Kinegram measurements

1. Introduction

Kinegrams are holograms used in labels for security purposes. These security holograms consist of overlapping (two- or three-dimensional) nanoscale diffractive structures that are manufactured with technologically advanced fabrication methods such as electron beam lithography. They are very difficult to forge, which makes them suitable for security labels. The word kinegram is officially a trademark of OVD Kinegram AG (a company in Switzerland), but the term is often used as a common noun for security holograms. The motivation of this work is to illustrate the working principle of these holograms, carry out spectroscopic measurements on a white LED illumination, and inspect the diffraction effect produced by a grating structure on the incident light distribution.

2. Theory

2.1. Diffraction

Diffraction is a fundamental phenomenon occurring when light bends from the corners of an encountered obstacle such as an aperture. Diffraction gratings are optical components which split and diffract light into several waves travelling into distinct directions. An idealized grating is made up of a set of slits with certain periodic spacing. The diffracted light is then composed as a sum of the interfering waves that emanate from the grating structure. These waves add or subtract from each other and create diffraction maxima and minima through additive and destructive interference. Different wavelengths are viewed at different angles. This gives rise to phenomenon called “iridescence”, which refers to the gradual change of color as a function of viewing & incident angles. This makes diffractive structures very useful in monochromators, spectrometers, and chromatic aberration correction. Furthermore, manufacturing of nanoscale diffractive structures requires sophisticated fabrication methods and expensive equipment, which makes them difficult to forge. Therefore, diffractive structures are highly useful in security holograms, for example.

Gratings can be designed to modulate various properties of incident light such as transmittance, reflectance, phase, and polarization. In this work, a reflection grating is used (Fig. 1). The diffracted light from such grating has intensity maxima of order m at diffraction angles θ_m (with respect to the grating normal) as described by the grating equation

$$d(\sin\theta_i - \sin\theta_m) = m\lambda, \tag{1}$$

where d is the spacing between the slits in the grating, θ_i is the angle of incidence, and λ is the wavelength of light.

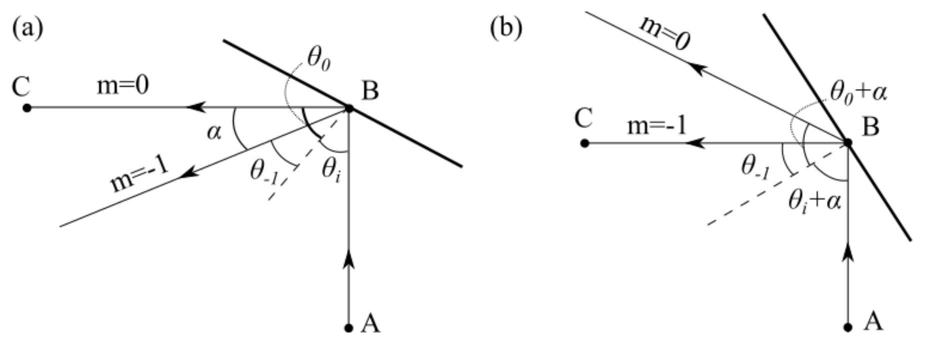


Figure 1. Diffraction from a reflection grating, when (a) the incoming light is incident at an angle θ_i to the grating normal, and when (b) the grating is rotated by angle α that corresponds to the angular separation between diffracted light of orders $m = -1$ and $m = 0$. Note that $\sphericalangle ABC = 90°$ in both situations.

2.2. LEDs

Light Emitting Diode (LED) is a semiconductor light source which emits light as electric current goes through it. Technically it is a p-n diode which consists of semiconductors of p- and n-type. When current is applied to the diode, the electrons of the n-type material recombine with electron holes of p-type material. As a result, the higher energy levels of electrons will decrease, and the change of energy level can be detected as a photon. The phenomenon is called electroluminescence. The energy of emitted photon is equal to the change of energy, and it depends on the semiconductor material that is used in the diode. Therefore, various colors and even ultraviolet and infrared wavelengths can be produced with LEDs by selecting proper semiconductor materials.

3. Measurements

The goal of the measurements is to illustrate the applicability of diffractive structures and elucidate the principles of security holograms. In particular, the aim is to build an experimental setup for inspecting the diffraction effect created by a reflective diffraction grating and carry out measurements with the built setup.

Your task is to design a measurement configuration for determining the period of the used grating (along with the other tasks given in Sec. 4). The available components are presented in Fig. 2. The primary devices are the reflective diffraction grating and Spectra-1 spectrometer. In addition, the available light source is a white LED flashlight. Additional equipment are various optical components and holders, and a rotation table.

You can use your own consideration when building the setup. However, keep in mind that you must be able to determine the grating period based on the measurement geometry. Document the used alignment carefully for yourself, so that you can present it and the following tasks clearly in the report. To help you accomplish this task, a rough outline of the recommended setup alignment is presented in Fig. 3.

First, use the built setup to measure the spectrum of the LED source (the instructions for using the spectrometer software are given below). After this, measure also the angle of first-order diffraction for three distinct wavelengths found from the spectrum. For the first wavelength, select the peak wavelength that corresponds to the maximum intensity in the spectrum of the LED (approximately at 450 nm). For the other two wavelengths, aim for selections that are located approximately at the regions corresponding to green and red colors in the spectrum. It might be necessary to tweak with the exposure time in the spectrometer software to achieve clear spectral peaks for these two. However, do not change the settings between measuring the LED spectrum and the highest diffraction peak.

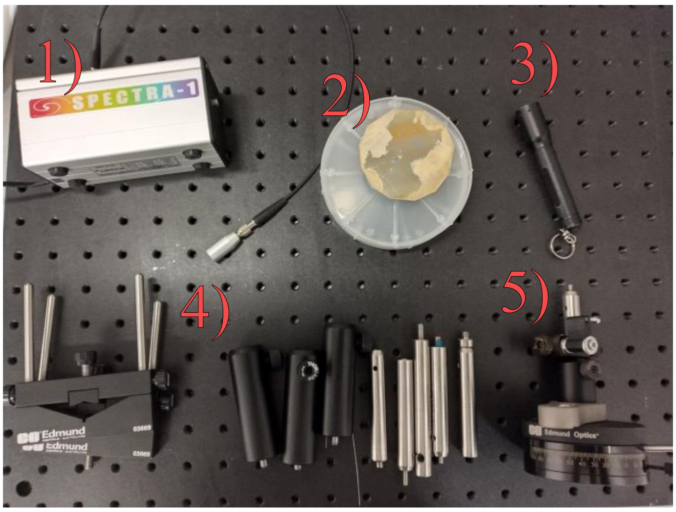


Figure 2. The available equipment: 1) Spectra-1 spectrometer, 2) the reflective diffraction grating, 3) LED flashlight, 4) optical components and holders, and 5) a rotation table.

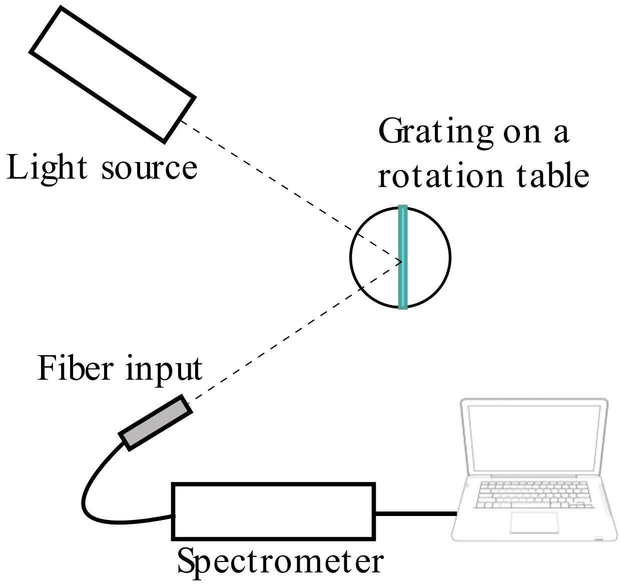
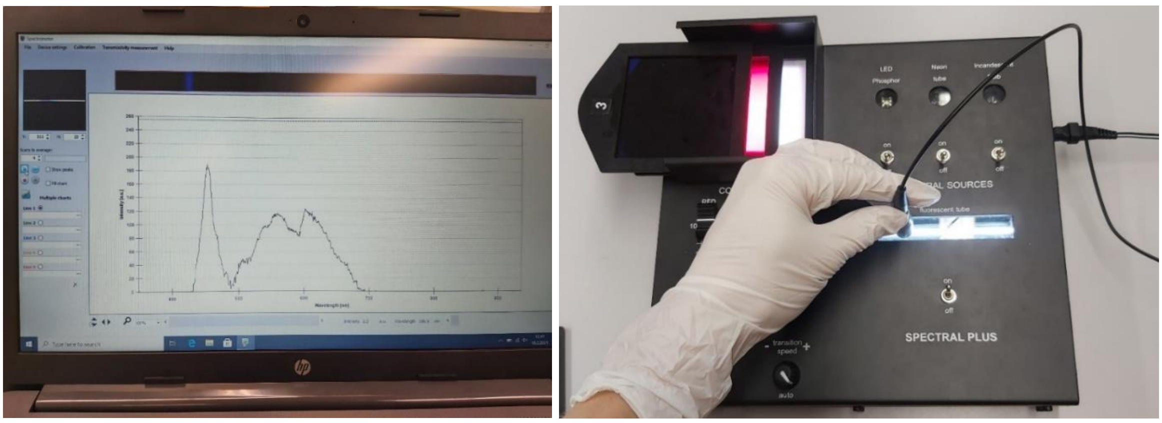


Figure 3. Sketch of the measurement setup.

<u>Instructions for using the spectrometer:</u>

You have a computer containing the software ‘spectrometer’ for controlling the spectrometer. The software works in a following way:

1) The user interface is presented in Figure 4 (a). You can press the small arrow on the left to take one single measurement with the spectrometer. Pressing the button next to that one updates the graph constantly (recommended for this work).
2) The measurement situation can be done in a similar way to what is presented in Figure 4 (b). However, place the fiber input into a holder for stability.
3) Export your spectrum as a text-file from the ‘File’ menu which you can find from the upper left corner of the software.



(a) (b)

Figure 4. (a) The user interface of the software. (b) Measuring a light source spectrum with spectrometer fiber which has a lens on top of it. You may need to find the correct height from the light source to not have saturated spectrum or you can change the exposure time from the camera settings that you can find from ‘Device settings’ menu.

4. The report

In the report, consider the following topics:

1) Plot the measured spectra and present them in the report. Define the wavelengths corresponding to the maximum intensities of the three diffraction spectra.
2) Present a clear sketch of the experimental alignment that you built. Based on the sketch, derive an expression for the grating period. Define the uncertainty[1] for this expression.
3) Use your formula together with the measured angles and wavelengths of the first-order diffraction peaks and define the period of the used grating (you can take an average of the three calculated values). In addition, calculate the error of the period by using the derived expression for the uncertainty.
4) Calculate the full width at half maximum of the measured first-order diffraction spectrum of the highest peak. Determine the change of energy (use electronvolts) between the valence and conduction bands that corresponds to this peak. In addition, estimate the widths of the valence and conduction bands. Compare then the intensity of this peak to the corresponding peak in the LED spectrum and estimate the efficiency of the first diffraction order of the grating for that wavelength, assumed that the zeroth-order efficiency is optimized.

[1] If correlations between different variables are neglected, the uncertainty can be estimated with the error propagation formula $\Delta f = \sqrt{\sum_{i=1}^{n}\left(\frac{\partial f}{\partial x_i}\Delta x_i\right)^2}$. This formula gives the uncertainty Δf of a n-variable function f, where $\frac{\partial f}{\partial x_i}$ denotes the partial derivative of f with respect to the variable x_i, and Δx_i is the uncertainty of x_i.