부산대학교
PUSAN NATIONAL UNIVERSITY

AMOI
Advanced Manufacturing & Optical Instrumentation Lab

Advanced Manufacturing & Optical Instrumentation Lab.

첨단생산 및 광계측 실험실

Pusan National University

School of Mechanical Engineering

Prof. Yangjin Kim

Principal Investigator

Prof. Yangjin Kim, PhD

- Precision measurement
- Machine tool

Education

- **The University of Tokyo** — 04/2012 – 03/2015
  PhD in Mechanical Engineering
- **The University of Tokyo** — 04/2007 – 03/2009
  MS in Mechanical Engineering
- **The University of Tokyo** — 04/2003 – 03/2007
  BS in Mechanical Engineering

Experience

- **Pusan National University** — 09/2025 – Current
  Professor, School of Mechanical Engineering
- **Pusan National University** — 09/2020 – 08/2025
  Associate Professor, School of Mechanical Engineering
- **The University of Tokyo** — 03/2024 – 02/2025
  Associate Professor, Department of Mechanical Engineering
- **Pusan National University** — 09/2016 – 08/2020
  Assistant Professor, School of Mechanical Engineering
- **The University of Tokyo** — 02/2016 – 08/2016
  Assistant Professor, Department of Mechanical Engineering
- **The University of Tokyo** — 04/2015 – 01/2016
  Postdoctoral Researcher, Department of Mechanical Engineering
- **Korea Institute of Machinery and Materials** — 02/2009 – 03/2012
  Technical Research Personnel (Military Service)

Interferometric Measurement

Target sample

+

Interferometer

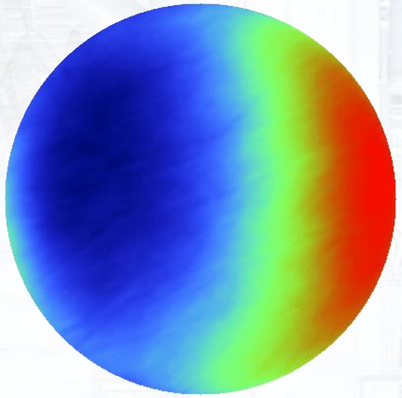
→

Fringe pattern

→

Phase extraction

Geometric properties

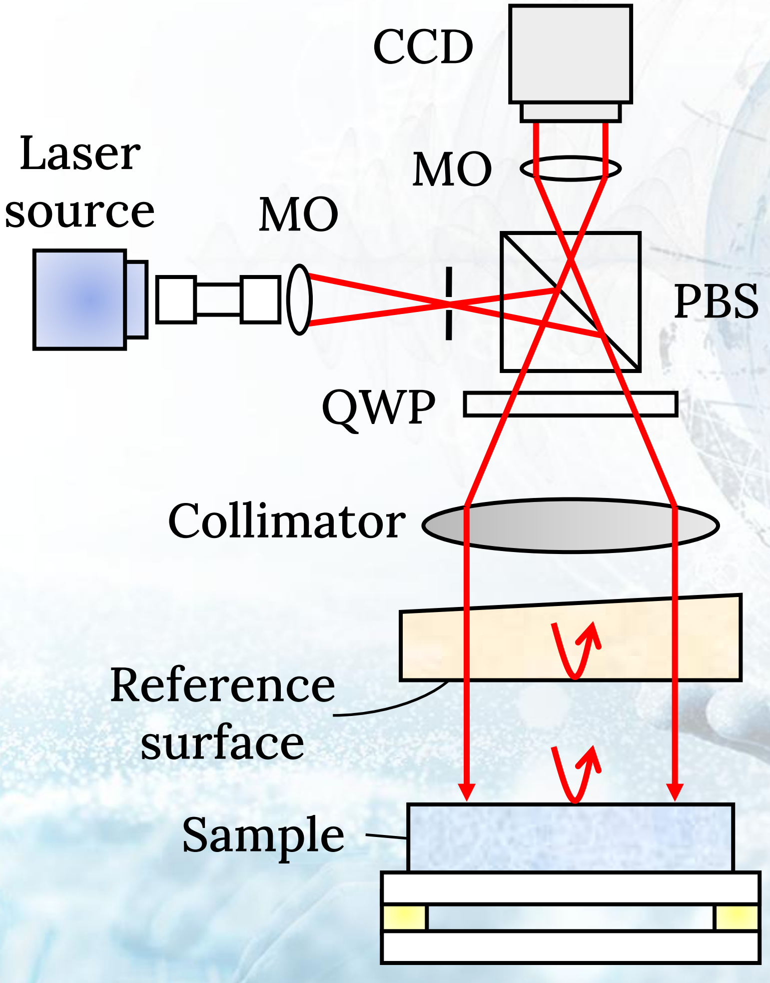


Hardware system

Software system

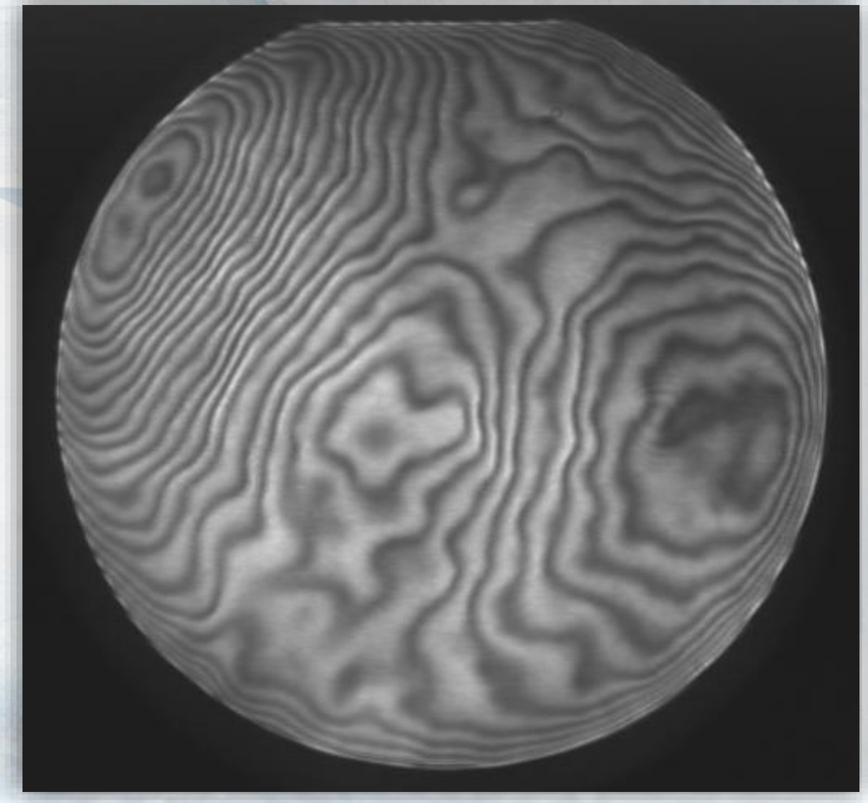
- High accuracy (excellent measurement uncertainty)
- Low cost (large-aperture measurement: Fizeau interferometer)
- Non-contact testing
- Simultaneous measurement (thickness & surface shape...)

Hardware System: Fizeau Interferometer



- Less susceptible to air disturbance
- Easily scalable for large-aperture measurements

- Interference fringe pattern (sample: silicon wafer)



$$I(x,y) = I_0(x,y) + I_1(x,y)\cos\varphi(x,y)$$

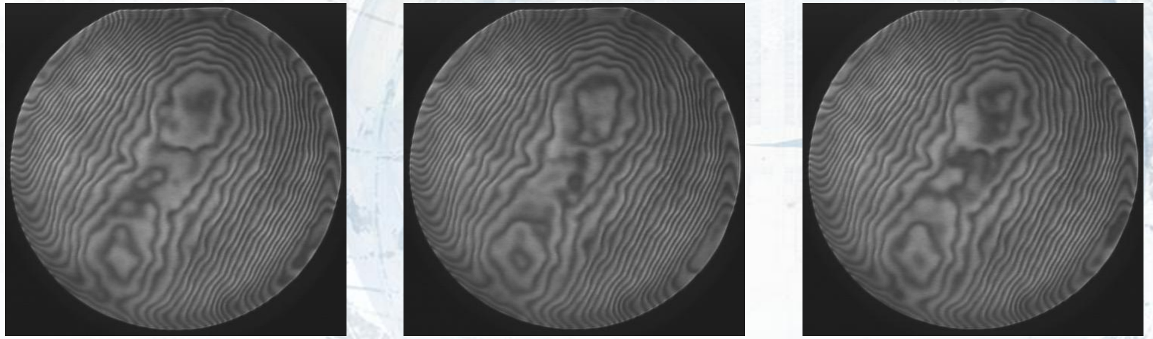
$\varphi(x, y)$: information about surface shape

Software System: Phase Extraction

AMOI
Advanced Manufacturing & Optical Instrumentation Lab

$$I(\alpha_r) = I_0\left[1+\gamma\cos(\alpha_r - \varphi)\right]$$

3 variables → Minimum **3** fringe patterns



Phase Extraction φ

Phase-shifting technique

- Fringe patterns (~ 50)
- Environmental uncertainties
- Commercialized (ZYGO)

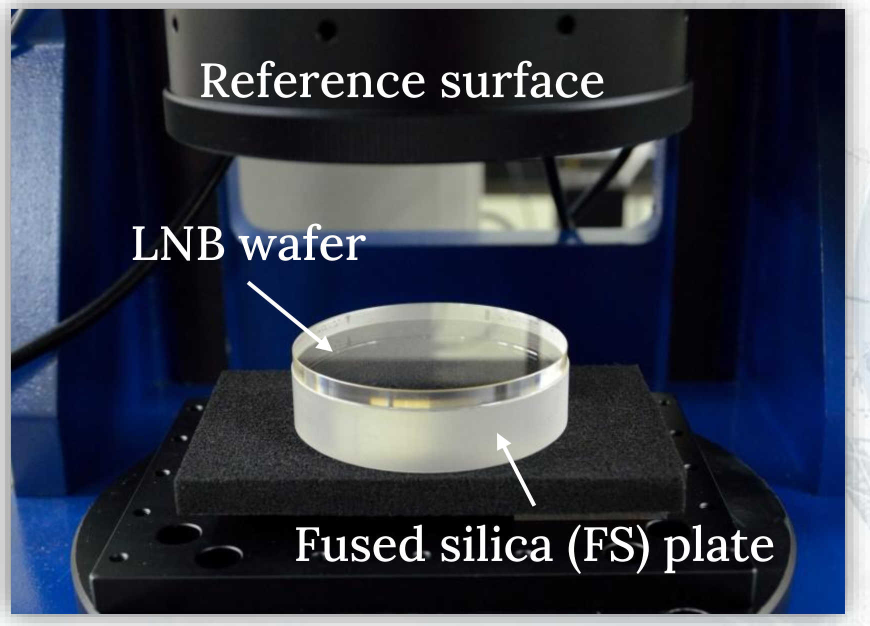
Iterative analysis

- Fringe patterns (~ 10)
- Error from singular matrix
- Not commercialized

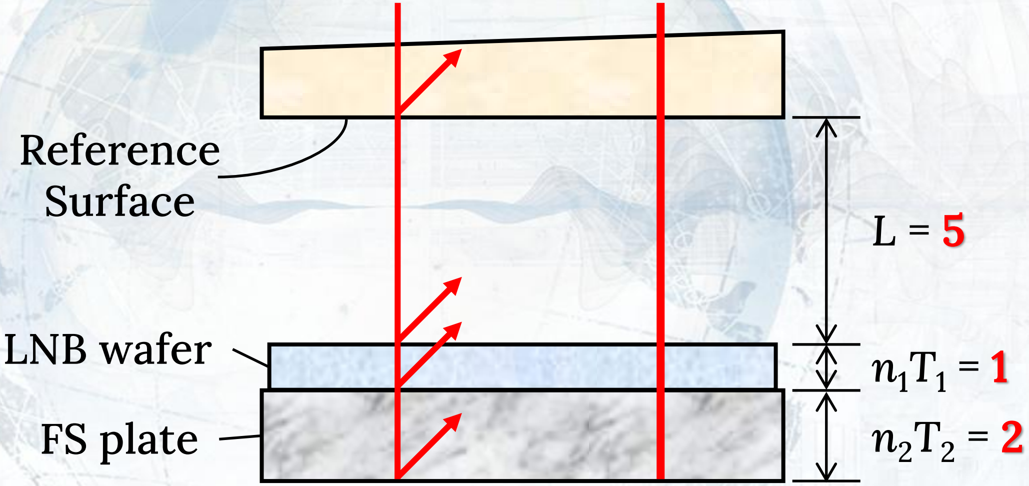
Machine learning method

- Fringe patterns (only 1 & 2)
- Excellent accuracy
- Optimization error

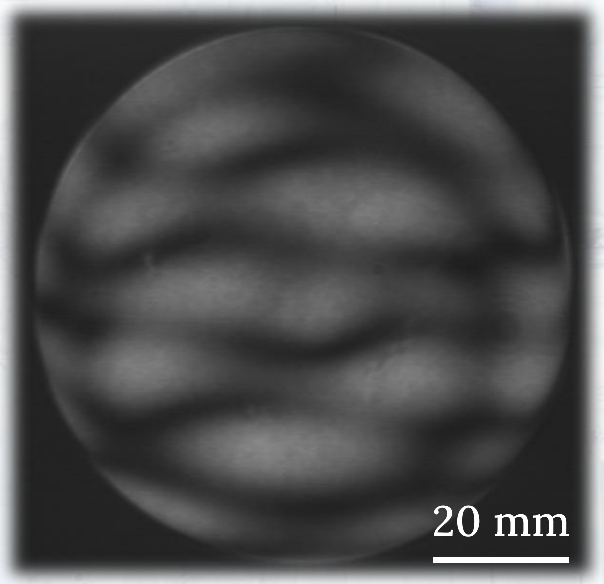
Application : Multi-Layer Interferometry



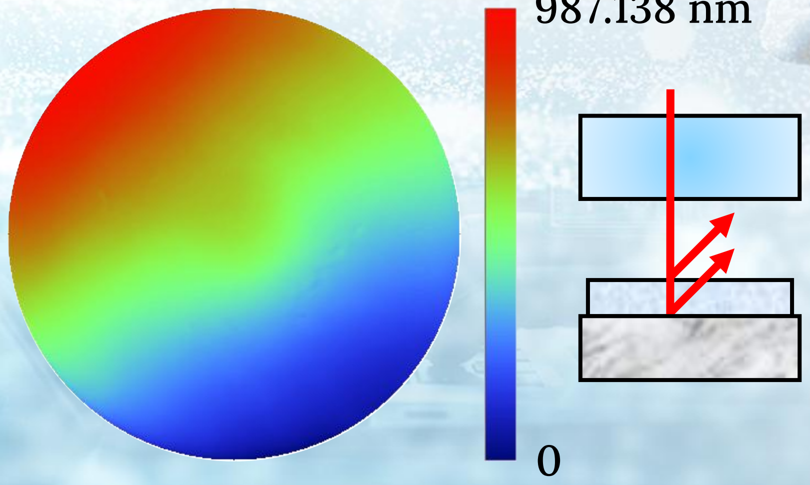
- 6 different fringe patterns ($_4C_2 = 6$)



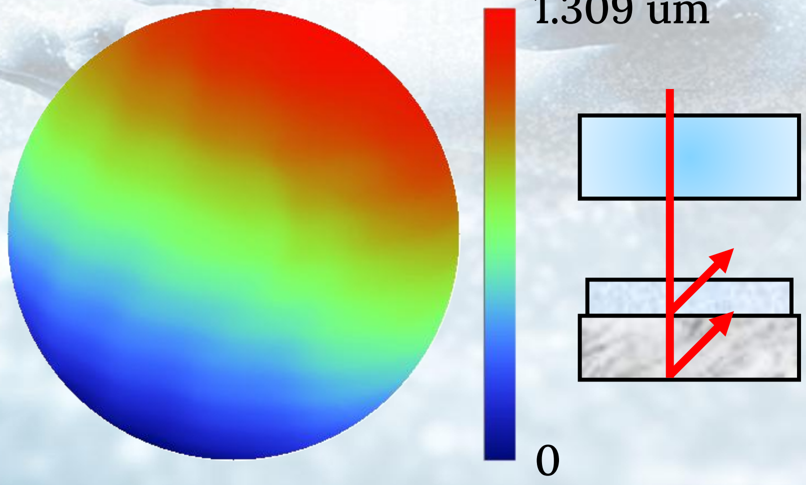
Raw fringe pattern



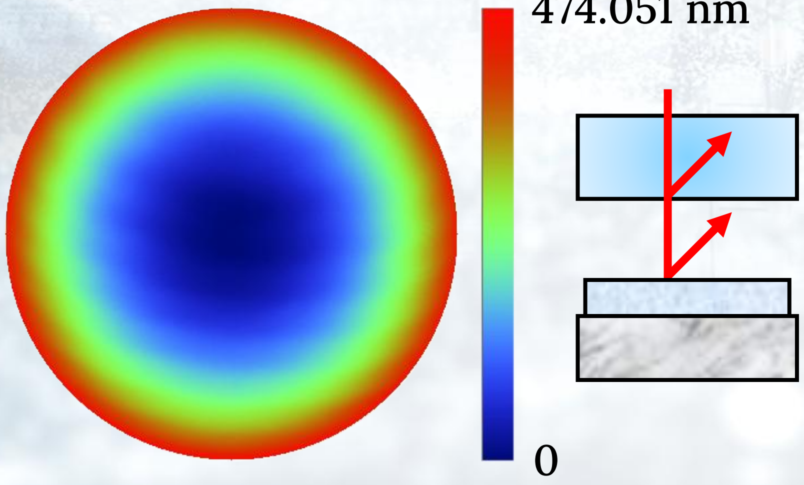
- Thickness (LNB)



- Thickness (FS)

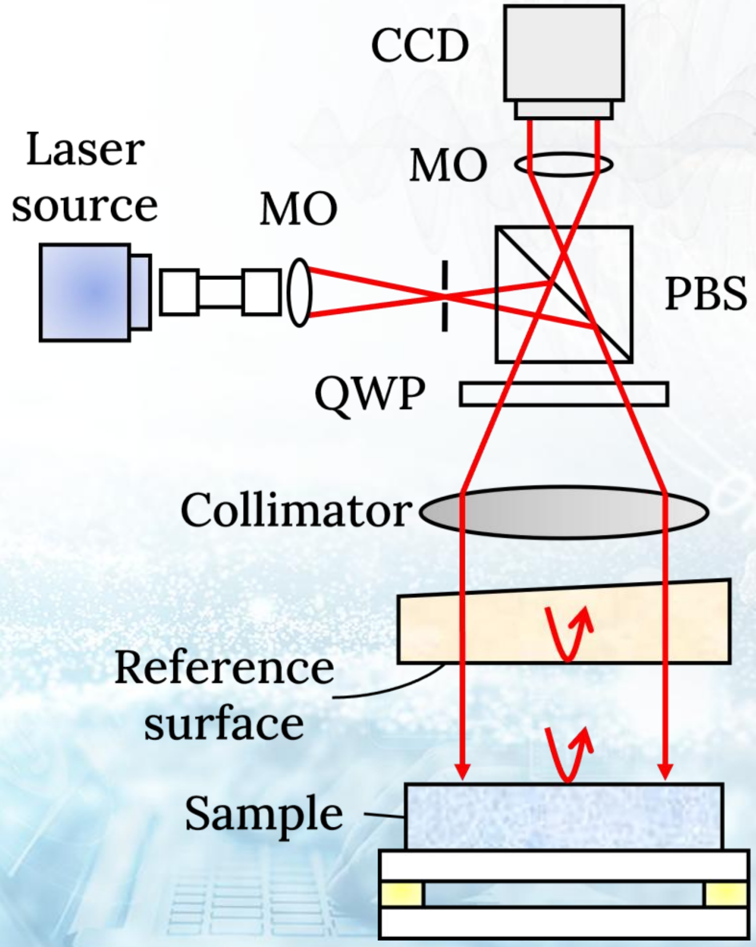


- Surface (LNB)



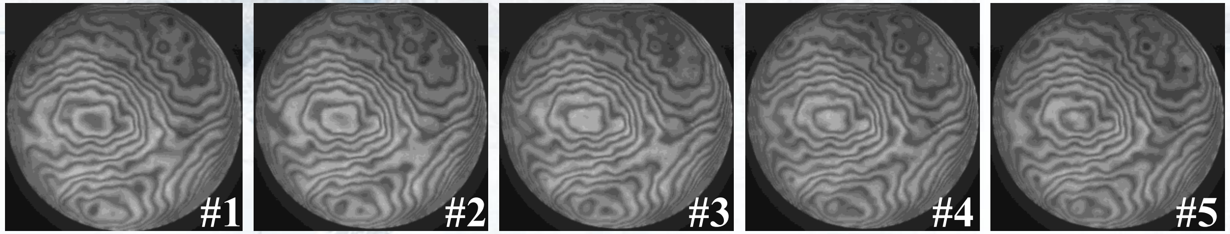
Application: Surface Profiling of Silicon Wafer

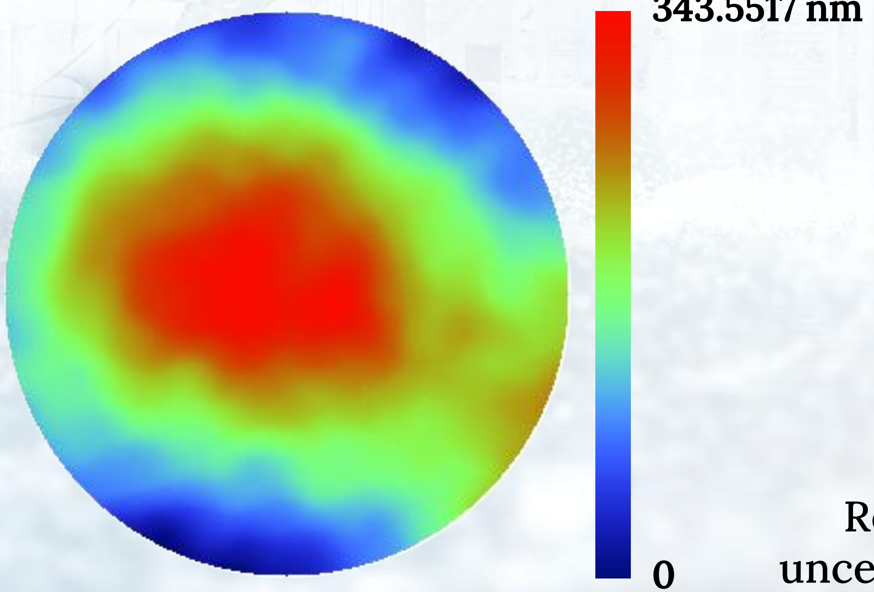
- **Larger-aperture Fizeau interferometer**



Reflectivity: 30%

- **Surface profiling of silicon wafer**
  - Surface of the four-inch silicon wafer was obtained by using the harmonic phase-iterative analysis and five-frame interferograms.





Repeatability uncertainty: 2.6 nm

Approaches using Machine Learning Method

AMOI
Advanced Manufacturing & Optical Instrumentation Lab

1 Pre-Processing

- Fringe pattern *denoising* process considering the second harmonics

2 Phase Extraction

- Deep learning-based phase extraction using 2 fringe patterns
- AI based phase shifter (Deep learning method + Conventional phase-shifting techniques)

3 Applications

- Absolute optical thickness of transparent parallel glass plate
- Total thickness of silicon wafer

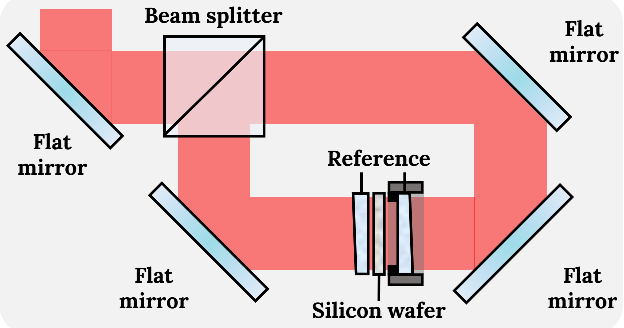
Application: TTV of Silicon Wafer

Advanced Manufacturing & Optical Instrumentation Lab

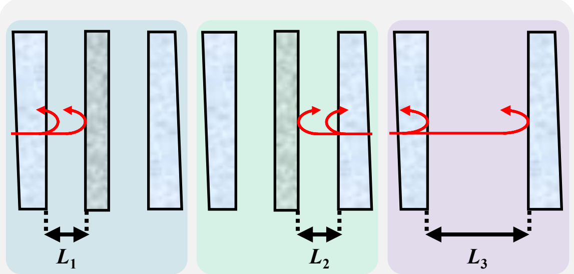
- Development of optical testing system of silicon wafer TTV based on deep learning

Research flow

- Testing for total thickness variation (TTV) of silicon wafer



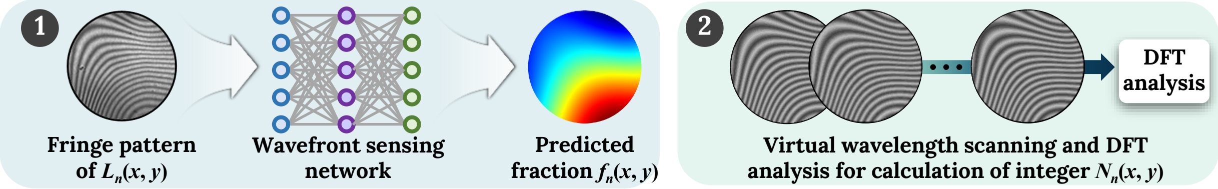
► 4-layer stage for testing silicon wafer TTV

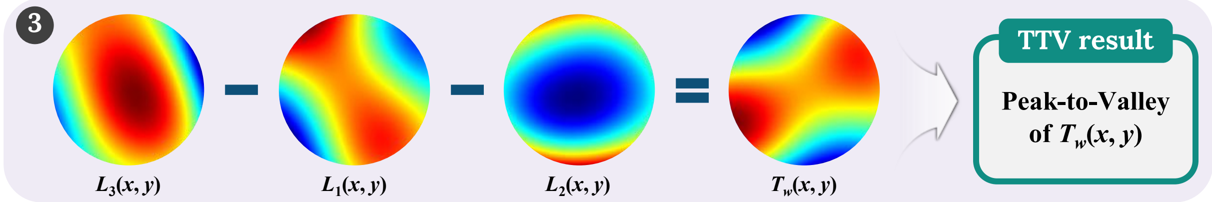


$$T_w(x, y) = L_3(x, y) - [L_1(x, y) + L_2(x, y)]$$

► Measurement process for TTV calculation

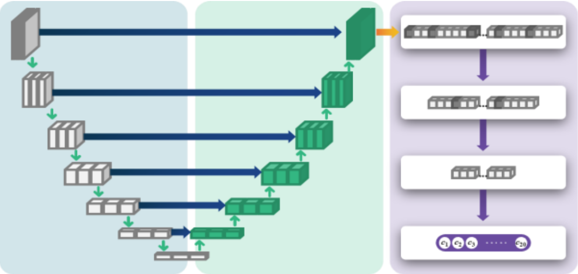
- Absolute distance measurement method



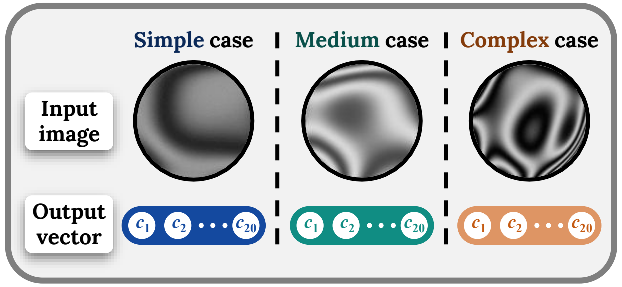


Absolute distance measurement

- Fraction calculation based on deep learning

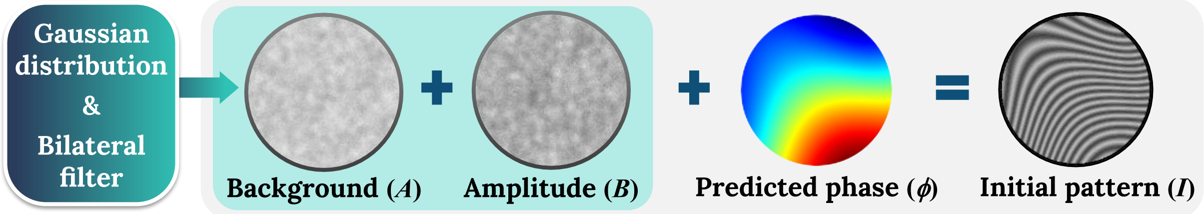


► One-frame wavefront sensing network

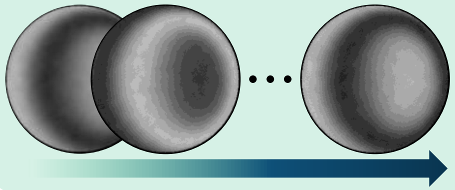


► Learning data based on Zernike polynomial

- Integer calculation based on virtual wavelength scanning



Virtual wavelength scanning



$$I(x,y) = A(x,y) + B(x,y)\cos[\delta(\lambda) - \phi(x,y)]$$

$$\delta[\lambda(n)] = 2\pi(N_1 - N_2 + f_1 - f_2)\frac{\lambda(n) - \lambda_1}{\lambda_2 - \lambda_1}$$

$$\lambda(n) = \lambda_1 + \Delta\lambda(n-1) \quad \Delta\lambda = (\lambda_2 - \lambda_1)/(M-1)$$

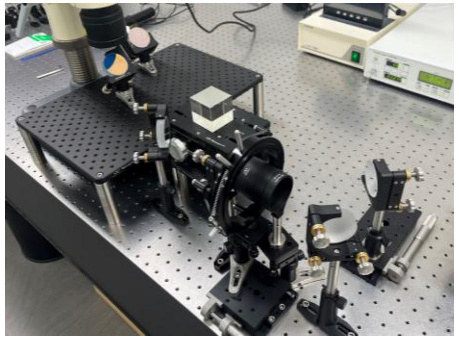
- ✓ δ: Linear phase shift
- ✓ M: Total fringe number
- ✓ λ_1: Initial wavelength
- ✓ λ_2: Final wavelength

Application: TTV of Silicon Wafer (Cont.)

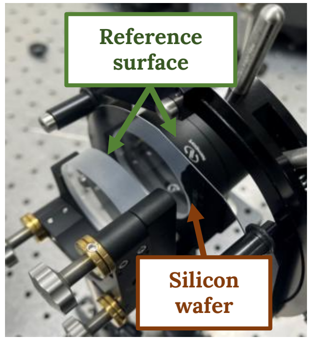
- Development of optical testing system of silicon wafer TTV based on deep learning

Experiment and verification

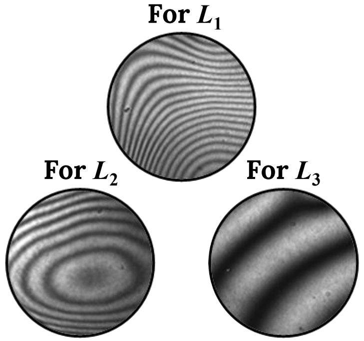
- 4-layer stage design and interference experiments



▶ Optical setup of 4-layer stage



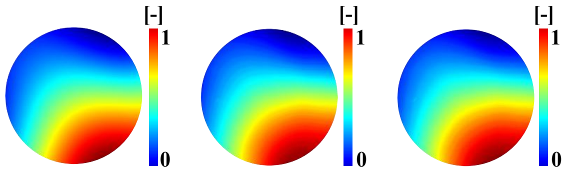
▶ Interference mechanism



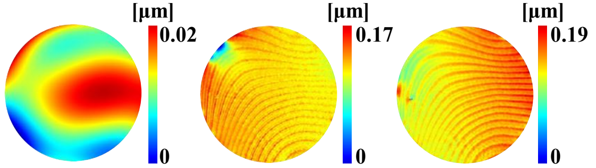
▶ Fringe patterns for each part

- Verification of methods in the proposed method

Wavefront sensing using deep learning

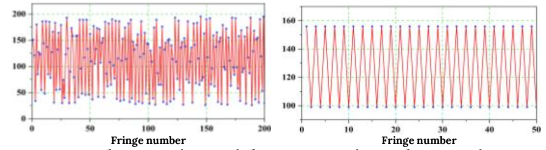


▶ $f_1(x, y)$ by DL ▶ $f_1(x, y)$ by AIA ▶ $f_1(x, y)$ by PSA

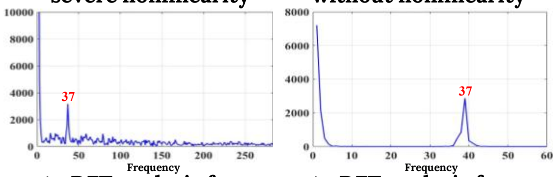


▶ Residual by DL ▶ Residual by AIA ▶ Residual by PSA

Virtual wavelength scanning method



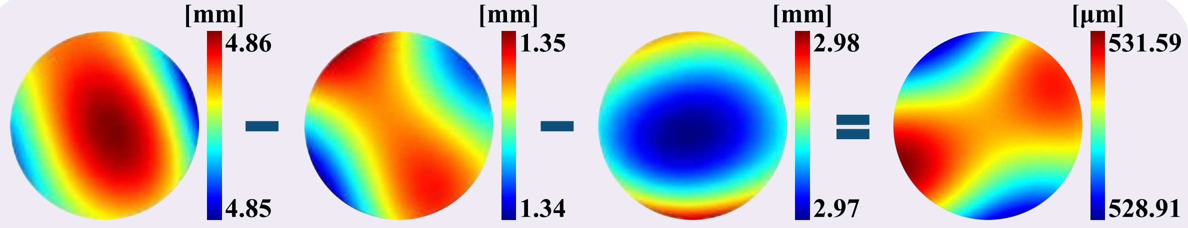
▶ Actual scanning with severe nonlinearity ▶ Virtual scanning without nonlinearity



▶ DFT analysis from actual scanning ▶ DFT analysis from virtual scanning

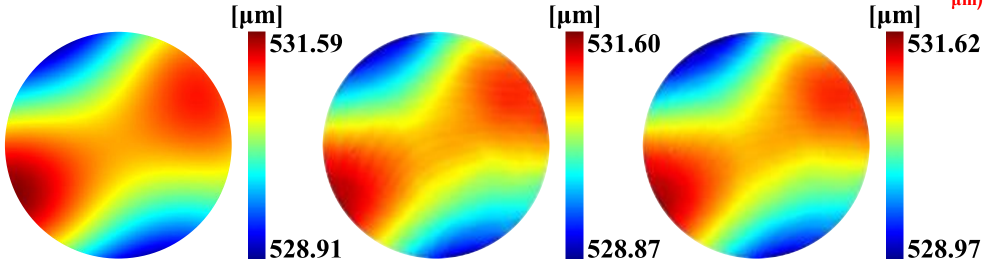
Measurement results

- Results of total thickness measurement of proposed method



▶ Measured $L_3(x, y)$ ▶ Measured $L_1(x, y)$ ▶ Measured $L_2(x, y)$ ▶ Measured $T_w(x, y)$

- Comparison with existing methods (Wafer Spec. : Thickness = 525±25 μm, TTV < 10 μm)



▶ Total thickness of silicon wafer by DL ▶ Total thickness of silicon wafer by PSA ▶ Total thickness of silicon wafer by AIA

	TTV [μm]
DL	2.69
AIA	2.65
PSA	2.73

	DL	AIA	PSA
Nonlinearity	X	O	O
Standard deviation [nm]	0.80	6.49	7.26

	DL	AIA	PSA
Total fringe number	3	1719	1722
Compensation	X	O	O

CFRP Machine Tools

AMOI
Advanced Manufacturing & Optical Instrumentation Lab

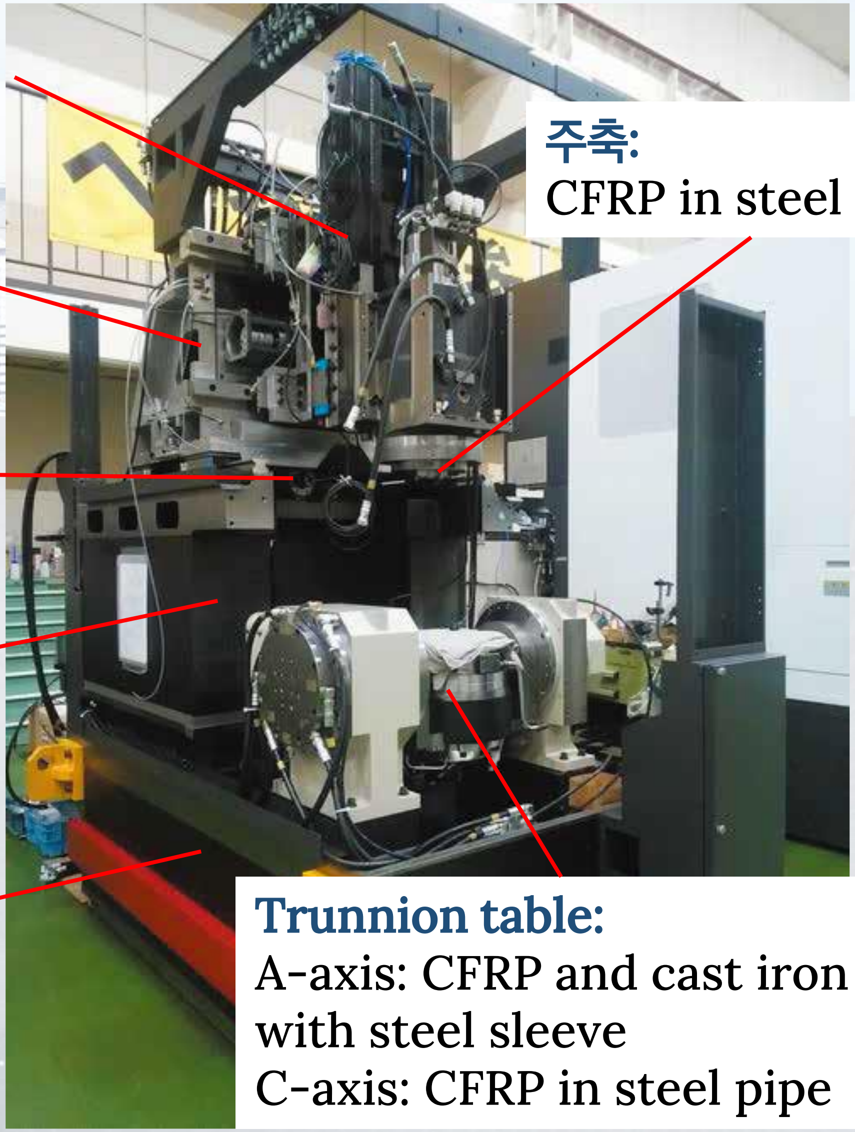
램:
CFRP in steel square pipe

새들:
CFRP + Aluminum alloy

이송축:
CFRP in steel pipe

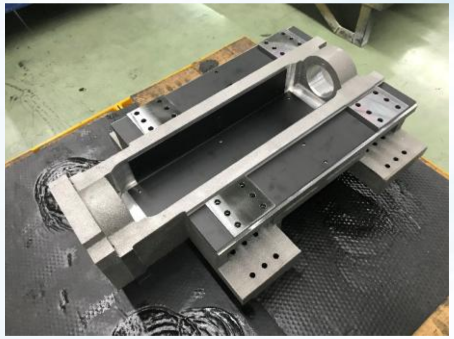
칼럼:
CFRP & REC in gray cast iron

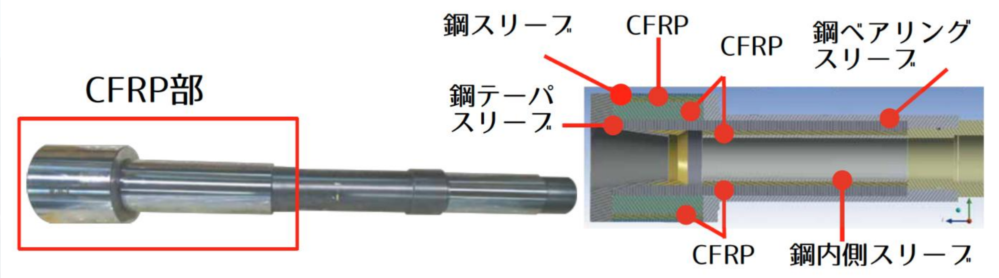
베드:
CFRP & REC in gray cast iron

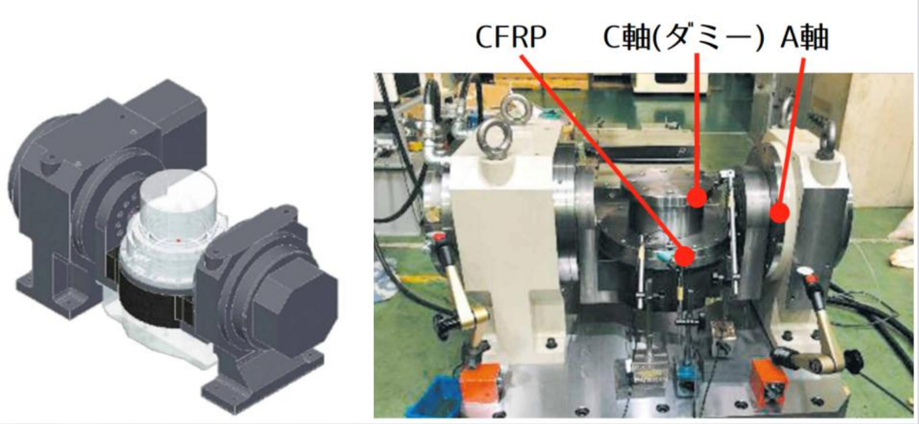


주축:
CFRP in steel pipe

Trunnion table:
A-axis: CFRP and cast iron with steel sleeve
C-axis: CFRP in steel pipe



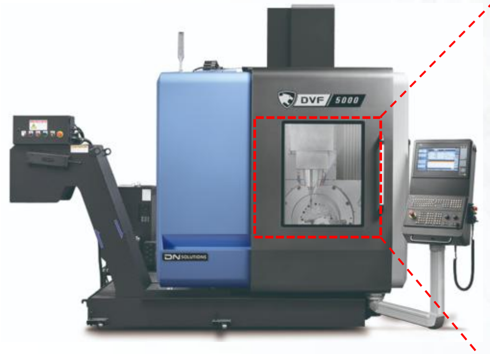




5축 공작기계 오차 보정

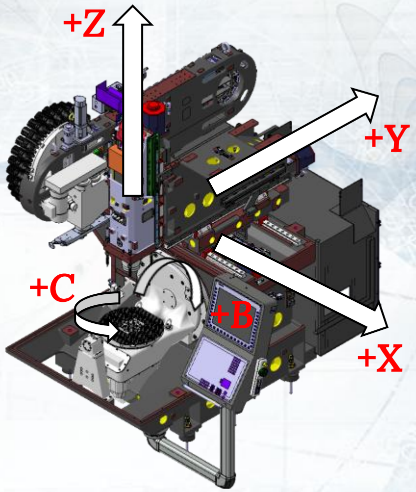
AMOI
Advanced Manufacturing & Optical Instrumentation Lab

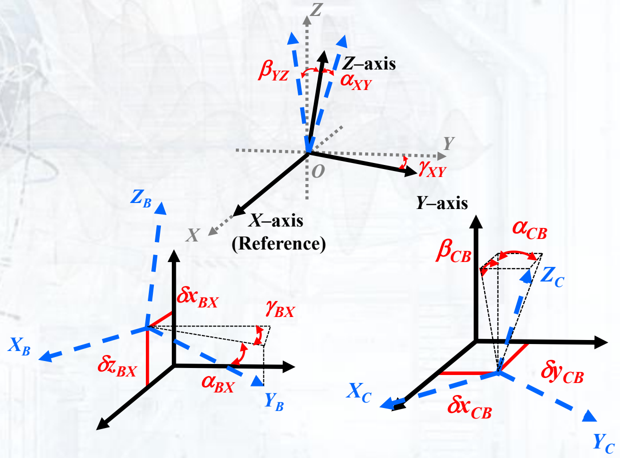
- 5-Axis machine tool



DVF 5000 (DN Solutions)

- Kinematic error modeling



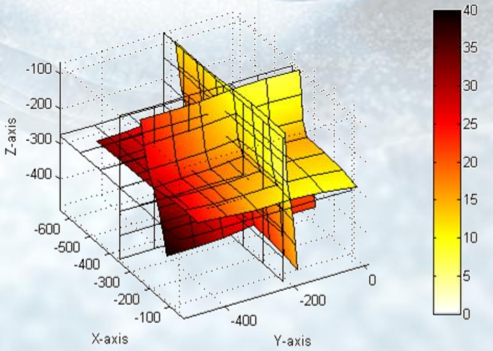


Kinematic error

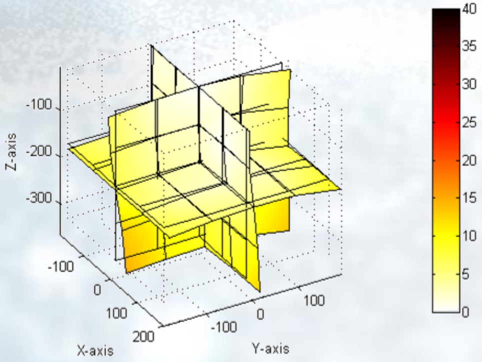
- Identification of kinematic error

Measurement cycle

- Compensation of volumetric error



Before compensation



After compensation