Optics, Spring 2024

Submit your answers as a PDF file via Google Classroom before deadline (11.04.2024 at 10.00).

If problems, contact the course assistant joonas.mustonen@helsinki.fi.

Exercise 10 (Max points 14)

1. Human eye (4p.)

a) Calculate the diffraction limited spatial resolution for naked human eye. Assume that normal near point is approximately 4 diopters, the diameter of pupil in bright light is c. 4 mm, and the color of the light is visible blue. Is this a good approximation for a human eye resolution?

b) Explain Helmholtz's theory of accommodation (by defining two lens conditions) and define accommodative amplitude.

c) Explain briefly Fincham's theory of presbyopia.

d) The shape of the lens can be modified to correct aberrations by using fs-lasers. Method does not require cutting a flap and it avoids thermal damage in other regions. In a vision correction, a burst of ultraviolet light (0.5 mJ) is projected onto the cornea of the patient (ø = 1 mm). The energy heats up the corneal tissue to 100 ºC from 34.0 ºC, and it evaporates the volume (without further temperature increase). By approximating thermal properties of the tissue as water, calculate the depth of the layer ablated.

2. FTIR (Ch 9.4.2) (5p.)

Fourier-Transform Infrared Spectroscopy is a common gas characterization technique, which is based on the design of Michelson Interferometer (Ch 9.4.2). Different gas molecules have different resonance frequencies, implying that the frequency dependency of light absorption differs between different types of molecular composition. In FTIR, source produces a broad spectrum of infrared light that passes through the gas sample. Beam splitter divides the light into two paths. The fixed mirror reflects one beam back to splitter and another mirror does the same thing, but its position can be adjusted precisely. Finally, detector captures the combined interference of these signals.

a) Draw a schematic of the described Michelson interferometer. First, consider situation, in which a monochromatic light source is used, and the mirror is adjusted in a way that creates a constructive interference. What is this maximum intensity as a function of electric field **E**?

b) Now, consider the case that the position of the second mirror is moved a length that corresponds to the length of the wavelength. Sketch its intensity profile as a function of distance.

NB! If the mirror is changed 1 um, the optical path is changed 2 um, because wave goes that part of the path twice due to the reflection.

c) Based on your sketch, what is the separation between adjacent maxima / fringes?

d) Quantity *finesse* characterizes the sharpness of the interference fringes by indicating, how many fringes will be well-resolved and visible in the interference pattern. It can be calculated by dividing the separation between adjacent maxima by the full width at half maximum (FWHM). Derive the equation for finesse.

e) Why is Fourier transformation required to determine the final gas composition?

3. Photo-acoustic effect and Laser-Doppler vibrometer (3p.)

Laser-ultrasonics is based on the light-matter interaction via photoelastic effect. Consider sound propagation in the solid plate, excited by a light pulse. Grüneisen parameter χ links the specific energy deposition of the light pulse I (J/m^3) to initial pressure rise p (Pa) as follows:

$$\chi = \frac{p}{I} = \frac{\delta v^2}{C}$$

a) Calculate the Grüneisen coefficient for mild steel in right units.

Specific heat capacity	480 J/(kg·K)
Volume thermal expansion coefficient	$3.07 \cdot 10^{-5}\ K^{-1}$
Longitudinal speed of sound	5960 m/s

b) Light can force matter to vibrate via photoelastic effect. LDV (Laser-Doppler Vibrometer) is an interferometer-based device that can measure these vibrations in a non-contacting manner, based on frequency shift due to Doppler effect. Consider using a Polytec OFV-505 Vibrometer Sensor Head (HeNe, < 1 mW). Calculate the recorded frequency for 0.1 mm / s vibration. Why is LDV good option for detecting small vibrations?

$$\Delta f = 2\frac{v}{\lambda}$$

c) Laser-induced displacement can be approximated for isotropic, common bulk metals (Lamé parameters: $2\mu=\lambda$) far away from edges as follows:

$$d = \frac{\alpha}{6\pi\rho C v r} P$$

, in which α = volume thermal expansion coefficient, ρ = density, C = specific heat capacity, v = longitudinal speed of sound, r = distance from the generation point and P = absorbed power.

Consider Nd:YAG laser (wavelength = 532 nm), shooting a 12 mJ light pulse with duration of 13 ns, and a pick-up LDV (OFV-505), that is located at a distance r. What is the maximum r for detectable displacement in mild steel, if the smallest displacement that the LDV can detect is around 5pm?

4. Light microscopy (2p.)

Explain the meaning of each marking on the microscope objective.