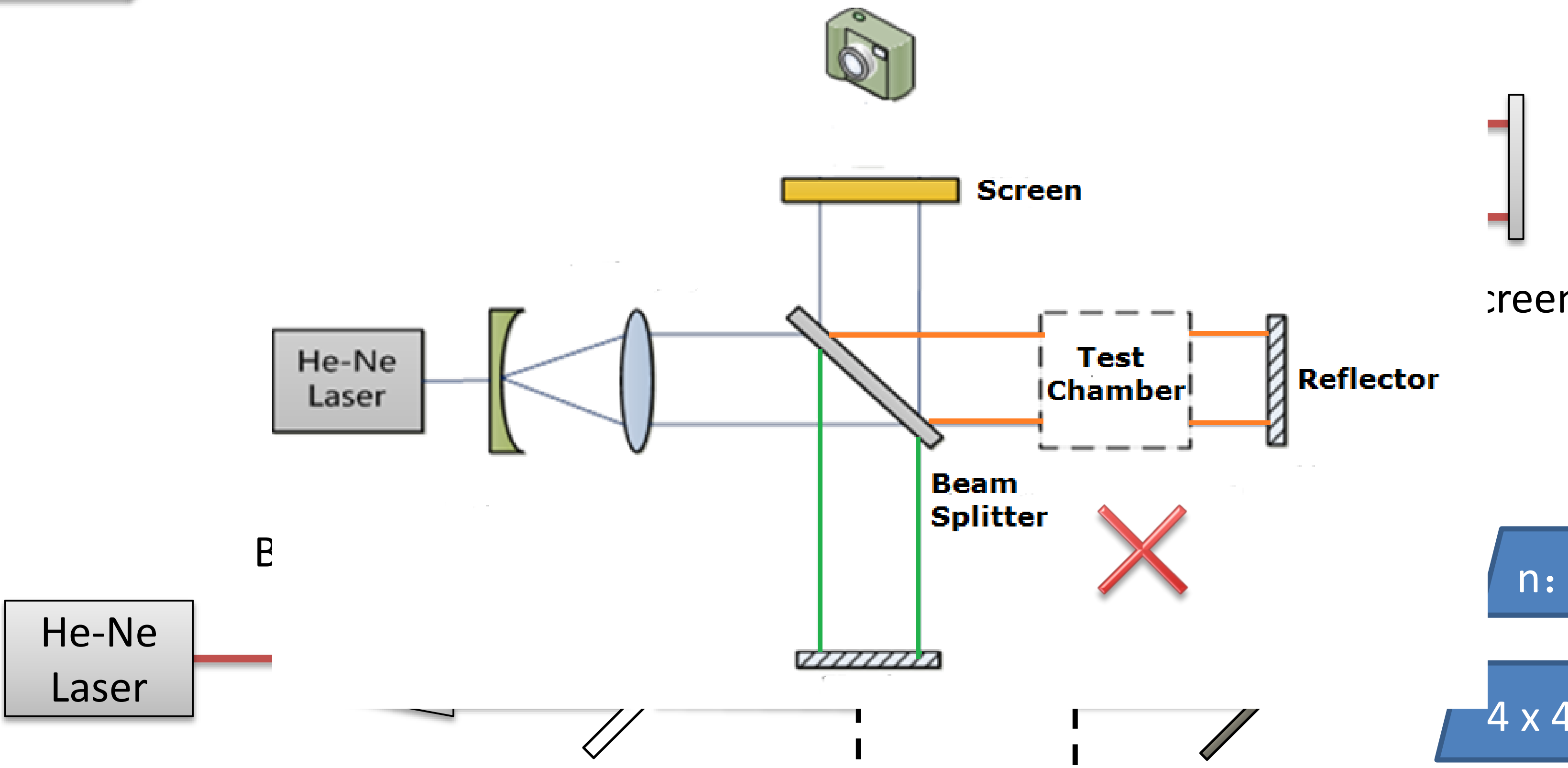
seal
heat insulation
} problems ⟺ **contradiction** requirement: visualization

Experimental setup



System flowchart

Optical system



Michelson interferometer

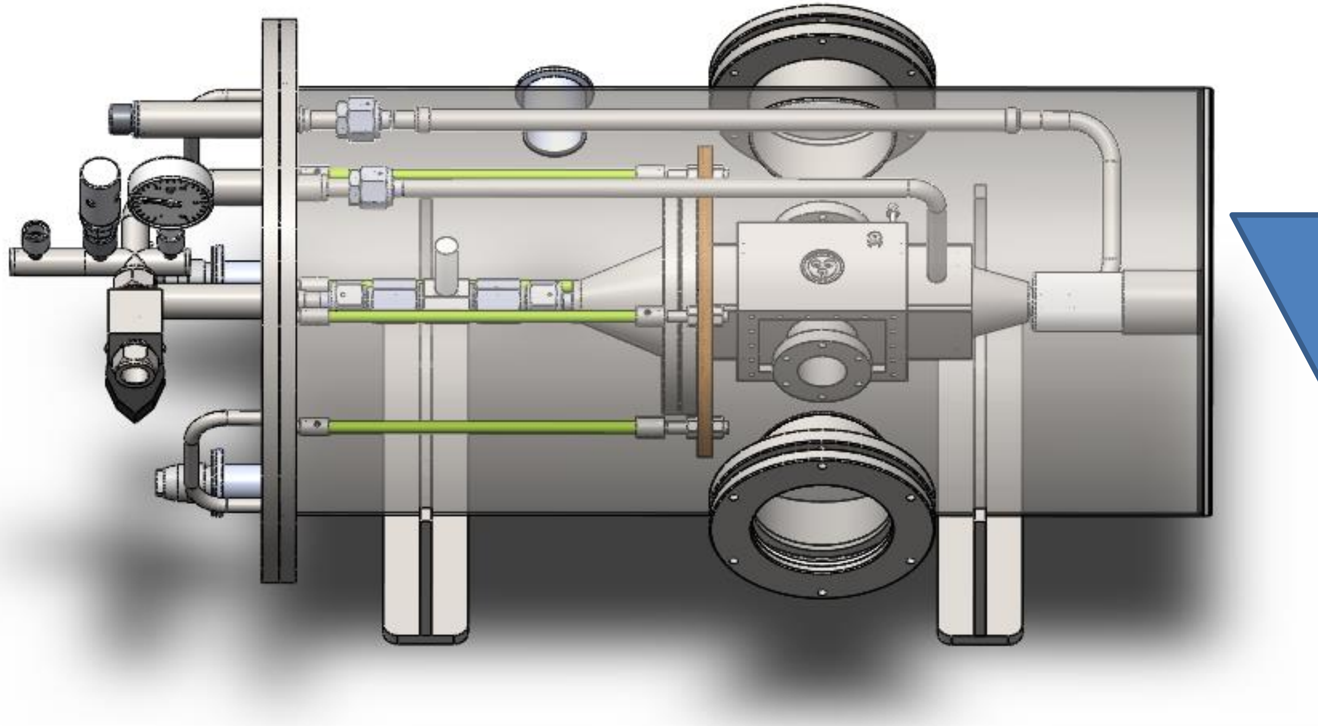
Mach-Zehnder interferometer

n: 1

4 x 45°

equal-height

Cryogenic system



Visual testing chamber

Key details

Glasses:
high transmittance
mutual parallel

Heat
insulation
vacuum :10^{-4}

Shock
insulation

Cryogenic system

Inner window

glass-ceramic seal welding with kovar

oxygen-free copper gasket

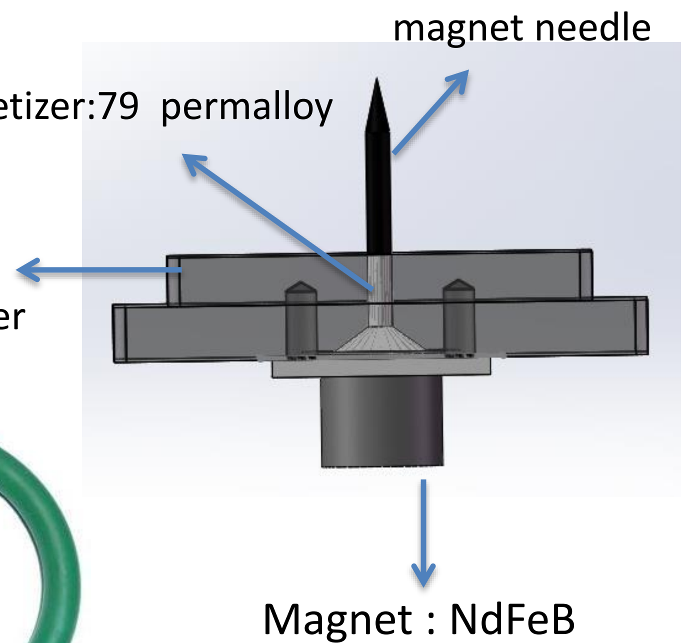
Outer window

PTFE gasket

quartz glass

fluorine rubber O-ring

Magnetic field



Calculation

binary mixture refractive index calculation

$$\frac{n^2-1}{n^2+2} = x_1 \frac{{n_1}^2-1}{{n_1}^2+2} + x_2 \frac{{n_2}^2-1}{{n_2}^2+2} \quad (1)$$

Lorentz–Lorenz formula

n, n_1, n_2—refractive index

x_1 , x_2 —volume fraction

$$\Rightarrow n=[x_1({n_1}^2 - {n_2}^2) + {n_2}^2]^{\frac{1}{2}} \quad (2)$$

$$\Rightarrow n'=\frac{1}{2}[x_1({n_1}^2 - {n_2}^2) + {n_2}^2]^{-\frac{1}{2}}({n_1}^2 - {n_2}^2) \quad (3)$$

What's the corresponding change of an interference fringe?

$\Delta n \cdot d = \lambda$

$\Delta x_1 \cdot n_x' = \lambda/d$

λ —laser wavelength

d—liquid thickness

$$\Delta x_1 = \frac{2\lambda}{d({n_1}^2 - {n_2}^2)}[x_1({n_1}^2 - {n_2}^2) + {n_2}^2]^{\frac{1}{2}} \quad (4)$$

n_1=1.221=n_{LO2}， n_2=1.205= n_{LN2}， λ=632nm， d=12.7cm

If x_1=0.5, Δx_1 = 3.1737*10^{-4}

Summary

A non-contact dynamic optical measurement system using laser interferometry are brought in to research the cryogenic fluid

- sensitive to subtle changes of cryogenic fluid concentration
- flexible to study the influence of gradient magnetic field on paramagnetic fluids

As there are rarely related researches, we have much more wok to do

- more refractive index data in low temperature are needed
- more experimental data to make a correction of Lorentz-Lorenz formula

THANK YOU!