University of Liège - Faculty of Applied Sciences

Graduation Studies conducted for obtaining the Master's degree in Engineering Physics, 2019-2020

Photonic properties of periodic arrays of nanometer-wide metal lines

Supervisors:
Benoît Vanderheyden
Janusz Bogdanowicz
Andrzej Gawlik

Author:
Quentin Elias

January 25, 2021

Abstract

In this master thesis, the interaction of light with periodic arrays of nanometer-wide metal lines was studied. To do so, extensive use of wave optics, waveguide and diffraction grating theories was made to better understand the interaction of light with a structure made of perfect electrical conductor (PEC) lines, both for TE and TM polarizations. In particular, we proposed to gather the results of those theories in an original band structure to understand how light can couple into the array as a function of the geometrical parameters. The structure was viewed as periodic metallic waveguides simultaneously constituting a diffraction grating. The model was used to analyze quantitative numerical finite element calculations of reflectance and transmittance spectra (obtained using COMSOL Multiphysics) and was able to explain the different variations of the spectra, although it could not predict their amplitudes for a given set of geometrical parameters, nor could it predict the proportion of power that was located in each propagating mode of the band structure.

For the PEC array, the pitch was responsible for the activation of waveguide and diffraction modes. Cutoff was observed for TE while extraordinary optical transmission was observed for TM. The width was responsible for the activation of waveguide modes but had no effect on the diffraction modes and had an effect opposite to the pitch. The height was responsible for thin-film interferences which had a strong dependence on the pitch in the case of TE. The TE band structure was able to describe the observations, while the TM one had to be adapted with an effective medium approximation to include a geometric dependence of the TEM mode.

For the copper array, the band structures were slightly different. Due to the absorbing nature of the real metal, there was no sharp cutoff and the effective refractive index varied more smoothly with the pitch. The pitch was also responsible for the activation of both waveguide and diffraction mode, although no cutoff was seen for TE. For the same reasons, the effect of the width on the cutoff was no longer visible for TE, and surface plasmon polaritons (SPPs) could be observed for TM. The thin-film interferences induced by the height were also present but less intense than for PEC, due to the more slowly varying refractive index. The copper TE modes were similar to those of PEC, while the TM modes featured a slight difference in the electric field distribution.

In conclusion, the insight developed by studying an array of PEC lines was crucial to understand the interaction of light with the an array of real metal lines. While the TE behavior could be predicted by the corresponding band structure, some particular attention was required by the TM description, which in some cases failed to describe the spectra.