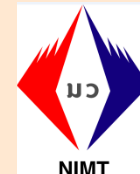
2016 APMP Mid-year Meeting

Technical Workshop: Semiconductor



Wafer Metrology at KRISS

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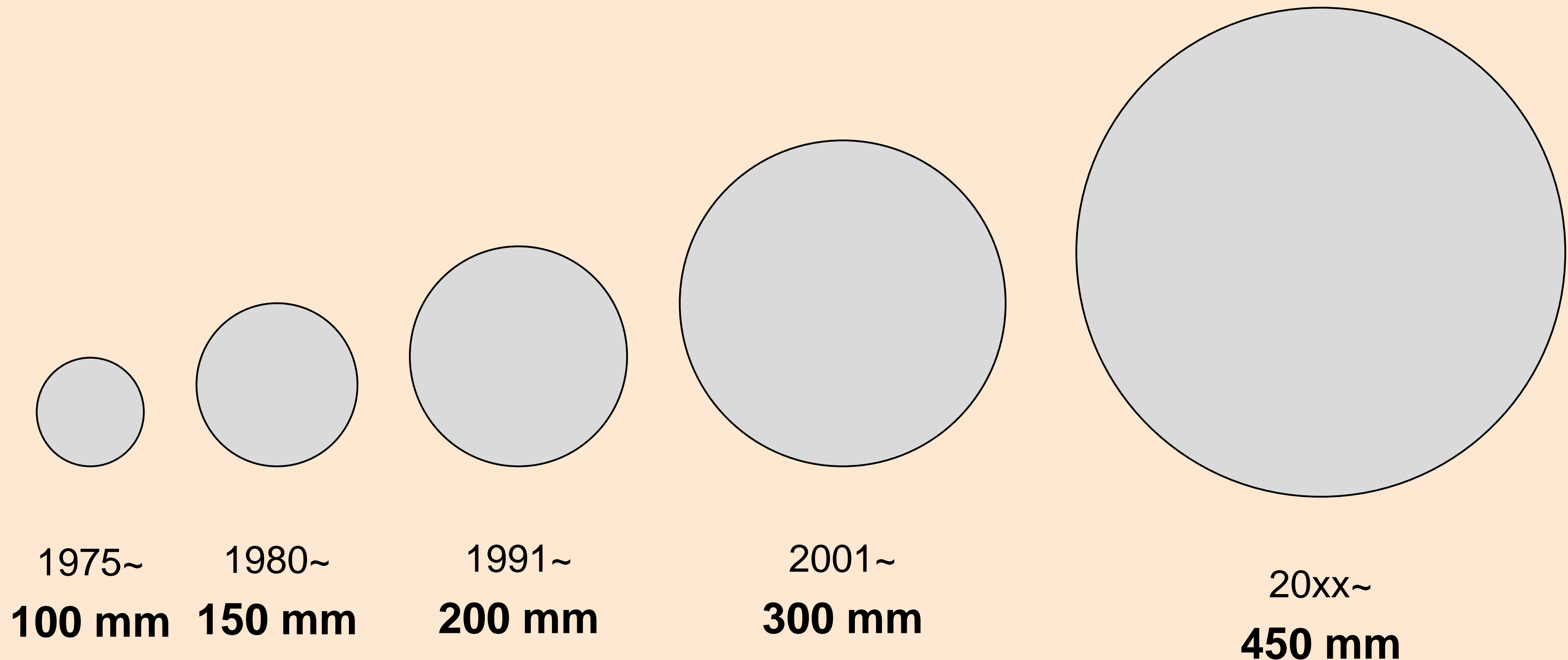
Outline

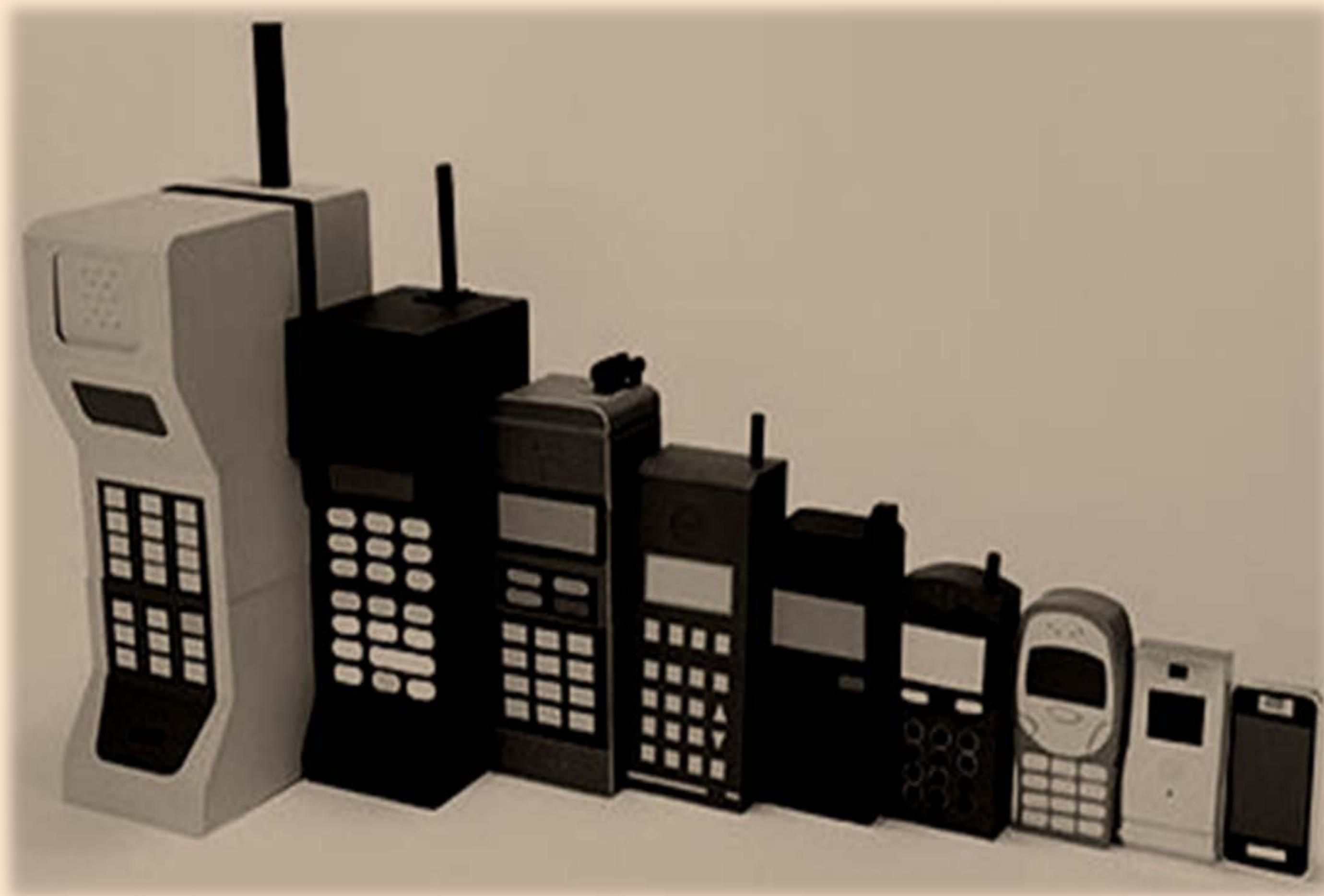
- Introduction
- Wafer metrology
  - wafer thickness
  - wafer thickness and refractive index
  - warpage (warp, bow, sori, etc)
  - depth of TSV (through silicon via)
  - diameter of TSV (through silicon via)

Evolution of silicon wafers

- Productivity $\propto$ (diameter)^2
- Size being larger (thickness < 1 mm)

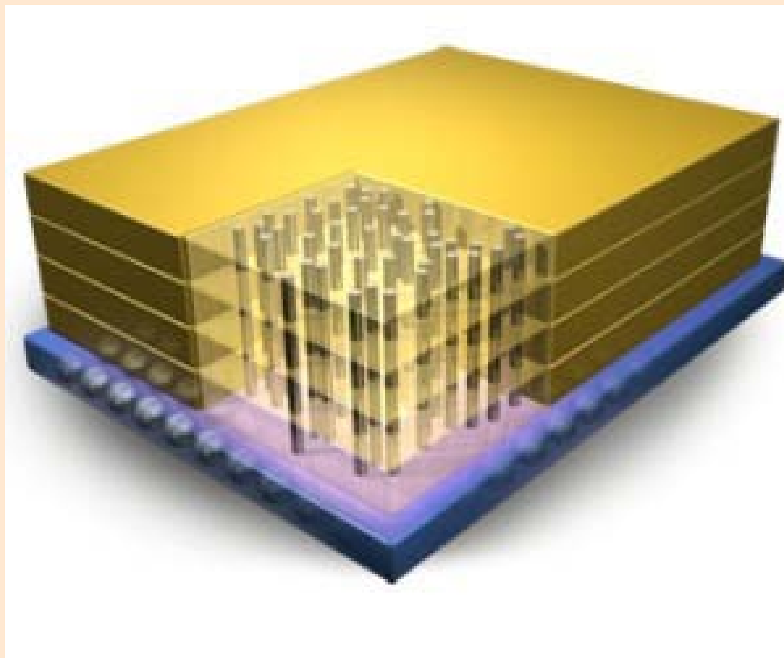


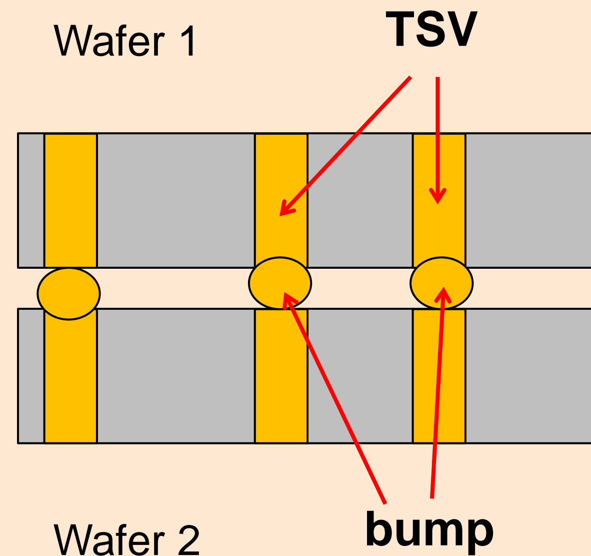
Compact size with high performance



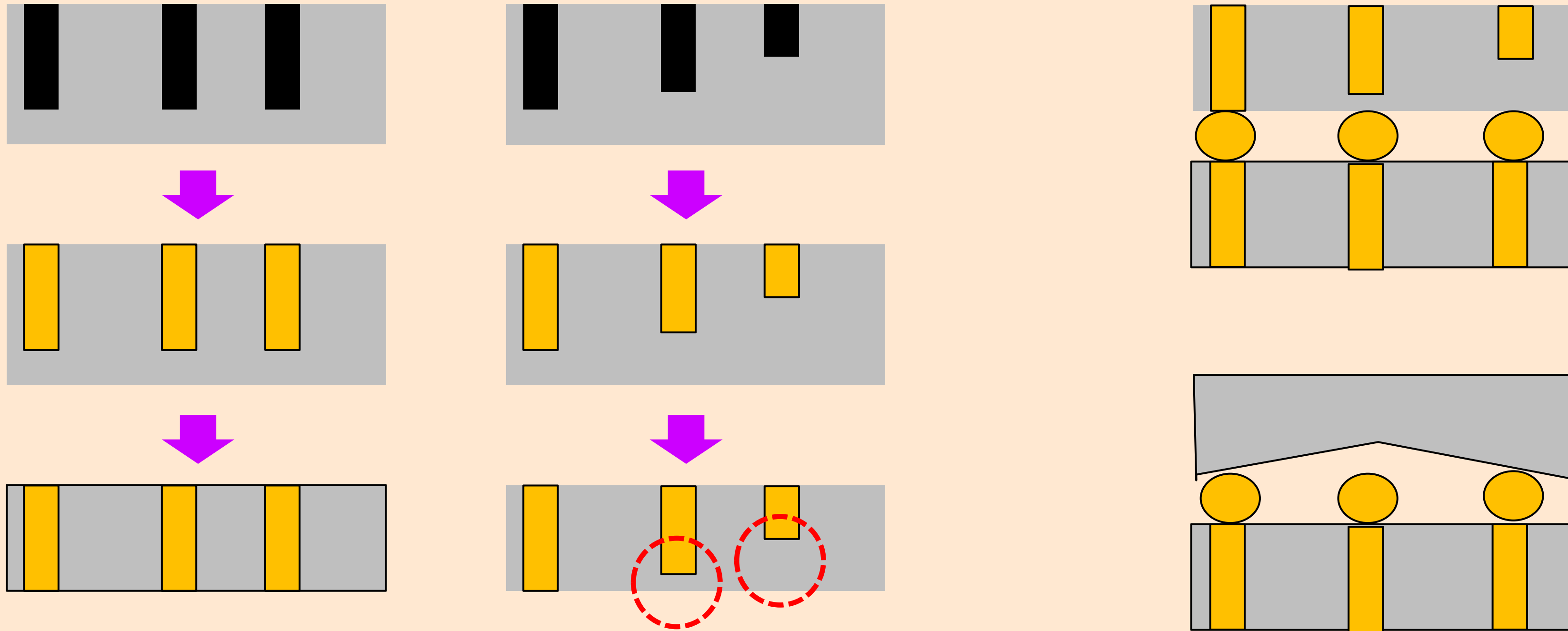
Wafer level packaging and TSV

- Solution: multi-level structure
  - wafer-level packaging
  - Wafer-on-wafer structure, Through-Silicon Vias (TSVs) and bumps replace wires





Wafer level packaging and TSV (2)



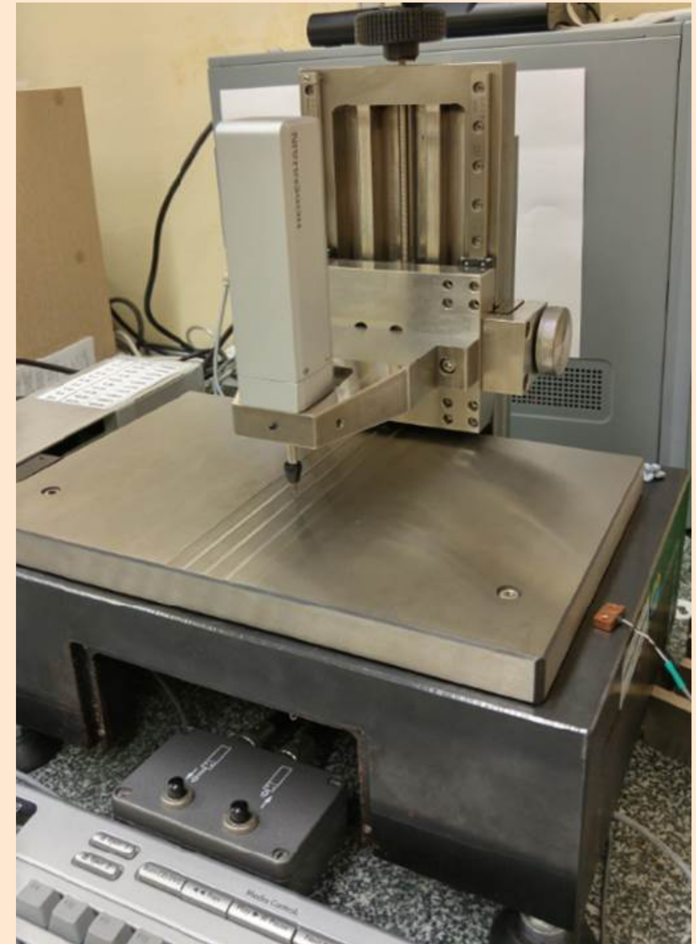
- Measurement of thickness profile and warpage is important
- Measurement of depth and diameter of TSVs is important

Wafer thickness measurement

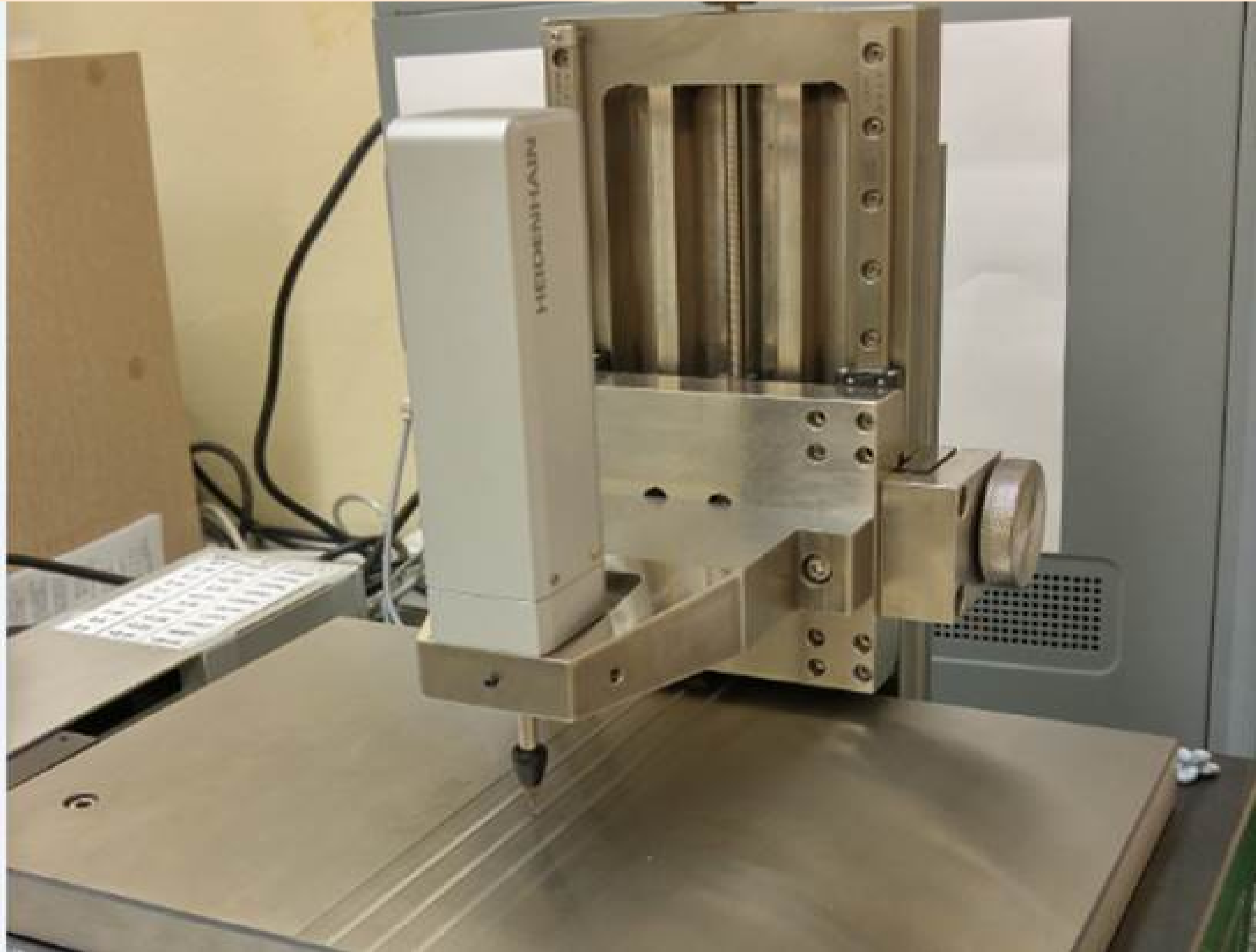
1. Mechanical measurement system

Mechanical measurement of thickness

- Contact type measurement
  - high precision length gauge
  - 2-probe system
  - uncertainty (k=2)
    - 50 nm (single point)



Mechanical measurement of thickness (2)



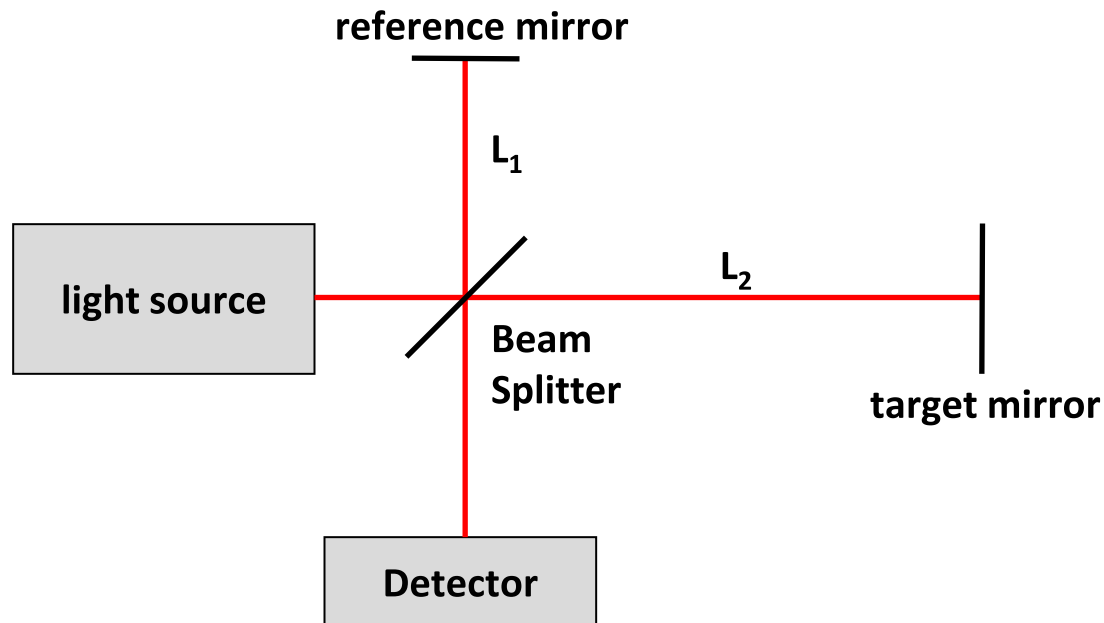
Mechanical measurement of thickness (3)

- Strong point:
  - high precision measurement of "**geometrical thickness**"
  - good for small area measurement
- Weak point:
  - limited measurement range
  - not efficient for whole area measurement of large wafers

Wafer thickness measurement

2. Michelson type spectral interferometer

Optical interferometer (1)



Interference intensity

$$I(z,f)=I_0\left[1+\cos\left(\frac{2\pi zf}{c}\right)\right]$$

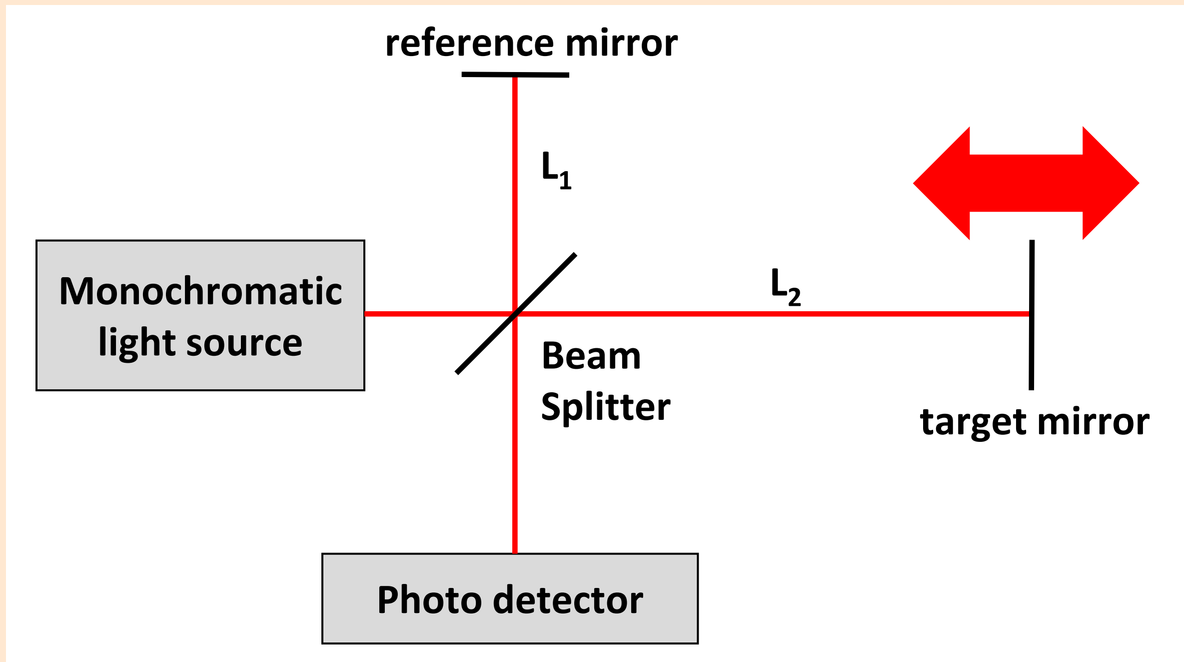
optical path difference (OPD)

$$z=2n(L_2-L_1)$$

- Interference intensity changes by
1. change in OPD (by moving one mirror)
2. change in frequency of light

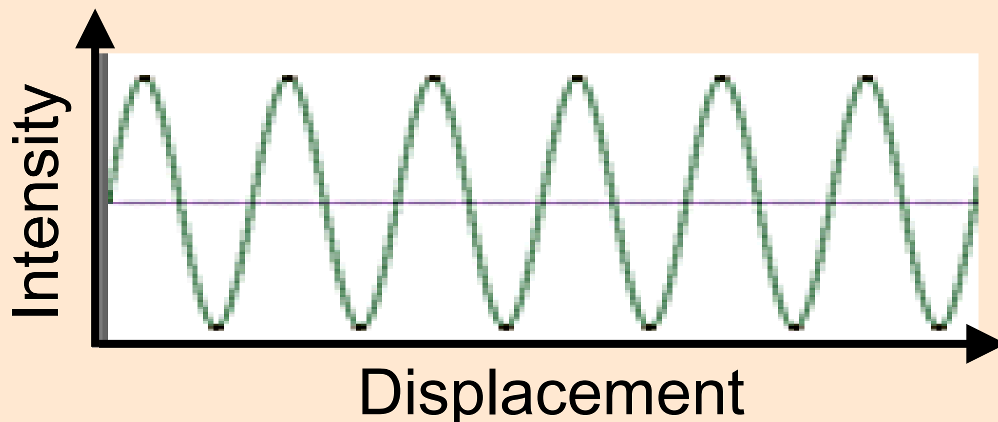
- c: speed of light in vacuum
- f: frequency of light
- n: refractive index of air

interferometer (2)



Change OPD by moving a mirror

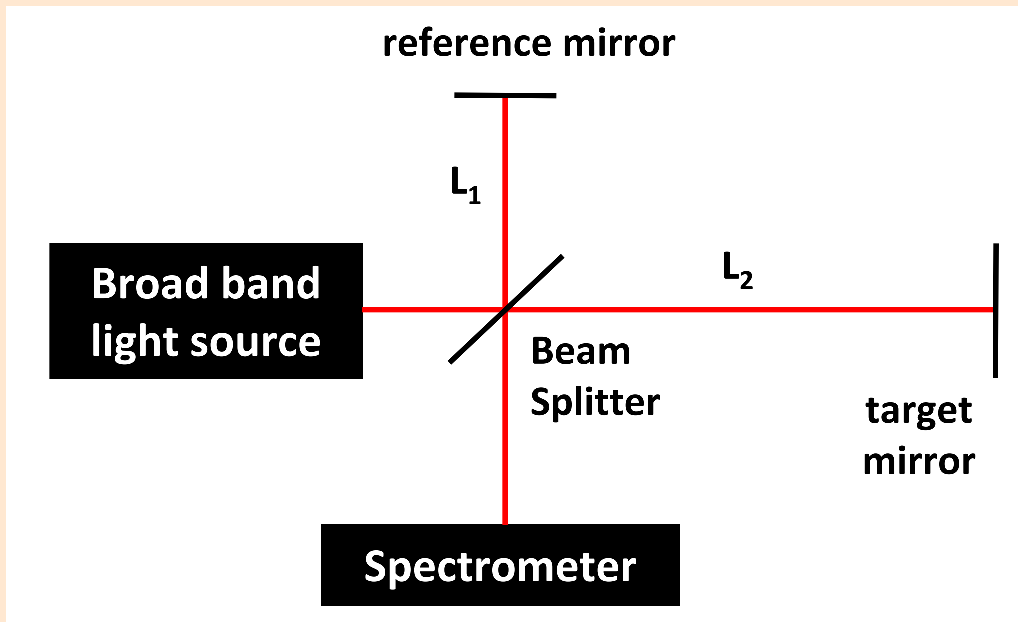
$$z = 2n(L_2 - L_1)$$



Interference intensity

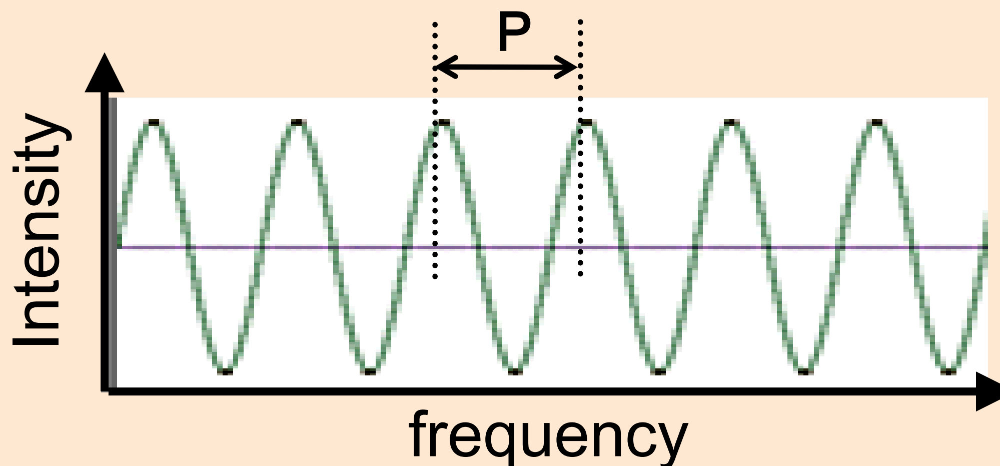
$$I(z, f) = I_0\left[1 + \cos\left(\frac{2\pi z f}{c}\right)\right]$$

Spectral interferometer (1)



- Tunable light source + photo detector
- Broad band light source + spectrometer
- (fixed optical path difference)

$$I(z,f) = I_0\left[1+\cos\left(\frac{2\pi f}{c/z}\right)\right]$$

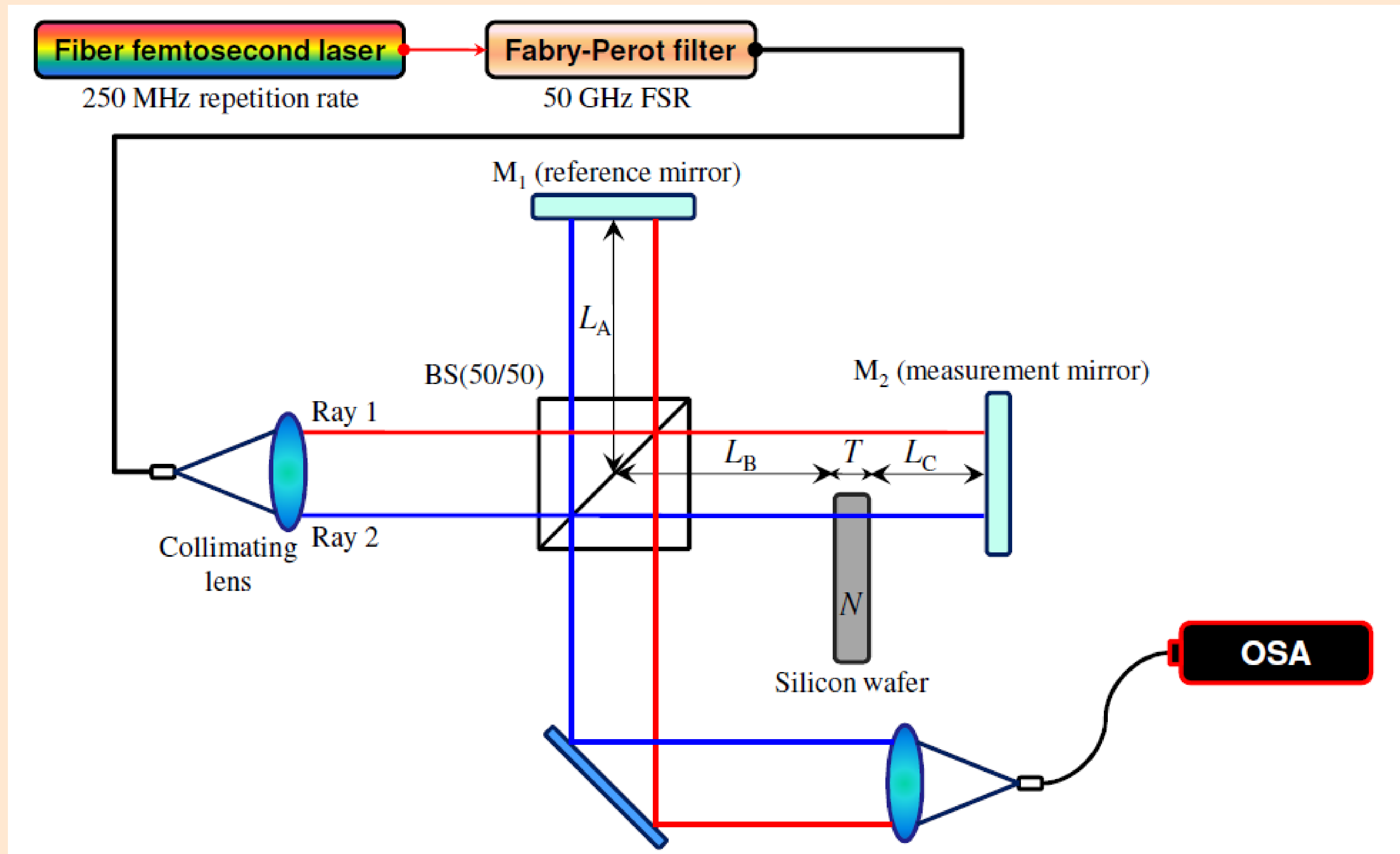


FFT

$$P = \frac{c}{z}$$

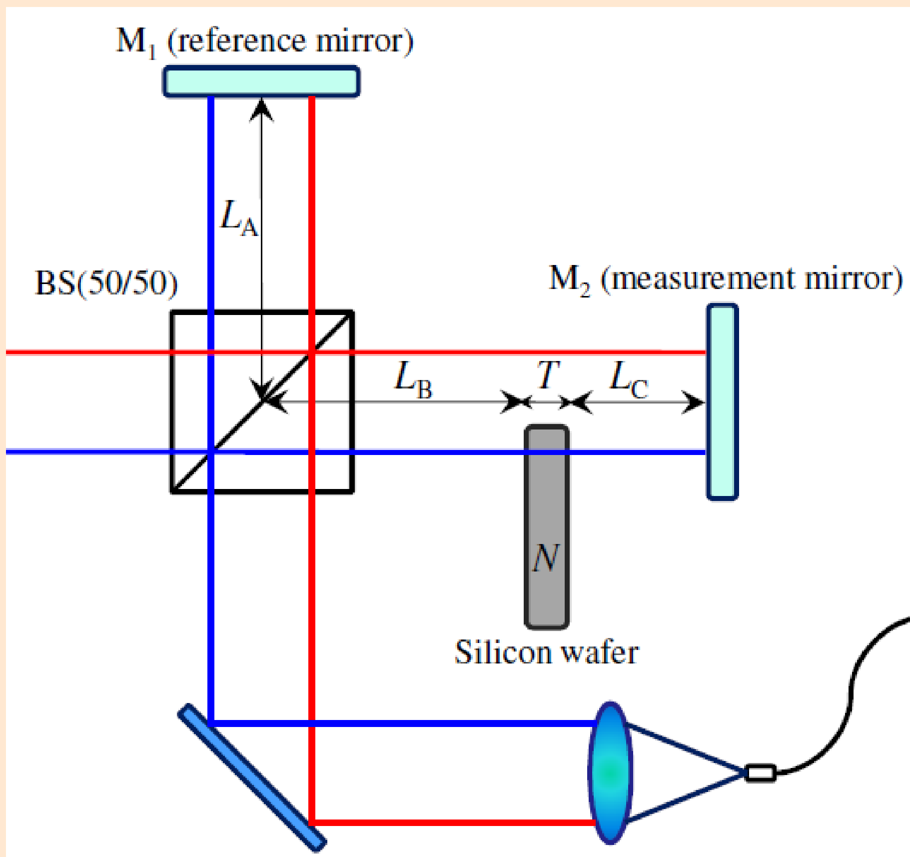
$$z = \frac{c}{P}$$

Schematic of spectral interferometer



BS: beam splitter, OSA: optical spectrum analyzer, M: mirror, N: refractive index of wafer

Thickness and refractive index



OPD of Ray 1:

$$Z_1 = 2(L_B + T + L_C - L_A)$$

OPDs of Ray 2:

$$Z_2 = 2N \cdot T$$

$$Z_3 = 2(L_B + N \cdot T + L_C - L_A)$$

Geometrical thickness of wafer:

$$T = (Z_1 + Z_2 - Z_3)/2$$

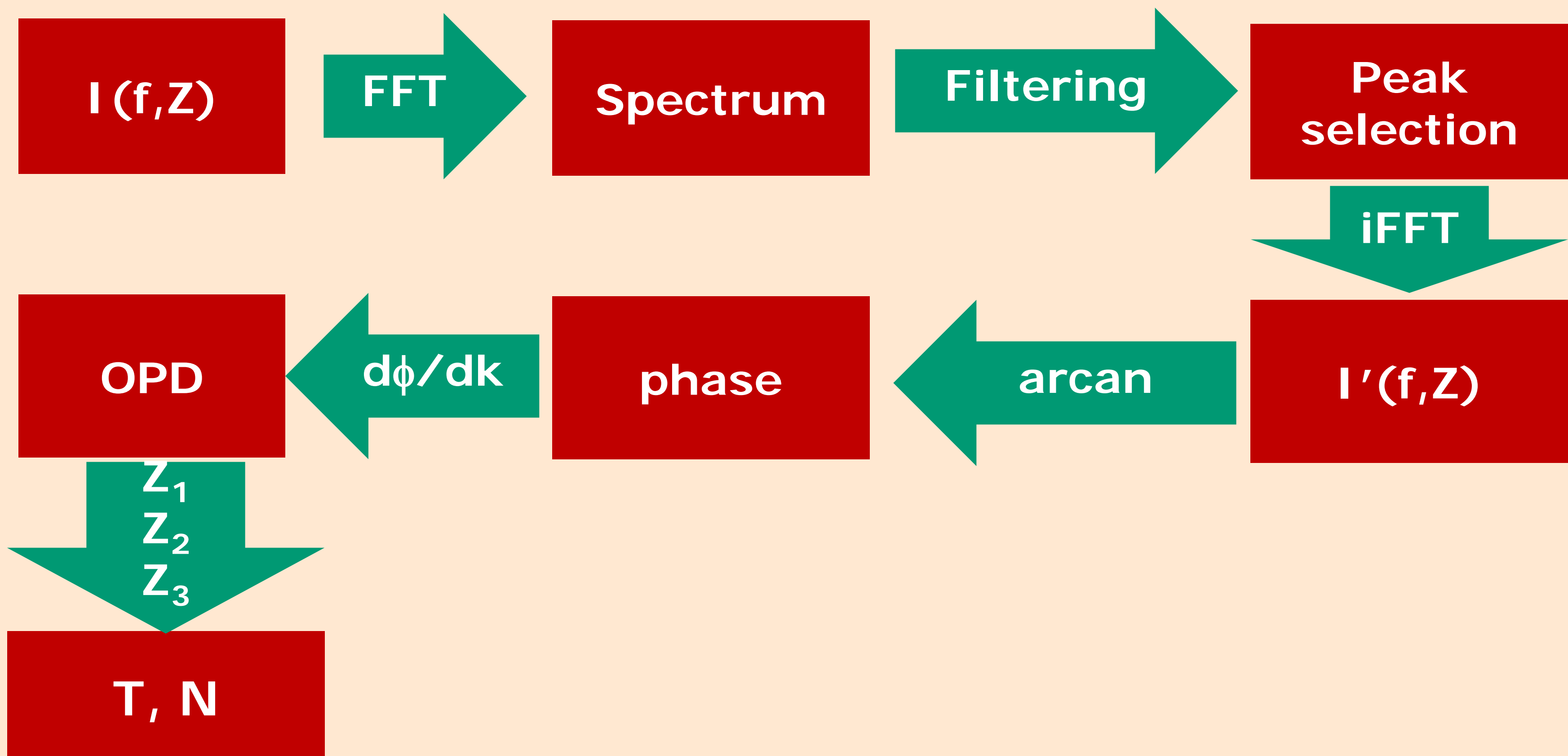
Refractive index of wafer:

$$N = Z_2/(2T)$$

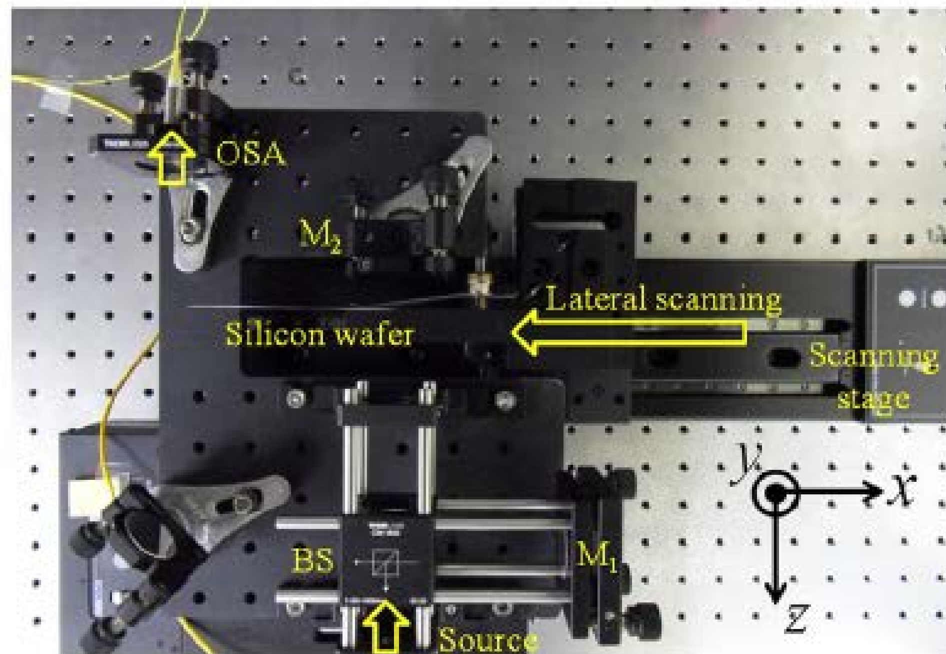
Thickness and refractive index can be measured simultaneously

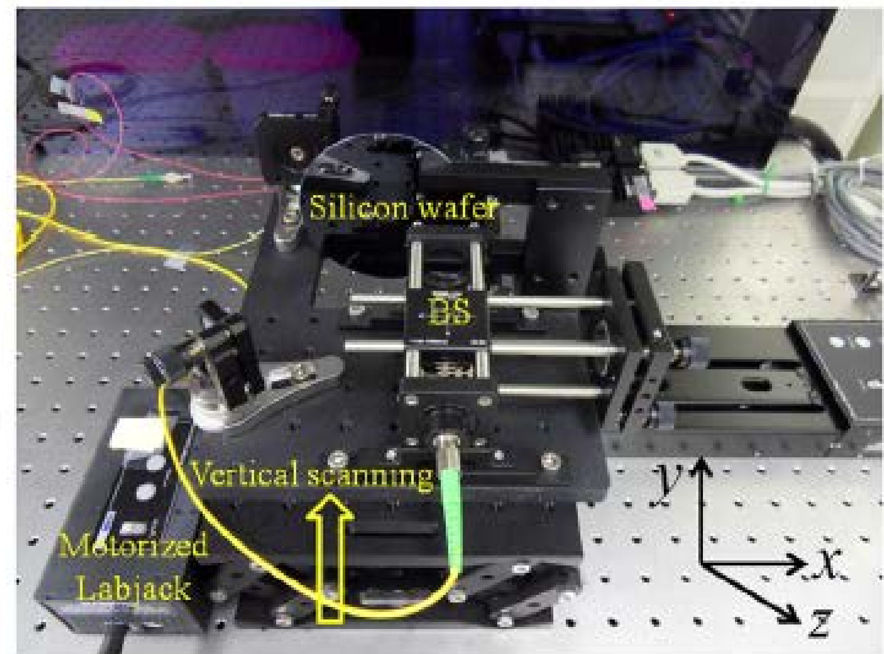
Flow chart of measurement

$$I(f,Z) = I_0(f)\cdot\left\{1+\cos\left(\frac{2\pi f}{c/Z}\right)\right\} = I_0(f)\cdot\{1+\cos\phi(f,Z)\}$$



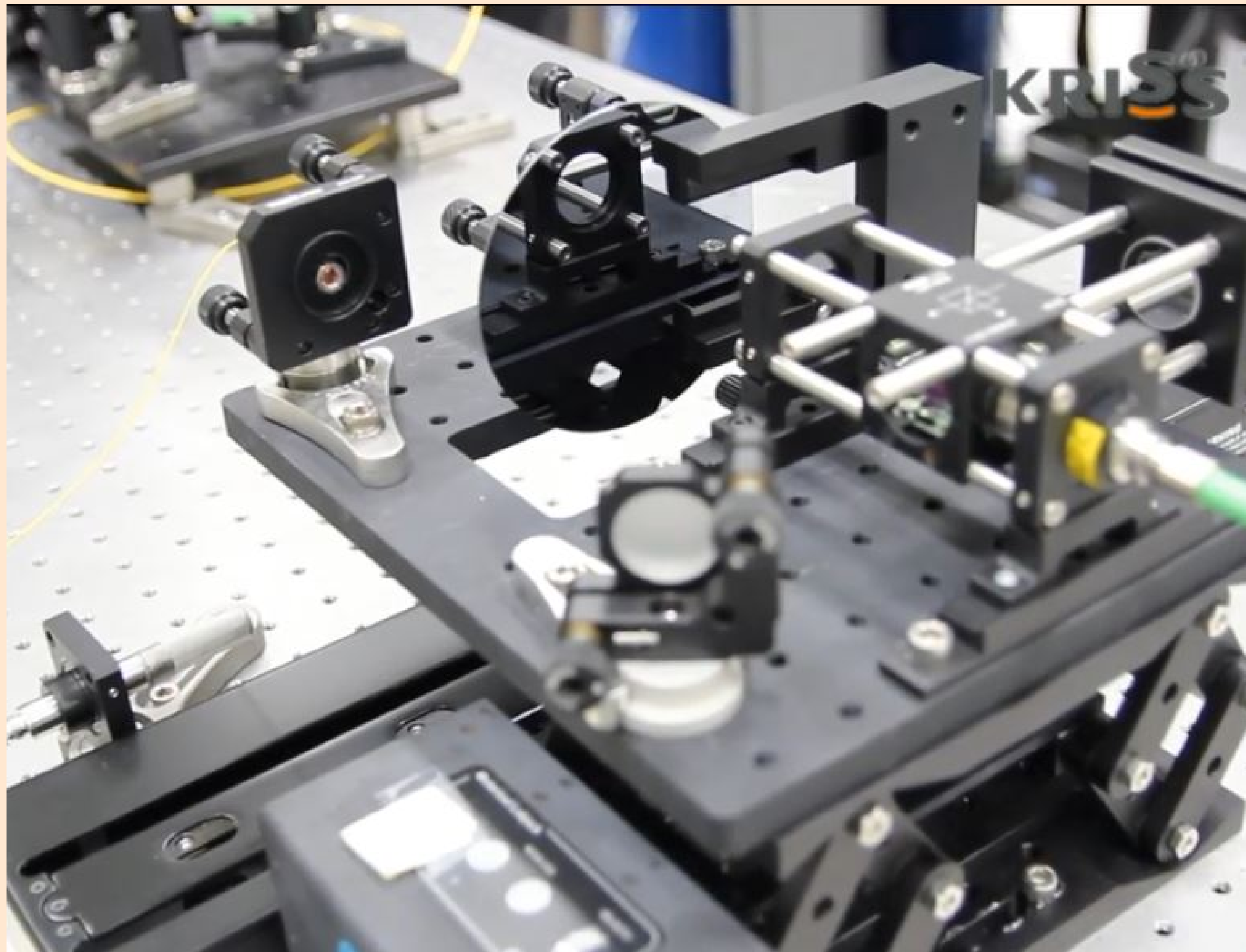
Experimental setup



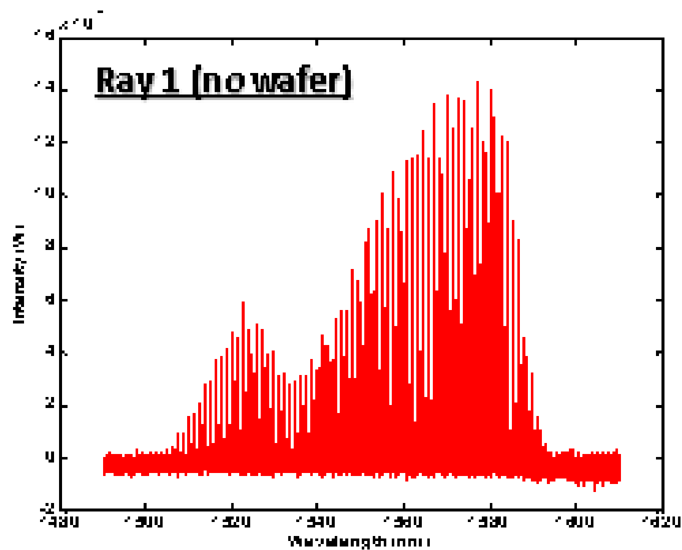


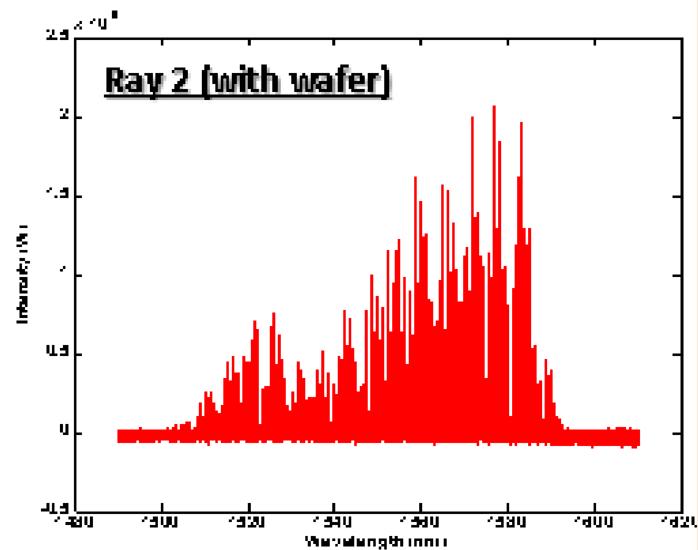
- scanning range:
  - lateral: 90 mm
  - vertical: 90 mm

Experimental setup



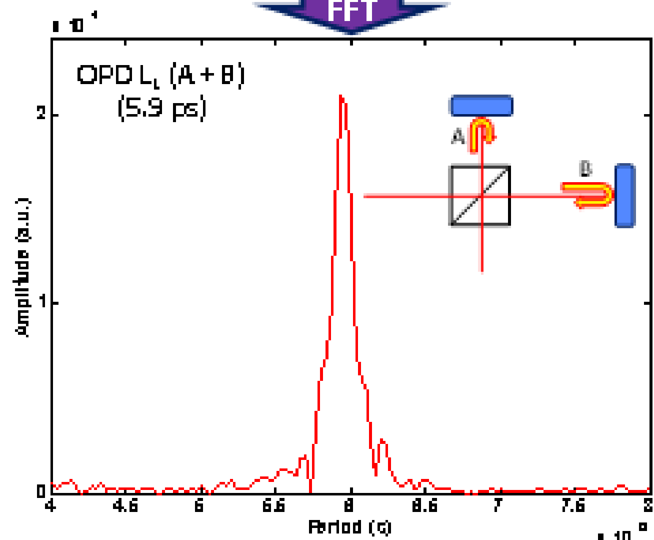
Spectrum and FFT results

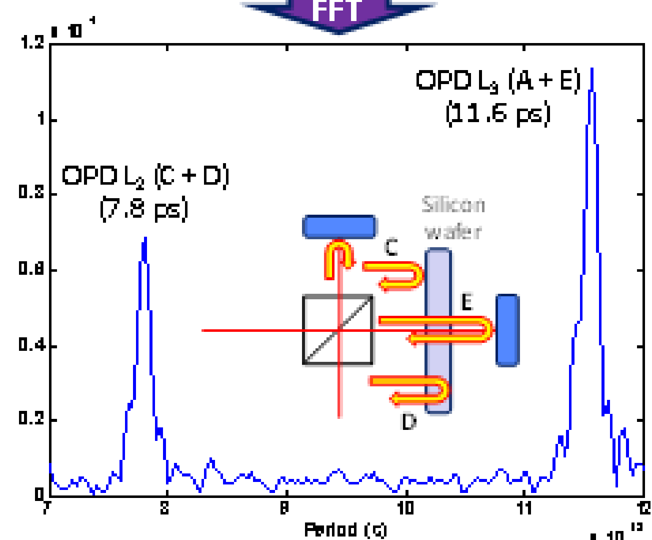




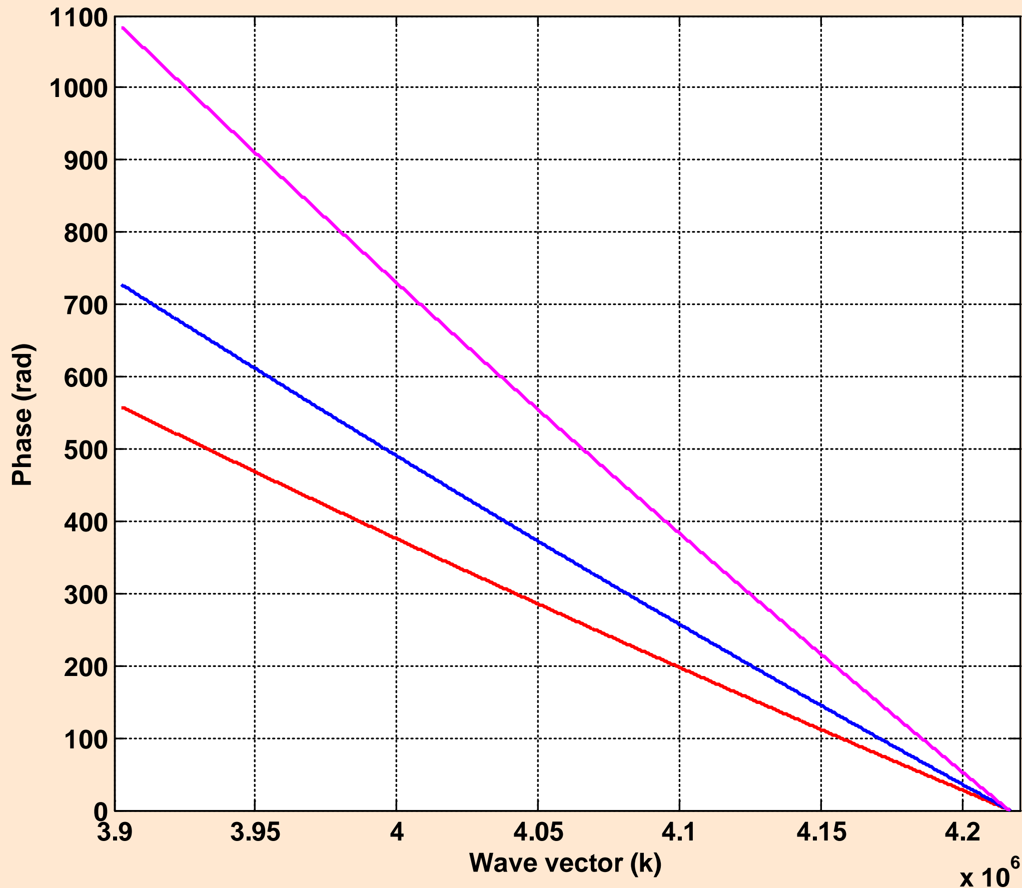
FFT

FFT





Phase, T, and N



- OPD
- $Z_1 = 1.777 \times 10^{-3}$ m
- $Z_2 = 2.323 \times 10^{-3}$ m
- $Z_3 = 3.459 \times 10^{-3}$ m

- Geometrical thickness: T = 320.699 μm
- Group refractive index: N = 3.6208

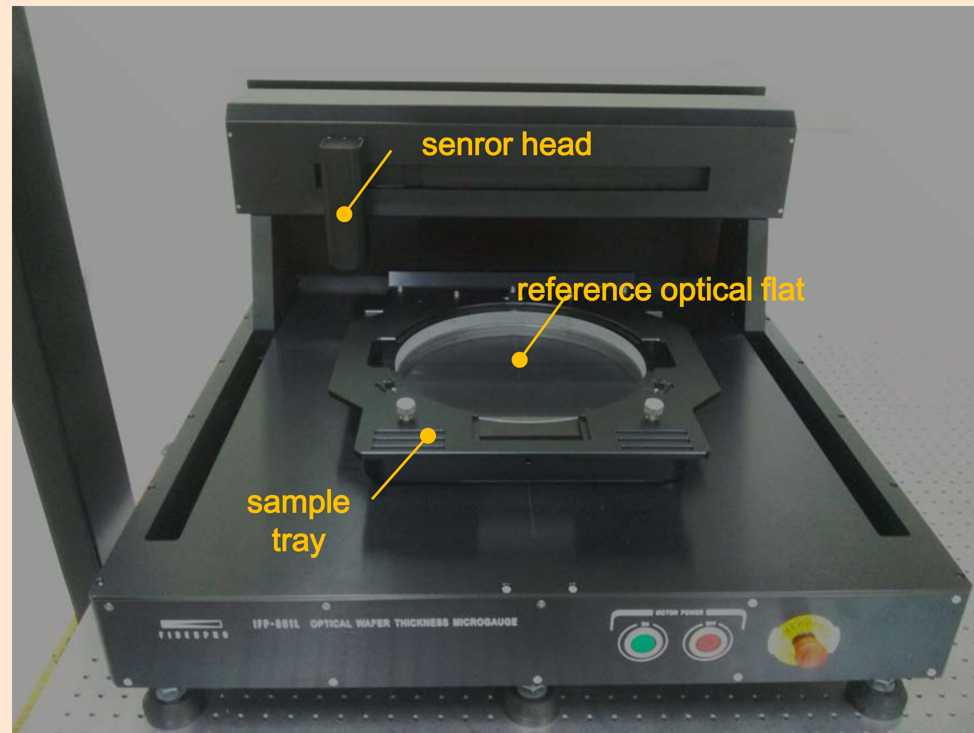
- Uncertainty of thickness measurement (k=1): 48 nm

Wafer thickness measurement

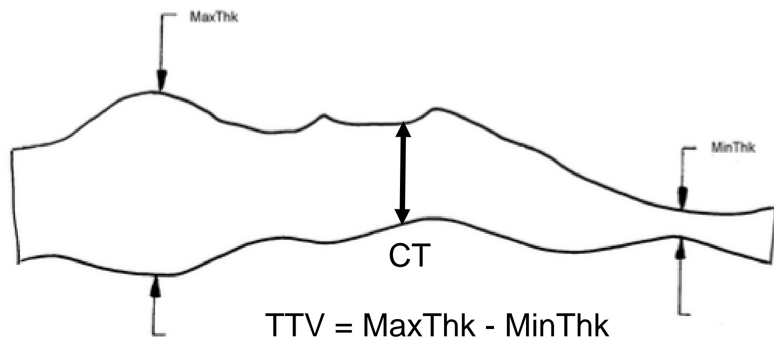
3. Fizeau type spectral interferometer

Fizeau type spectral interferometer

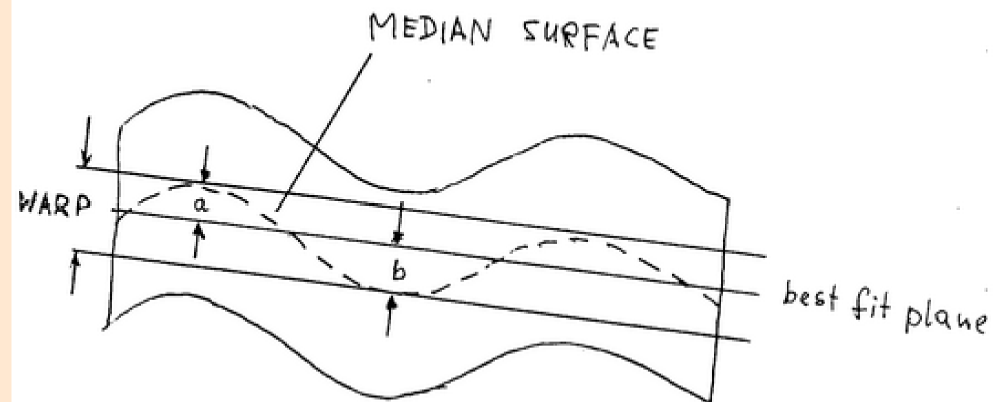
- optical source: super luminance diode (SLD)
  - center wavelength: 1550 nm
  - bandwidth: 70 nm (FWHM)
- measurement range:
  - diameter: up to 300 mm
  - thickness: 0.1 mm – 1 mm
- measurand
  - thickness
    - center thickness (CT)
    - total thickness variation (TTV)
  - warpage
    - warp, bow, sori, etc



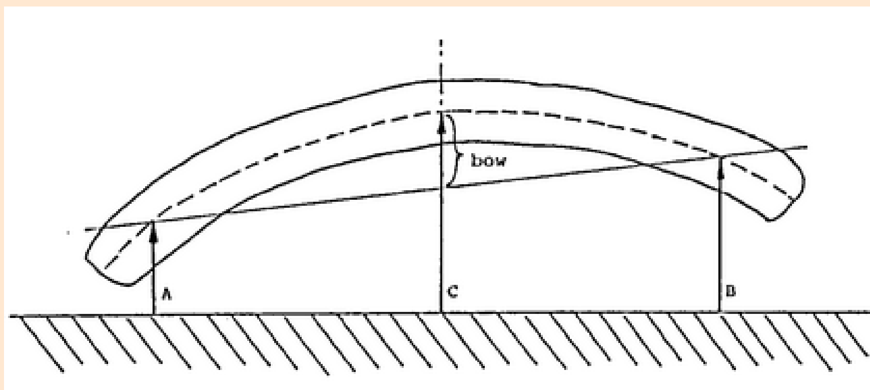
Definition of measurands



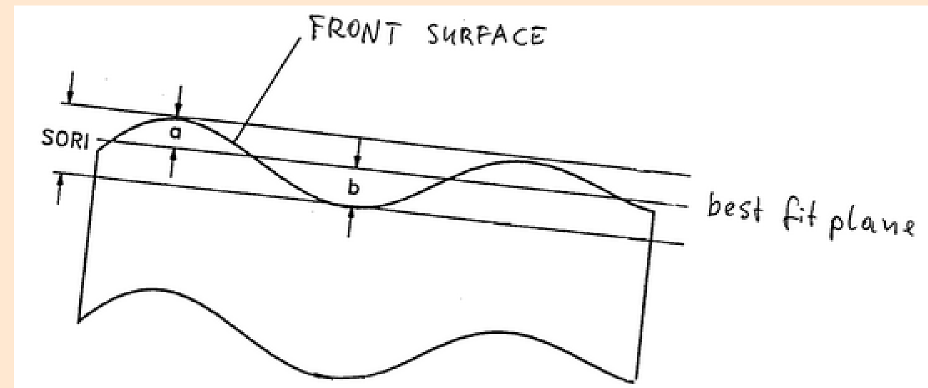
- CT and TTV



- Warp

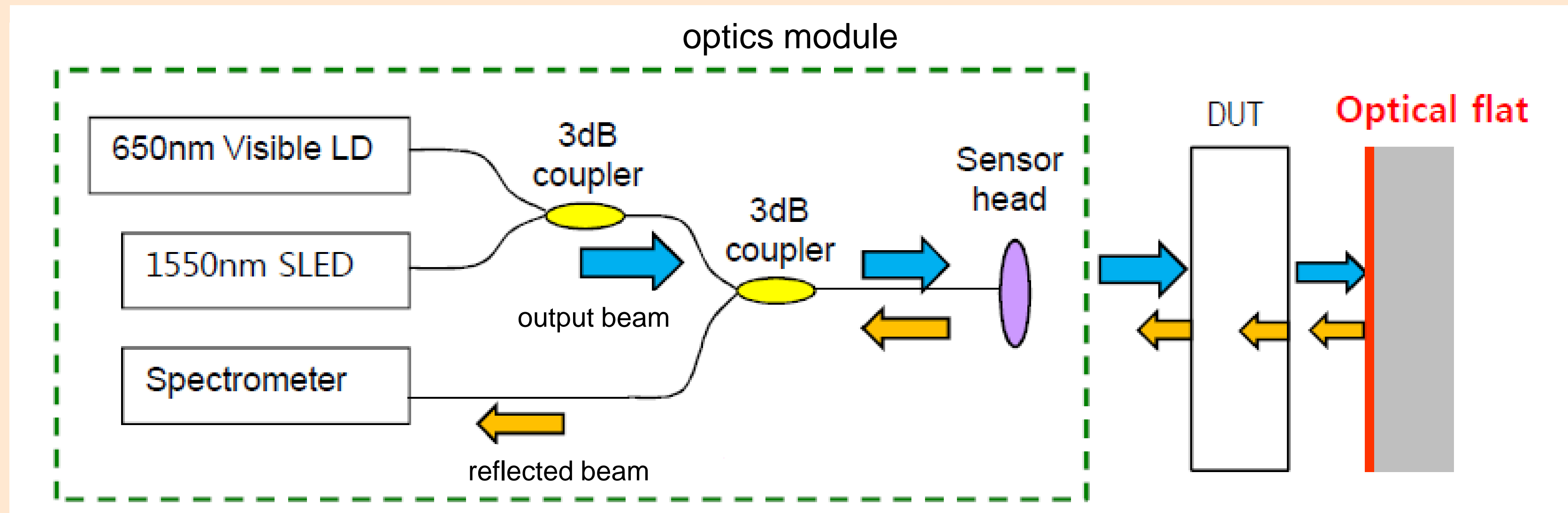


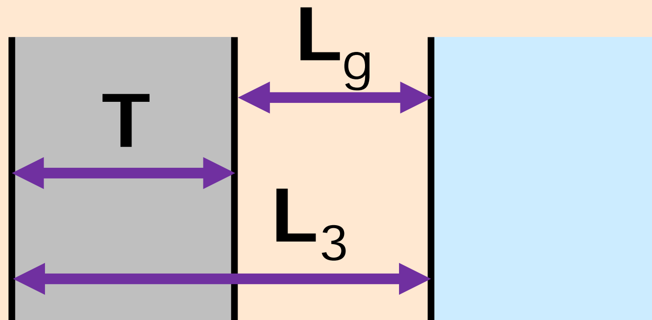
- Bow



- Sori

Structure of the interferometer

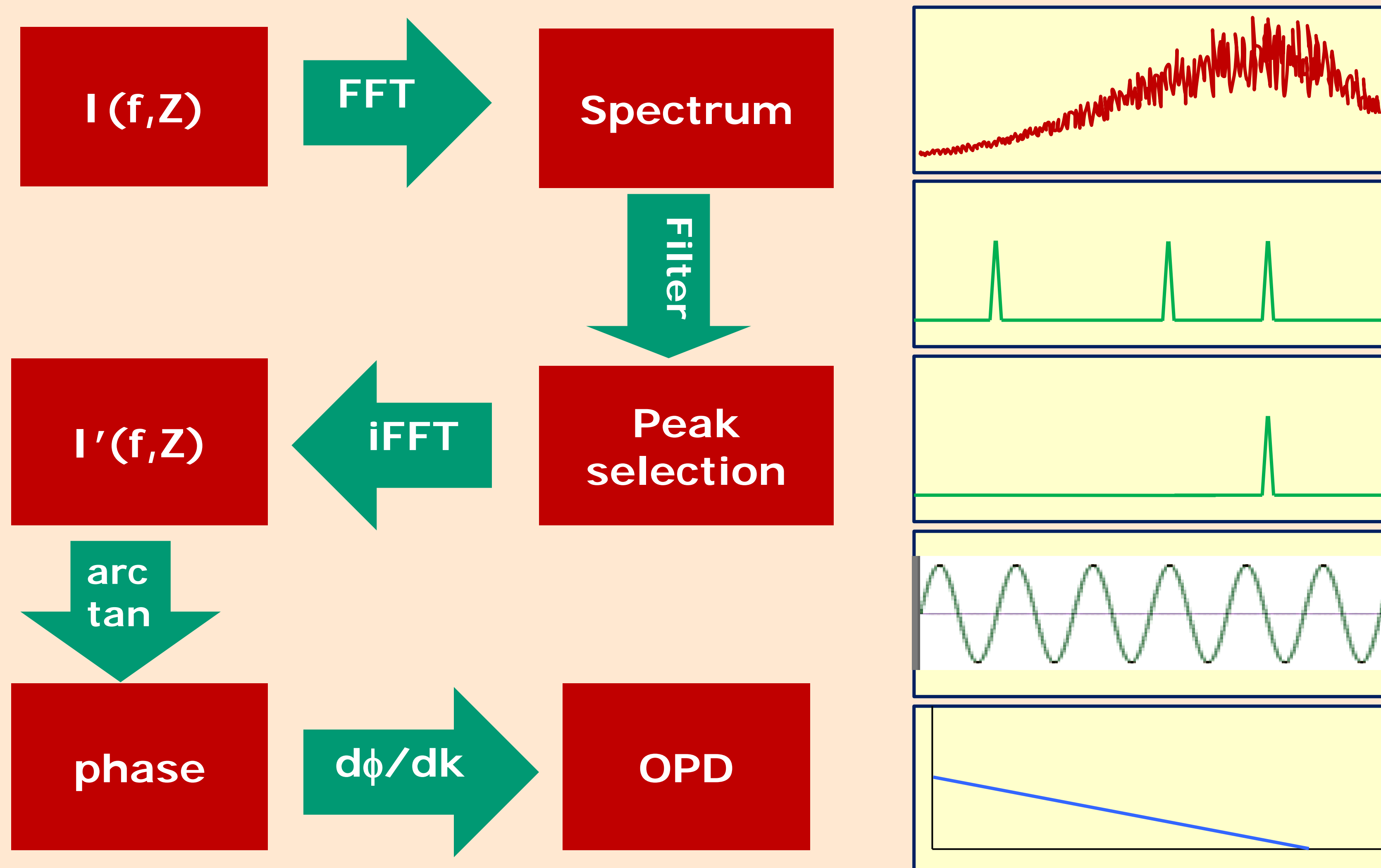




- Optical path differences (OPD)

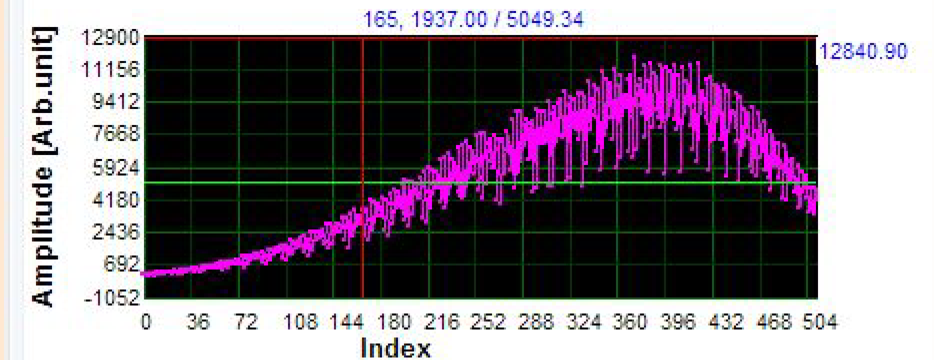
$$Z_1 = 2\,L_g$$
$$Z_2 = 2NT$$
$$Z_3 = 2(NT + L_3\,)$$

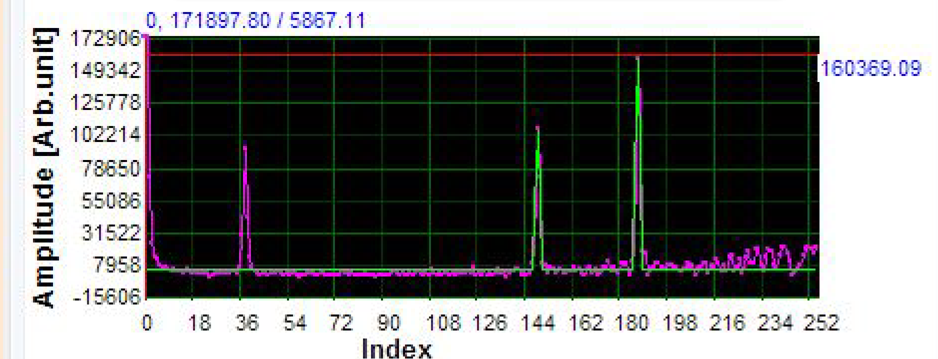
Flow chart of measurement



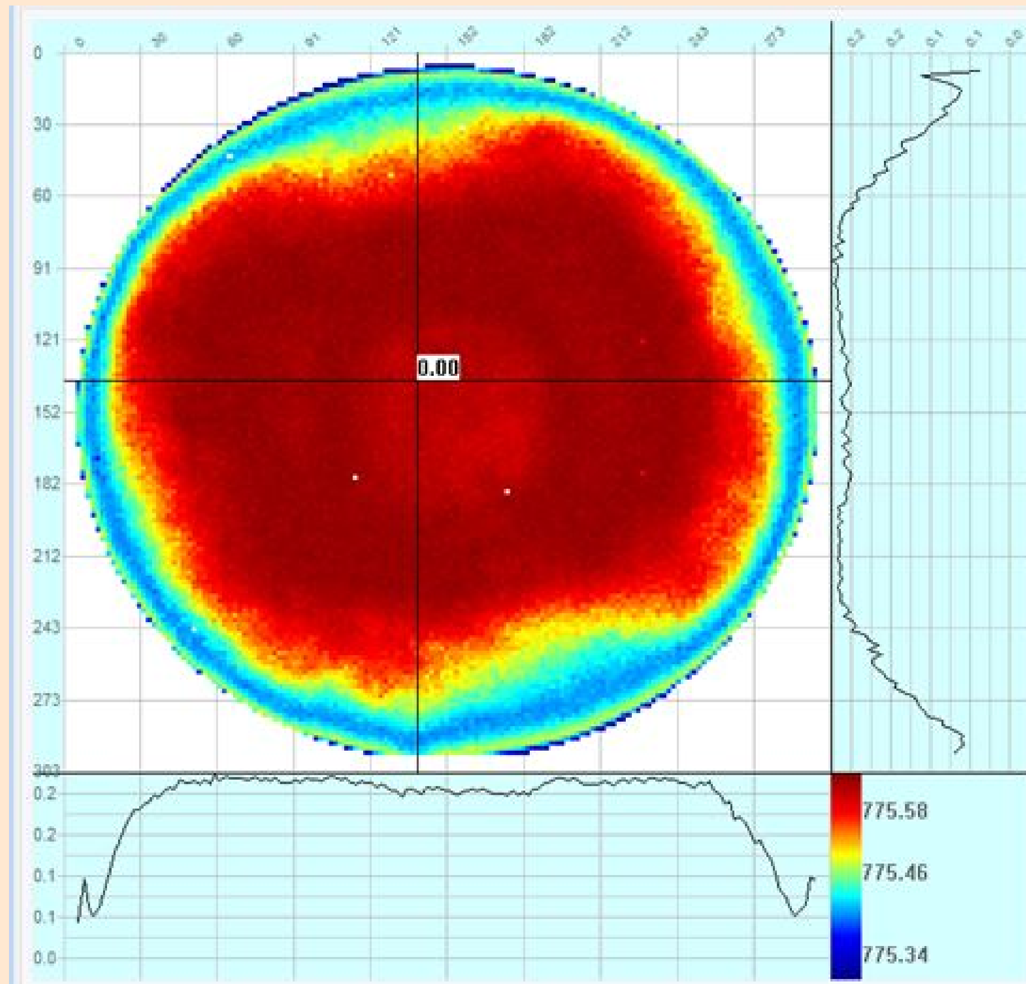
Profiler

Interference signal & its FFT

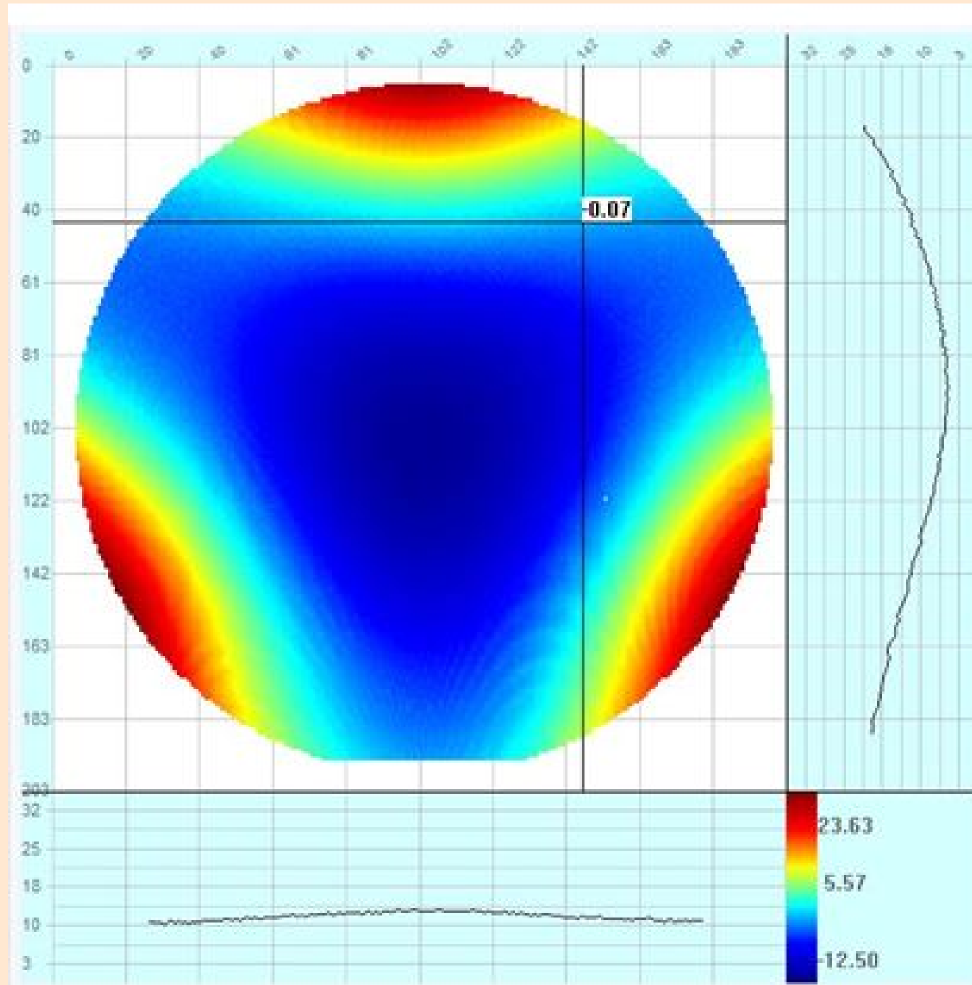




Thickness profile (example)

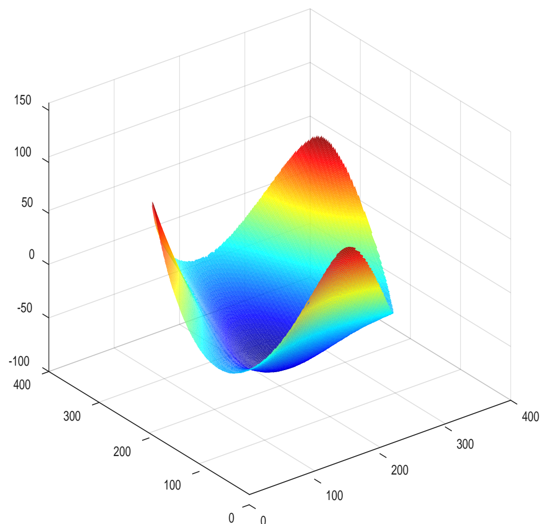


Warp measurement (example)



Gravitational sag correction

- Measure each side of wafer by flipping
- Gravitational effect eliminated by subtracting results



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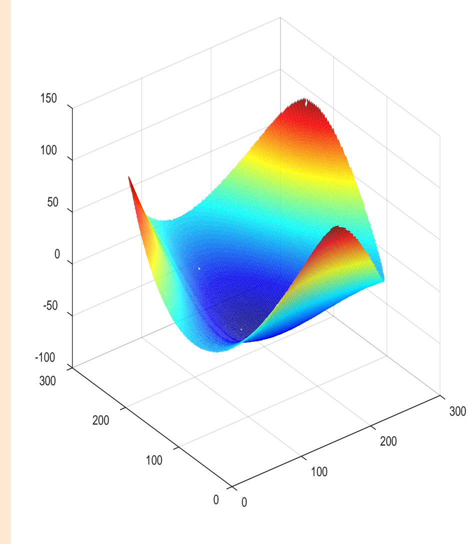

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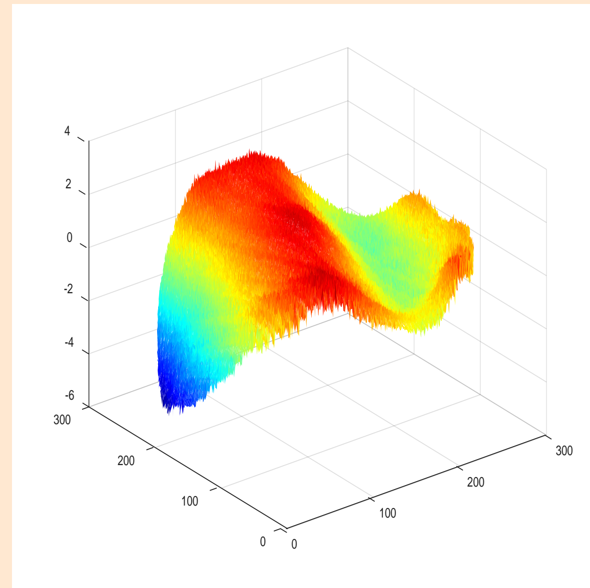
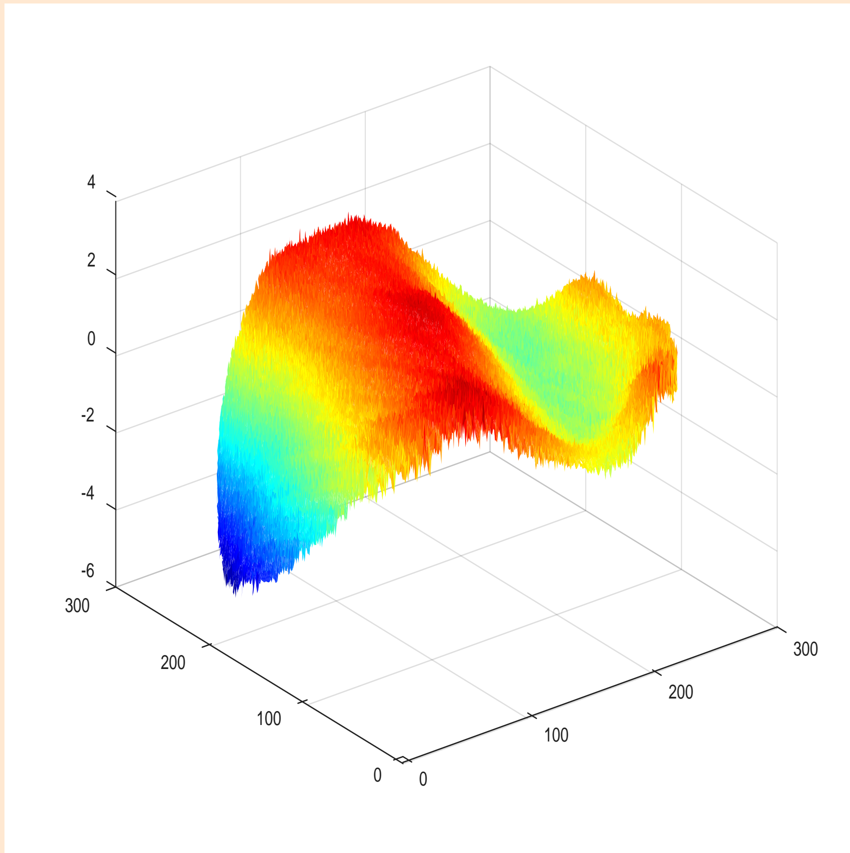
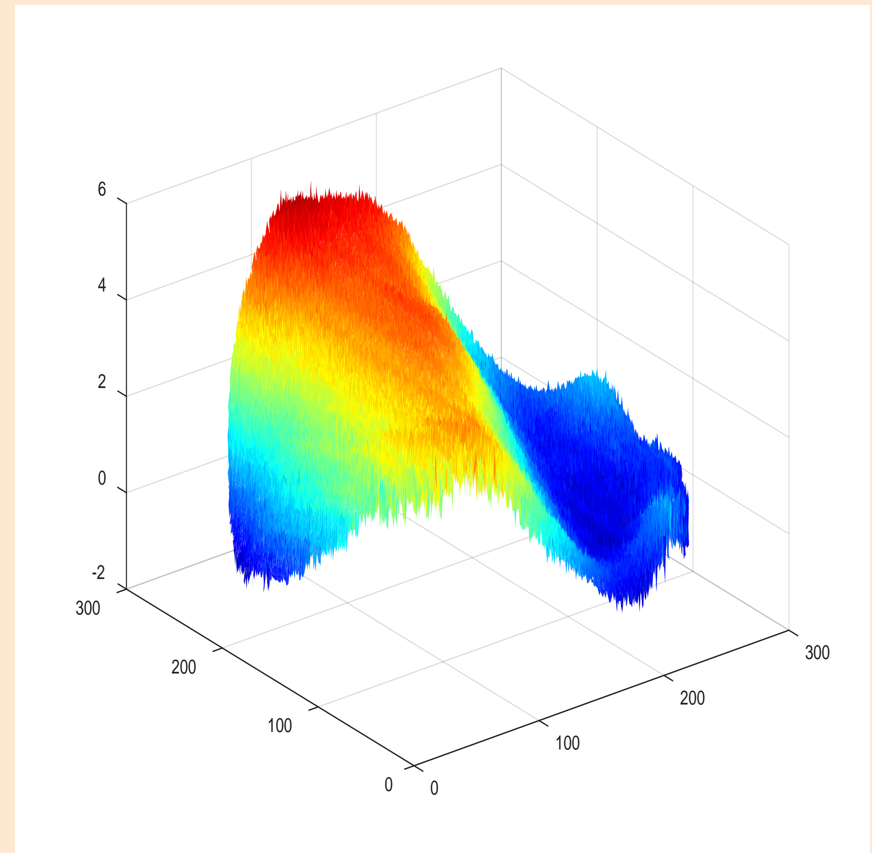


- warp with gravity effect
- extracted gravity effect
- warp without gravity effect

Gravitational sag corrected results

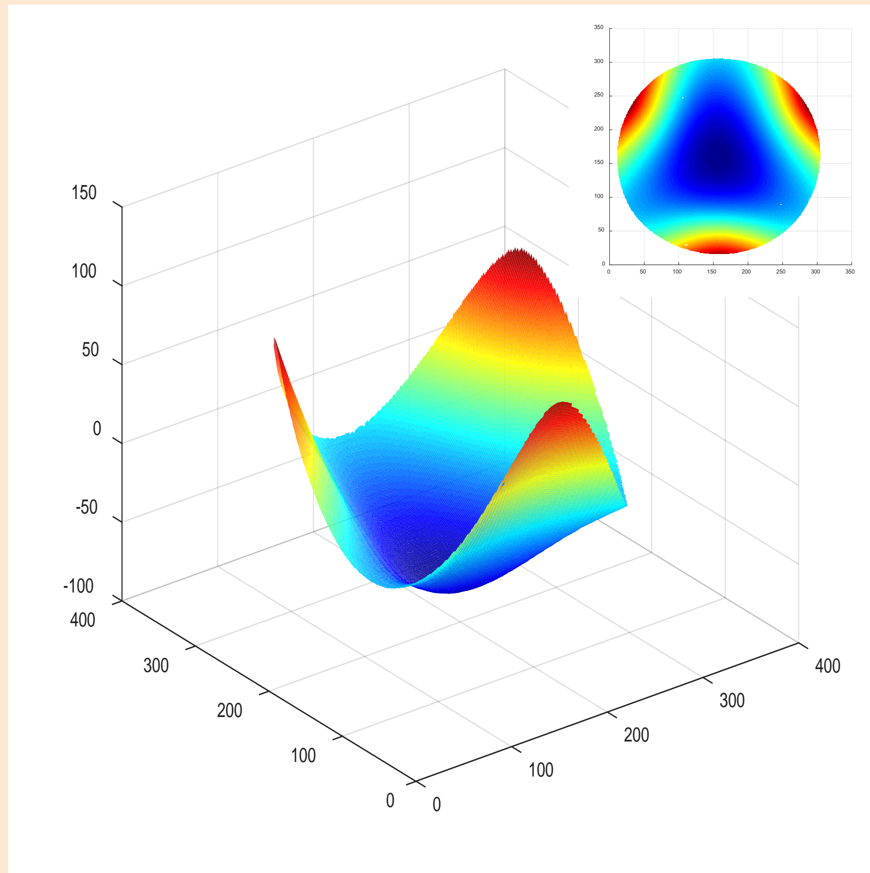


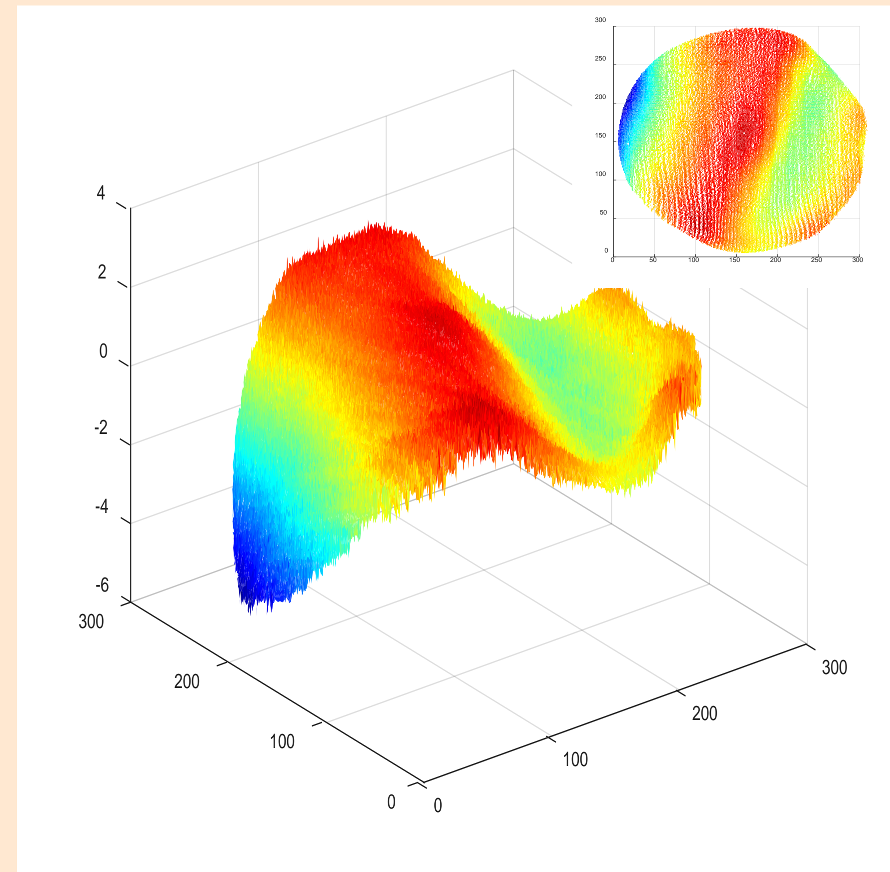


- gravity effect corrected warp
- gravity effect corrected bow

Comparison of warp values

- with gravity: 248.6 μm, without gravity: 7.2 μm

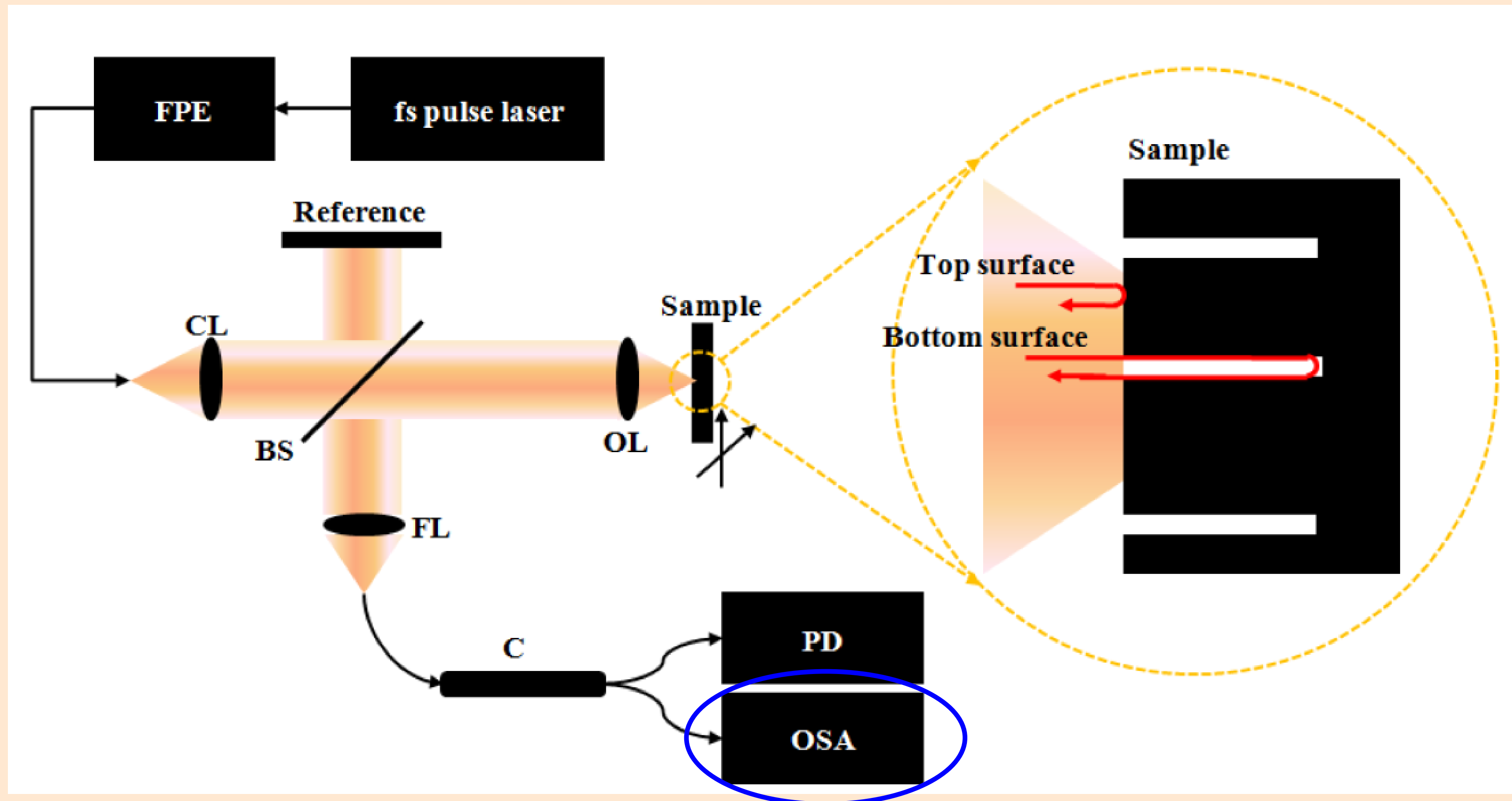




TSV measurement

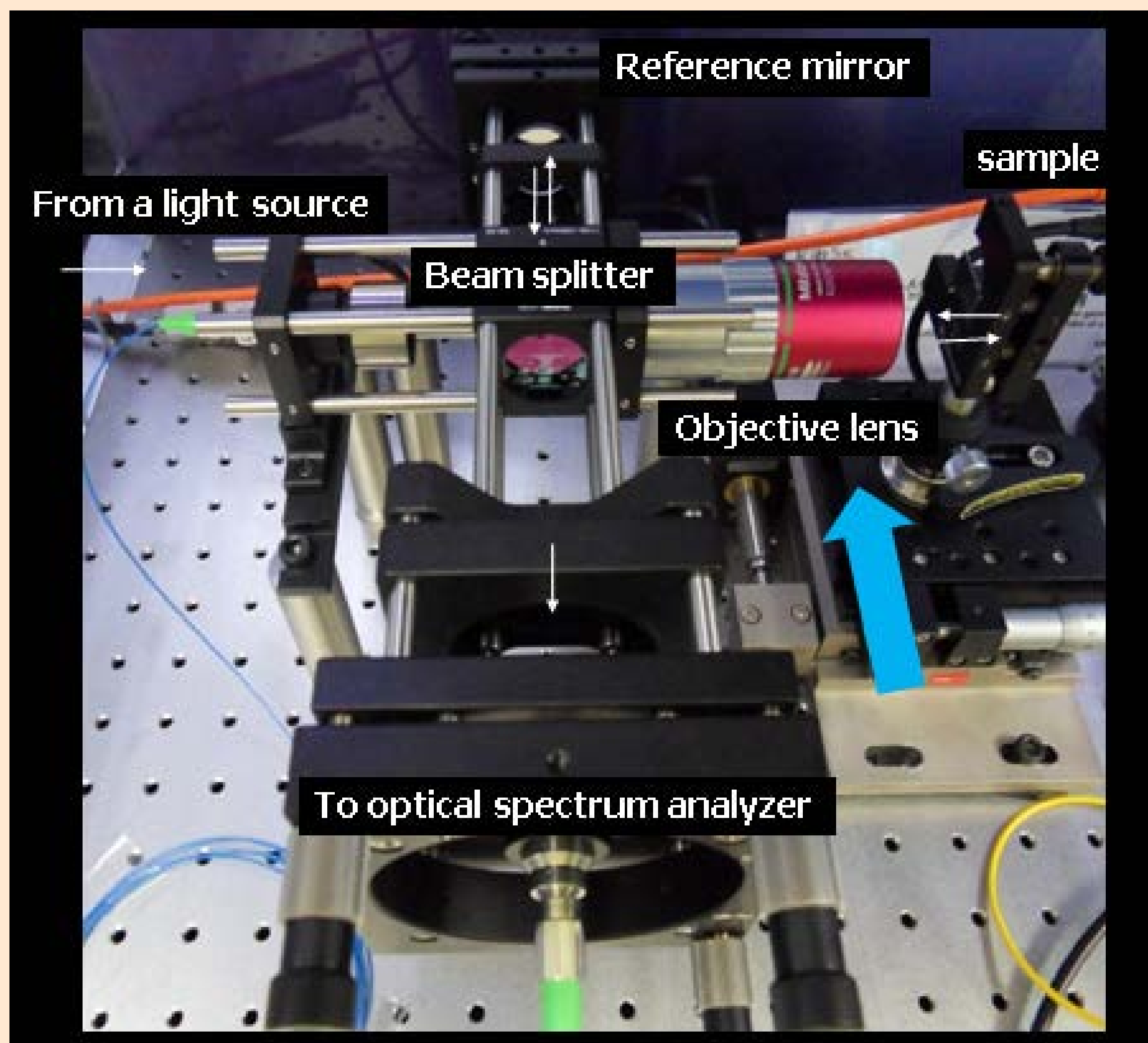
1. Depth measurement

Schematic diagram of setup

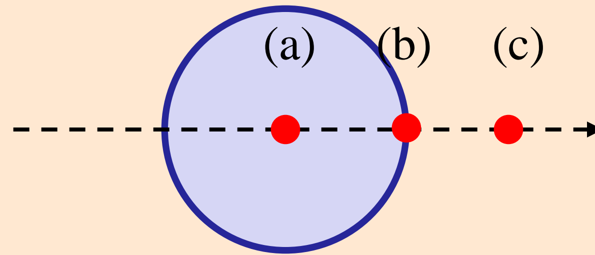


- spectral interferometer
- Sample stage is moved to scan the surface

Experimental setup



Fourier spectrum

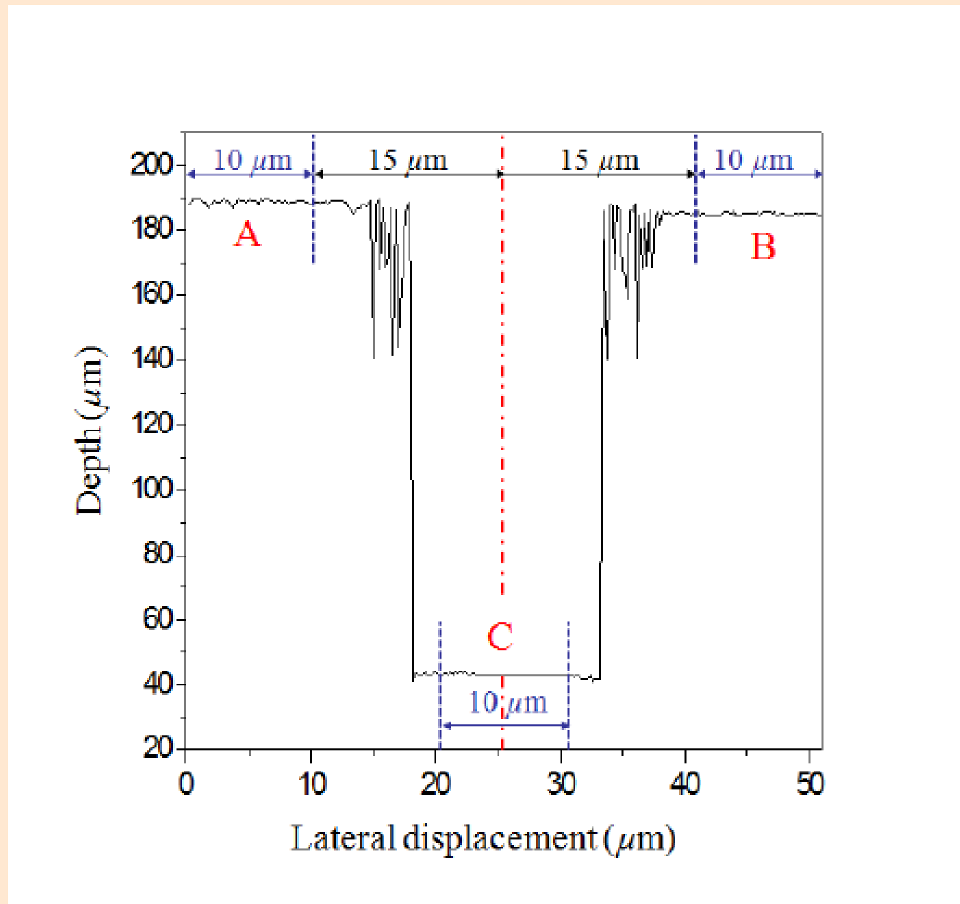


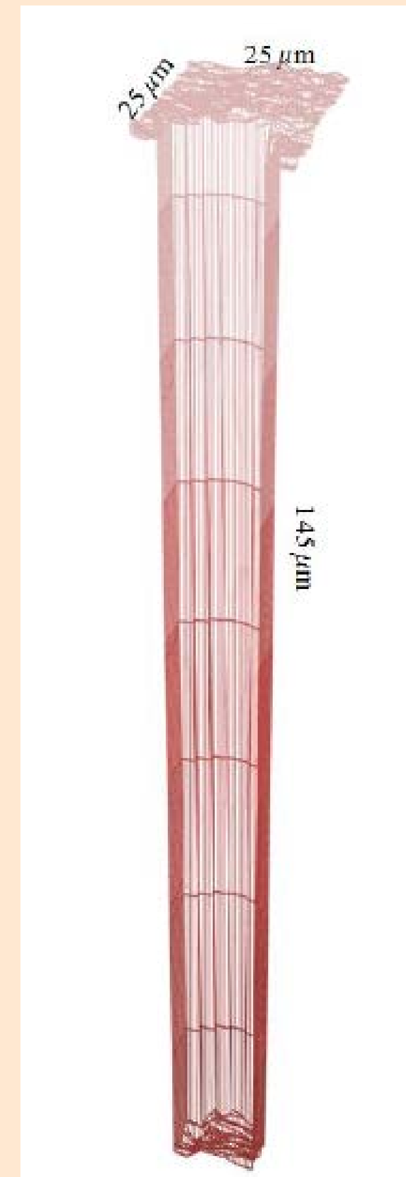
(a) Amplitude (a.u.) 0 50 100 Frequency (index)

(b) Amplitude (a.u.) 0 50 100 Frequency (index)

(c) Amplitude (a.u.) 0 50 100 Frequency (index)

Profile of TSV



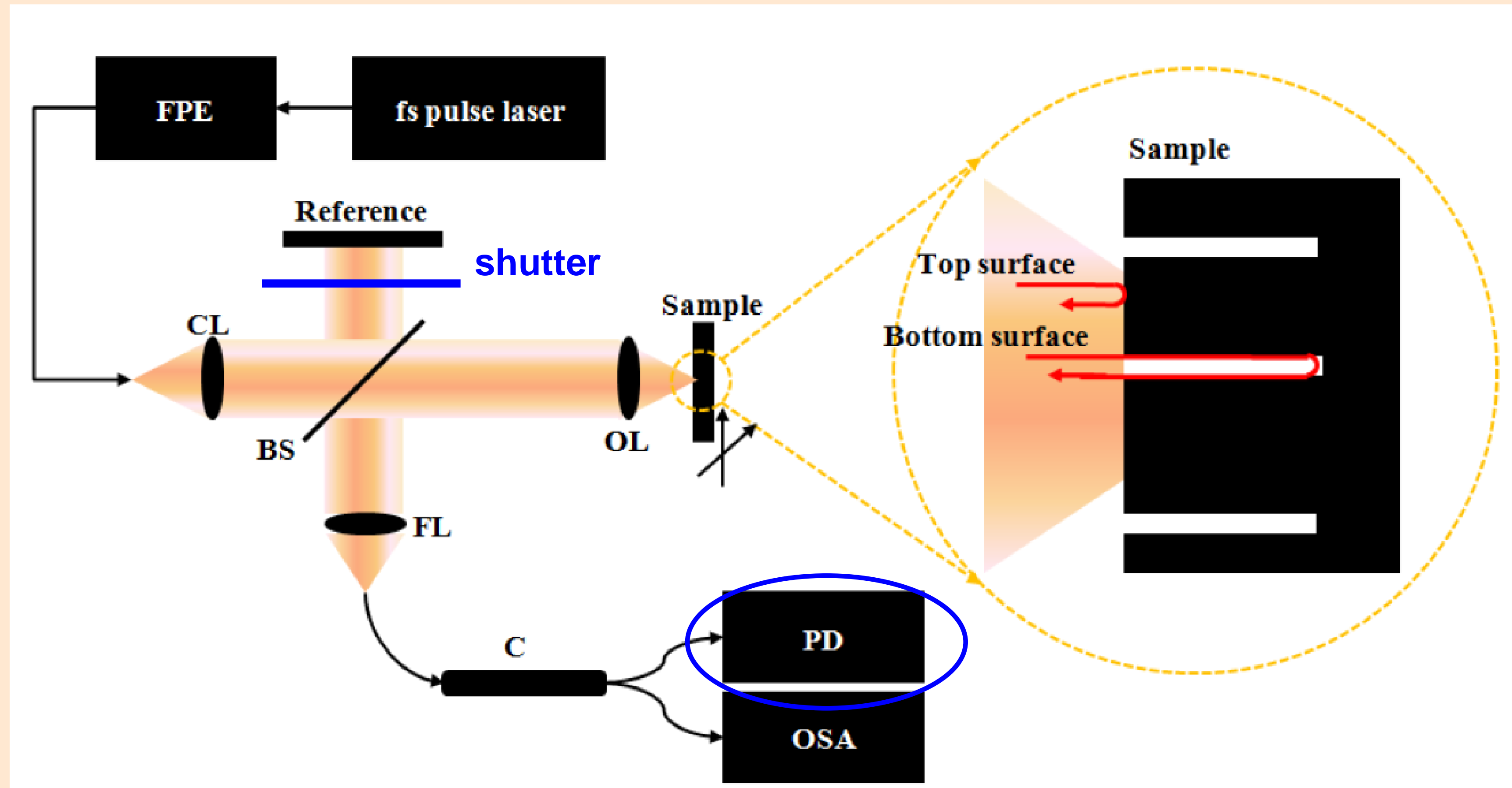


- Depth: 144.86 μm (@ diameter 20 μm)
- Repeatability: 30 nm

TSV measurement

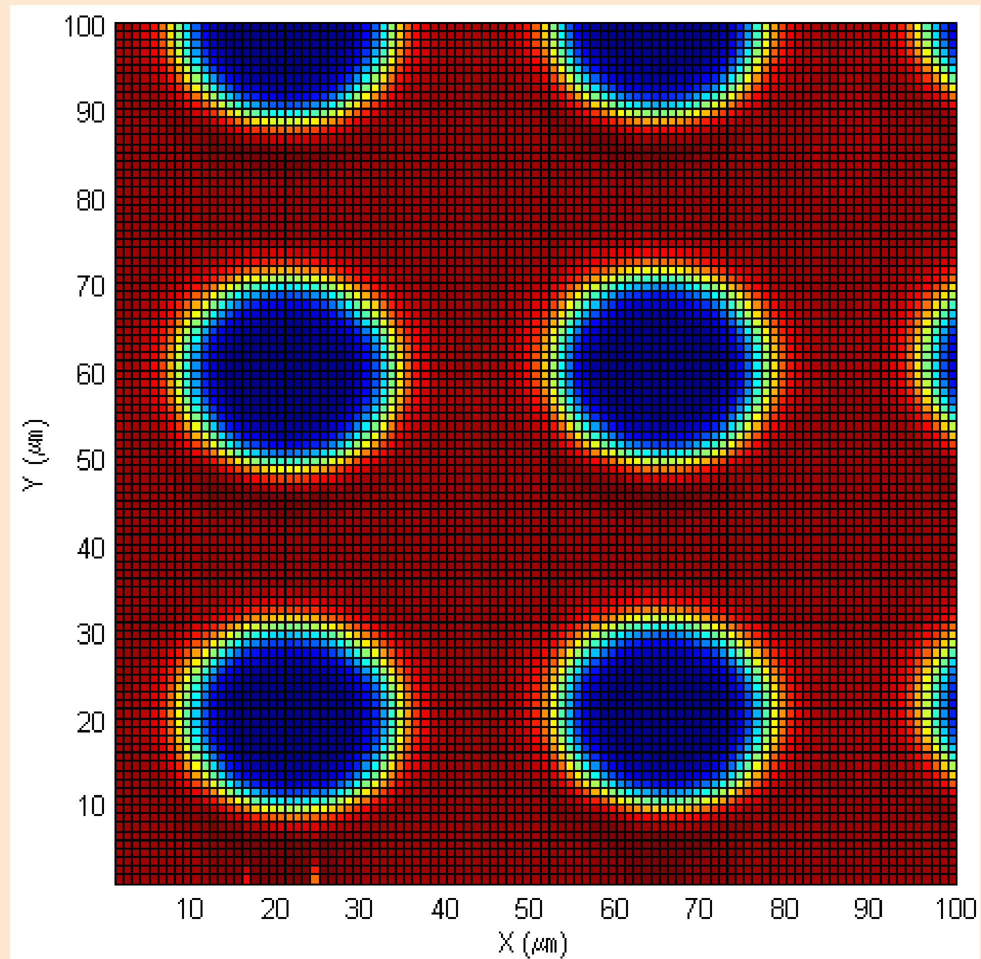
2. Diameter measurement

Schematic diagram of setup



- reference mirror is blocked → confocal microscope
- sample is scanned by moving stages

Example of measurement results



- repeatability: 8 nm, Uncertainty: 230 nm (diameter: 50 µm)

Summary

- wafer metrology at KRISS
  - wafer thickness measurement
    - mechanical method
      - geometric thickness, not efficient for large area
    - optical methods: spectral interferometer
      - Michelson type: thickness and refractive index measurement,
      - Fizeau type: optical thickness and warpage measurement over whole surface
  - TSV measurement
    - depth measurement: spectral interferometry
    - diameter measurement: confocal microscopy

Staffs related to these works
(in alphabetic order)

Dr. Eom, Tae Bong

Dr. Jin, Jonghan

Dr. Kang, Chu-Shik

Dr. Kim, Jae Wan

Dr. Kim, Jong-Ahn

Dr. Lee, Jae Yong

Dr. Park, Jung-Jae

Thank you for your attention!