NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 1 EXAMINATION 2018-2019

MA4842 – ENGINEERING METROLOGY

November/December 2018 Time Allowed: 2½ hours

INSTRUCTIONS

1. This paper contains **FIVE (5)** questions and comprises **FIVE (5)** pages.
2. Answer **ALL** questions.
3. Marks for each question are as indicated.
4. This is a **CLOSED-BOOK** examination.

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1 (a) What are the most significant instrumentation terms that are to be considered in a measuring instrument?

(5 marks)

(b) How indirect methods of measurement differ from direct methods? Explain with an example each.

(6 marks)

(c) Name a non-contact stylus based metrological equipment that can give large measurement range with a very good value of range to resolution.

(2 marks)

(d) An interferometer which belongs to the class of double pass interferometer is used to calibrate a high resolution piezoelectric transducer. This transducer is attached to one of the mirrors of the interferometer.

(i) When a voltage is applied to the transducer, it is found that 100 fringes moved against a reference mark on the screen. If the light source used is 600 nm, find the distance moved by the transducer.

(4 marks)

(ii) Name the interferometer that belongs to the double pass interferometer category.

(2 marks)

(iii) When repeated five times by giving the same voltage to the transducer, during a calibration measurement, the displacement of the high-resolution transducer read as 10.0 μm, 10.4 μm, 10.6 μm, 10.2 μm, and 9.8 μm. The nominal value of the transducer displacement is given as 10.0 μm. Find the error and relative error of measurement.

(6 marks)

2 (a) An autocollimator is used to measure tilt or small rotation angle of machine tool ways. Explain its working principle with the help of a simple schematic diagram.

(8 marks)

(b) What are the major convolution errors associated with a contact stylus based surface profiler?

(6 marks)

(c) What are the THREE major groups of parameters associated with a surface profile? Mark them on a simple surface profile sketch.

(8 marks)

(d) A phase shifting interferometer is used for measuring the surface height of a test specimen. What is the relationship between phase at each point and surface height?

(3 marks)

3 (a) Describe TWO representative optical phenomena which can be explained by wave optics but not by ray (geometrical) optics with one diagram for each phenomenon.

(4 marks)

(b) When a wave encounters an obstacle, two different phenomena shown in Figure 1(A) and (B) could be observed. Explain the conditions where one can observe either case (A) or case (B) based on the aperture size (a) and the wavelength (λ).

(6 marks)

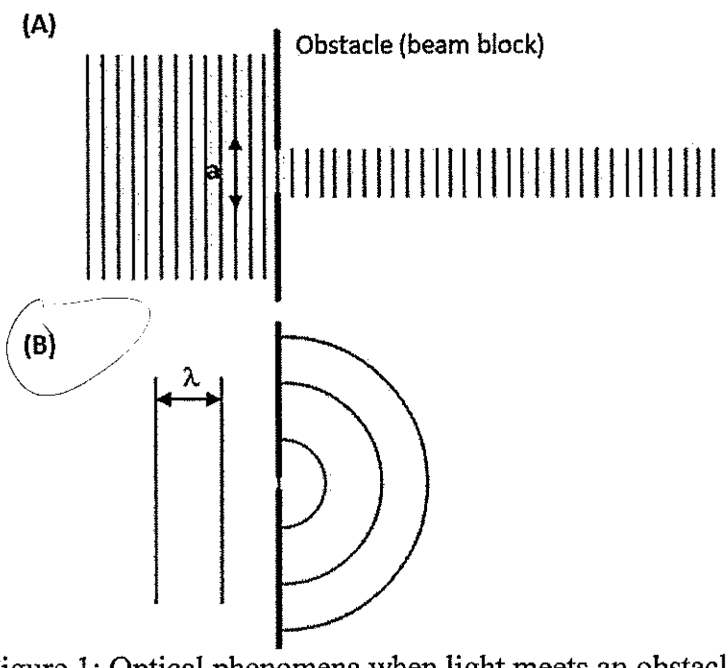


Figure 1: Optical phenomena when light meets an obstacle

Note: Question 3 continues on page 3.

(c) Fill out THREE blanks in the sentence on 'the definition of a metre' as below.

"The meter is length of the path traveled by ________ in vacuum during a ________ interval of 1/299,792,458 of a ________" in 1983 in 17^{th} CGPM. The speed of light is c=299,792,458 m/s (constant in vacuum). The second is determined to an uncertainty of 1×10^{-14} by the Cesium clock.

(3 marks)

4. Fizeau optical interferometer shown in Figure 2 is used for high-precision thickness measurement.

(a) For the interferograms shown in Figures 2(A), 2(B), and 2(C), match the corresponding thickness profile of the target sample from 2(D), 2(E), and 2(F), and explain the reasons for your answers.

(6 marks)

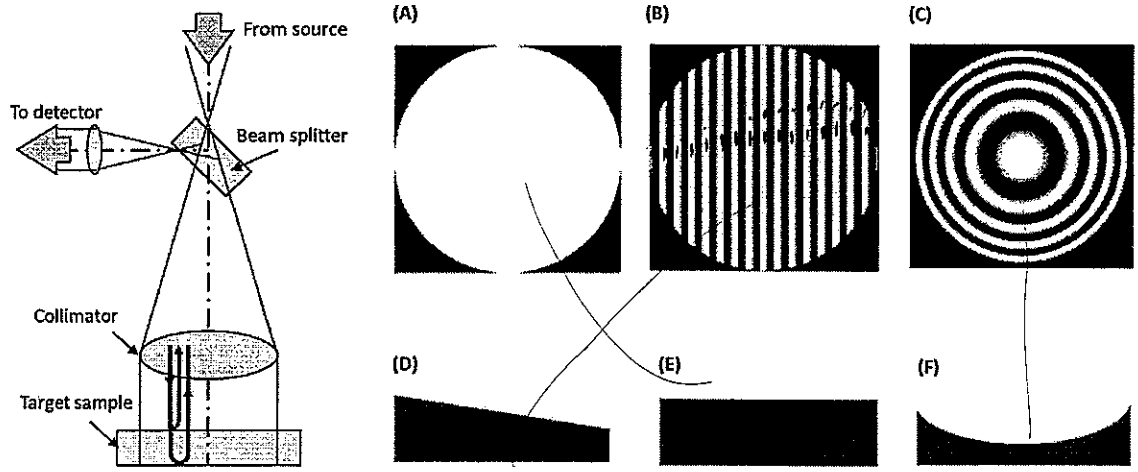


Figure 2: Fizeau interferometer: optical configuration and interferograms

(b) If you have acquired an interferogram shown in Figure 2(B) from the Fizeau interferometer using a 800 nm wavelength laser, what is the thickness variation of the sample? Can we tell which end is thicker from the interferogram? (hint: Fizeau interferometer is based on double-path optical configuration).

(5 marks)

(c) Figure 3 shows schematically the basic principle and an interferogram of a lateral shearing interferometer. Explain the principle of the lateral shearing interferometer. Also explain why it works well for testing industrial optical elements with large deformation or curvature.

(6 marks)

Note: Question 4 continues on page 4.
Figure 3 appears in page 4.

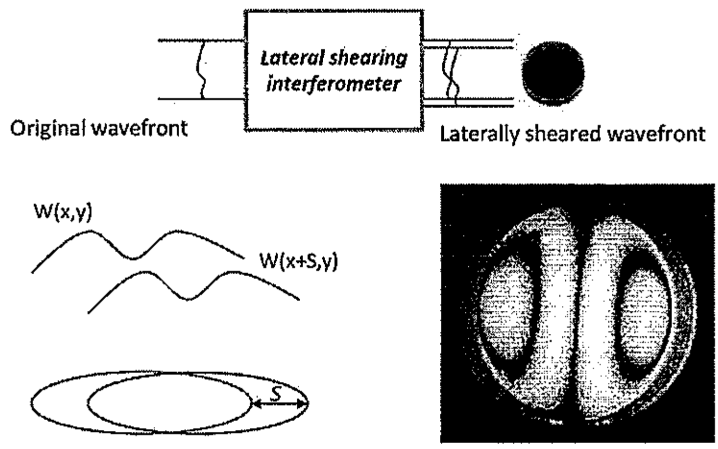


Figure 3: Lateral shearing interferometer: principle & interferogram

5. The resolution of most optical imaging system is fundamentally limited by the diffraction limit, d,

$$d = \frac{\lambda}{2 \cdot N.A.}$$

where $N.A.$ is the numerical aperture of a lens ($N.A. = n \cdot \sin\theta$), n is the refractive index of the medium and θ is the incidence angle of light from the surface normal.

(a) Figure 4(A) and (B) show the technological trends in laser wavelength and imaging optics design for semiconductor lithography machines. Explain THREE fundamental reasons behind these trends in terms of laser wavelength, diameter of the optics and material absorption.

(9 marks)

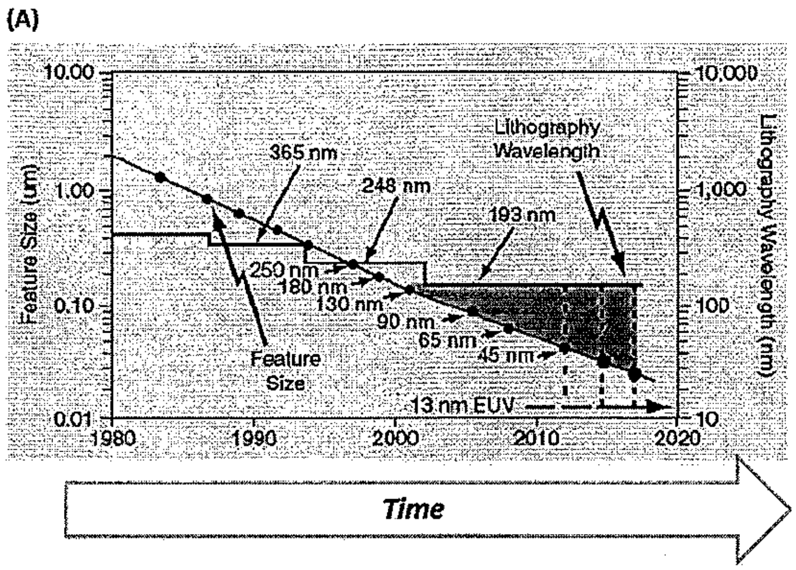


Figure 4(A): Trends in laser wavelength in lithography machines.

Note: Question 5 continues on page 5.
Figure 4(B) appears in page 5.

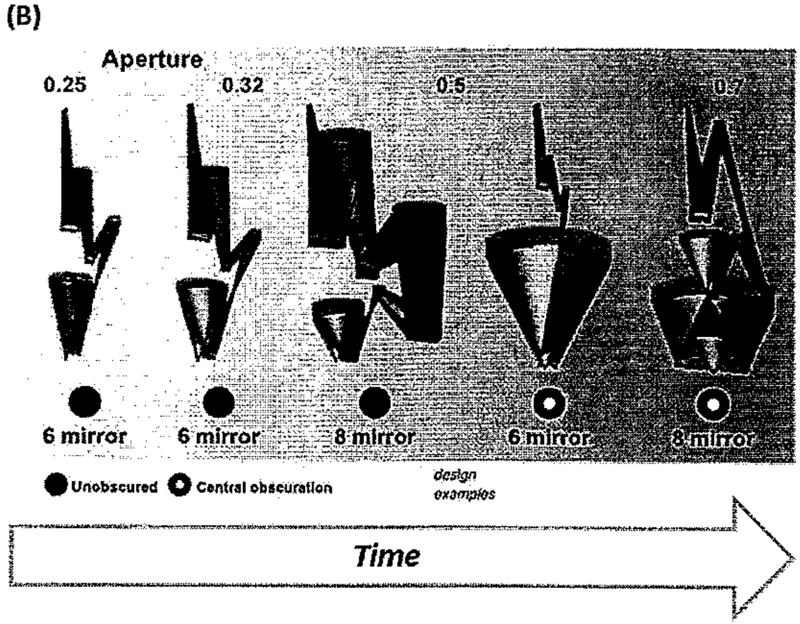


Figure 4(B): Trends in optics design in lithography machines.

(b) The minimum feature size in optical patterning is described by Rayleigh criterion. Explain the Rayleigh criterion with a clearly labeled diagram.

(3 marks)

(c) The spatial resolution of biological imaging is also limited by the diffraction limit to several hundreds of nanometers as shown in Figure 5. Explain the reason for this practical limit in terms of λ, n, and θ in a quantitative manner. Explain THREE possible ways to improve the imaging resolution.

(8 marks)

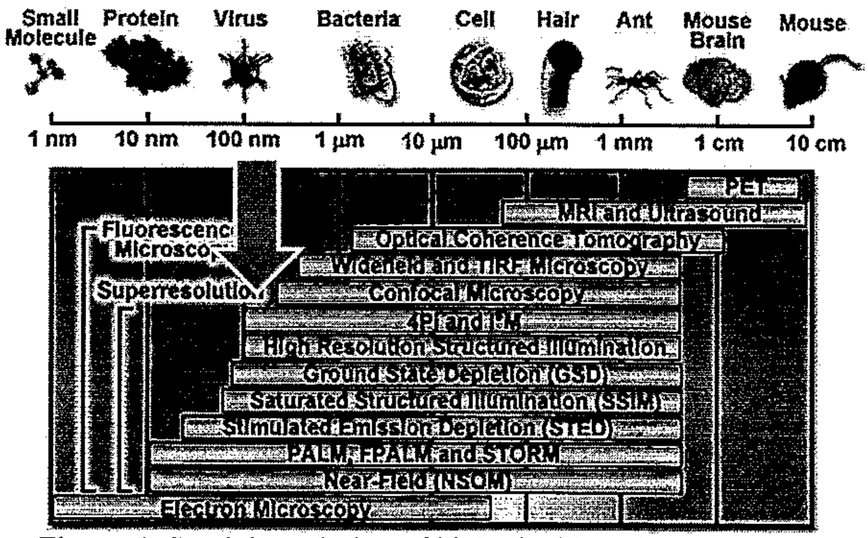


Figure 5: Spatial resolution of biological imaging techniques

END OF PAPER

Q1

1a) ① Range ② Repeatability / Precision ③ Accuracy ④ Resolution ⑤ Errors

1b) Direct Methods

① Simple method of measurement

② Value of quantity obtained directly without calculation

Example of Direct method: Vernier Caliper

Indirect Method

① More complicated

② Value of quantity obtained by measuring other quantity which are functionally related to required value.

Example of Indirect method: Sine bar.

1c) Confocal Microscopy

※ Note: laser Interferometric Transducer uses a contact stylus.

1d) i) Distance $= \frac{N\lambda}{2} = 100 \times \frac{600 \times 10^{-9}}{2}$

$= 0.00003\,m$

$= 0.03\,mm$

ii) Michelson Interferometer ✓

iii) Error = Average − Nominal

Average $= (10.0 + 10.4 + 10.6 + 10.2 + 9.8)\frac{1}{5}$

$= 10.2\,um$

Error $= 10.2\,um - 10.0\,um = 0.2\,um$.

Relative Error $= \frac{\text{Error}}{\text{Average}} = \frac{0.2\,um}{10.2\,um} = 0.02$

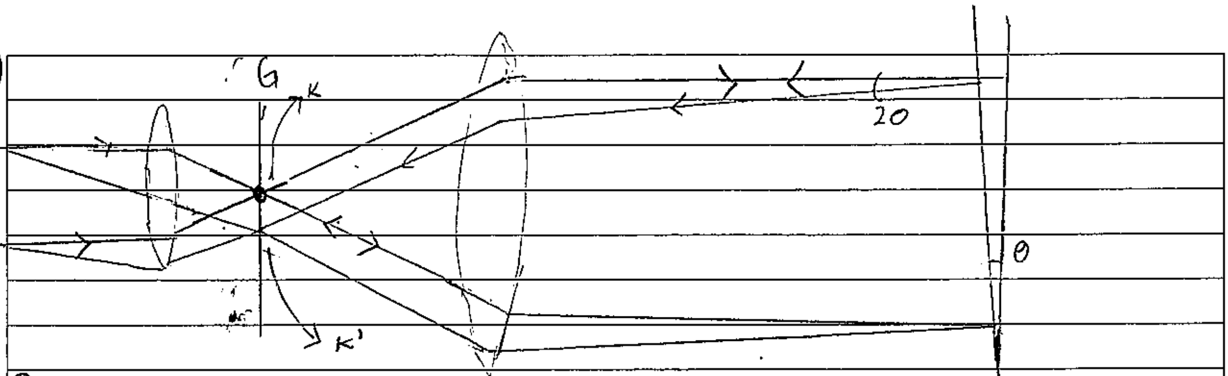
or 2%.

DISCLAIMER: *The solutions are done by students who scored A or above in this subject. MAE Club and Campus supplies are not liable or responsible for any errors in the contents of these solutions. Students are advised to take the solutions as a guide rather than absolute answers to exam paper.*

Should there be any mistake identified, please proceed to the Facebook link encoded in the QR code to feedback or submit correct answers. The link is: http://bit.ly/2lW2C32

Q2)

a)



① Figure G is the illuminated graticule projection by objective O.

② Light from mirror M refleited back normal to colliminator bundle

③ As the light is focused by objective lens, an image of graticule are formed.

④ When the mirrors are rotated slightly about any perpendicular axis to the optical axis, returning image of K now forms at K' graticule displace by a distance s, which is then measured.

⑤ The distance s is proportional to angle of rotation θ by the ~~#~~ relationship $s = 2f\theta$, where f is focus length of objective lens.

b) The major convolution errors are:

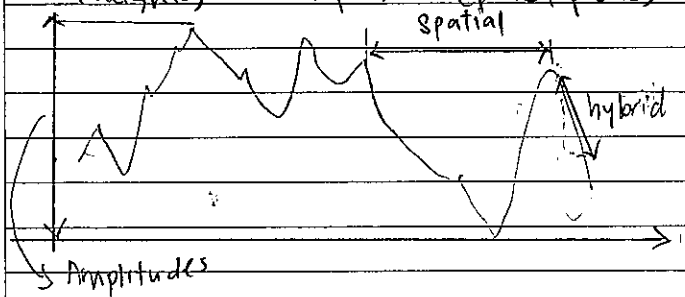
① Rounding the peaks and steps (form errors)

② lengthing the peaks (length error) and shortening valleys (height errors)

③ The stylus can't record undercuts, overhangs, or ~~en~~ re-entrant angles.

c) 3 major group of surface parameter:

① Amplitude ② Hybrid ③ Spatial
(heights) (slopes) (peak to peak)



2d) phase difference = $\left(\frac{2\pi}{\lambda}\right)$ OPD where OPD is 2d ~~...~~ michelson interferometer d is the height difference from reference.

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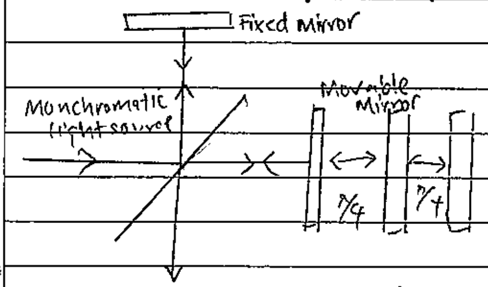
3a) ~~Interference~~

Interference → corresponds to the interaction of 2 or more light waves yielding a resultant irradiance that deviates from the sum of the component irradiance

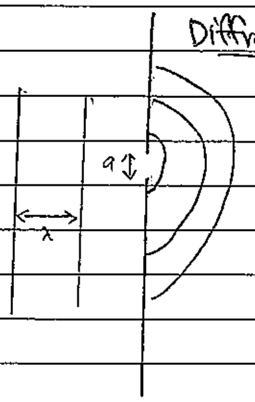
and

Diffraction → No significance difference from interference. Interference is the superposition of a ~~few~~ waves, and diffraction is the characteristic of a large number of waves.



~~The michelson~~ interferometer make full use of the interference phenomena to measure small displacement.

Diffraction limit Diagram



when $a << \lambda$ light spread out when passed through apeture.

b) when $a >> \lambda$, the ~~[illegible]~~ diffraction limit will not happen and the image can be ~~ob~~ observed, such as in in (A). However when $a << \lambda$, the diffraction limit will disperse the light by diffraction, hence one cannot observe (B) as $\lambda >> a$.

c) Light, time, second

4a) A ↔ E   B ↔ D   C ↔ F

A) The surface is smooth for (A) such that no fringe pattern are formed

B) The surface height vary constantly such that a constant straight line fringe pattern are formed.

C) The surface height vary little in the center of the concave resulting in thick fringe pattern, however as the height varying become steeper at the edge we note the distance between each fringe pattern narrowing.

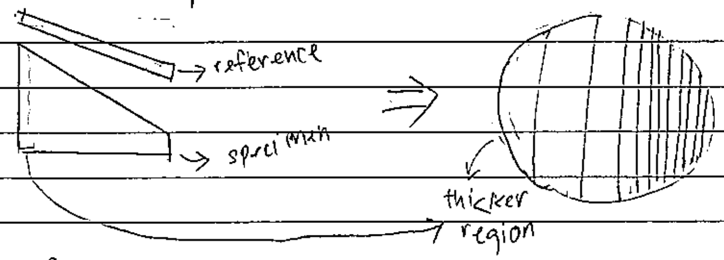
4b)

$\lambda = 800nm$

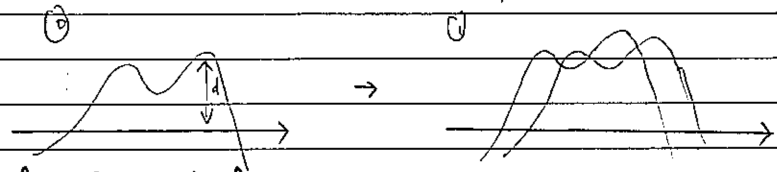
$N = 15$

$s = \frac{N\lambda}{2} = \frac{15 \times 800nm}{2} = 6000nm$

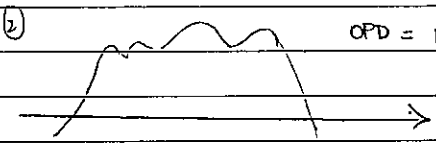
We can tell which end is thicker by using a tilted reference. if the distance between each fringe pattern is thicker than the region that is thicker is at the higher end of the reference as shown



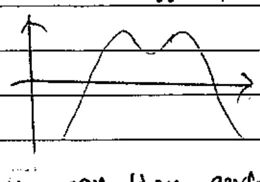
4c)



A measurement of big height variation in normal interometer is difficult, due to camera limitation and 2π ambiguity limitation of normal optical interferometry measurement ⇒ In lateral shearing interferometer, 2 interferometry fringe pattern are measure at a δx distance difference



By substracting the lateral shearing interferometry wave by original wave we get the OPD of the interferometer



~~we can then perform~~ integration ~~to rebuild~~ the surface pattern (OPD.

Such system allow the interferogram density to be more far apart But precision is the same as optical interferometry and it work for larger height variation >100 μm, hence it is good for testing industrial optical element.

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5a) ① Laser wavelength has decrease ~~at~~ over the years in lithography wavelength.

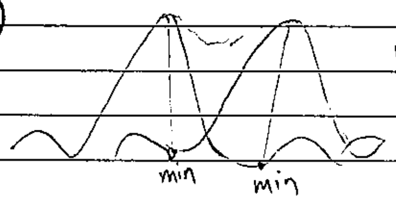
~~①~~ The decreasing wavelength has allow a smaller d value, given the relation $d = \frac{\lambda}{2NA} \rightarrow \downarrow\lambda \rightarrow \downarrow d$

② The increase in the size of the optics by increasing diameter also allow a small d value as $d = \frac{\lambda}{2NA} = \frac{\lambda}{2n\sin\theta}$

The increase in diameter of optics means a larger θ value and hence a smaller d value.

③ Changing of material absorption ~~at~~ property is hard. ~~as the~~ and hence it is hard to increase refractive index n by changing material absorption, as short wave length is absorbed by ~~media~~ common mediums like oil, water etc

b)



When an object is incoherent point source, image will consist of a distribution of partially overlapping, yet independent and airy patterns.

Image will be distinct and easily resolved if Rayleigh criterion is met, when the central maximum of one coincide with the first minimum of the other, the Rayleigh criterion is met.

c) The practical limit in Biology imaging are as followed:

$d = \frac{\lambda}{2n\sin\theta}$, $\lambda \cong 600nm$

$n \cong 3.0$ (silicon)

$\sin\theta \cong \sin 90$ (max)

$\cong 1$

$d \cong \frac{600nm}{2(3)\sin 90} \cong 100nm$ ✗

③ possible way to improve the imaging resolution:

① $\downarrow\lambda$ by using light with shorter wavelength like UV or gamma ray

② $\uparrow n$ by changing the material for light absorption to one with higher refractive index

③ Increase the size of lens ~~to~~ or bring object nearer to the specimen to increase θ. (limit to 90 however)

tips: Attend the physical lecture after watching LAMS! (only 1 hour)