



**Moscow State Technical University
named after N.E. Bauman,**

Intelligent Optoelectronics, Ltd

Image Processing for Precision Measurement and Quality Control

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Introduction

In optics and computer science, image processing is any form of signal processing for which the input is an image, such as photographs or frames of video; the output of image processing can be either an image or a set of characteristics or parameters related to the image.

Image processing is an important component of modern information technologies because the electromagnetic field in free space is the fastest channel for data transmission and has a large volume information capacity.

Main directions of research

1. Image improvement
2. Automatic quality control
3. Interferogram processing
4. Lensless digital holography

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Image restoration



Input image



Output image

Resolution increasing by matrix microscanning



One of 16 input images



Output image

Filtering



Input image



Output image

Rotation, shift and scale invariant



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Quality control

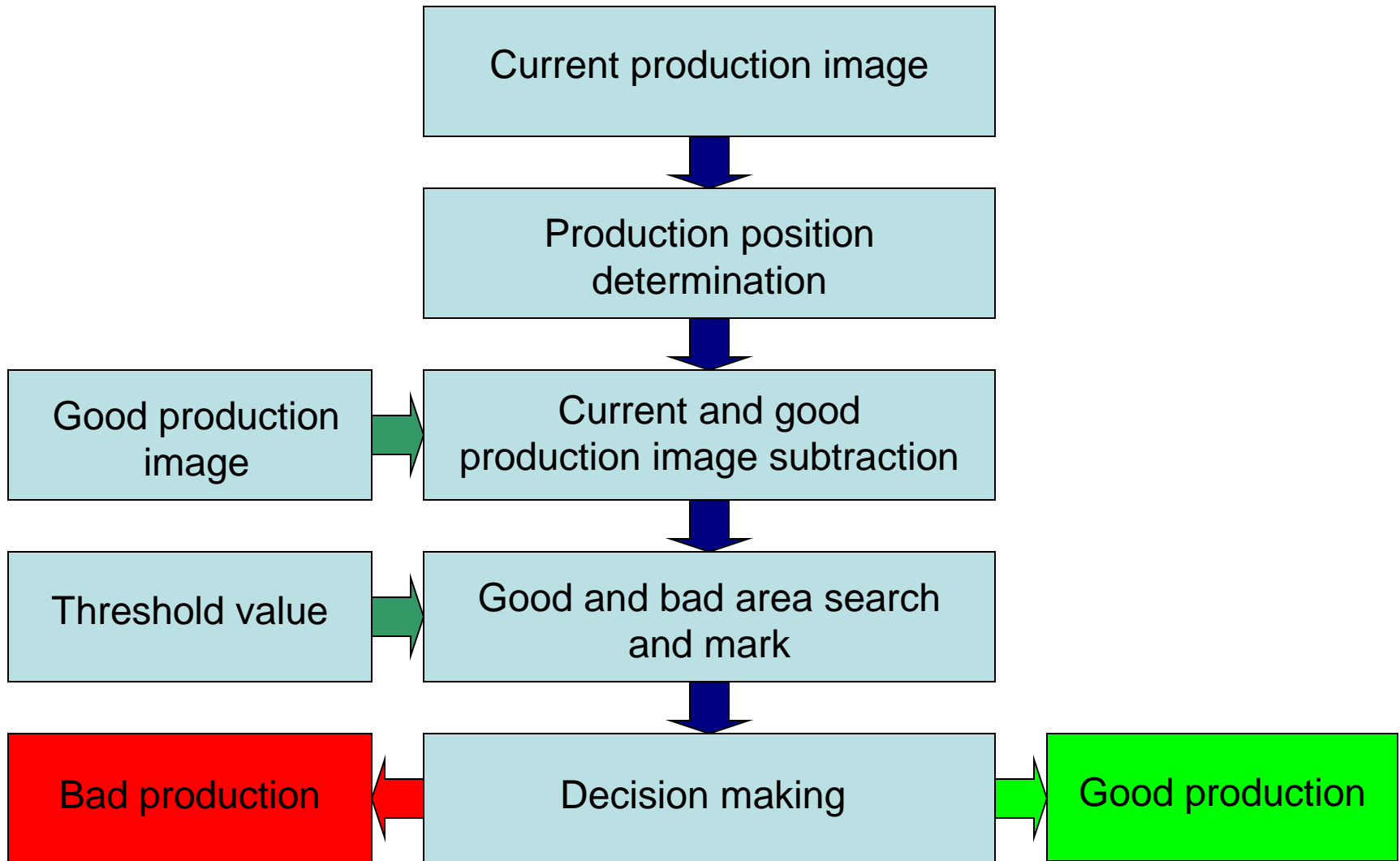


Quality control is very important for mass production.



But visual human quality control for mass production is very expensive and takes a long time

Automatic quality control system



Application example: Coin Defect Control

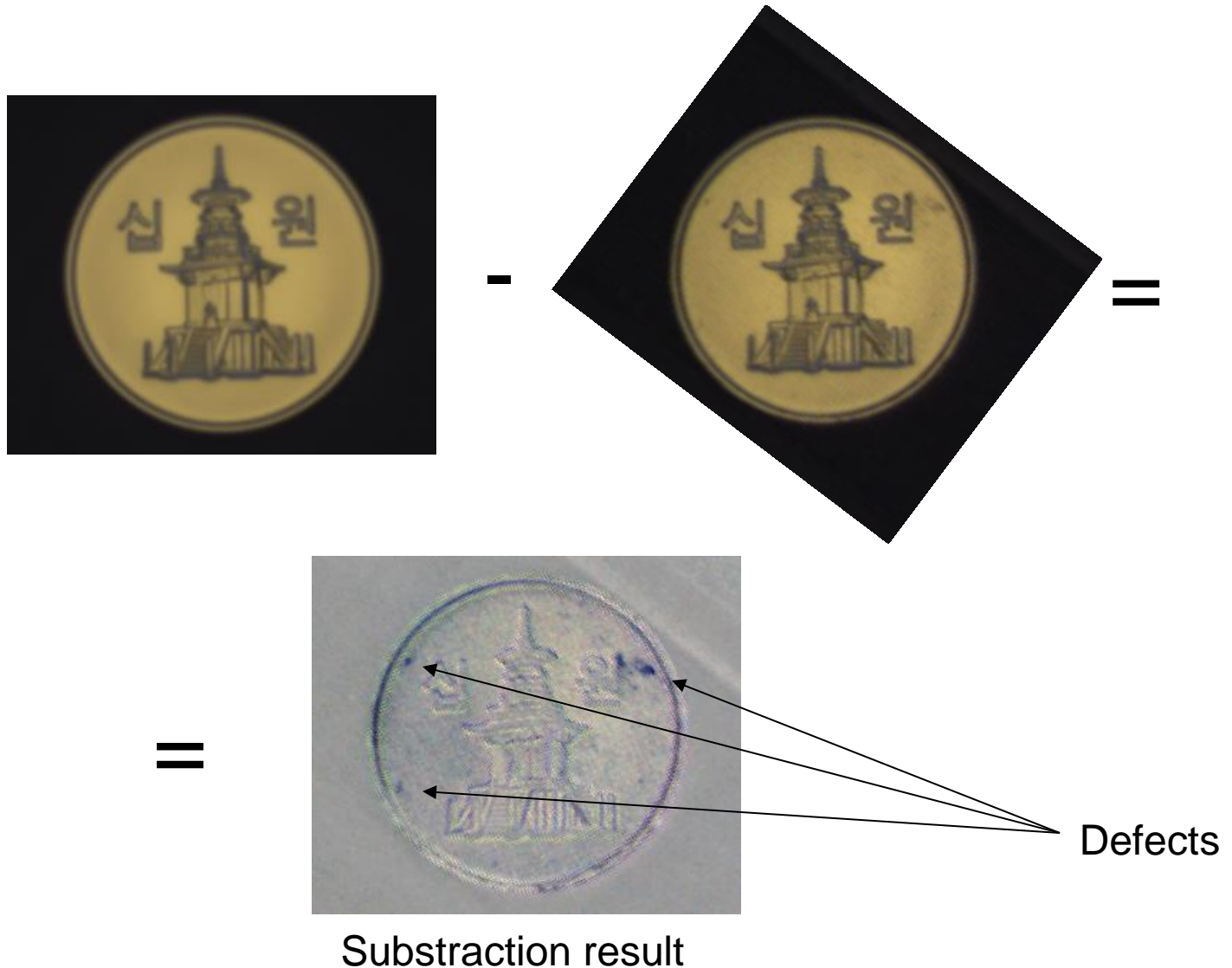


Example #1



Example #2

Comparison with original image

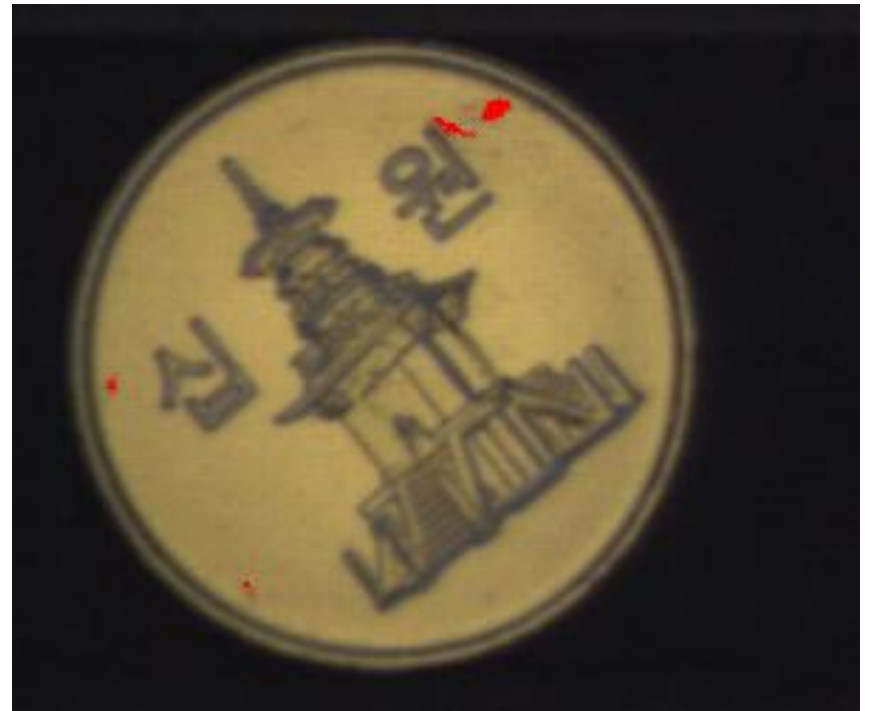


Threshold selection

For right decision making is coin good or defected, choosing right threshold value is important. It is possible to calculate the best threshold value after investigating statistics of reflection coefficient for more than 100-1000 images. Example of threshold influence to defect recognition result is shown below:



High threshold: 3 defects



Low threshold: more than 4 defects

Defect localization example #1



Original image



Processed image:
one defect recognized

Defect localization example #2



Original image



Processed image:
no defect recognized

Defect localization example #3



Original image

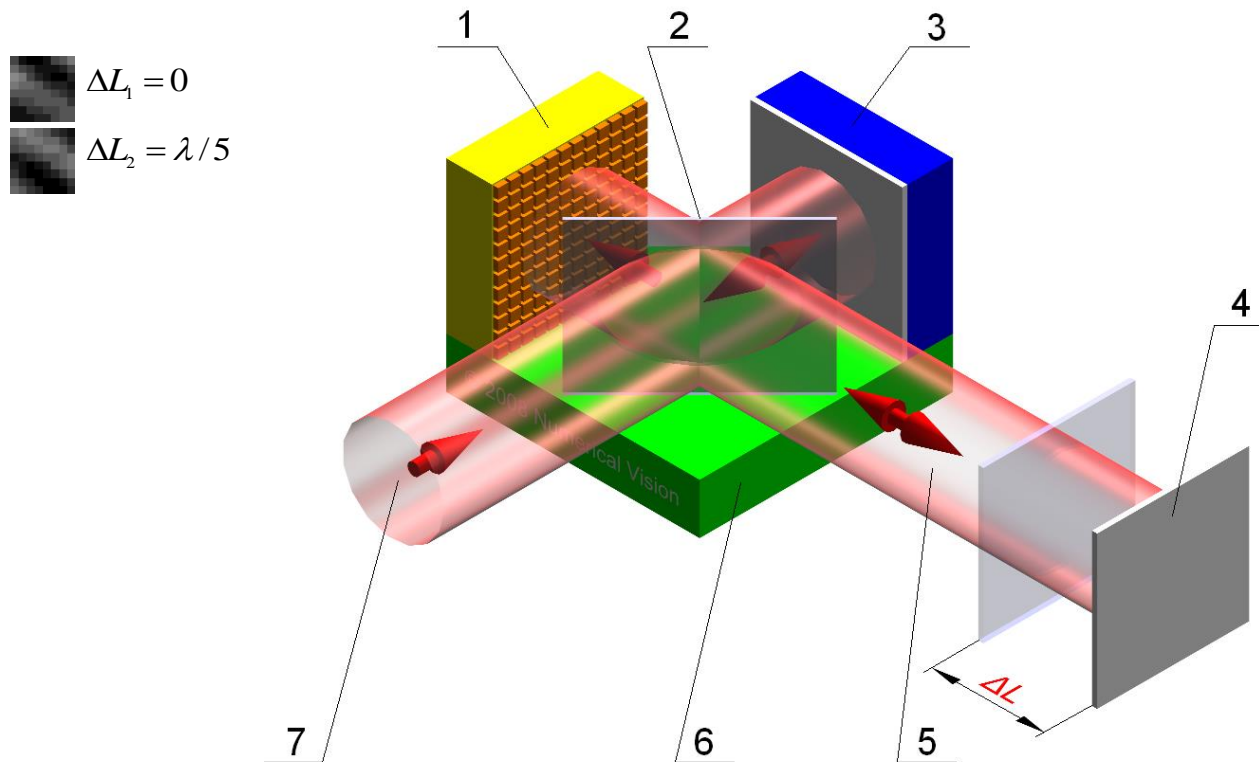


Processed image:
one defect recognized

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Image processing for interferometry



1 – multielement photo receiver; 2 – beamsplitter; 3 – mirror of reference channel; 4 – mirror of measurement channel; 5 – measurement beam; 6 – interferometer base; 7 – beam with etalon wavelength

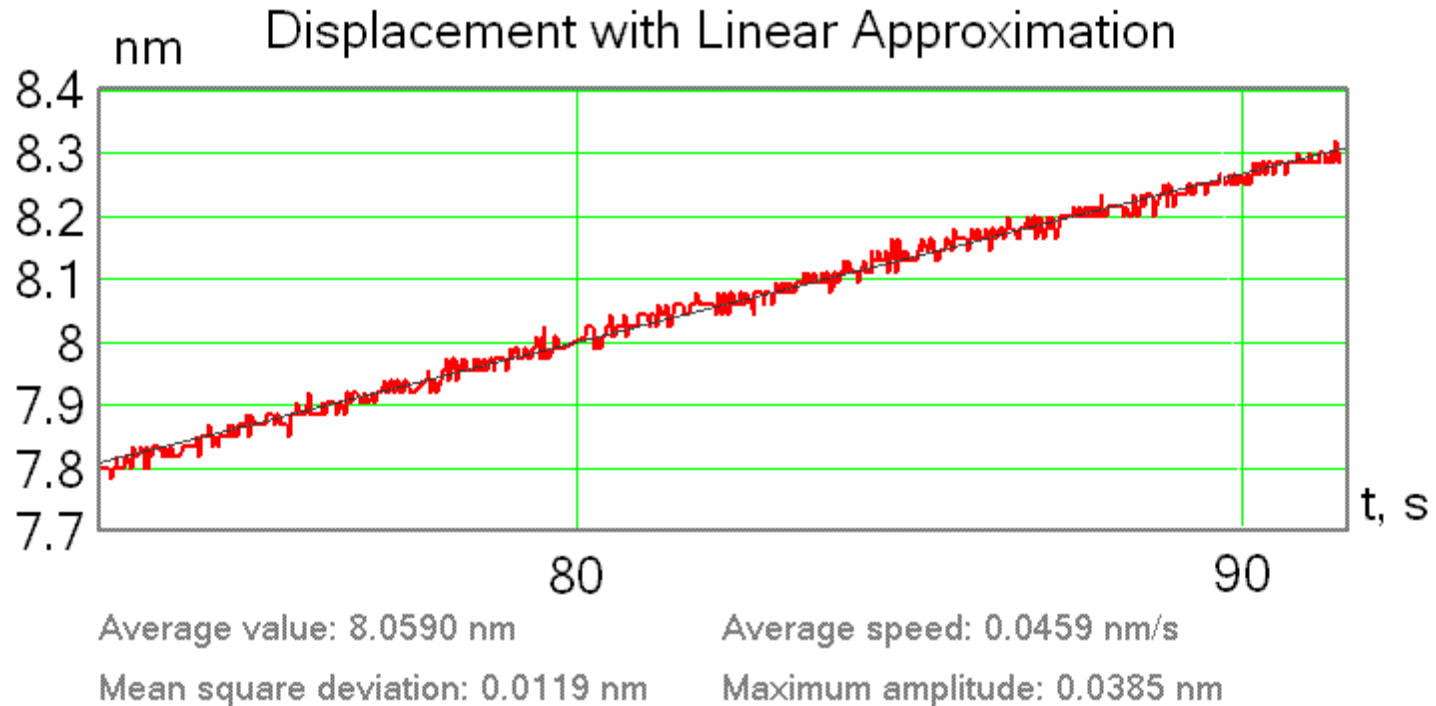
Realization of the base interferometer



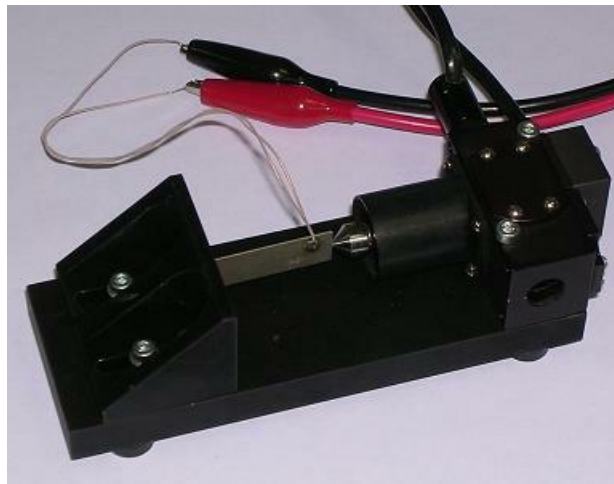
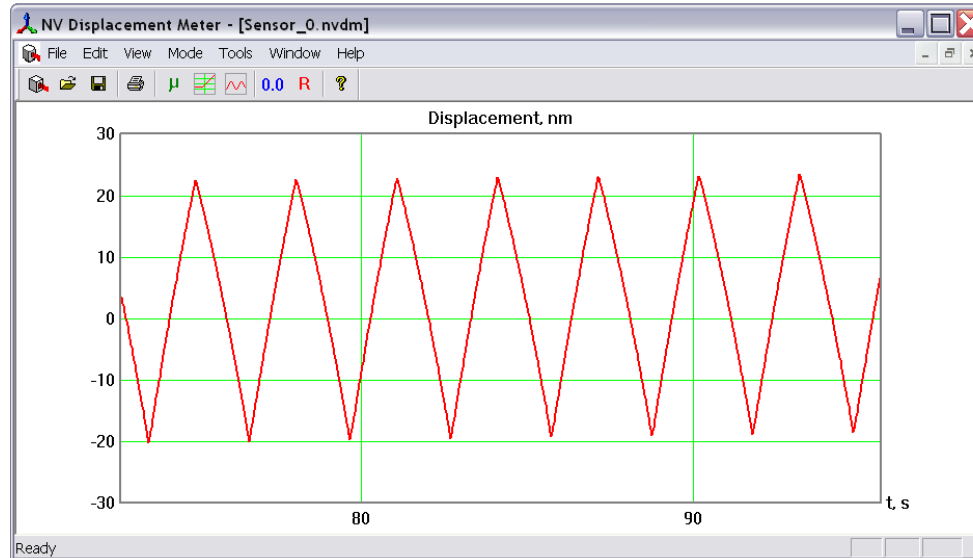
Characteristics:

- | | |
|---|-----------|
| ▪ Resolution | 0,015 nm |
| ▪ Relative error (laser depended) | 10^{-8} |
| ▪ Displacement measurement range (laser depended) | >200 mm |
| ▪ Maximum displacement speed | 2 mm/c |

Noise of the base interferometer



Displacement measurement result for a piezoelectric element



Advantages and applications of the base interferometer

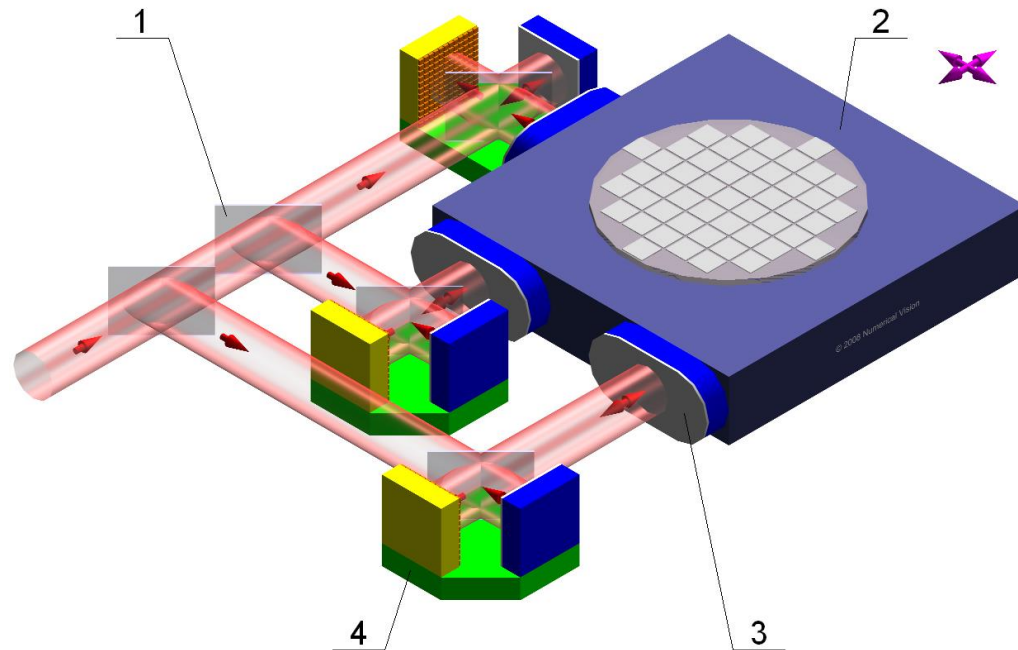
Advantages:

- High precision;
- Small gabarites;
- Low vibration and temperature error;
- Low cost;

Applications:

- Nanolithography;
- Atom by atom assembly;
- Optical surface control;
- Gene engineering;
- Translation stage for atom force and tunnel microscopes;
- Precise measurement for acceleration, pressure, deformation, mass, gravitation, temperature etc.

Application of the base interferometer for 2D translation stage control

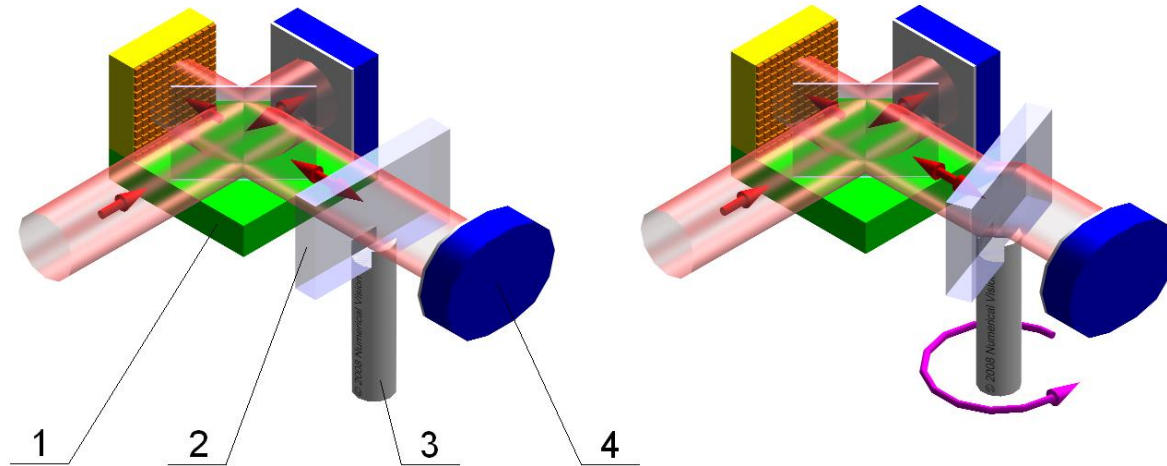


1 –beamsplitter; 2 – displacement platform; 3 – mirror; 4 – base interferometer

Characteristics:

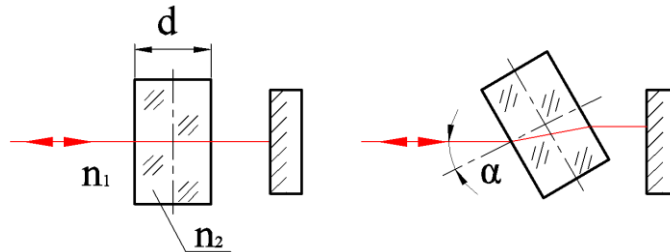
- | | |
|---|-----------|
| ▪ Resolution | 0,015 nm |
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Angle measurement



1 – base interferometer; 2 – glass plate; 3 – rotation axis; 4 – fixed mirror

$$\Delta L = f(\alpha, n_1, n_2, d)$$



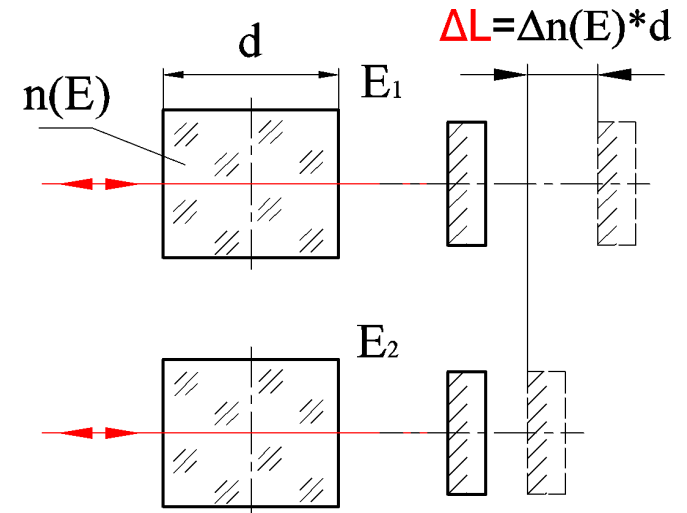
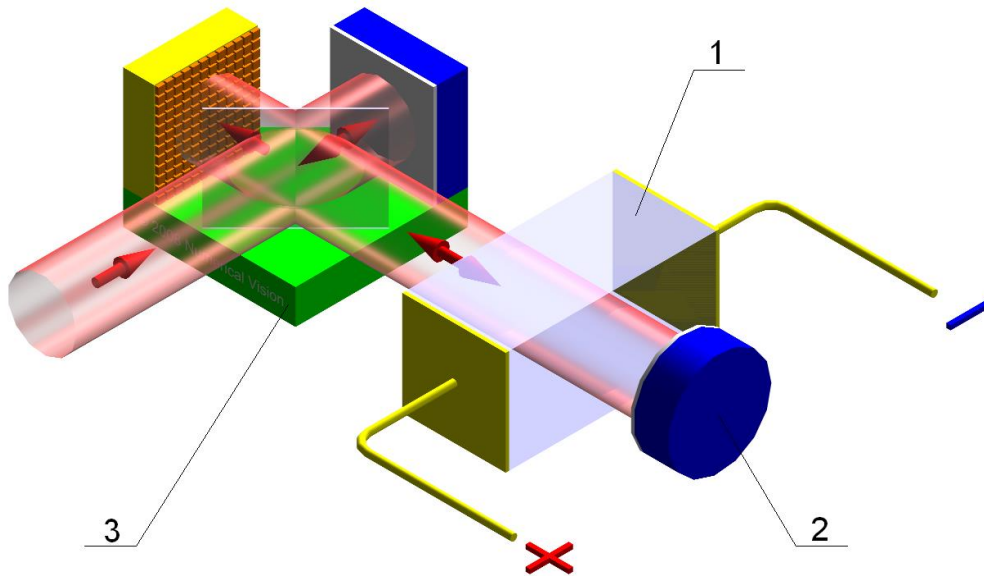
Characteristics:

- Resolution ($d=10$ mm)
- Displacement range

0,00002''

45°

Refractive index measurement for electro-optic materials

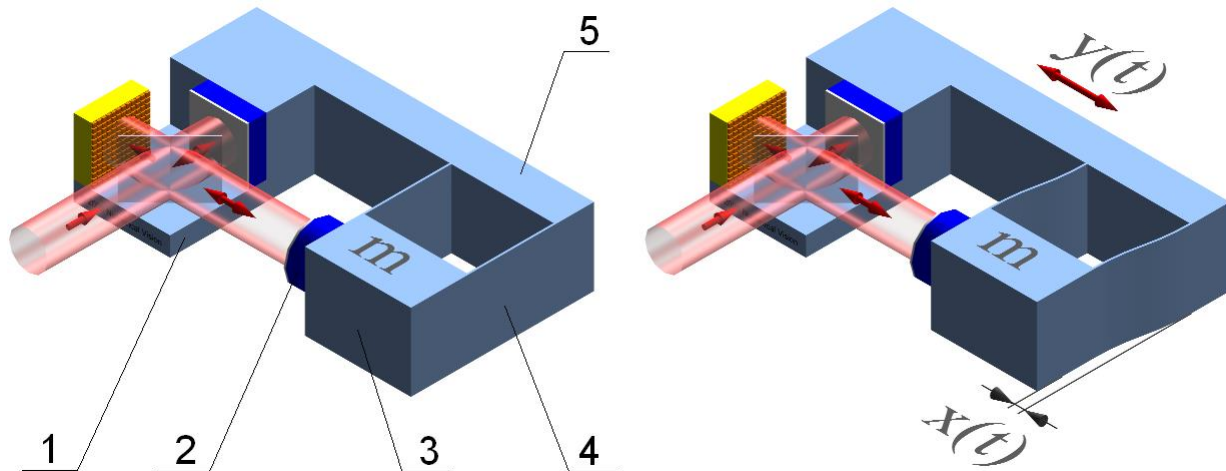


1 – electrooptic material; 2 – fixed mirror; 3 – base interferometer;

Characteristics:

- Relative error (for n) 10^{-7}
- Resolution (for n) 10^{-9}

Vibration measurement

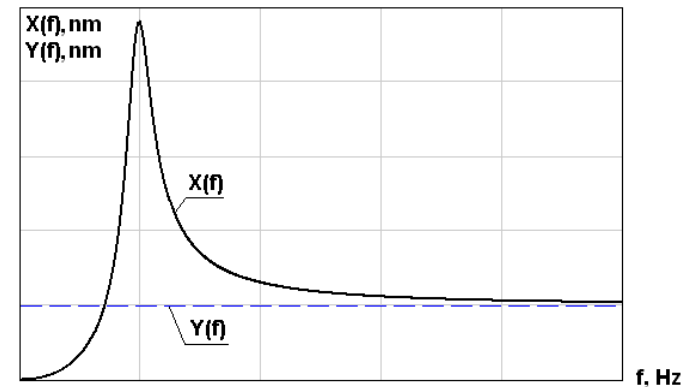


1 – base interferometer; 2 – mirror; 3 – weight m ; 4 – spring;
5 – moving base

Key differential equation

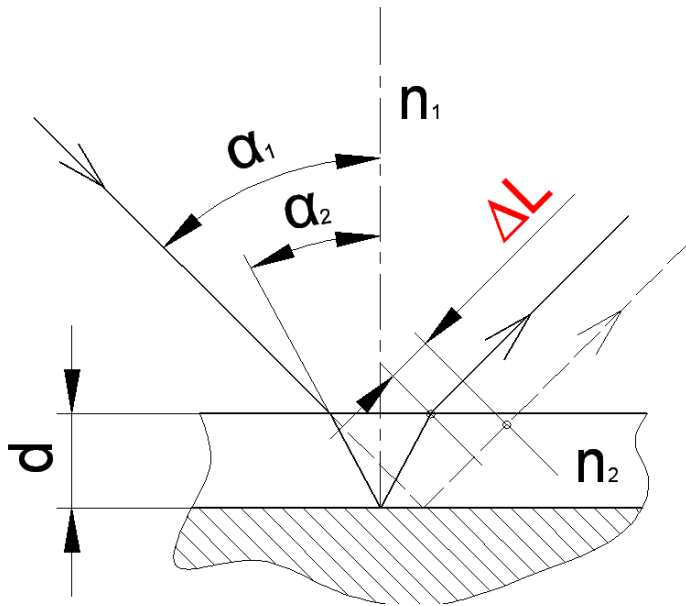
$$m \frac{\partial^2 x}{\partial t^2} + r \frac{\partial x}{\partial t} + kx = mY\omega^2 \cos(\omega t + \varphi)$$

Frequency characteristic

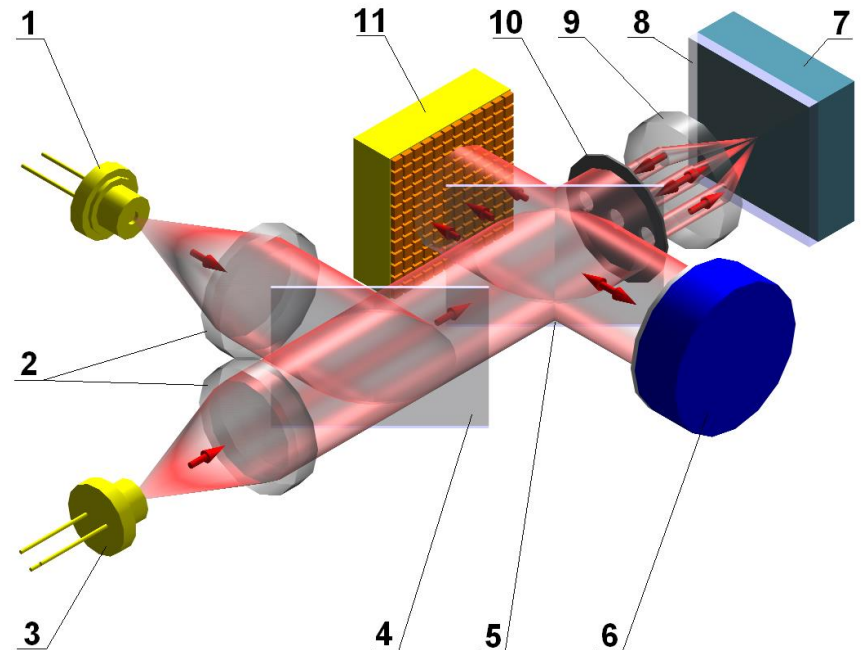


Resolution: $<0,01\text{nm}$ ($f > f_0$) f_0

Film thickness measurement

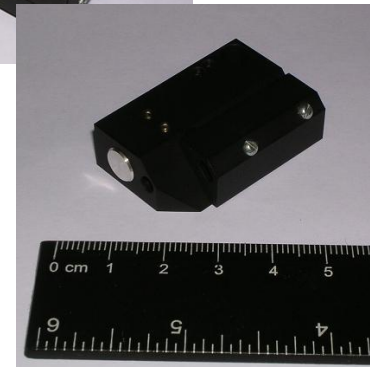
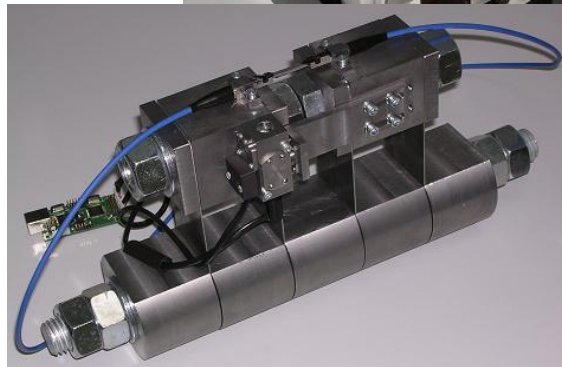
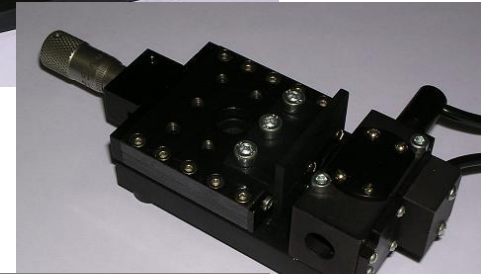
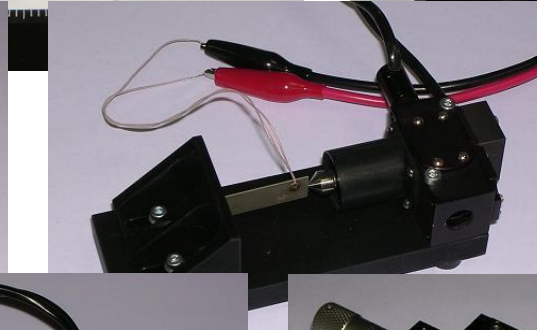


Optical path difference between reference and measurement beam



Film Thickness measurement setup scheme: 1 – Laser of the first channel; 2 – collimating lens; 3 – laser of the second channel; 4, 5 – beam splitter; 6 – reference mirror; 7 – sample; 8 – thin film; 9 – objective; 10 – diaphragm; 11 – multielement receiver

Application examples

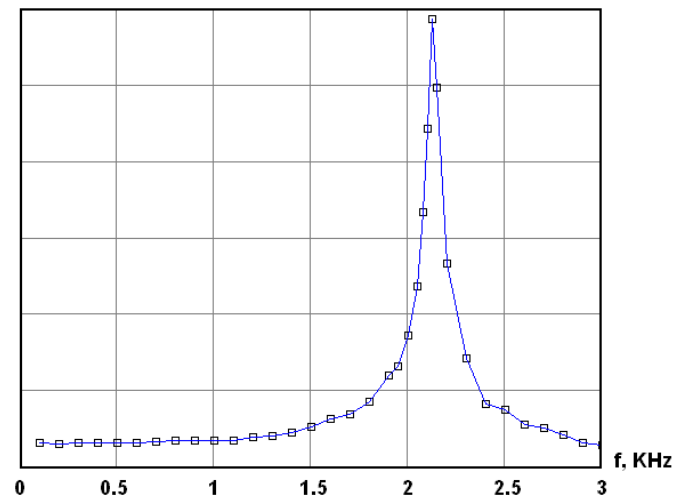


Translation stage with piezoelectric element and internal interferometer



Main characteristics:

- Displacement range – 30 μm
- Resolution – $<0,1 \text{ nm}$
- Blocked force – 1000 N
- Input voltage – 0...100 B
- Input capacitance – $<10 \mu\text{F}$
- Gabarites – 15x16x81 mm
- Gain-frequency characteristics:



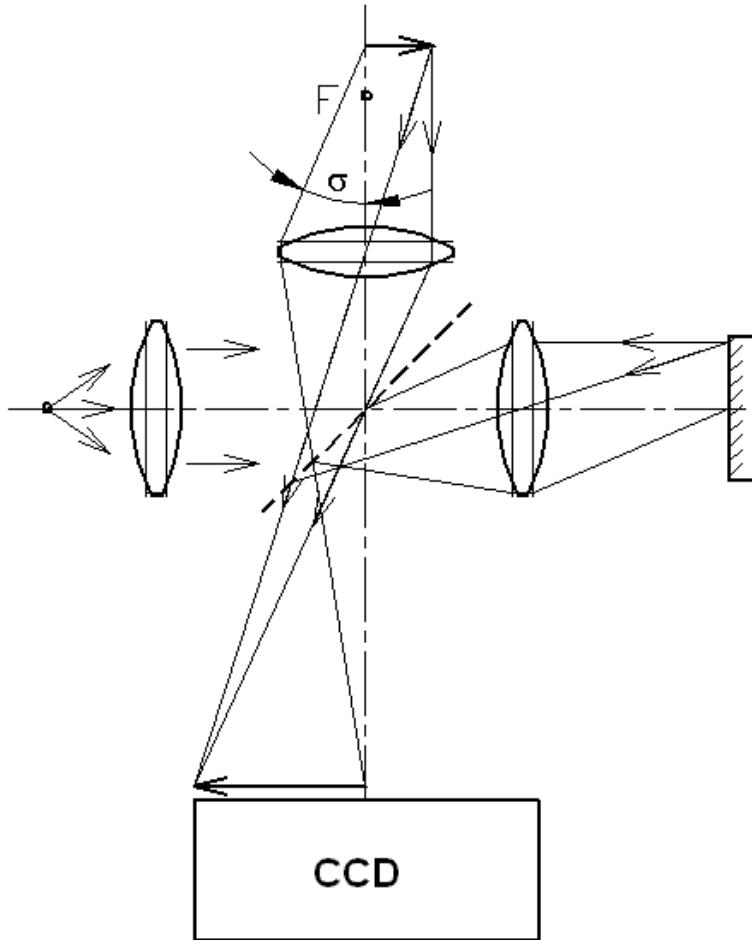
Applications:

- Nanotechnologies
- Microelectronics
- Bioengineering
- Auto focusing systems
- Machine tools

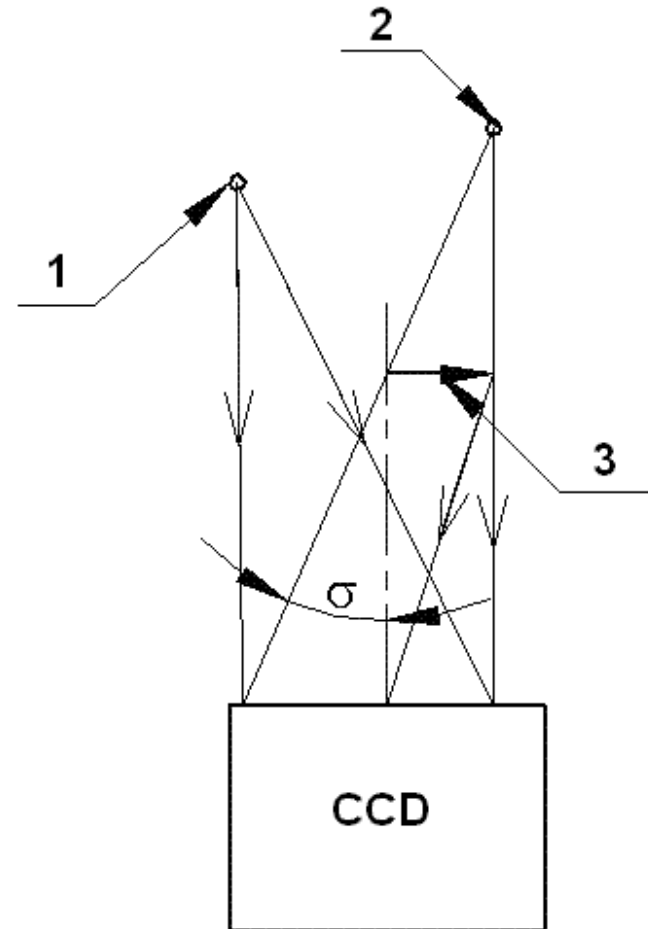
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Optical Scheem

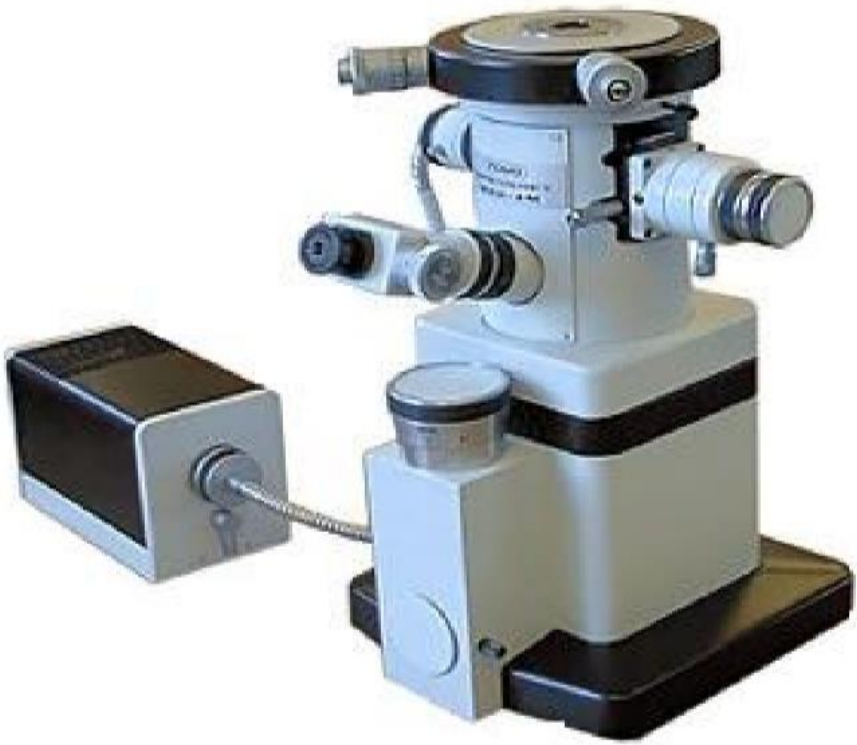


Common interferometric microscope
(Linnik scheme)

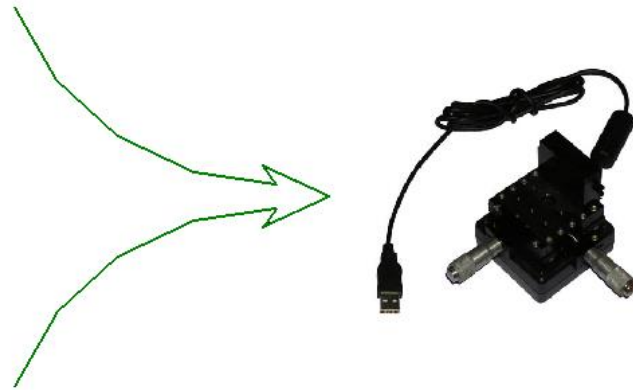


Lensless digital holographic microscope:
1- reference point source; 2-object point
source; 3-object

Microscope Size Reduction



Common interferometric microscope
(Linnik scheme)



Lensless digital holographic
microscope:

Lensless Digital Holographic Microscope LDHM-4

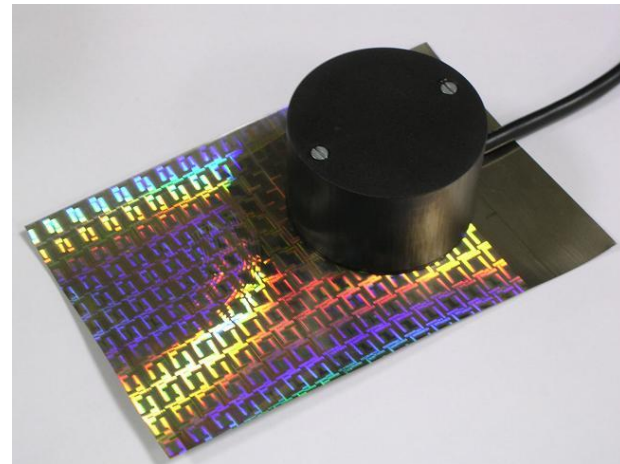


Main characteristics:

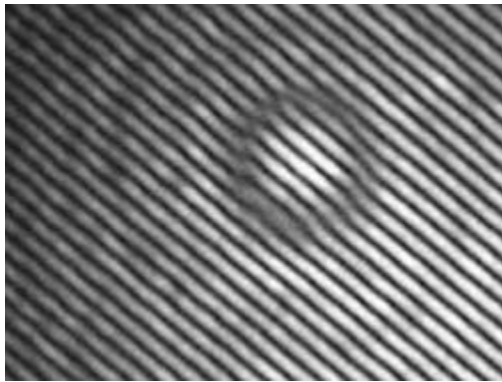
- Lateral resolution – $2,8 \mu\text{m}$
- Depth resolution – 3 nm
- Field size – $200 \times 200 \mu\text{m}$
- Small dimensions
- Lighting – reflection mode
- Interface – USB 2.0, SPI
- Supply voltage – 5B USB.

Applications:

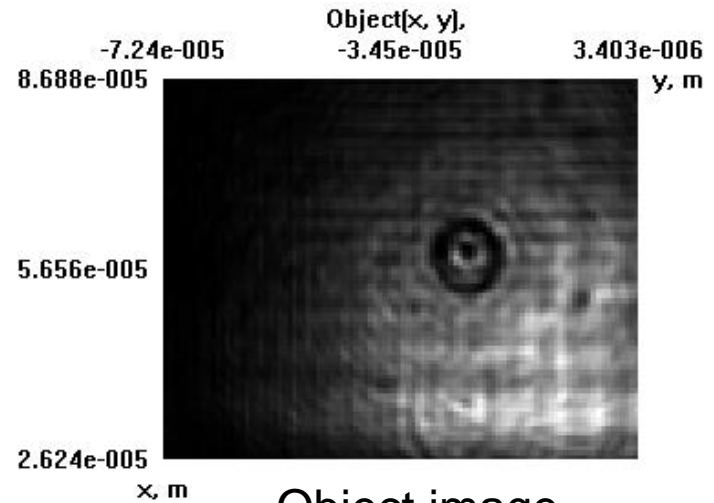
- Photolithography
- Biology
- Medicine
- MEMS
- Nanotechnologies



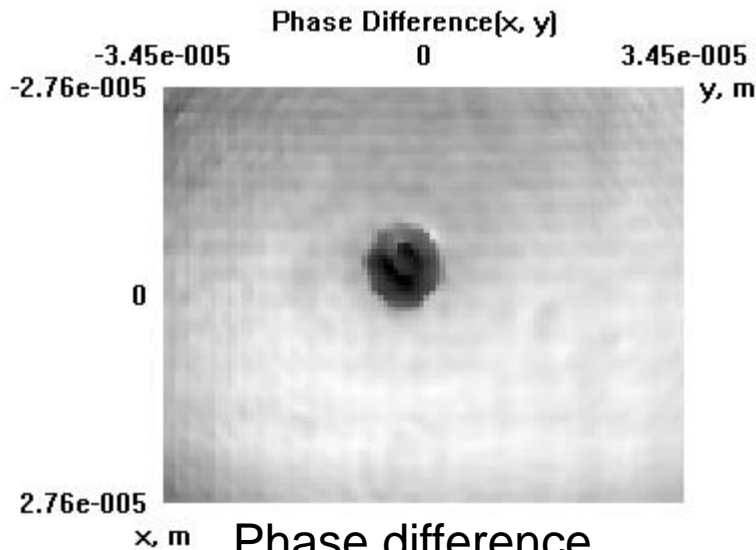
Digital hologram processing results



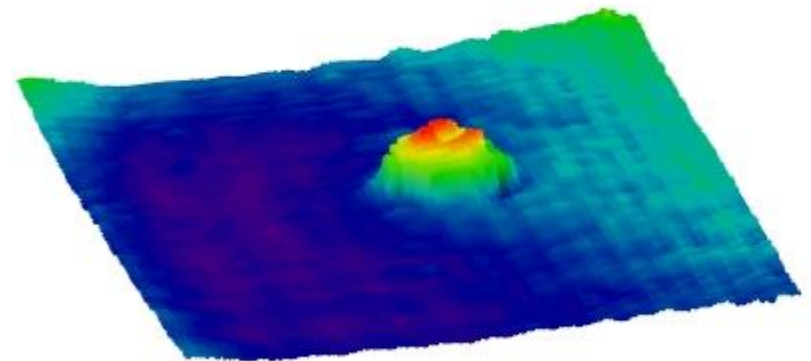
Initial image



Object image

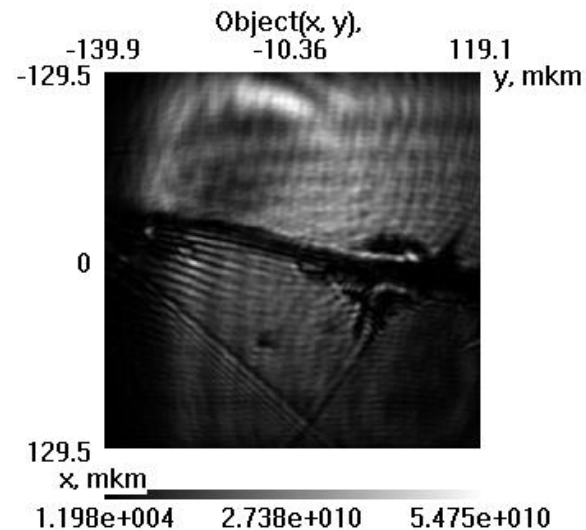
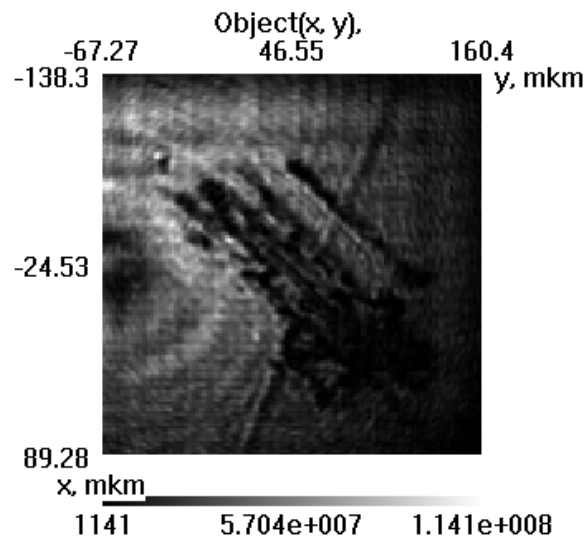
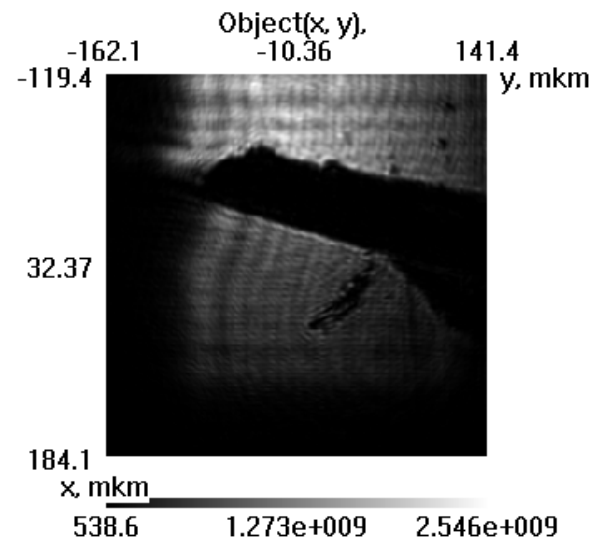
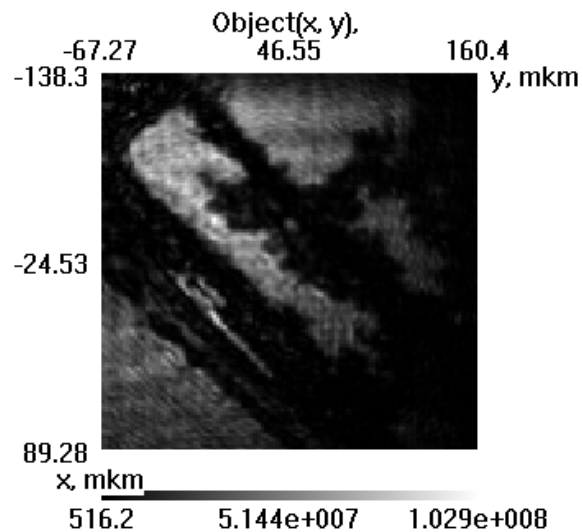


Phase difference



Height distribution

Image examples



Conclusion

- Image processing market grows with number of digital cameras and number of processors and their computation power
- BMSTU and Intelligent Optoelectronics Ltd. can help for Korean companies to open image processing market with new products
- Sales of joint product of BMSTU/Intelligent Optoelectronics Ltd. and Korean companies with image processing technologies reach 15 Million USD in 2018