Photonic properties of periodic arrays of nanometer-wide metal lines

Quentin ELIAS

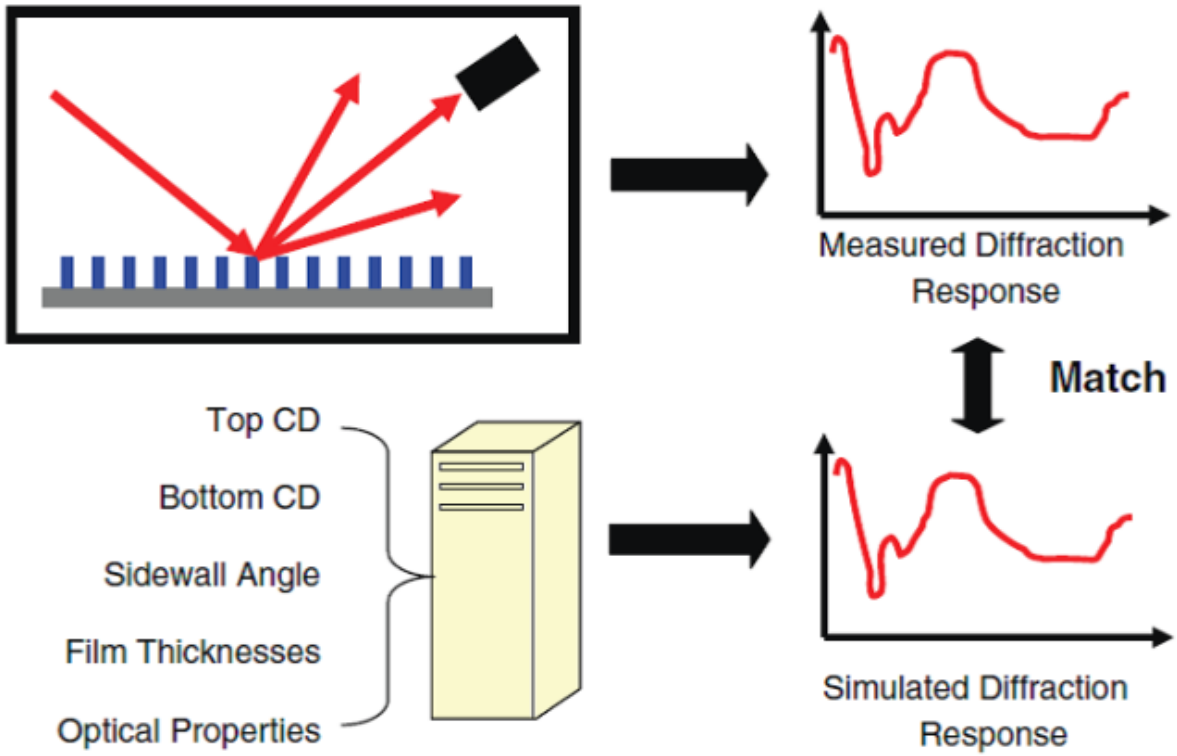
September 8, 2020

Table of contents

Table of Contents

Context

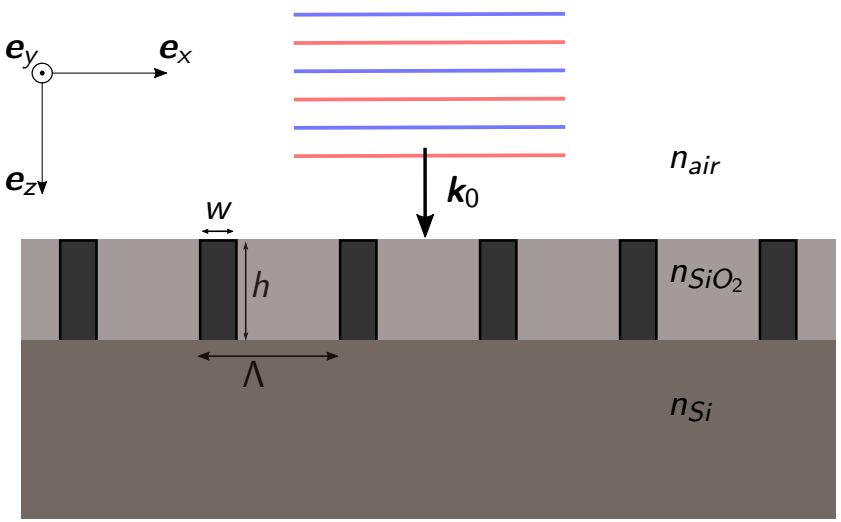
- Metallic interconnects in back end of the line (BEOL) in semiconductor manufacturing: importance of process control
- As dimensions shrink, need for high precision metrology results
- Scatterometry: precise, accurate, fast, versatile, non-contact, ...



Objectives and methodology

- Study the effect of geometry (pitch, width, height) of the array on the reflectance and transmittance spectra
- Qualitative description based on mode analysis, then compare with finite element simulations
- First Perfect electric conductor (PEC), then copper for both transverse electric (TE) and transverse magnetic (TM) polarizations

...



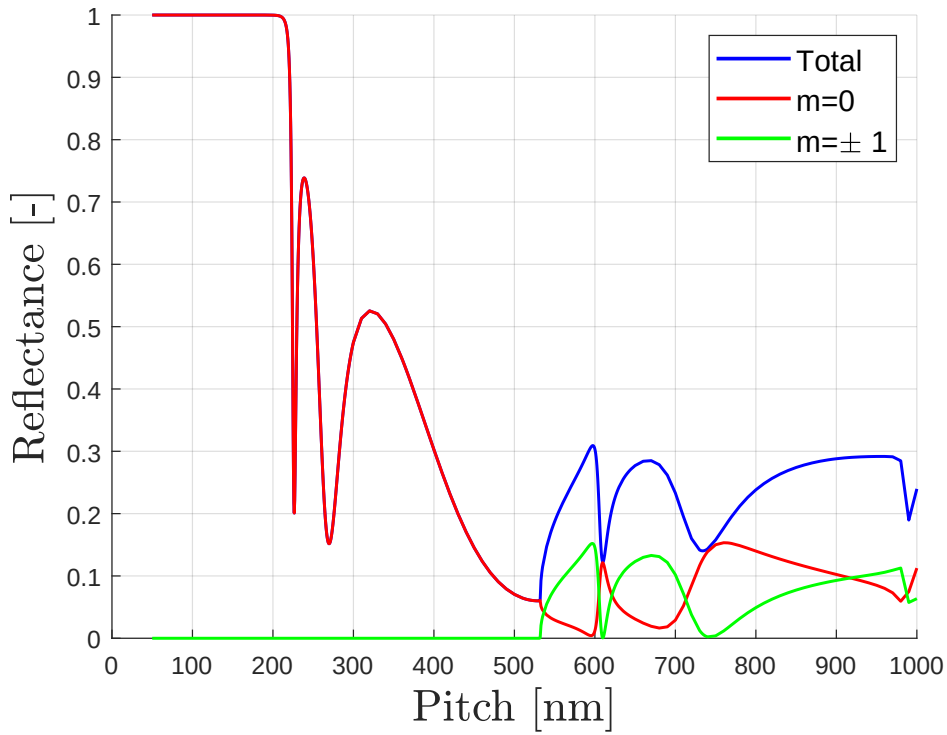
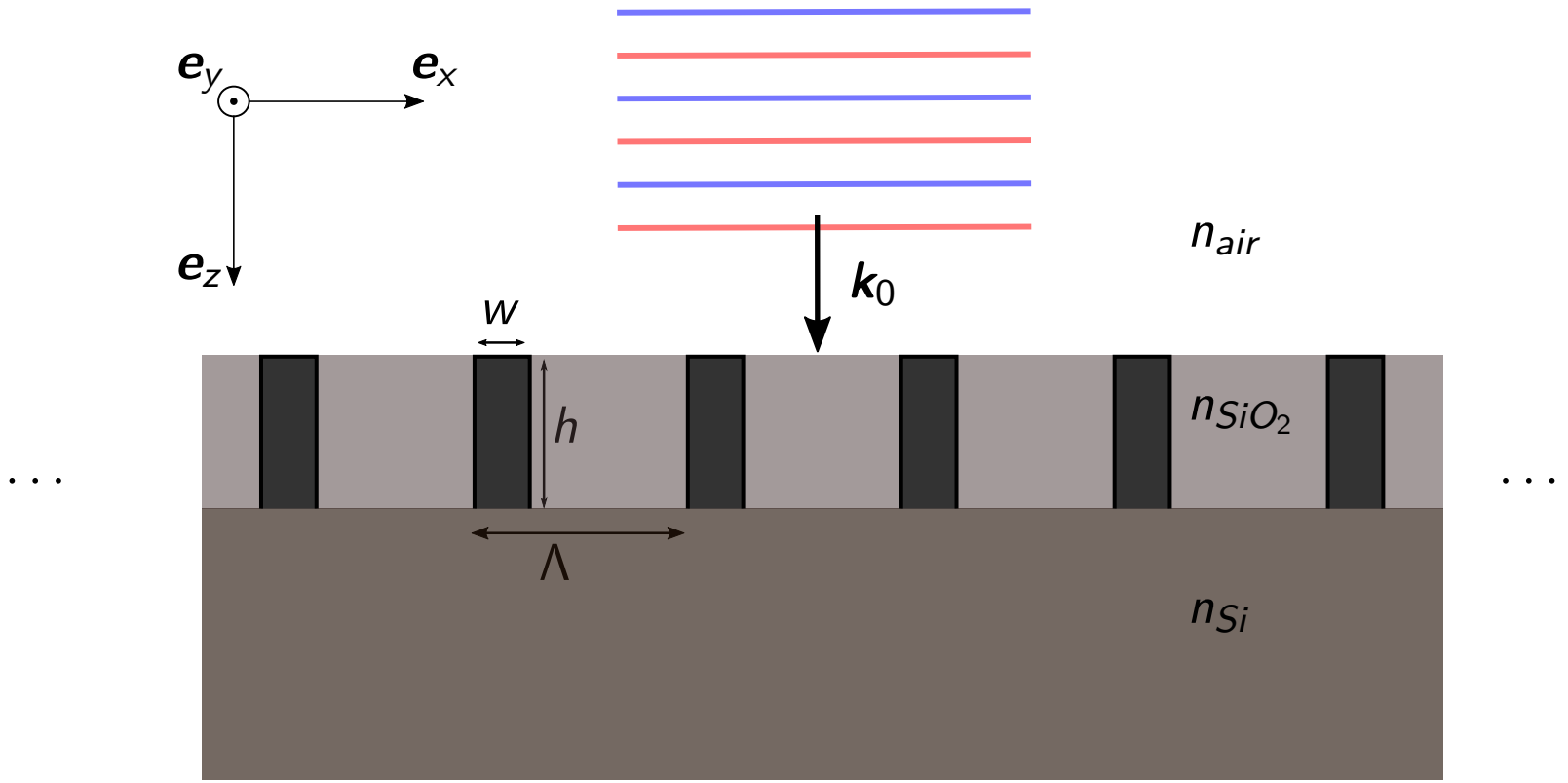


Table of Contents

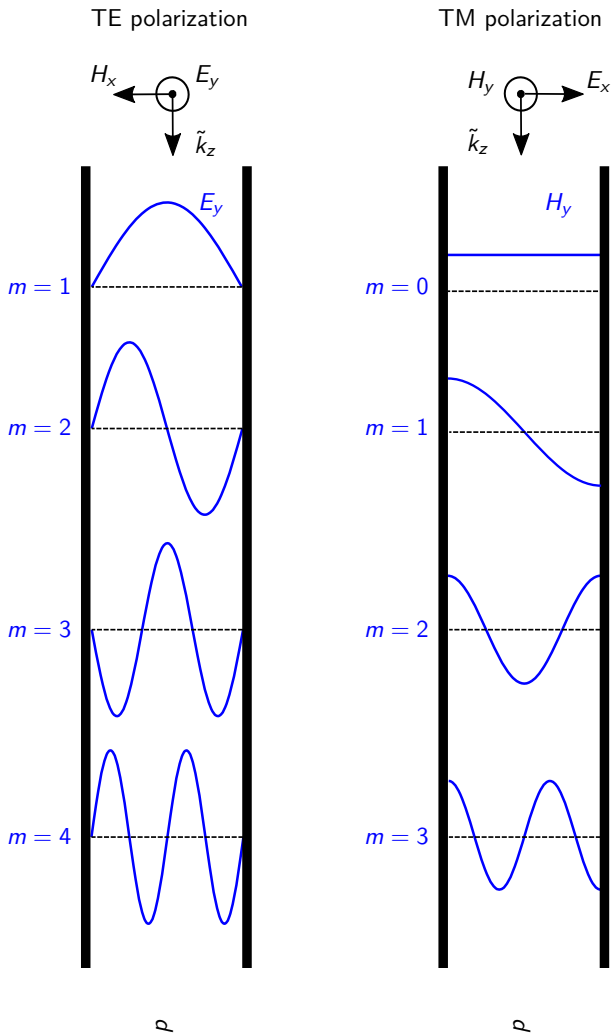
Idealized structure

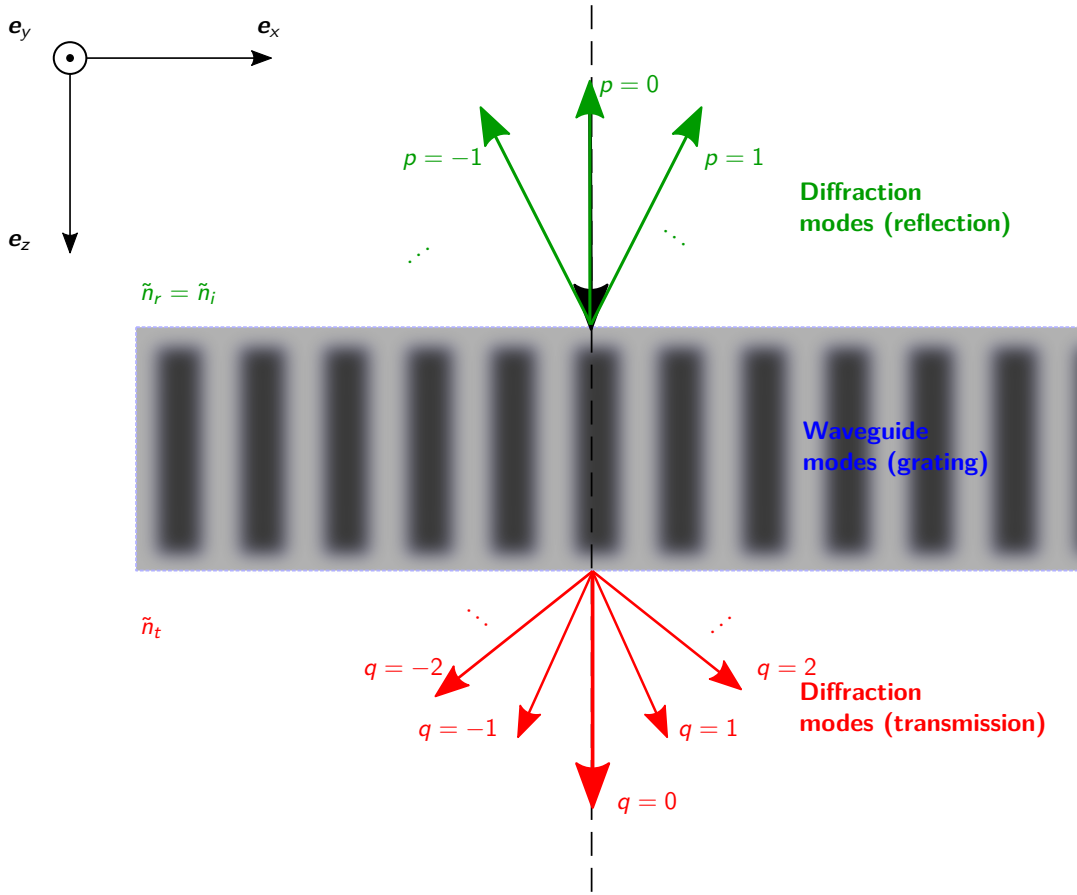
- Semi-infinite air/grating/substrate stack
- Normal incidence, single wavelength (532 nm) incoming plane wave
- Non-absorbing air/cladding/substrate



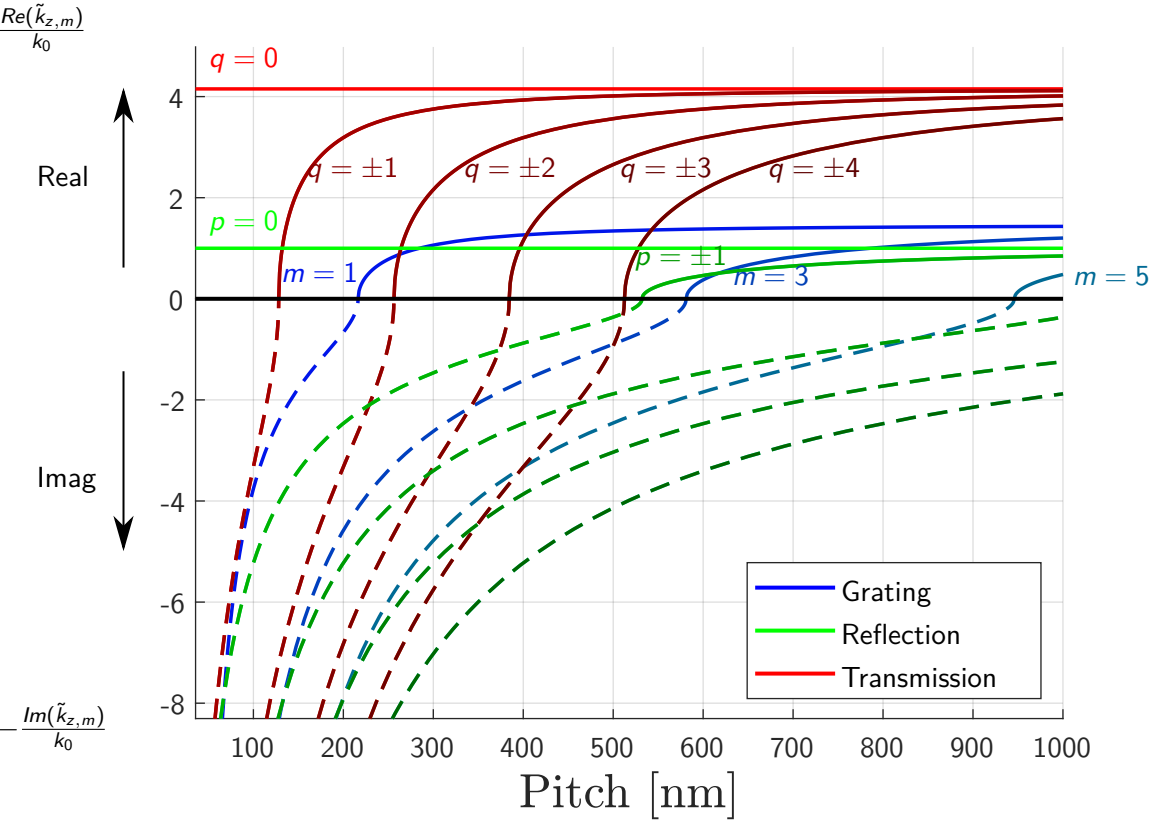
Perfect electric conductor (PEC) modes

- Array = waveguides + diffraction grating



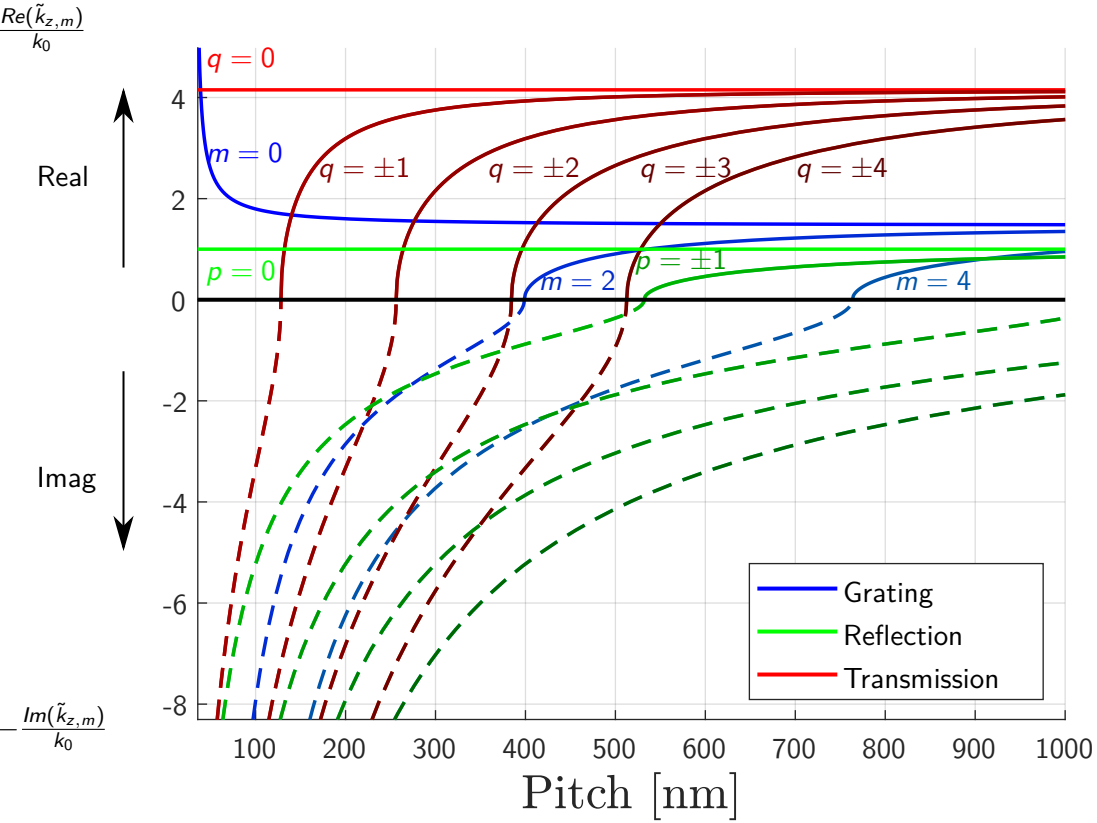


TE perfect electric conductor band structure



- Propagating vs. evanescent modes
- Cutoff pitch
- Effective refractive index $\tilde{n}_{eff}$

TM perfect electric conductor band structure

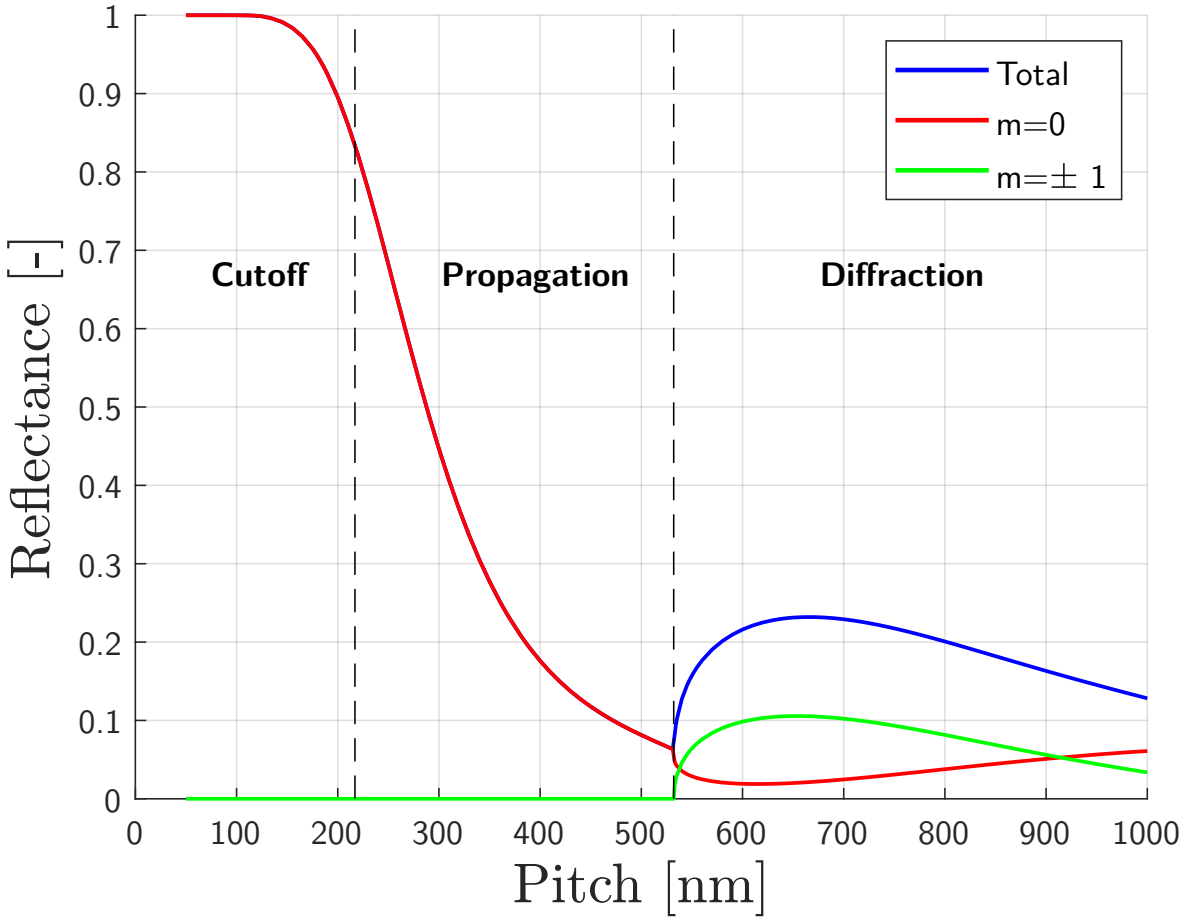


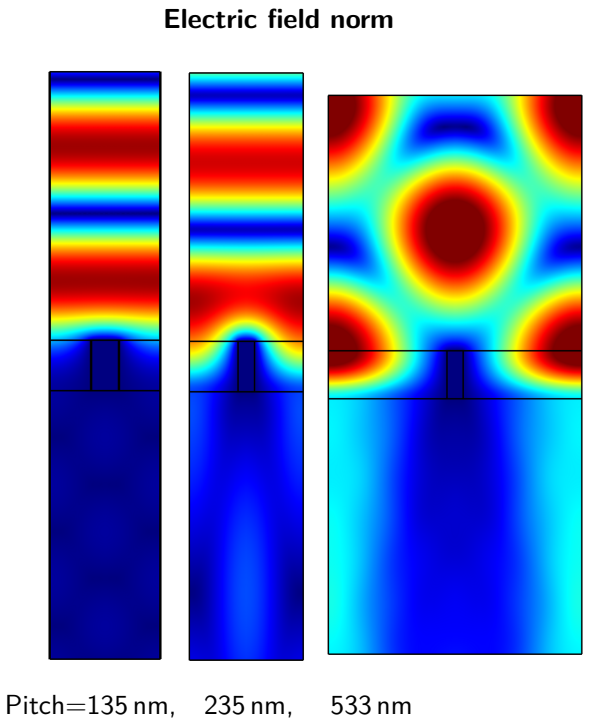
- No cutoff
- TM_0: Effective medium approximation (EMA)

Table of Contents

Perfect electric conductor - Pitch TE

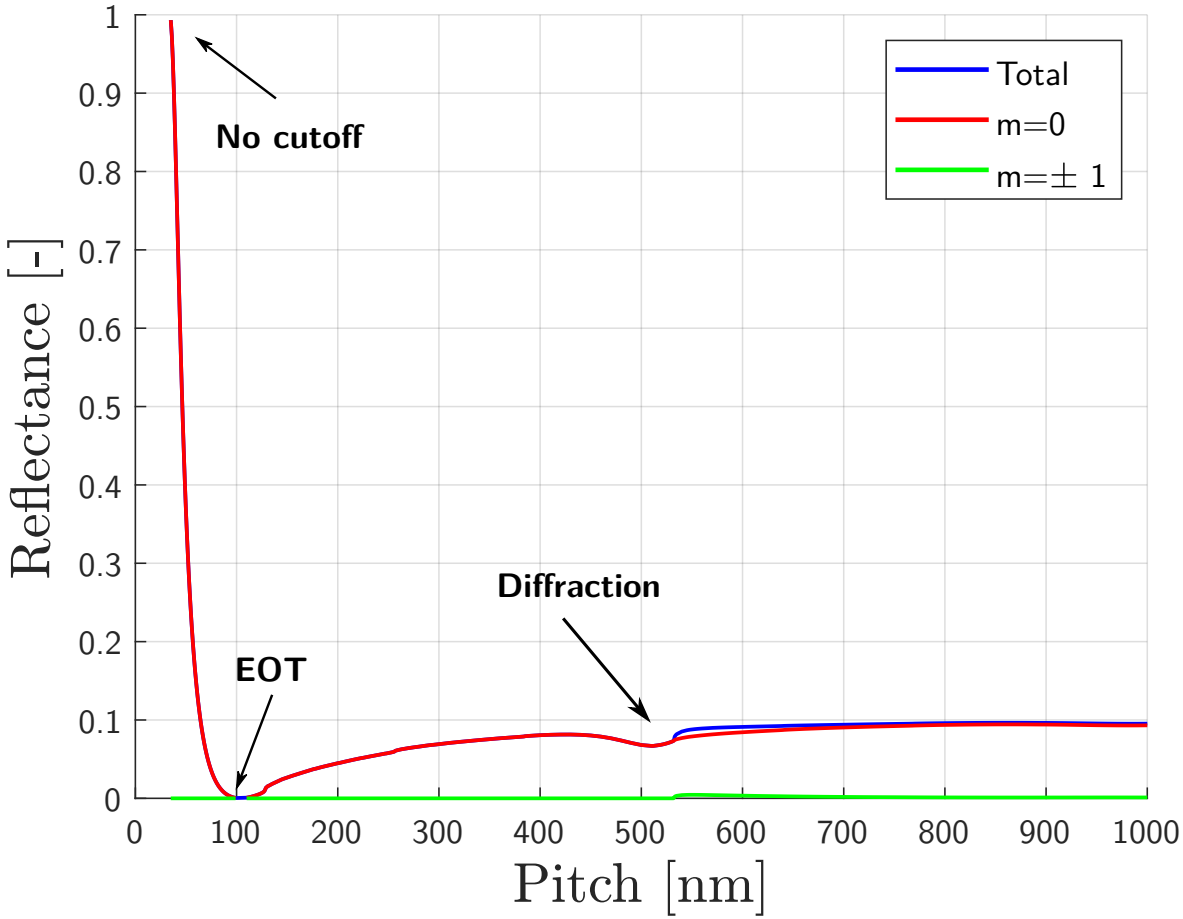
- Height=100 nm, Width=34 nm
- Activation of both grating and diffraction modes
- TE: cutoff at low pitch

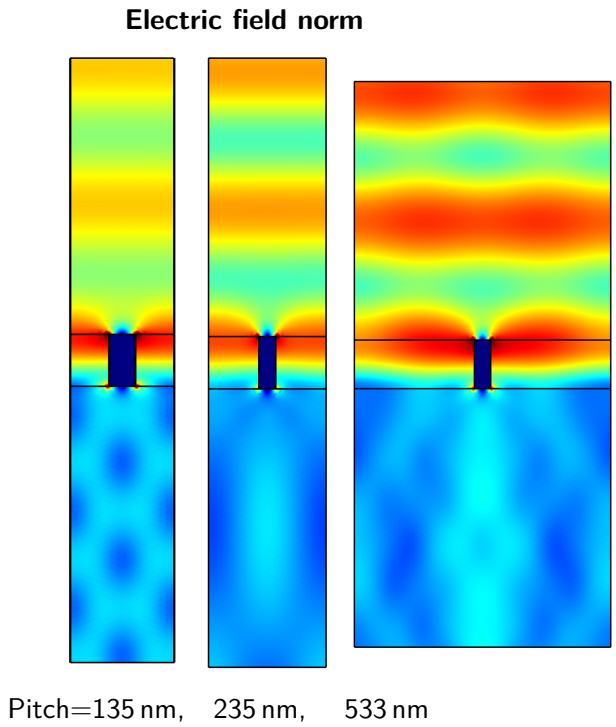




Perfect electric conductor - Pitch TM

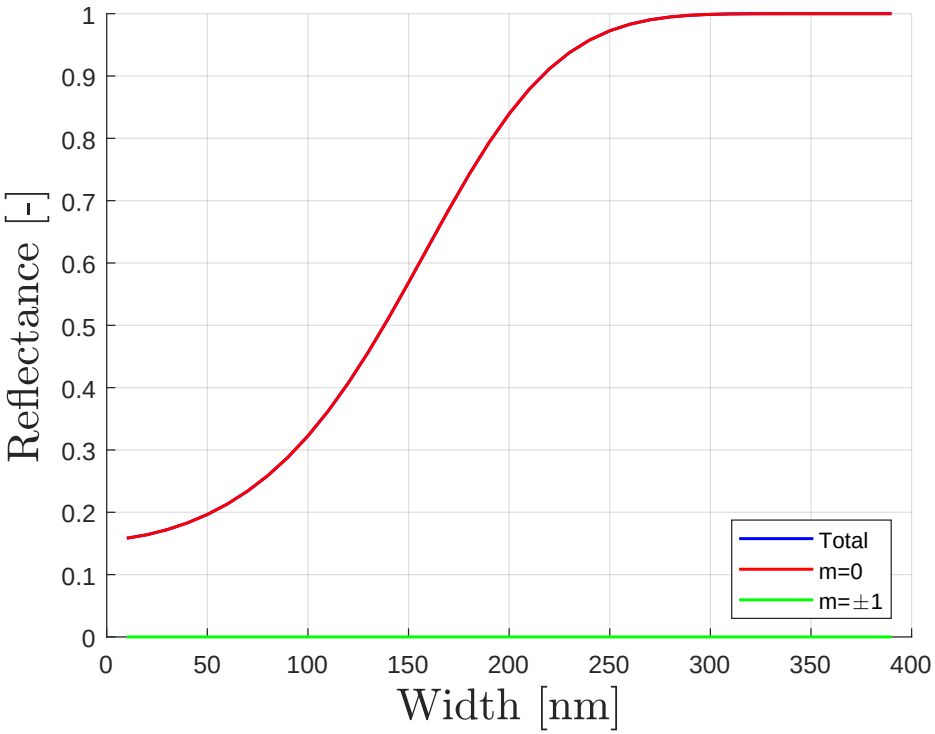
- TM: no cutoff
- Extraordinary optical transmission (EOT)



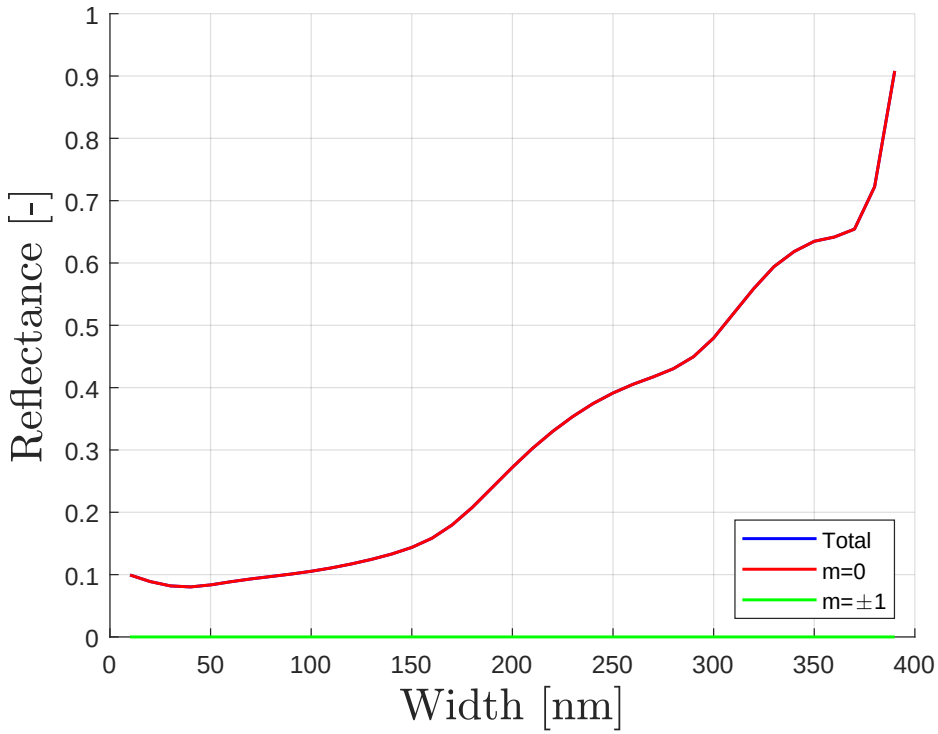


Perfect electric conductor - Width

- Activation of grating modes but no effect on diffraction
- Reflectance just increases with the width



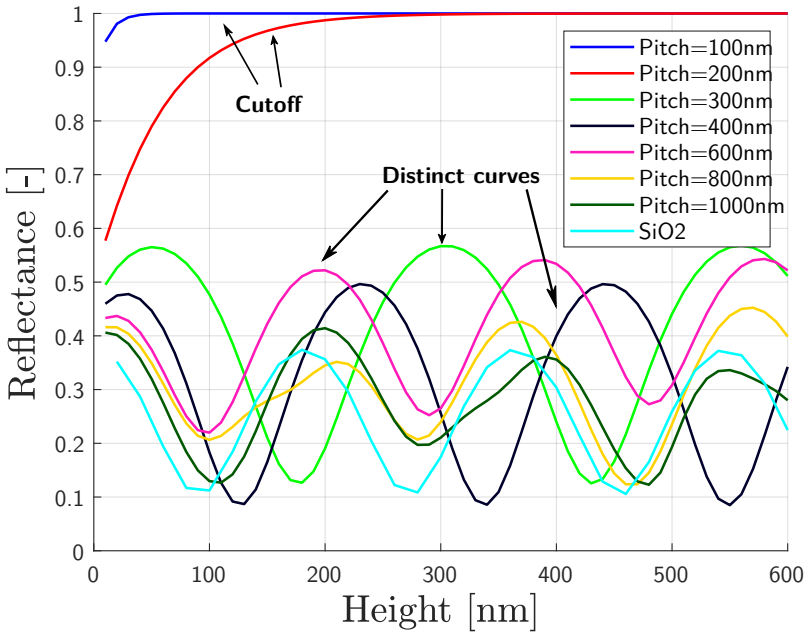
(a) TE Polarization



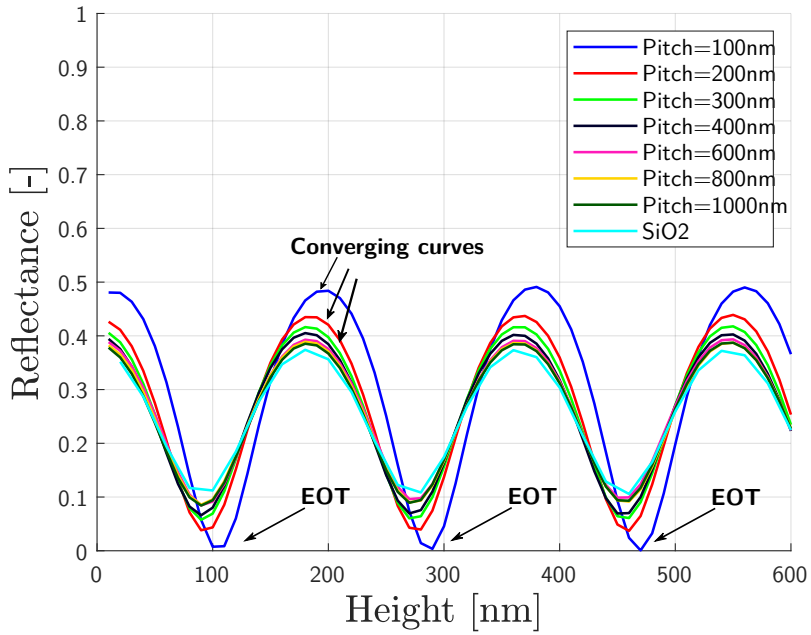
(b) TM Polarization

Perfect electric conductor - Height

- Thin-film interferences as a function of height
- TE: extreme sensitivity to pitch
- TM: less sensitive to pitch + extraordinary optical transmission (EOT)



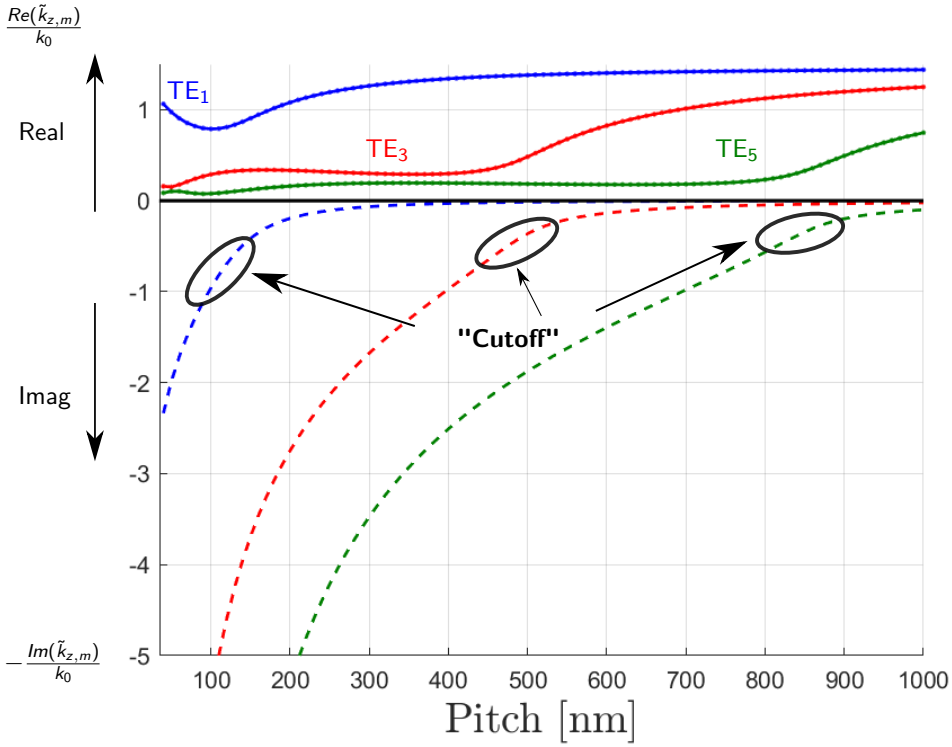
(a) TE Polarization



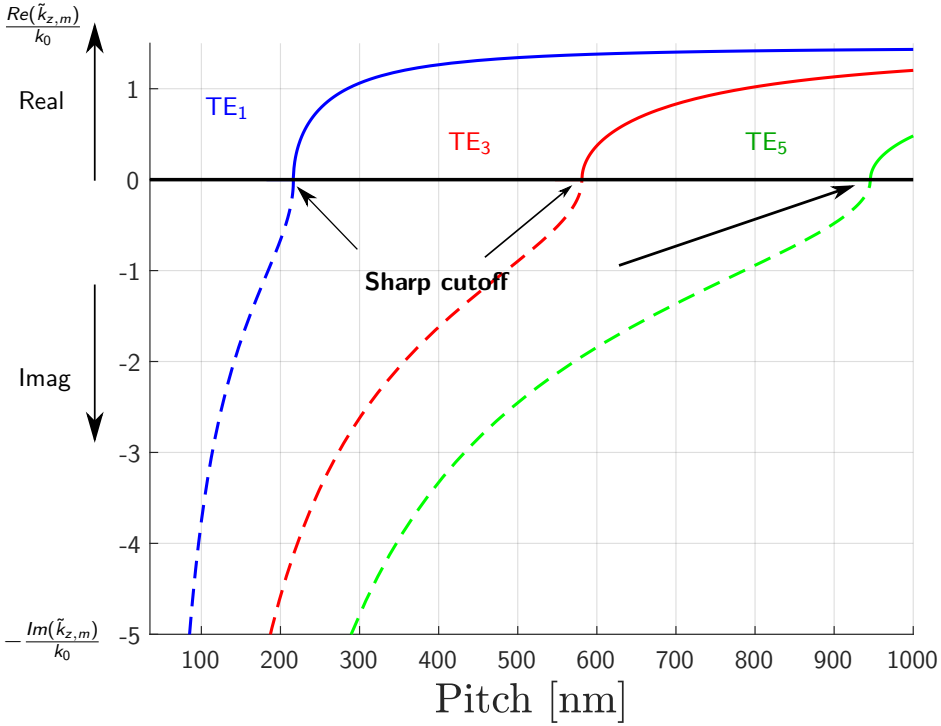
(b) TM Polarization

Copper TE band structure

- Non-zero real and imaginary parts
- No sharp cutoff
- Smoother refractive index



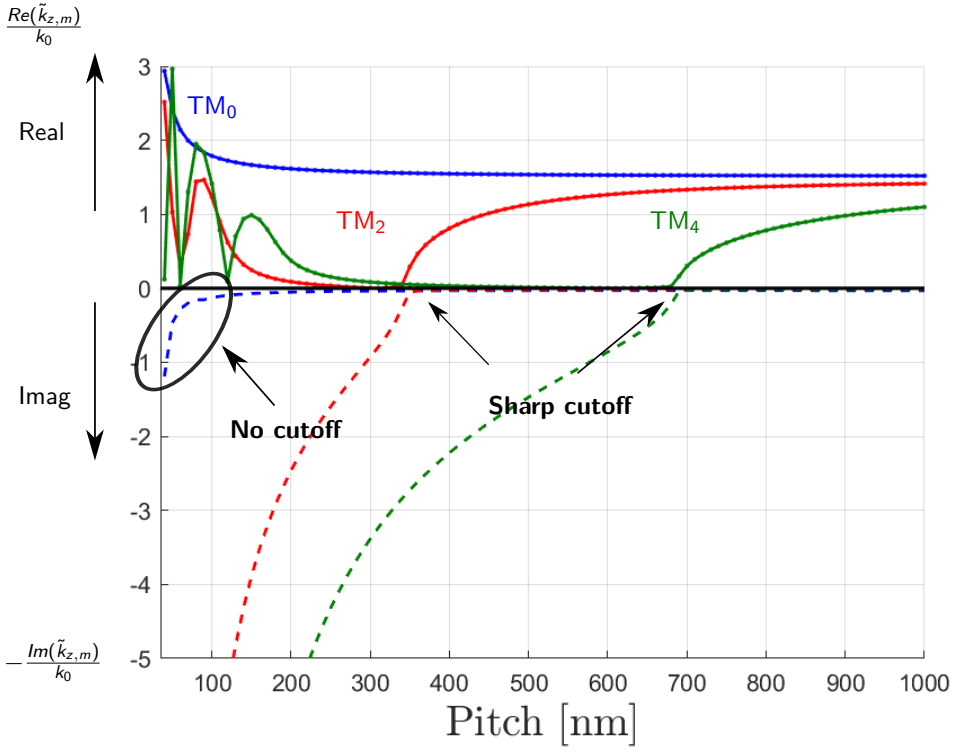
(a) Copper TE waveguide modes



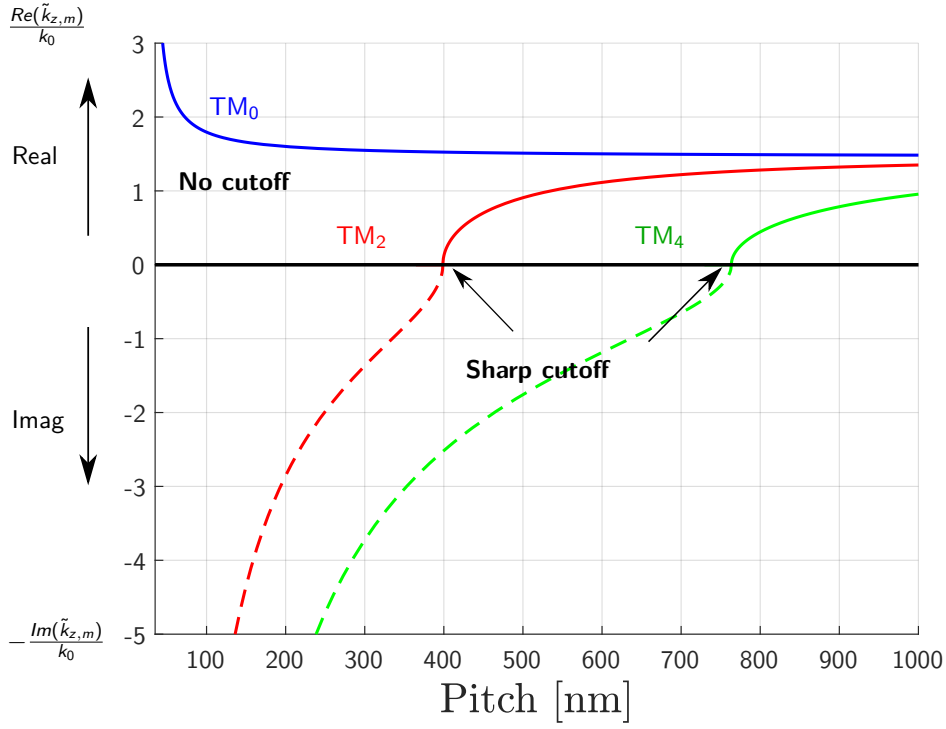
(b) PEC TE waveguide modes

Copper TM band structure

- Agreement with effective medium approximation (EMA)
- Still no cutoff



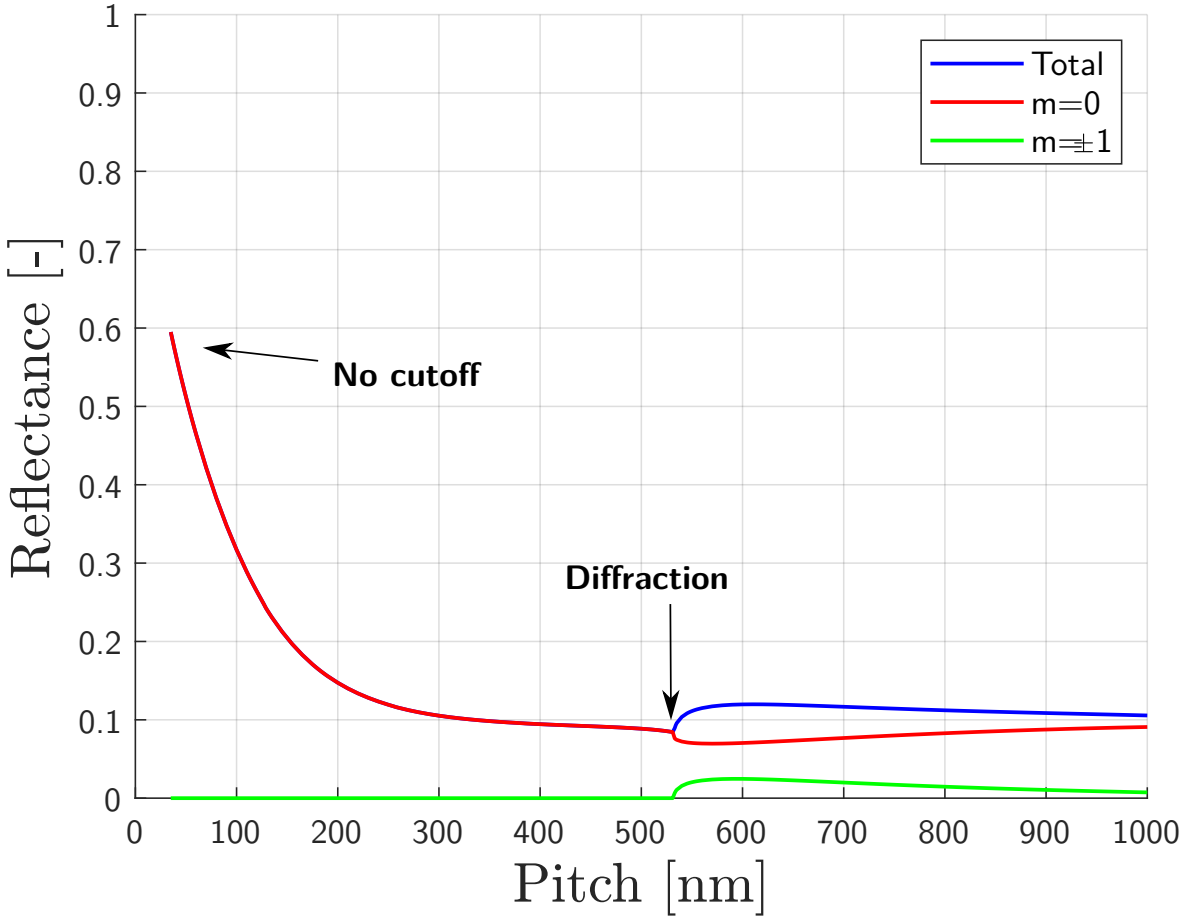
(a) Copper TM waveguide modes

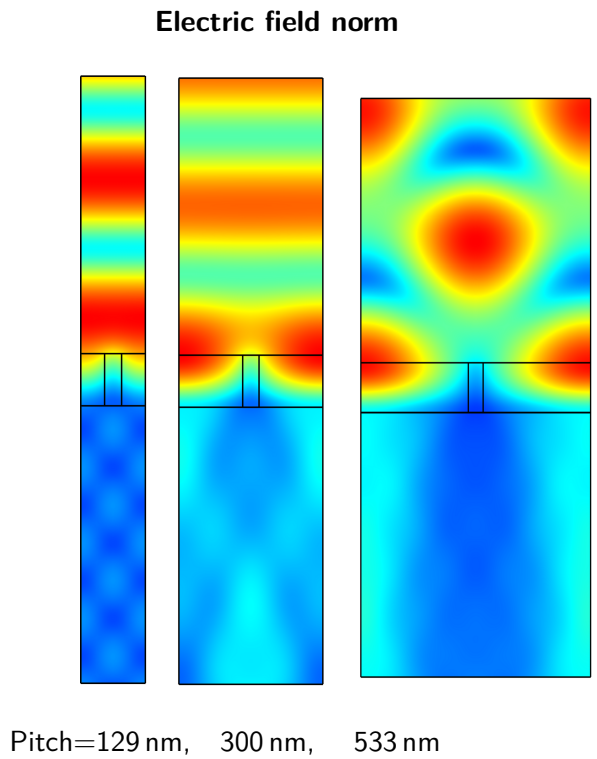


(b) PEC TM waveguide modes

Copper - Pitch TE

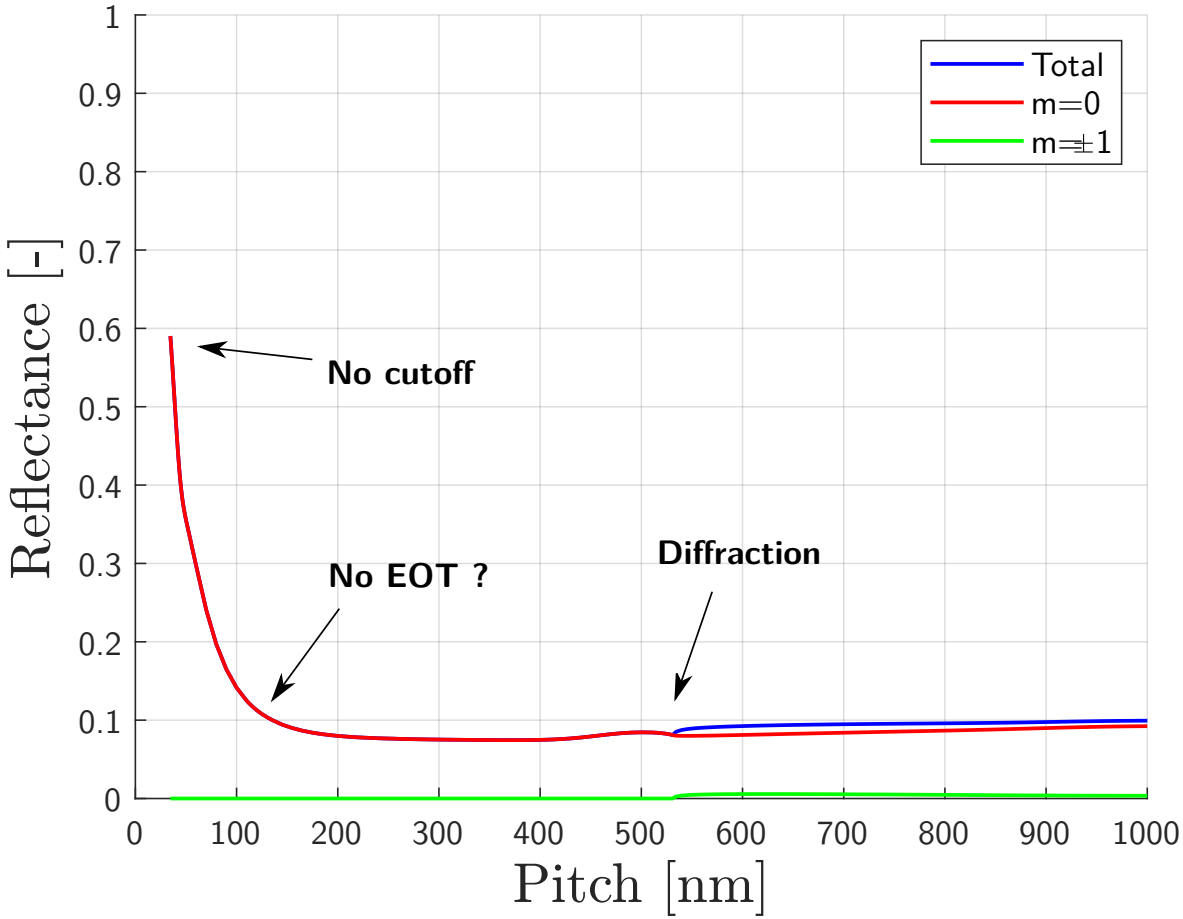
- Similar to PEC but smoother and $max(R) < 1$
- Diffraction orders excited at same pitch, but less efficiently
- TE: no sharp cutoff

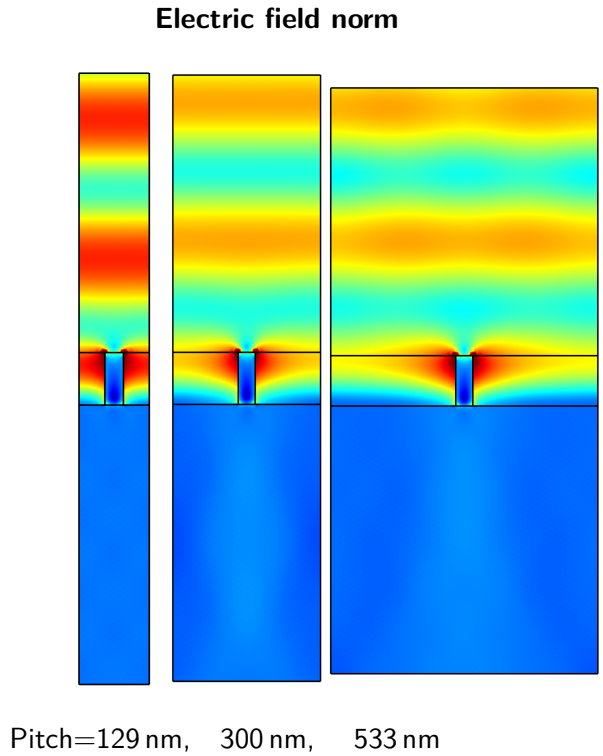




Copper - Pitch TM

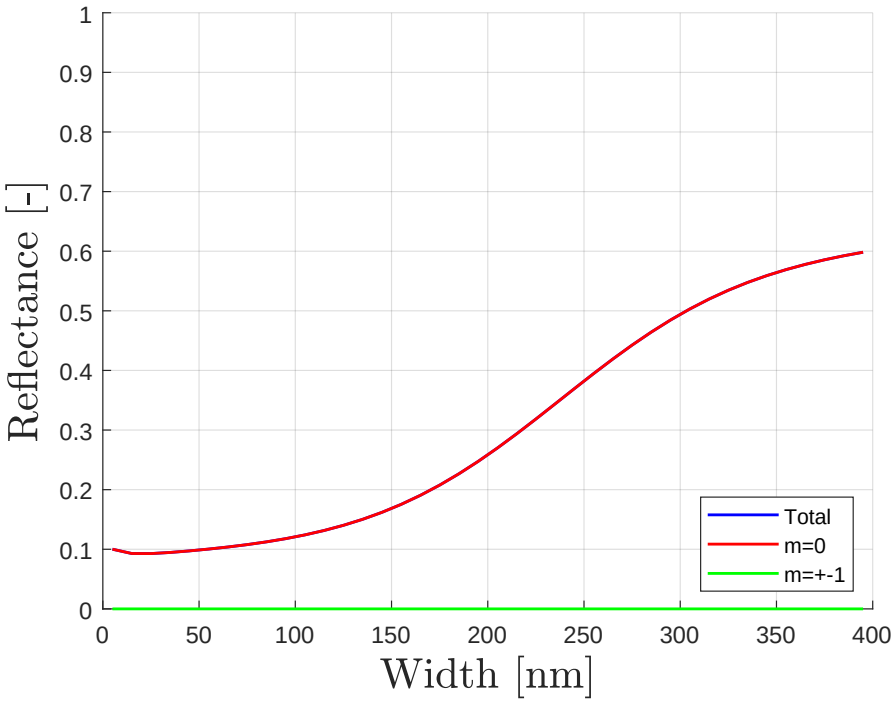
- TM: no cutoff
- No extraordinary optical transmission (EOT) at $h = 100\,\text{nm}$
- Less diffraction



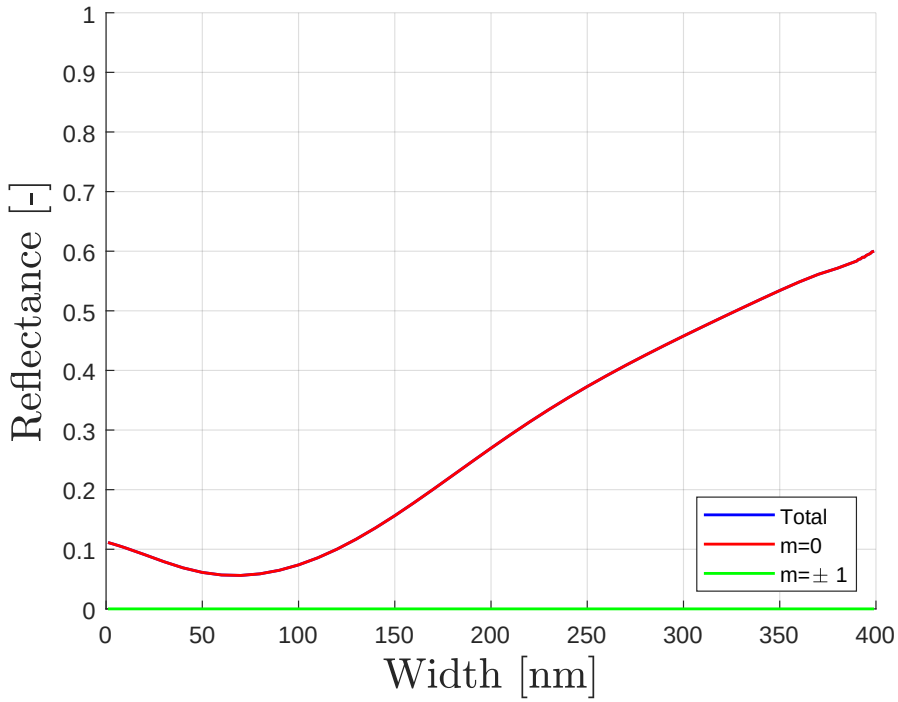


Copper - Width

- No sharp cutoff for copper
- Reflectance just increases with the width



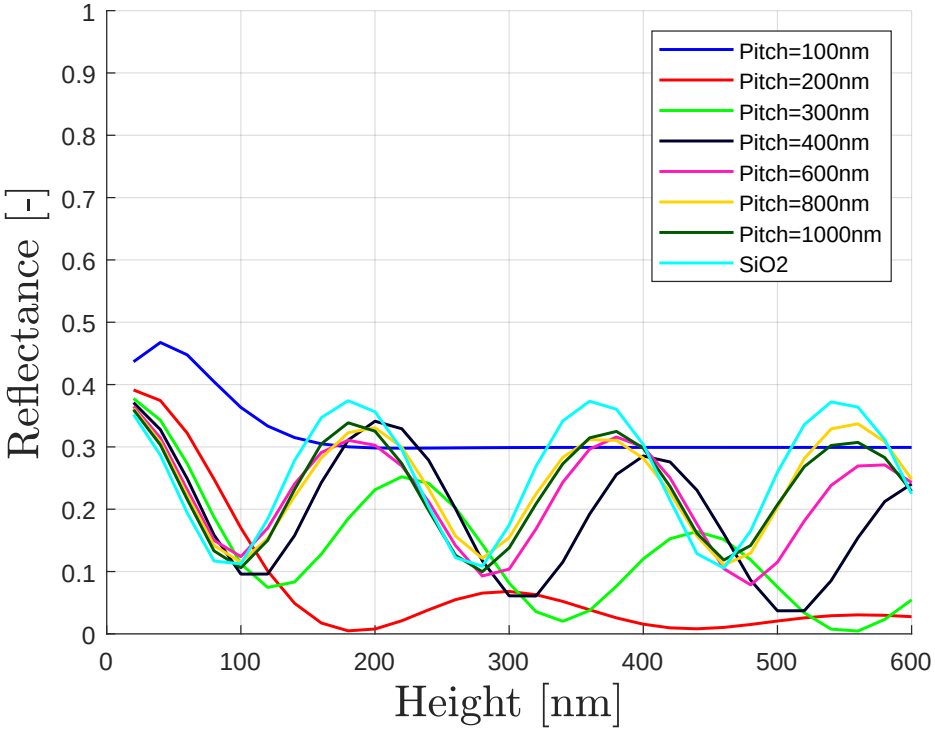
(a) TE Polarization



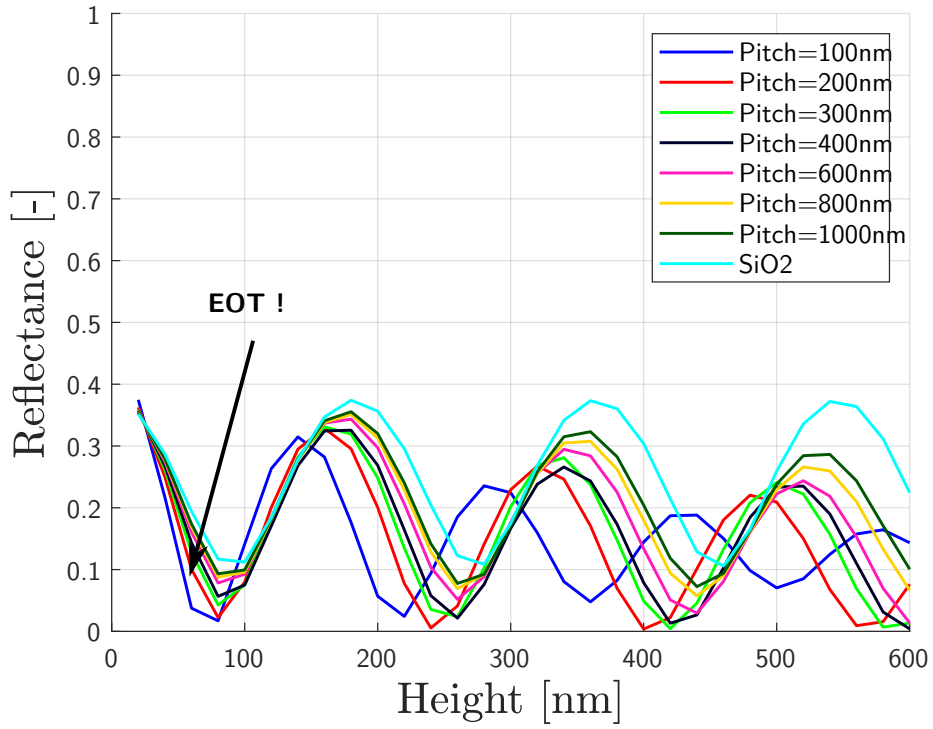
(b) TM Polarization

Copper - Height

- Thin-film interferences as a function of height
- TE: less pitch dependence due to smoother n_{eff}
- TM: more pitch dependence due to less constant n_{eff}
- Visible absorption



(a) TE Polarization



(b) TM Polarization

Conclusion

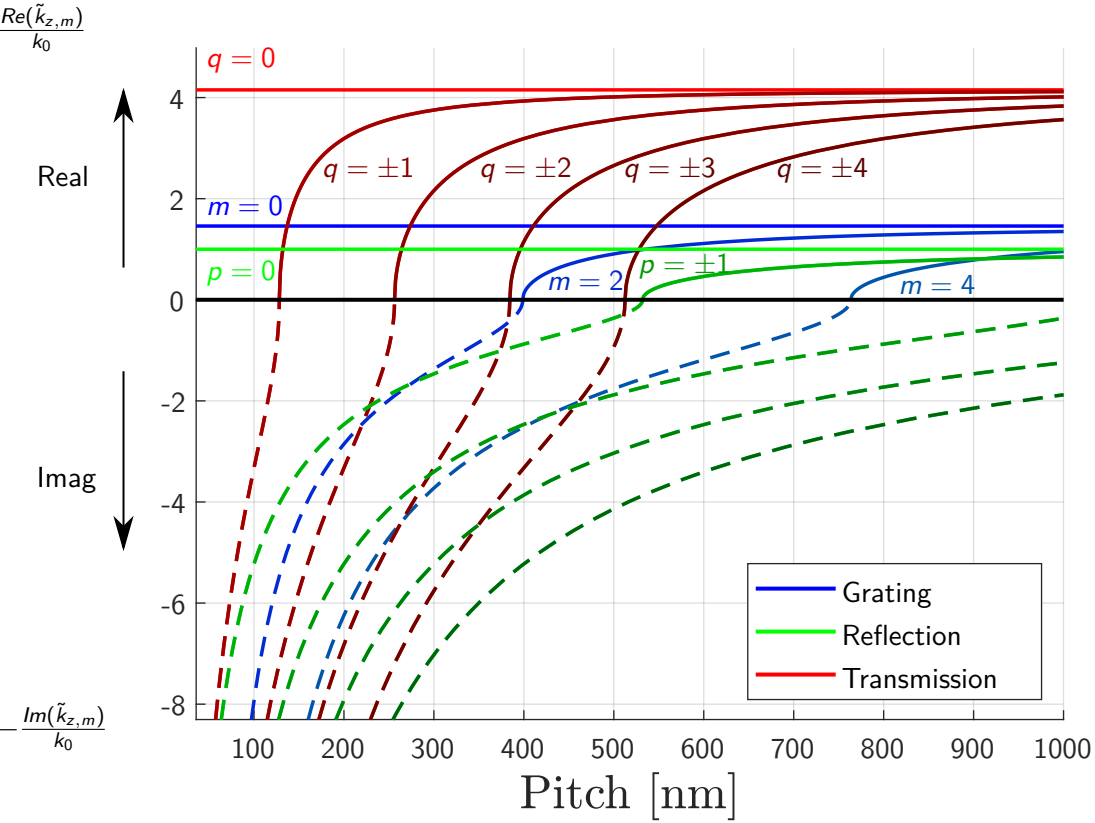
- Insight developed from PEC crucial to understand copper
- TE spectra variations could be explained qualitatively from band structure
- TM needed some adaptation

Questions ?

Thank you for your attention

Table of Contents

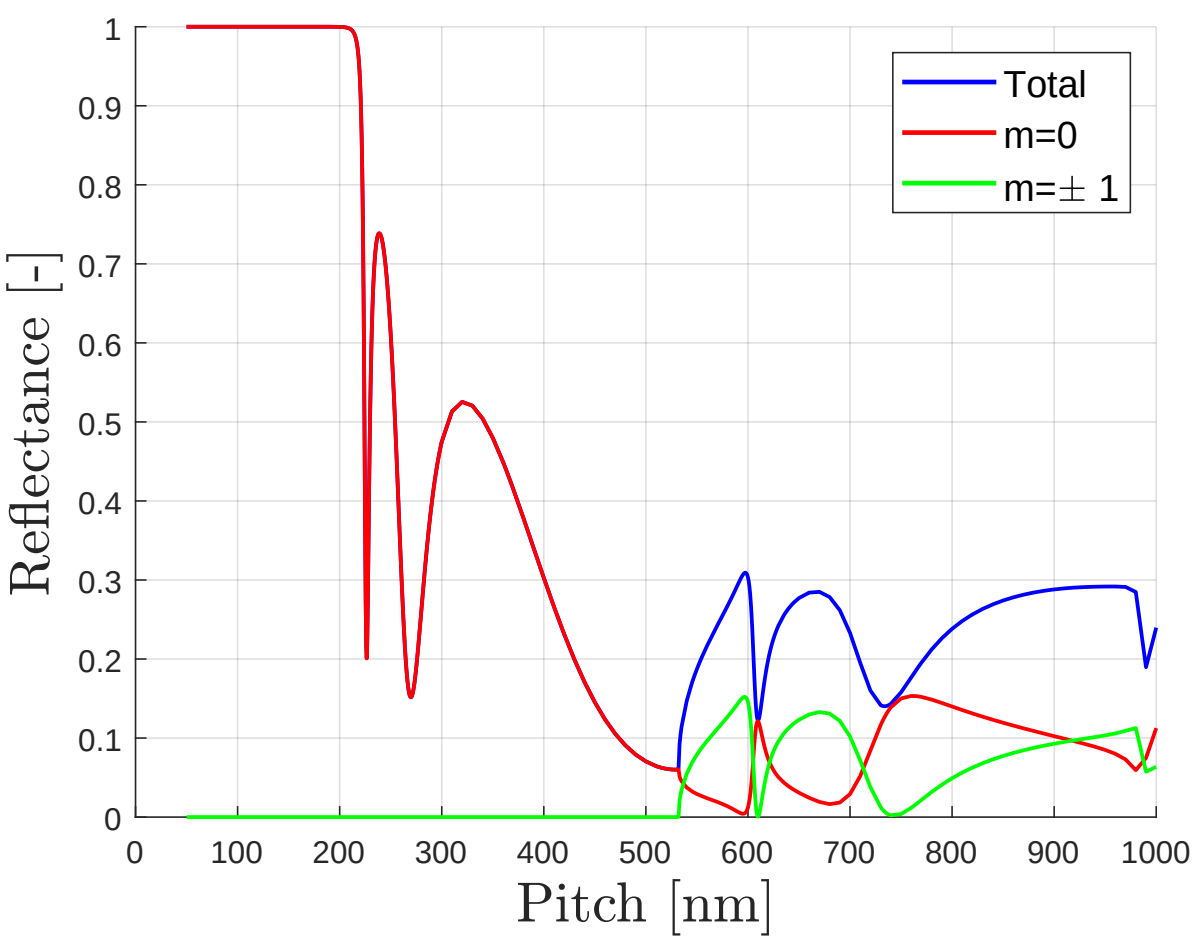
TM perfect electric conductor band structure

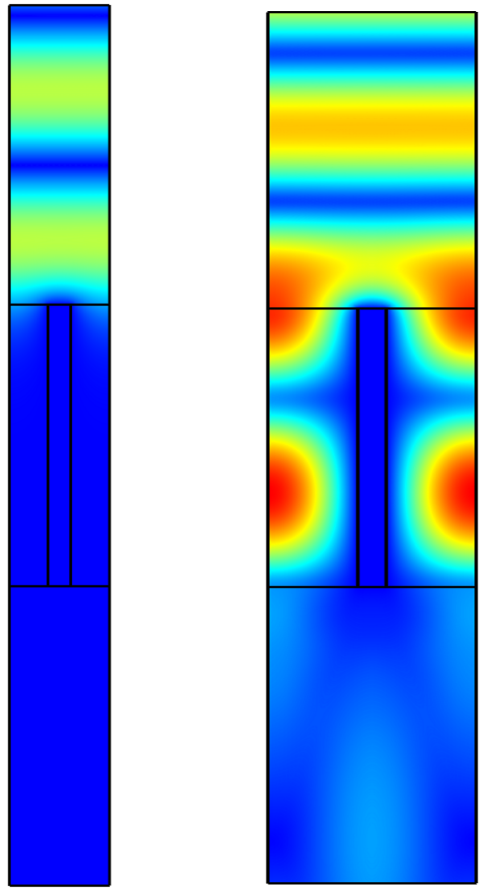


- No cutoff
- Non-dispersive TEM mode

PEC - Height $h = 500\,\text{nm}$ TE

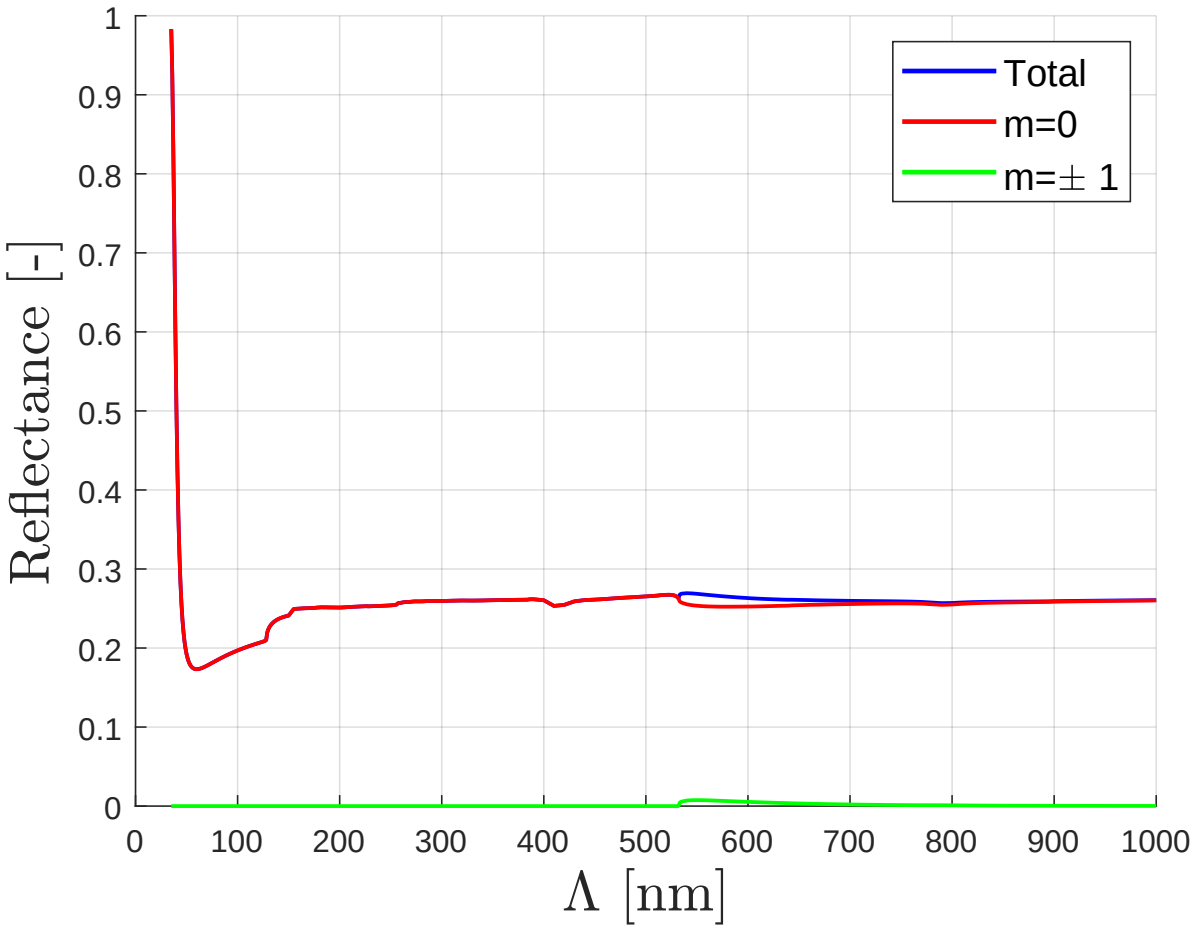
- Thin-film interferences, as function of the pitch ($\tilde{n}_{eff}$)
- TE: can better visualize cutoffs and wavelengths

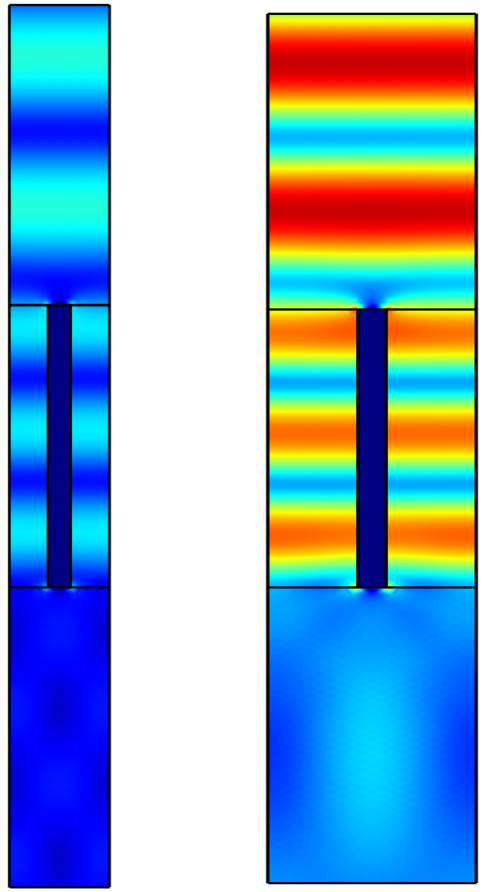




PEC - Height $h = 500\,\text{nm}$ TM

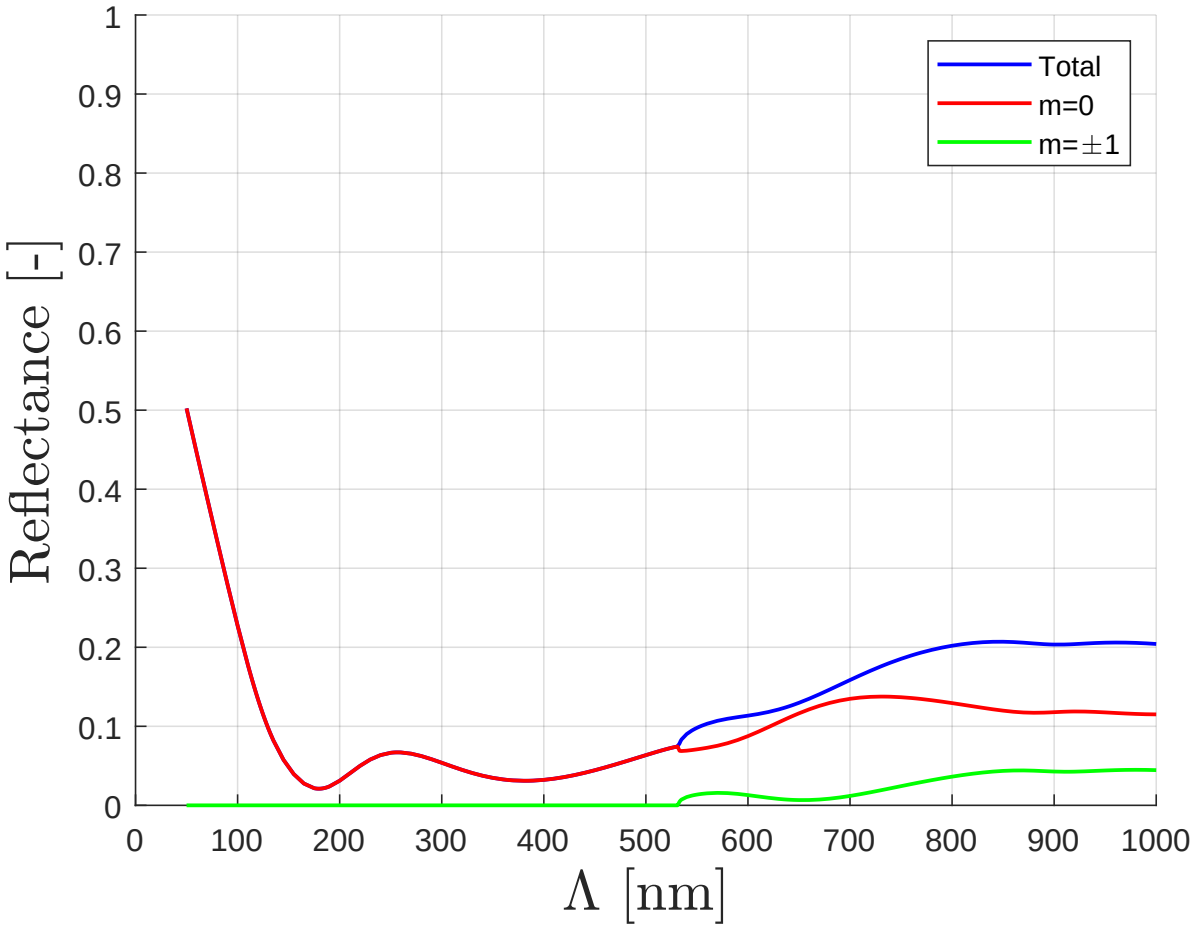
- TM: less intense EOT
- Little interference as a function of pitch

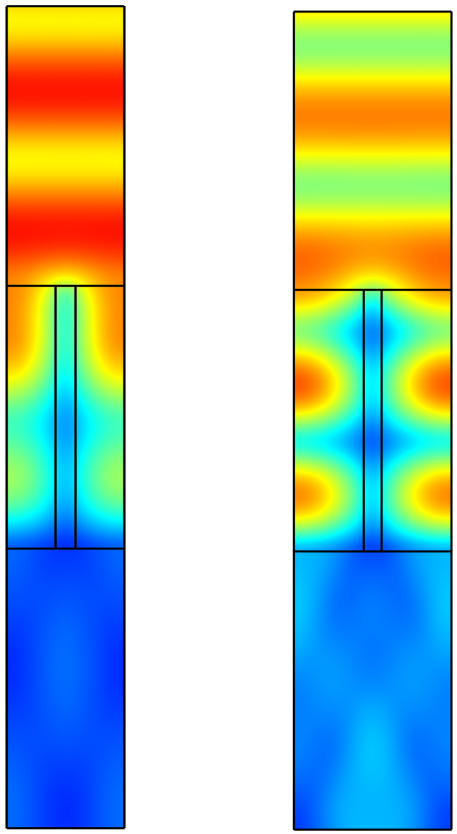




Copper - Height $h = 500\,\text{nm}$ TE

- Less oscillations than PEC due to smoother n_{eff}
- TE1 similar to PEC





Copper - Height $h = 500\,\text{nm}$ TM

- Minimum in reflectance but no EOT
- TM_0 slightly different than PEC