Optics, Spring 2024

Submit your answers as a PDF file via Google Classroom before deadline (22.02.2024 at 10.00).
If problems, contact the course assistant joonas.mustonen@helsinki.fi.

Exercise 4

1. Total internal reflection (TIR) (4p.)

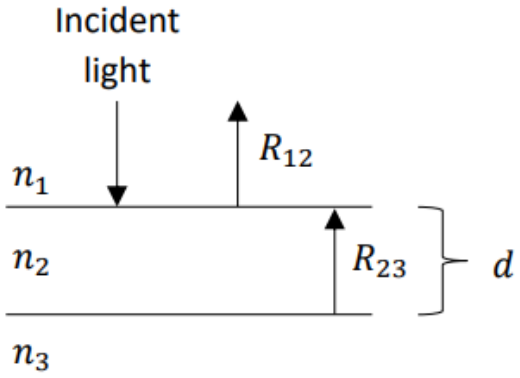
A ray of light is incident at an interface between two linear dielectric media.

a) (1p.) Derive the equation for critical angle at this interface. Explain, what happens, if the incident angle is smaller or higher than the critical angle.
b) (1p.) Calculate critical angle, if light propagates from diamond to air.
c) (1p.) Calculate critical angle, if light propagates from air to diamond.
d) (1p.) Explain qualitatively the concept of evanescent wave.

2. Antireflection coatings (3p.)

Anti-reflective coatings are used on the surface of optical lenses, to reduce undesired reflections. By selecting a proper material n and coating thickness d, the reflections can be minimized.

Consider the following case, with three materials. Incident light is propagating from medium n_1, it propagates through coating medium n_2 and hits the surface of the optical lens with corresponding n_3.



The reflections can be minimized by adjusting the n_2 and d parameters in a way, that destructive interference occurs.

a) (1p.) First, the reflection coefficients R_{12} and R_{23} need to be the same. Express n_2 in terms of n_1 and n_3, when such condition occurs.

Hint.

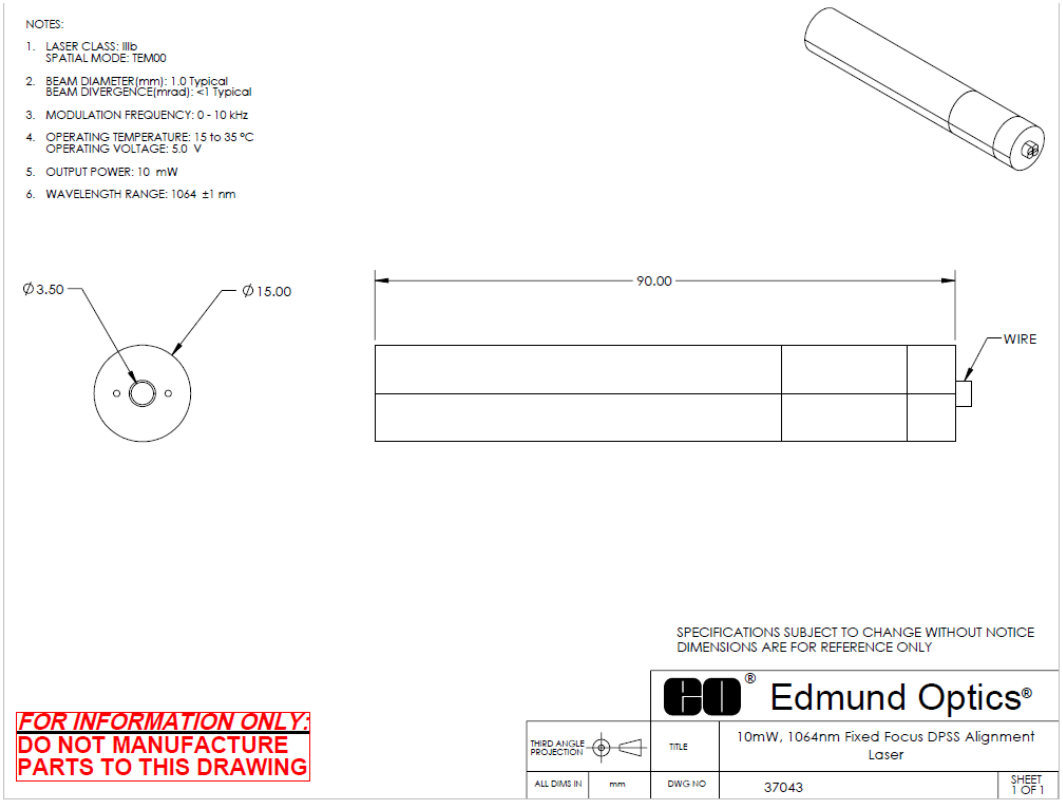
$$R = \left(\frac{n_o - n_i}{n_o + n_i}\right)^2$$

b) (1p.) The propagation distance d in the coating medium needs to ¼ of the wavelength, to enable destructive interference. This is because destructive interference occurs, when the interfering waves have opposite phases (1/2 wavelength difference), and in this scenario, light need to propagate the anti-reflective coating twice before the interference. Express the proper anti-reflection coating thickness d as function of wavelength and as function of refractive index of the coating.

Hint. Wavelength is a function of the refractive index of the medium.

$$n \sim \lambda^{-1}$$

c) Design an anti-reflective coating for a BK-7 lens in air to operate with the following infrared laser.



3. Attenuation (3p.)

Attenuation is a phenomenon, in which amplitude of the wave is reduced. This can be caused by scattering or IR absorption, for example.

a) (1p.) 1 mW of optical power enter a single mode optical fiber. How long can the optical fiber be, if the attenuation coefficient 0.385 dB / km and the detection limit at the other end is 10 nW?

b) (1p.) Additional to Rayleigh scattering, in optical fibers, IR absorption can also cause attenuation. Explain qualitatively, what is IR absorption.

c) (1p.) Total attenuation can be estimated as sum of attenuation from Rayleigh scattering and IR absorption in silica optical fibers. Discuss, which one is more dominant and if either of them be neglected at some cases.