# Characterization and polarization resolved simulation of diffractive optical elements.

Hallvard Angelskår* hallvard.angelskar@fys.uio.no
Grégory Bouquet‡ gregory.bouquet@sintef.no
Ib-Rune Johansen§ ib-rune.johansen@sintef.no
Matthieu Lacolle‡ matthieu.lacolle@sintef.no
Odd Løvhaugen‡ odd.lovhaugen@sintef.no
Håkon Sagberg§ hakon.sagberg@sintef.no
Aasmund S. Sudbø¶ aas@unik.no

*Center for Materials Science and Nanotechnology, Department of Physics, University of Oslo, PO Box 1048 Blindern, N-0316 Oslo, Norway
†SINTEF ICT, Optical Measurements and Data Analysis, Forskningsveien 1, N-0314 Oslo, Norway
‡SINTEF ICT, Microsystems and Nanotechnology, Gaustadalléen 23 C, N-0373 Oslo, Norway
§University of Oslo, University Graduate Center at Kjeller, PO Box 70, N-2027 Kjeller, Norway

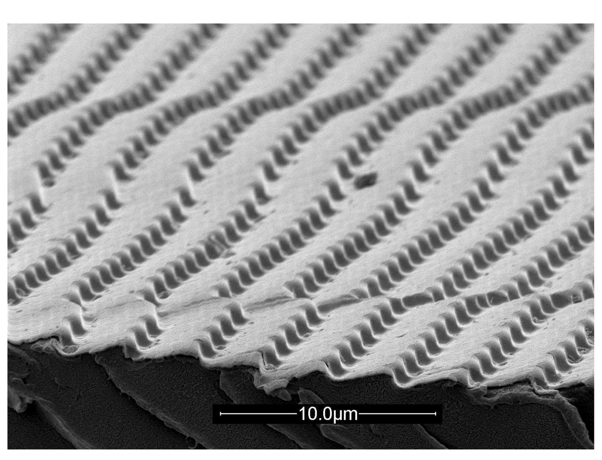
## Abstract

We present our activity on the characterization and simulation of diffractive optical elements (DOEs) for near infrared spectroscopy.
The DOE surface is designed to direct and focus light of a limited set of wavelengths onto a detector. In order to perform this, the surface pattern has a complicated structure and varies significantly over the element. This leads to a variation in the diffraction efficiency if the incident light only illuminates certain parts of the DOE. For the use of a DOE in a spectrometer, it is for some applications important that the local diffraction efficiency of each wavelength component relative to the others is as uniform as possible over the DOE. Otherwise, the spectroscopic measurement can become unreliable.
A measurement setup was built at SINTEF to characterize the DOEs. This setup uses a movable aperture in front of the DOE, so that it is possible to measure the diffraction efficiency in different positions on the DOE.
The simulations were carried out using the PCGrate software [1], which computes the diffraction efficiency for a periodic diffraction grating, employing full vectorial representation of the optical field. We carried out the simulations for one wavelength and position at a time, modeling the DOE surface by a perfectly periodic diffraction grating, with a period and an orientation designed to yield a surface with the same performance as the fabricated DOE. This yields a simple model that gives variations of local diffraction efficiency of the same order of magnitude as the measurements.

## Background/Application

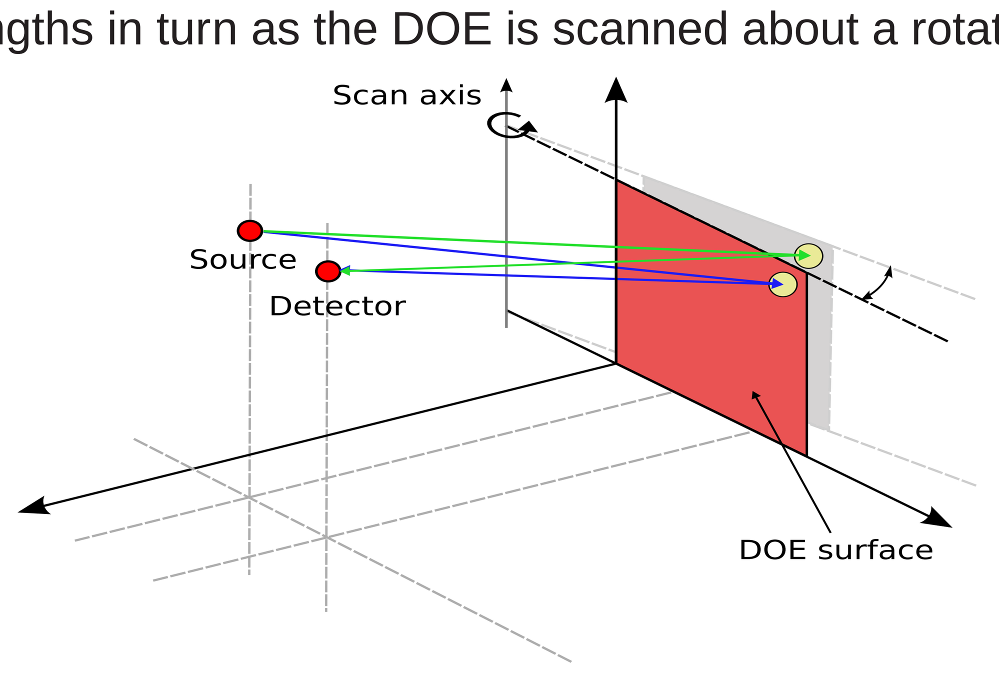
- By studying the absorption of a limited set of wavelengths one can determine which molecules are present in a sample.
- Near-infrared spectroscopy can be used to detect polymer materials in for instance waste recycling centers.

## Principle and measurement setup




Left: Scanning electron micrograph showing the surface patterning on a part of a DOE. Diffractive optical elements can perform several key functions such as dispersion, focusing and beam splitting in instruments for spectroscopy [2].

- The DOEs are patterned to function as reflective Fresnel lenses for five specific wavelengths in turn as the DOE is scanned about a rotation axis.

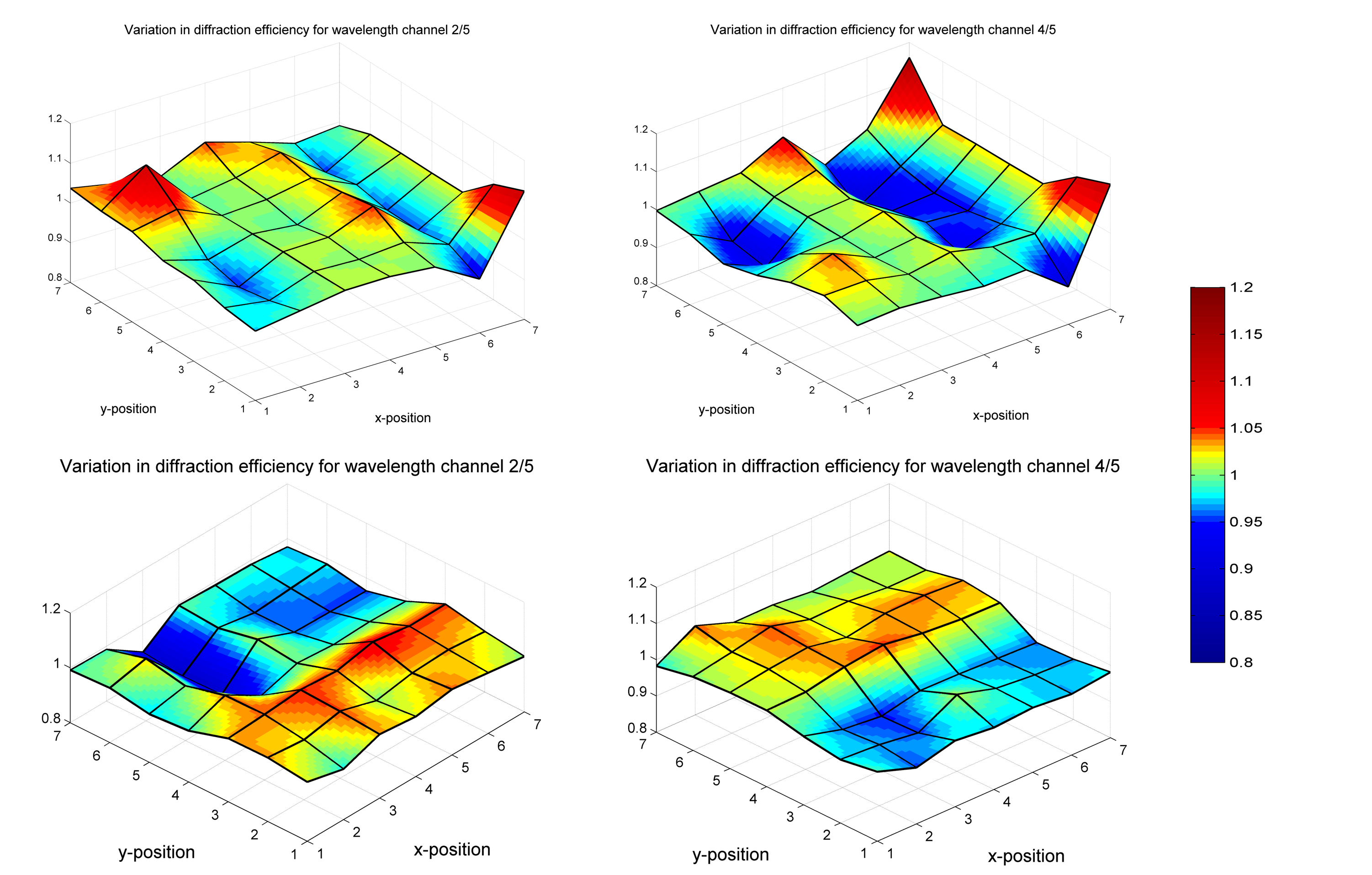



- The DOE is rotated, and at a certain rotation angle the surface pattern focuses a different wavelength onto the detector.
- The diffractive elements were characterized locally by moving a small aperture (3 mm and 1 mm) to different positions on the DOE and measuring the diffraction efficiency.

## Simulations

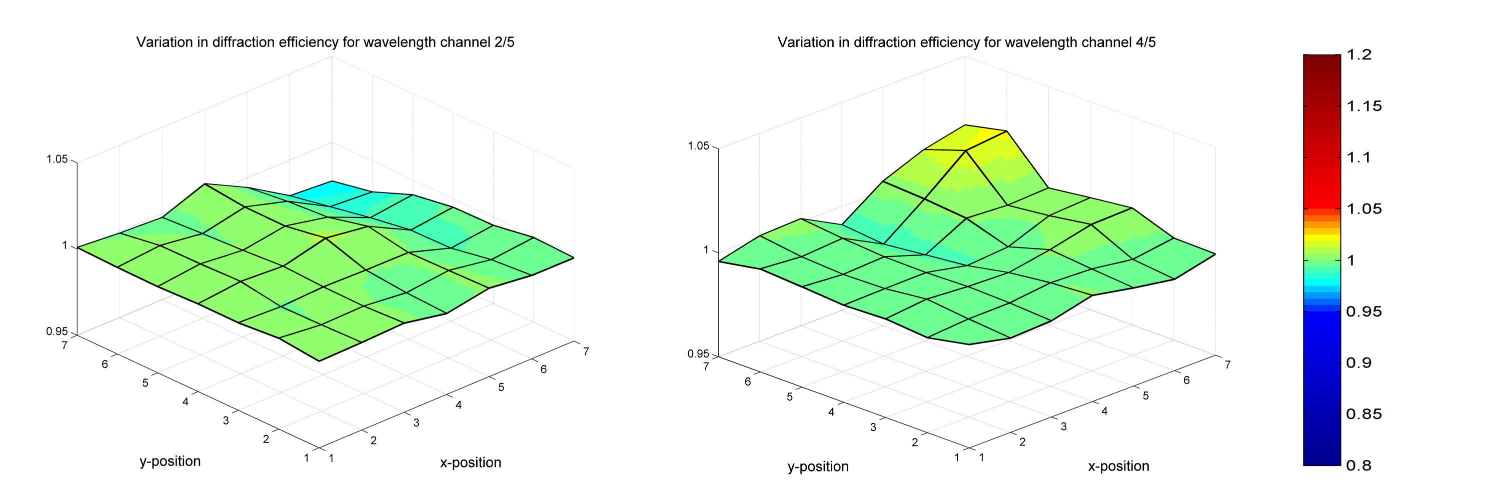
- Large incidence angles and small surface pattern details ⇒ need of a vectorial model.
- Locally, the DOE surface is modeled as a periodic diffraction grating with one of the diffraction orders in the direction of the detector. For each position we used the same incidence angle as in the measurement setup, and assumed a periodic grating with grooves perpendicular to the wave vector of the incident wave.
- The PCGrate software [1] was used to perform calculations of diffraction efficiency of the periodic gratings.

## Diffraction efficiency results




Normalized local diffraction efficiency from simulations (top) and measurements (bottom) on two-level silicon gratings coated with 30 nm of gold. The measurements and simulations are shown for two wavelengths, and for 7x7 positions on the DOE.

- Resonances result in variation of up to approximately 15% in the diffraction efficiency of the two channels shown in the figure both in measurements and simulations. However, we are not able to predict precisely where on the DOE they occur with the simple model used in the simulations.




Simulations for a four-level silicon grating coated with 30 nm of gold. This profile shows less of the resonances that we see for the two-level profile above.

- Simulations show that increasing the number of steps in the grating profile from two to four would reduce the maximum amplitude of those variations to approximately 3%.

## Summary

- Setup for spectral characterization of diffractive optical elements (DOEs) built at SINTEF.
- Full vectorial model used to simulate diffraction efficiency from periodic gratings as a simple first order approximation.
- Studied DOEs with various groove profiles and metal coatings.
- In a statistical sense, the observed variations in diffraction efficiency across the fabricated DOE can be reproduced by polarization-resolved diffraction calculations. The surface patterns that we have simulated are so different from the patterns that have been fabricated that detailed agreement cannot be obtained.

**References:**
[1] PCGrate, www.pcgrate.com.
[2] Løvhaugen et al, *Journal of Modern Optics*, vol. 51, no. 14, 2203-22, 20 Sept. 2004.

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