Spectral and Directional Control of Thermal Emission with Periodic Microstructures by Coupled Modes

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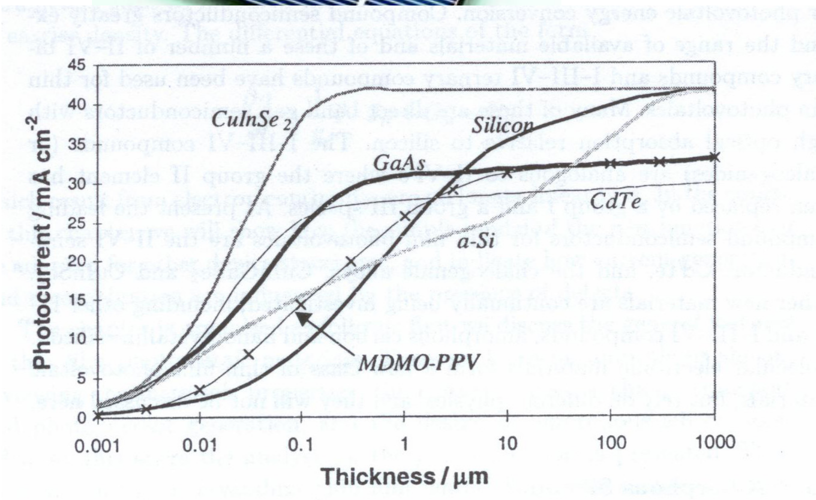
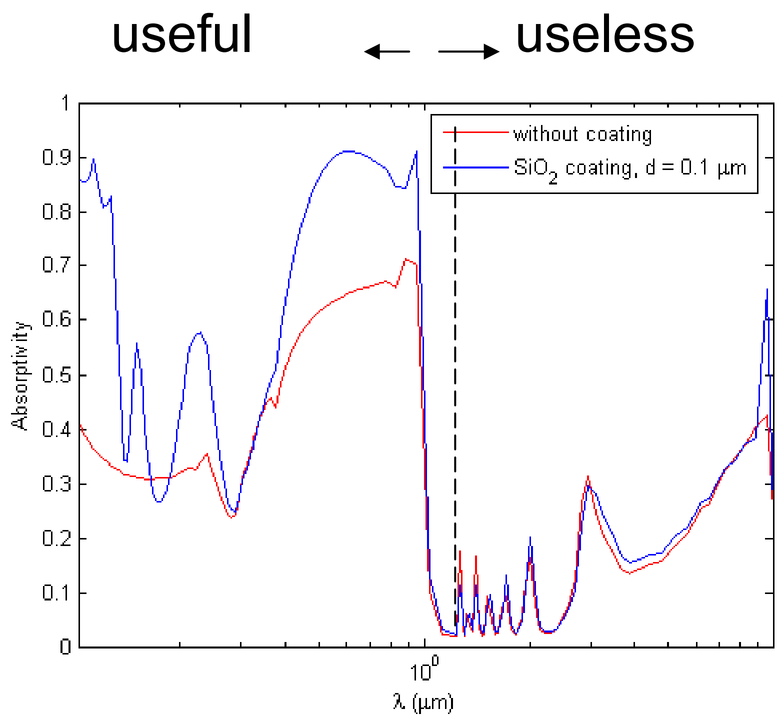
Outline

1. Significance
2. Fundamentals: Electromagnetic excited modes for realizing control of thermal emission with periodic microstructures
3. Spectral and directional control of thermal emission with coupled modes
4. Summary

Significance

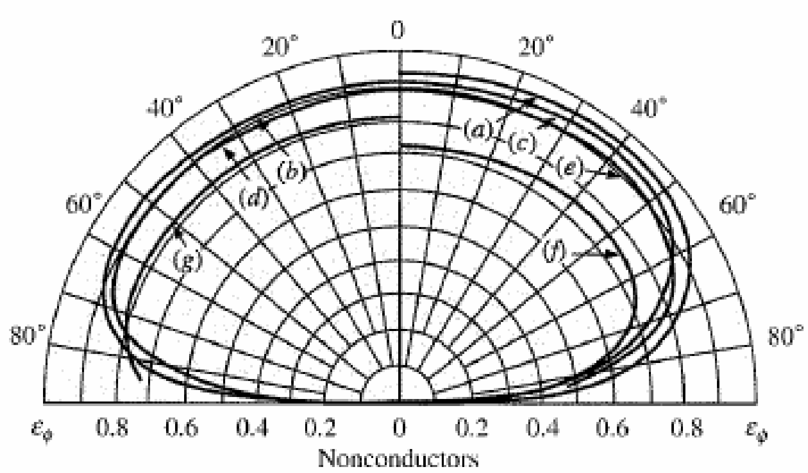
1. Spectral and directional control of thermal emission/absorption has important application in energy conversion devices such as solar cells and thermophotovoltaic devices





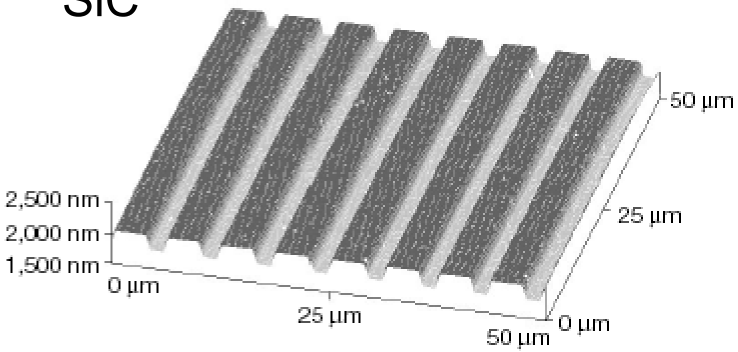
Significance

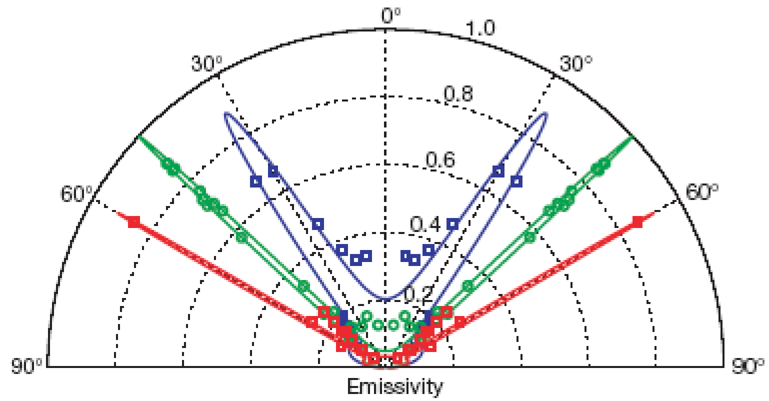
2. Study on spectral and directional control of thermal emission with periodic microstructures helps to understand the essence of thermal emission, thermal radiative wave – matter interaction phenomena at micro/nanoscale



Mechanisms for spectral and directional control of thermal emission with microstructures

SiC

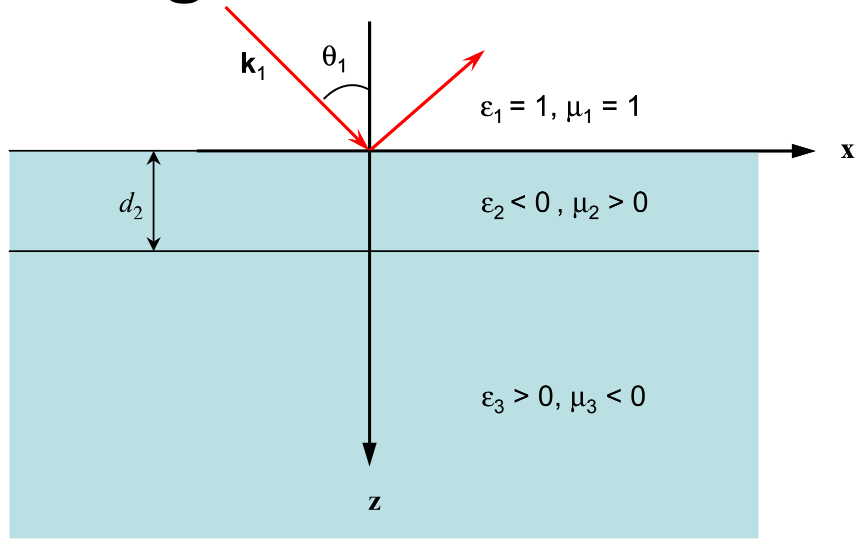


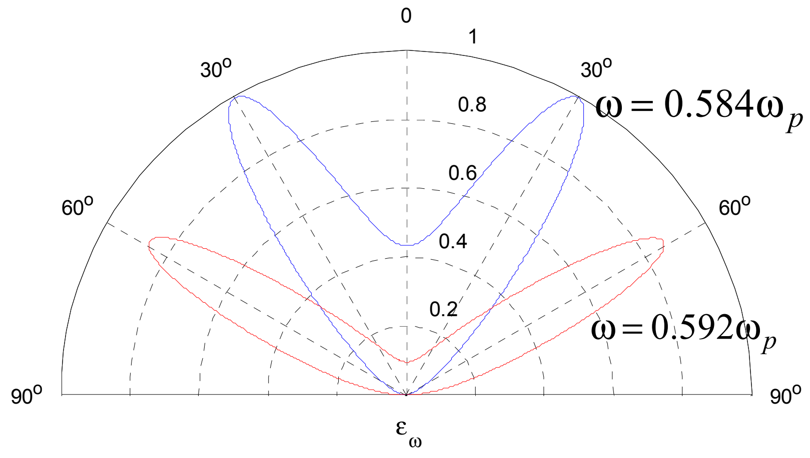


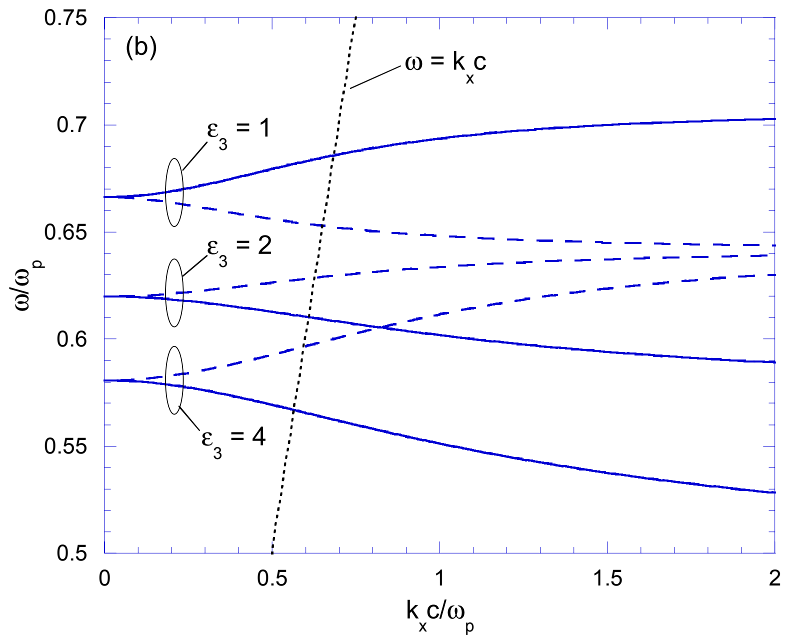
Greffet et al., *Nature* 416, 61 (2002)

Temporally and spatially enhanced thermal radiative absorption can be achieved in the mid-infrared due to excitation of surface phonon polaritons

Gratingless coherent emission source

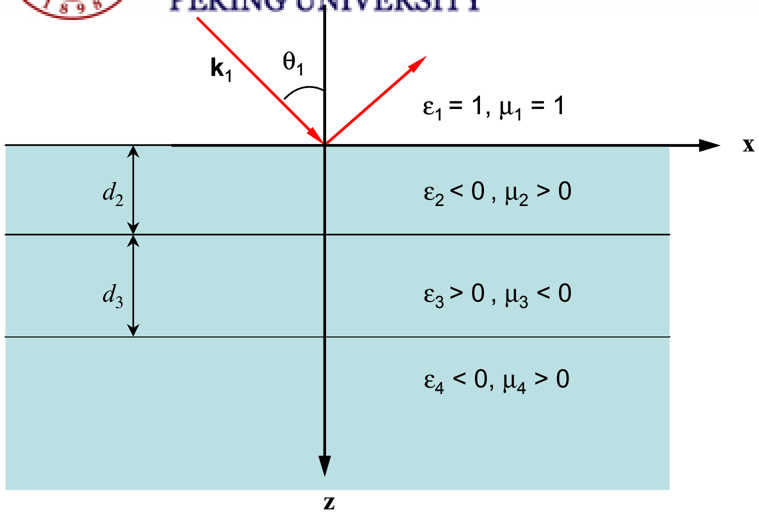


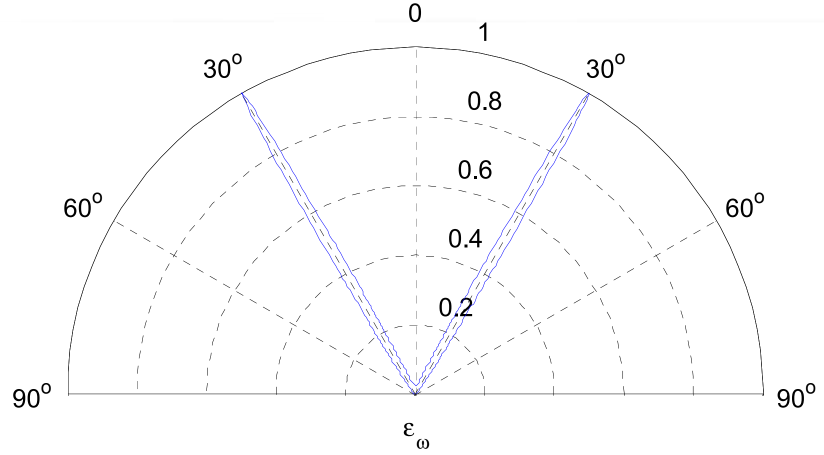




solid curves: *p*-polarization
dashed curves: *s*-polarization

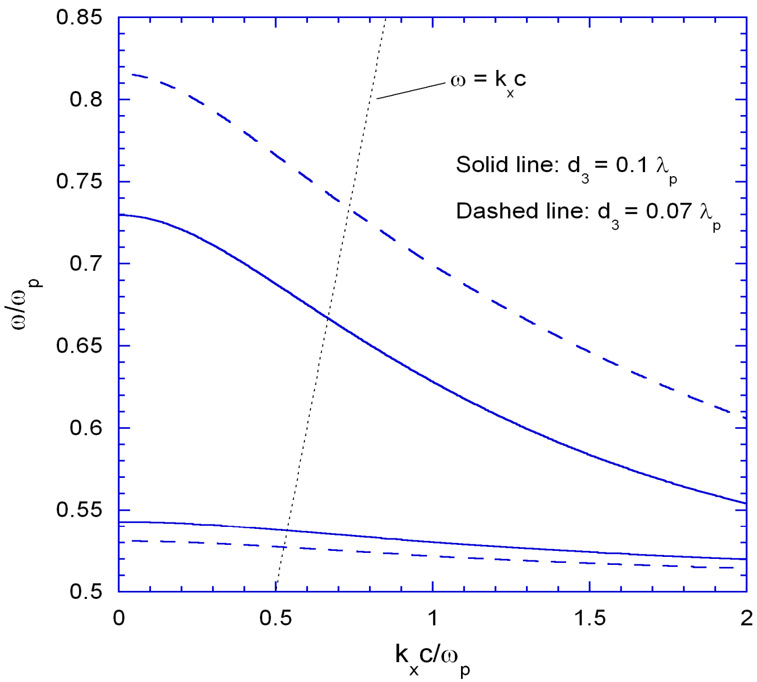
Fu and Zhang, Optics Letters, 2005, 14:1873

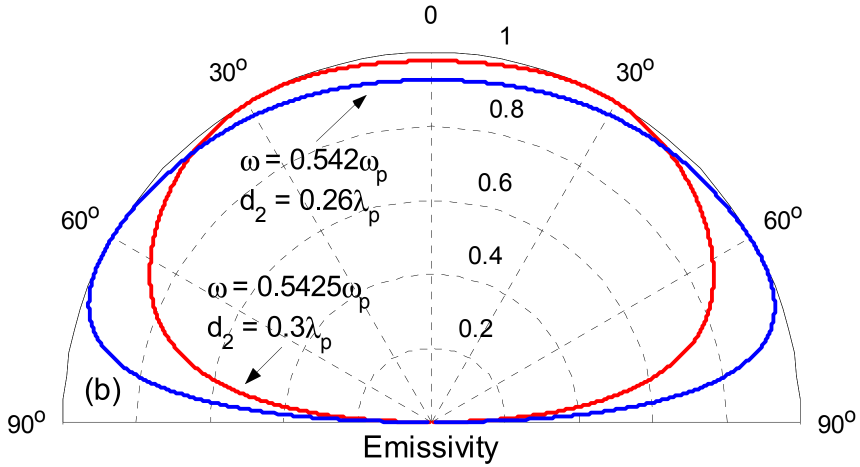




(b)

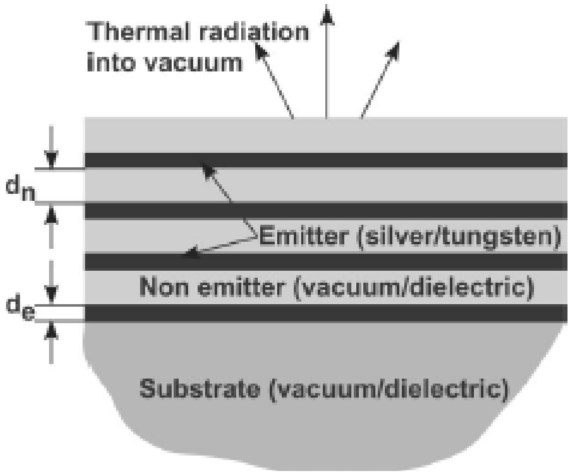
$$\omega = 0.706\omega_p$$

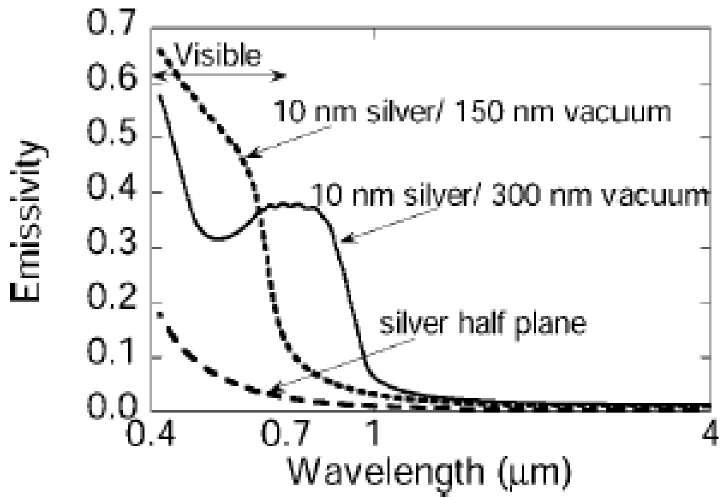




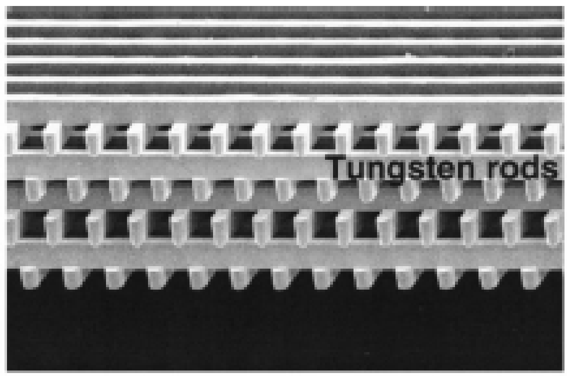
(b)

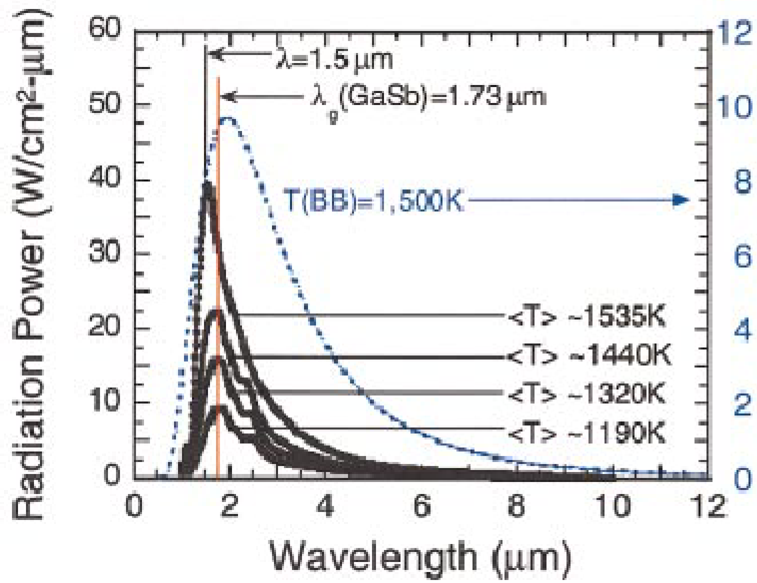
Application of photonic crystal (PC) for control of thermal emission





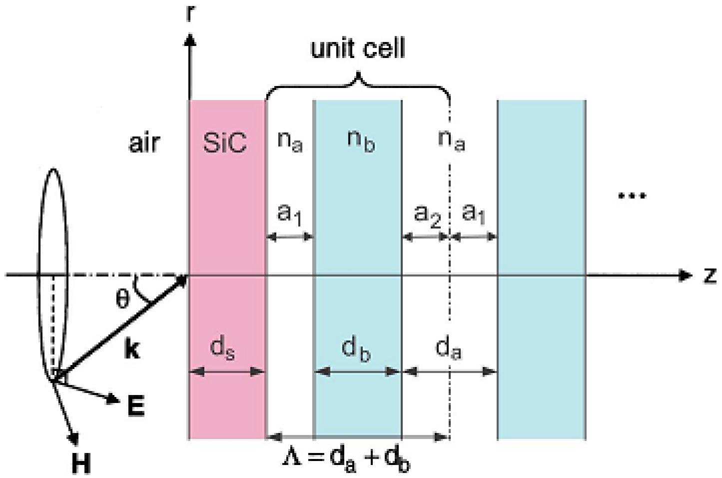
Narayanaswamy and Chen, *PRB* 70, 125101 (2004)

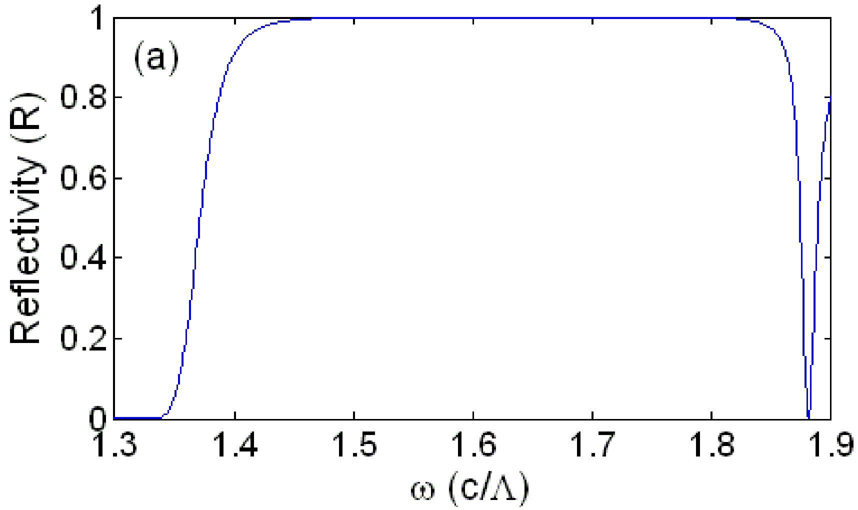




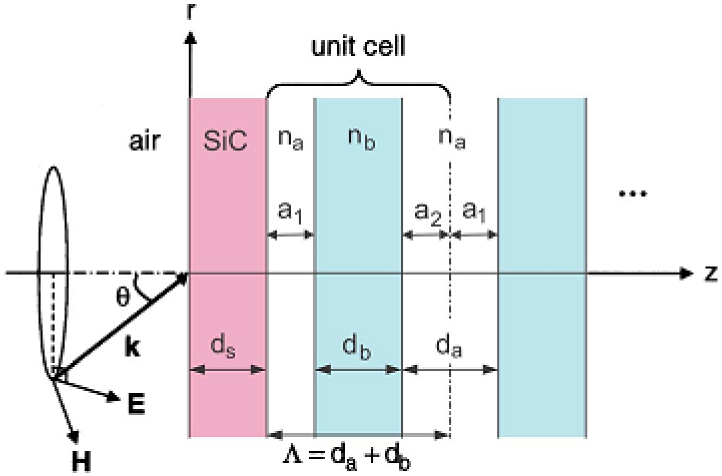
Lin et al., *Appl. Phys. Lett.* 83, 380 (2003)

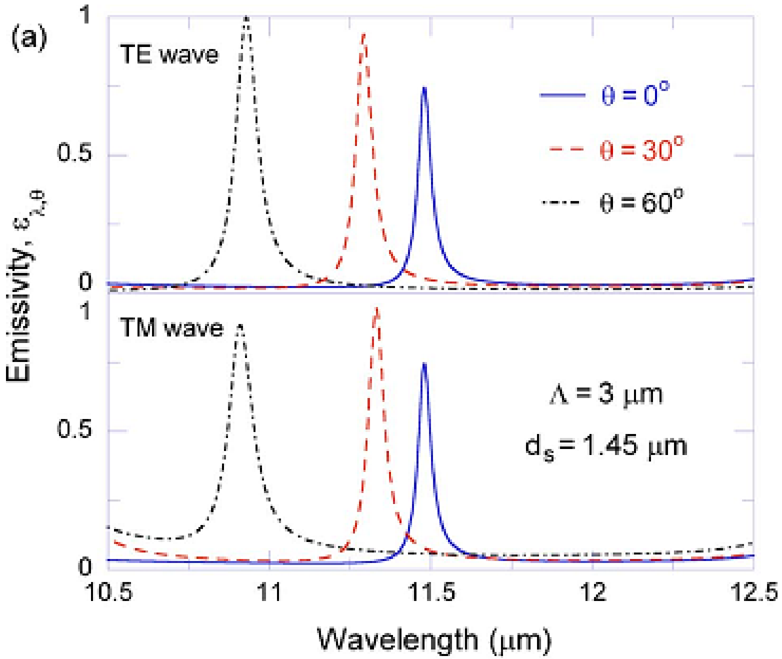
Manipulating thermal emission for SiC film by PC

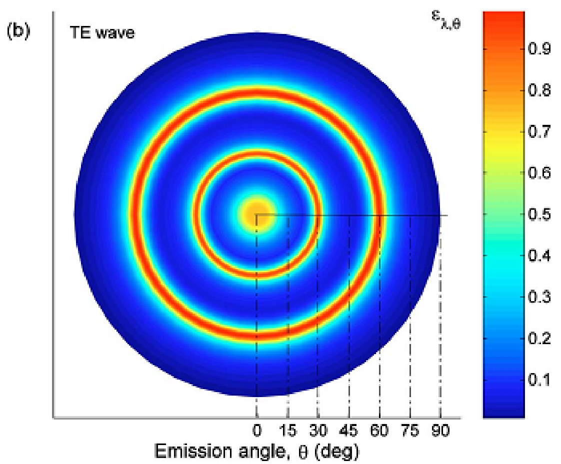




Manipulating thermal emission for SiC film by PC

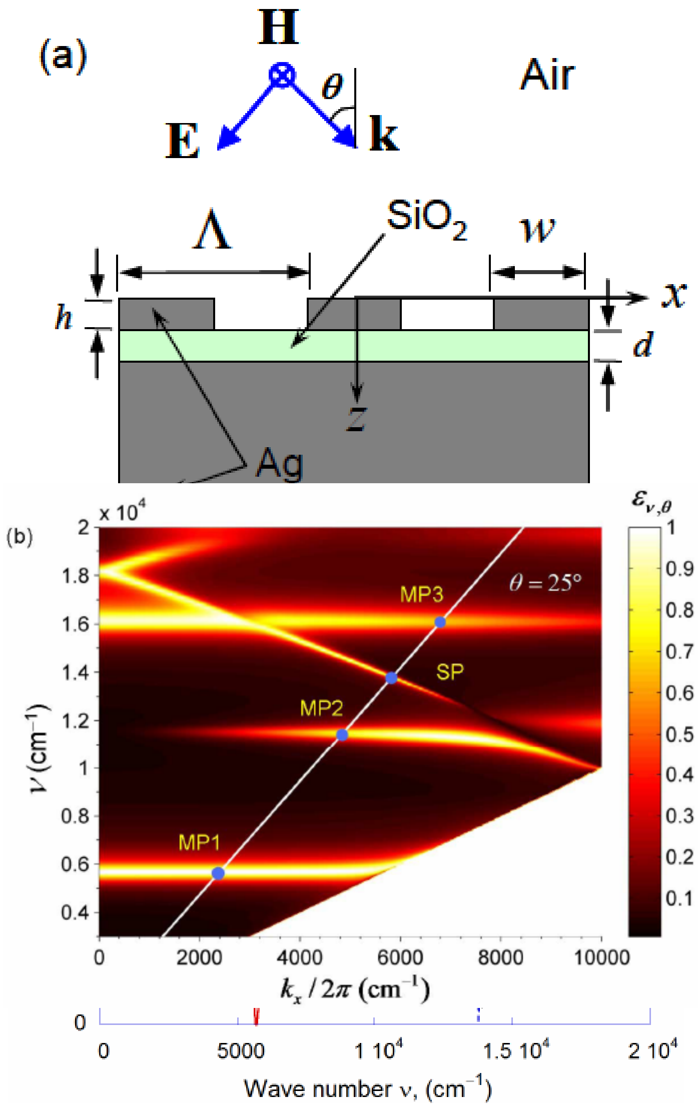


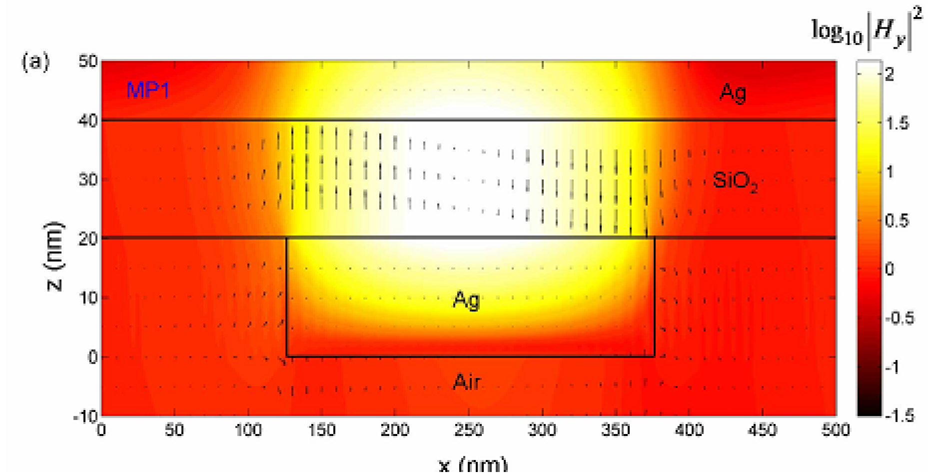




Lee, Fu, and Zhang, Appl. Phys. Lett, 2005, 87: 071904

Coherent Emission Realized using Magnetic Polaritons

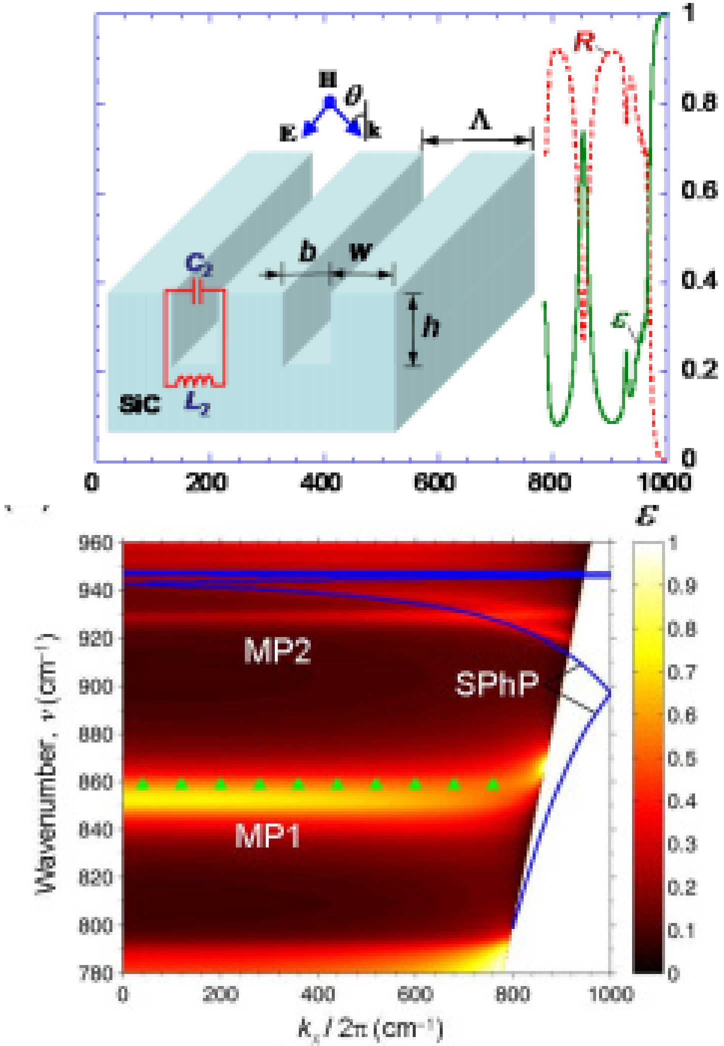


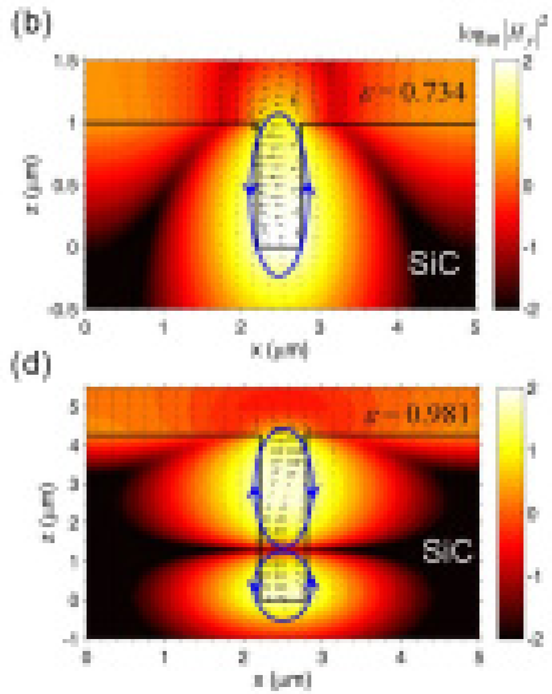


Magnetic field is strongly localized in the spacer between the strip and the film

B. J. Lee et al., Opt. Exp., 2008, 16, pp. 11328-11336

Magnetic polariton excited in deep SiC grating

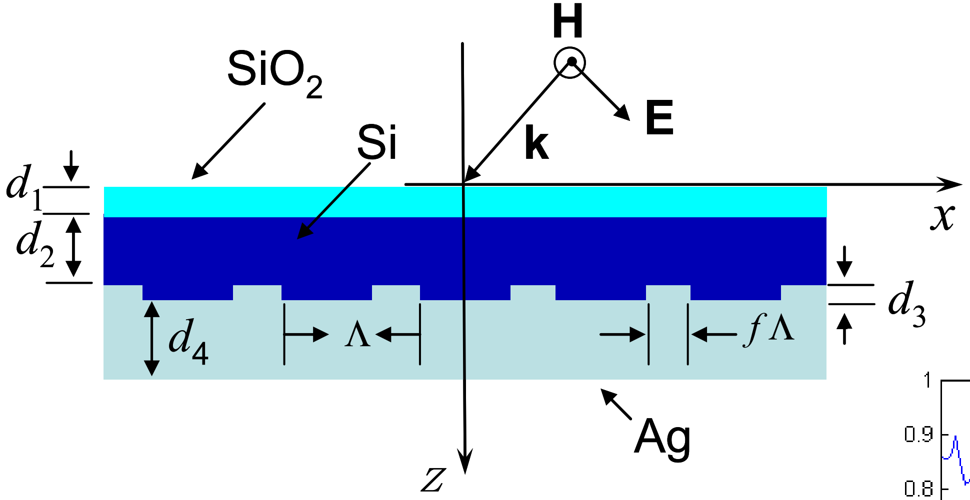




Wang and Zhang, Opt. Exp., 2011, 19, pp. A126-135

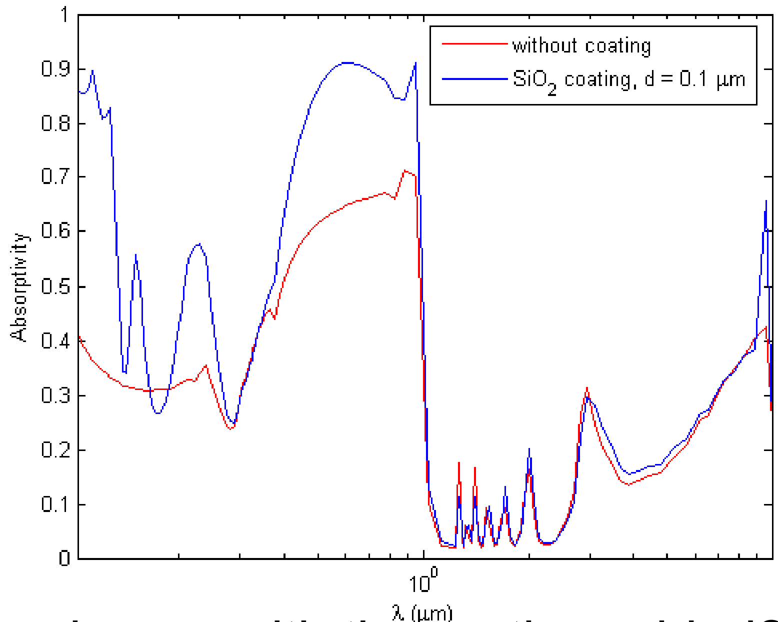
Why coupled modes?

Application of deep grating at the backside



AR coating

To control selectively the structure's thermal radiative absorption and emission.

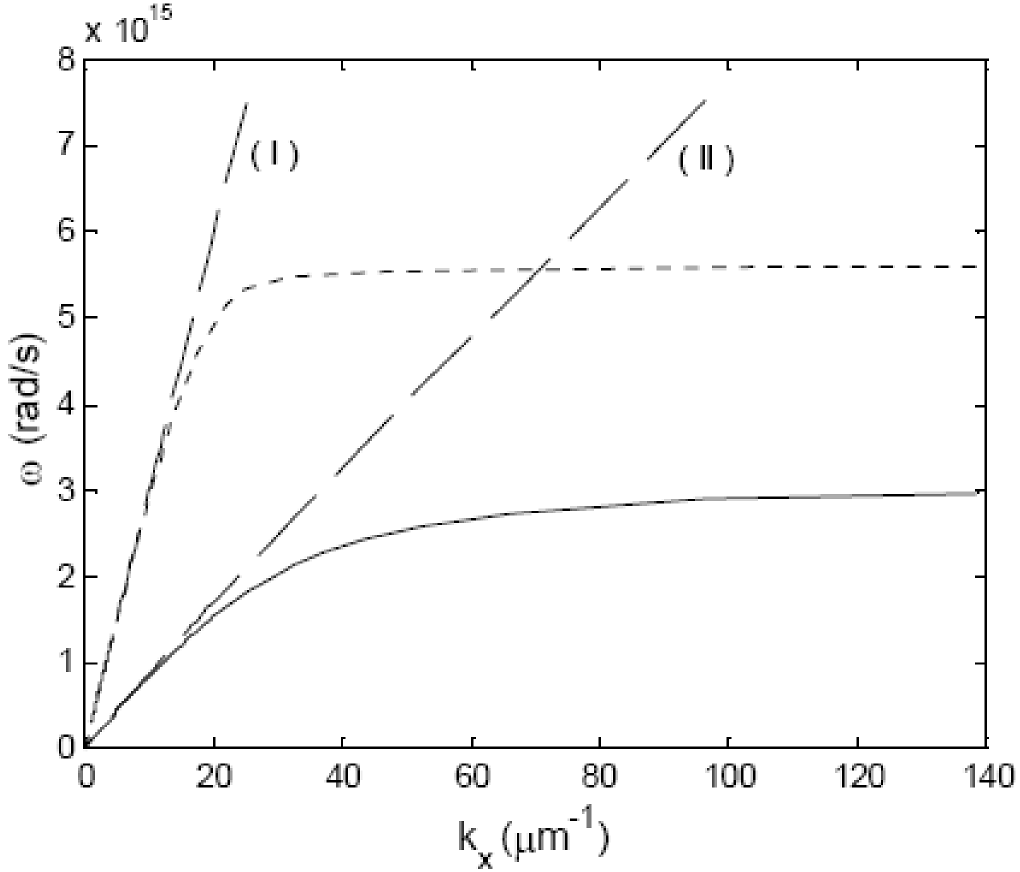


What will the curve change with the grating added?

•Dispersion relation of SPP at the interface between a dielectric and a metal.

$$\frac{k_{1z}}{\varepsilon_1}+\frac{k_{2z}}{\varepsilon_2}=0$$

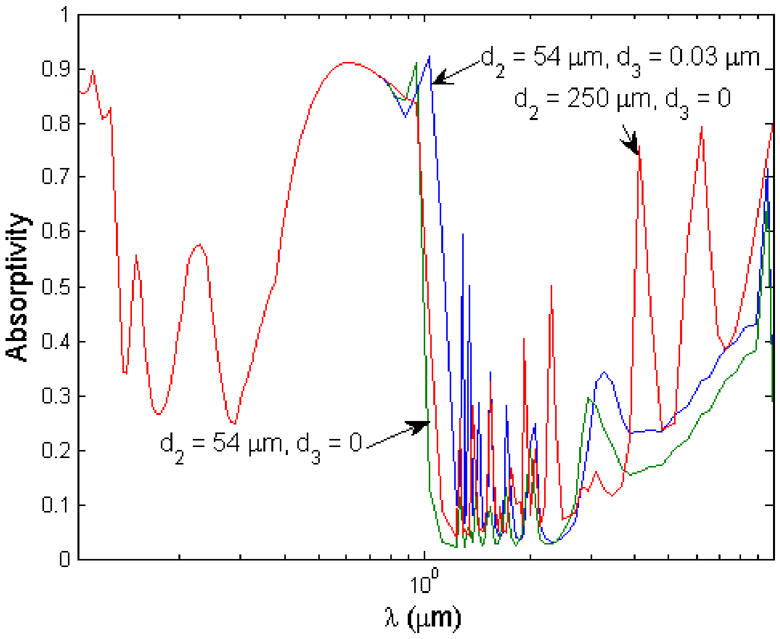
(p-polarization)

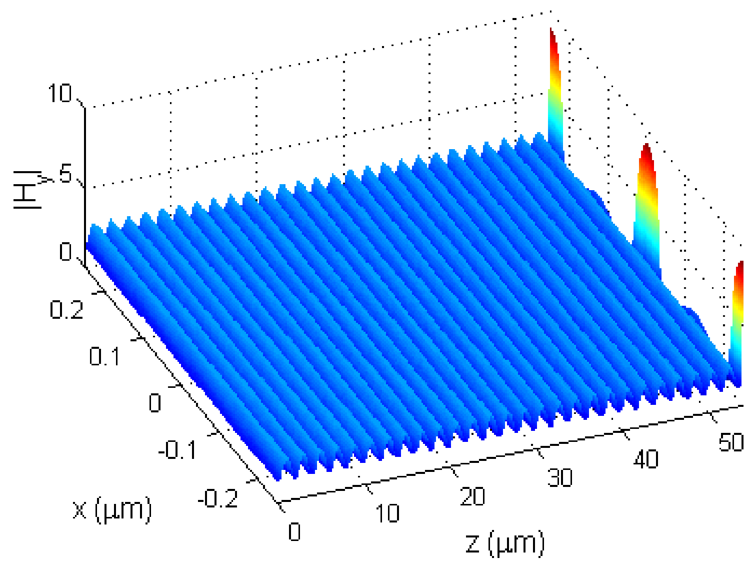


Short dashed： SPP at Ag/air interface

Solid： SPP at Ag/Si interface

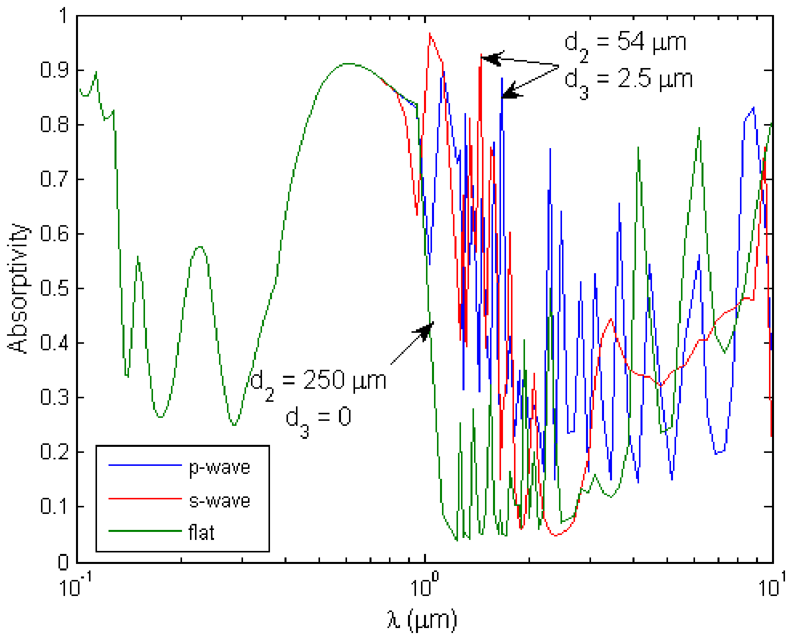
Calculated Results：Shallow grating





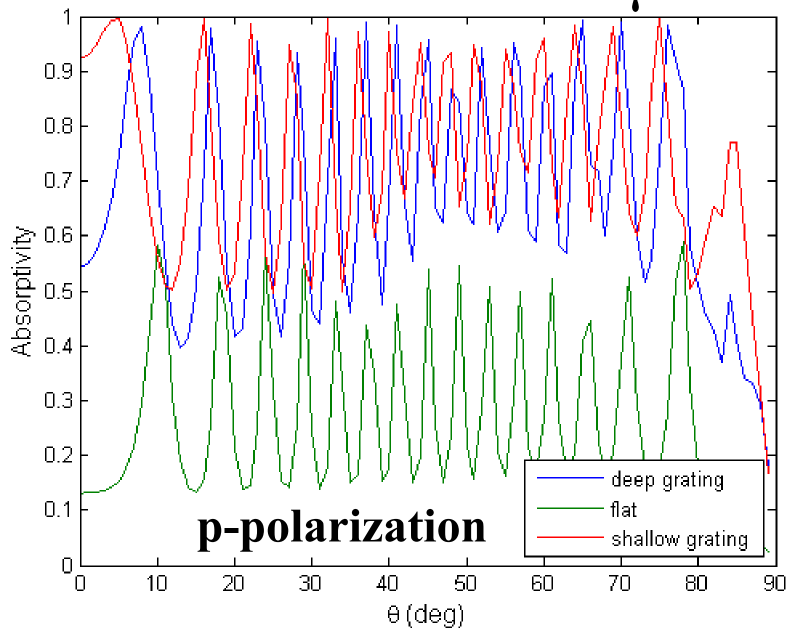
Normal incidence

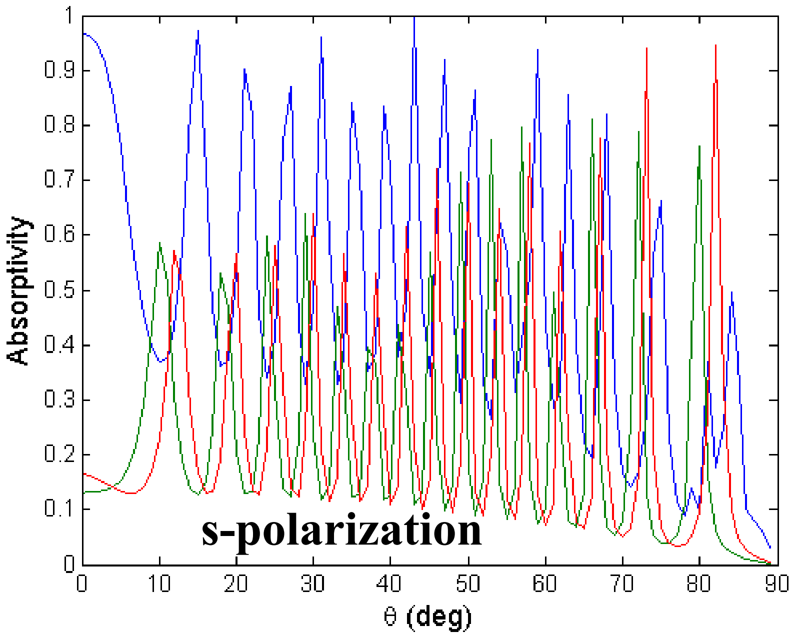
Deeping grating



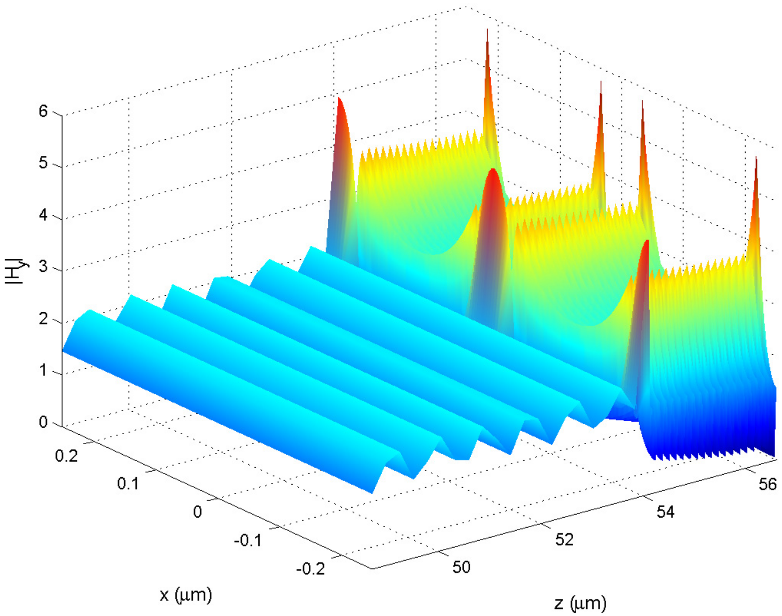
Normal incidence

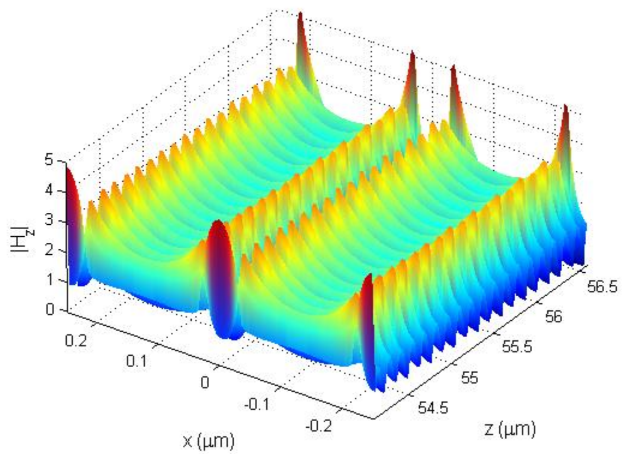
$\lambda = 1.033\ \mu m$



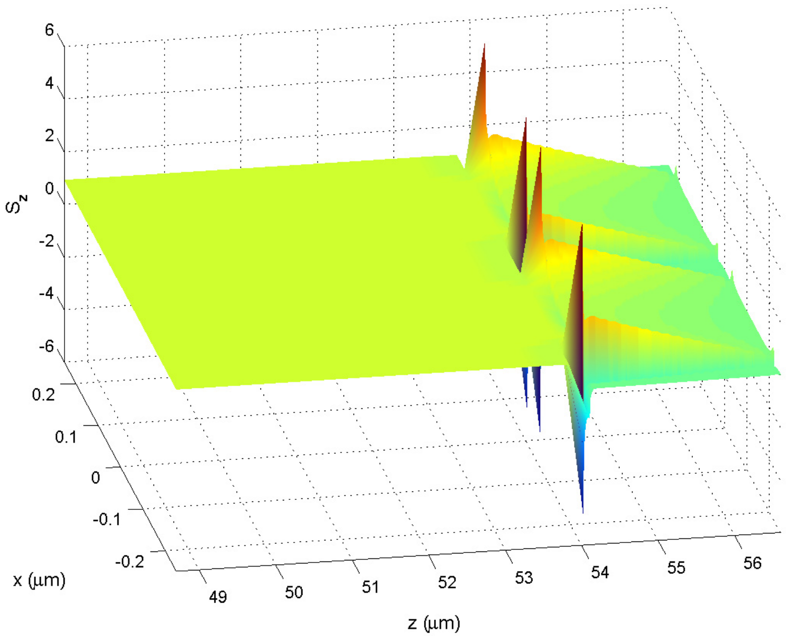


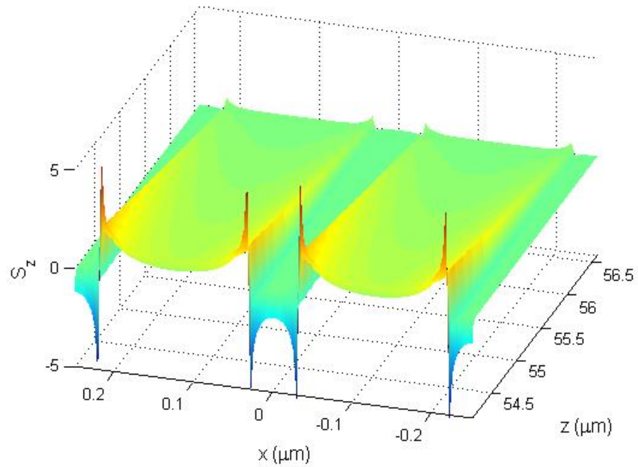
magnetic field amplitude distributions inside the Si layer and the grating region for p-polarization



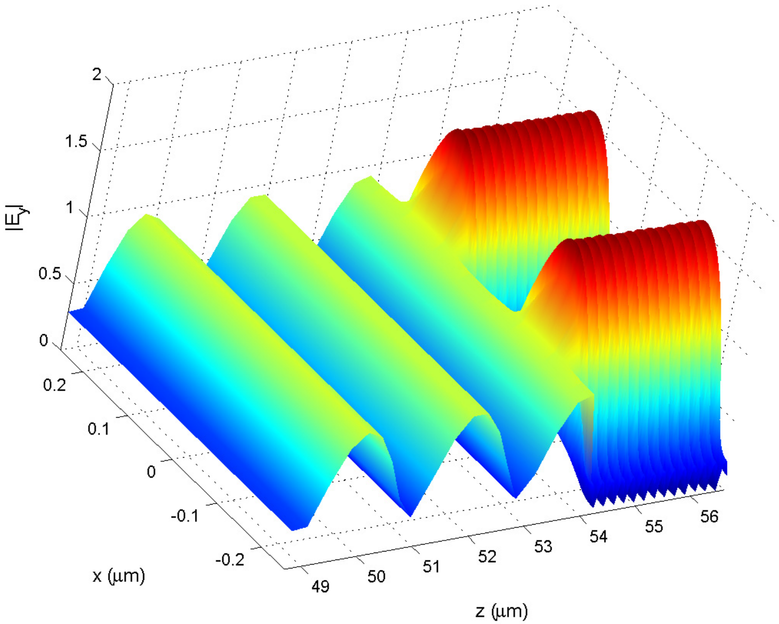


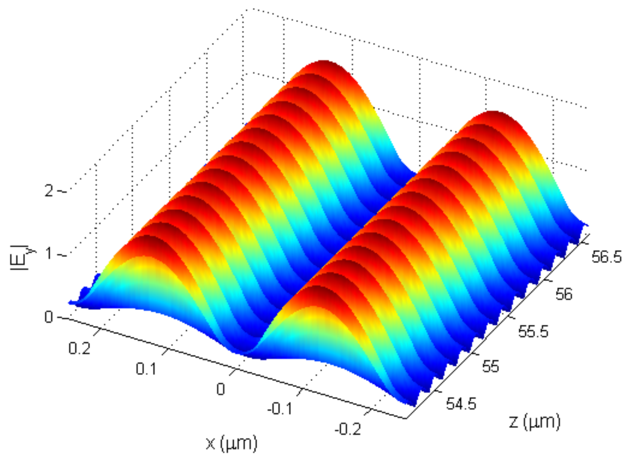
Decay of the radiant flux in the Si layer and the grating region for p-polarization





Electric field amplitude distributions inside the Si layer and the grating region for s-polarization





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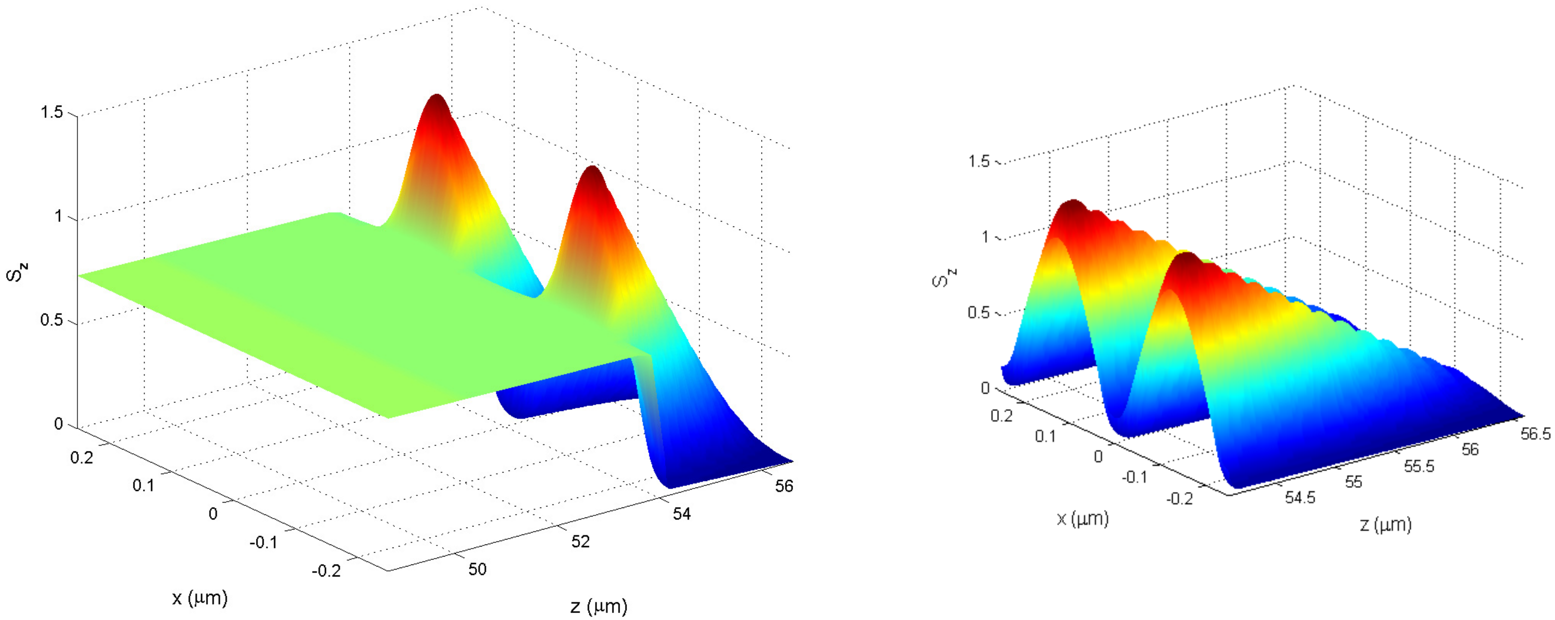
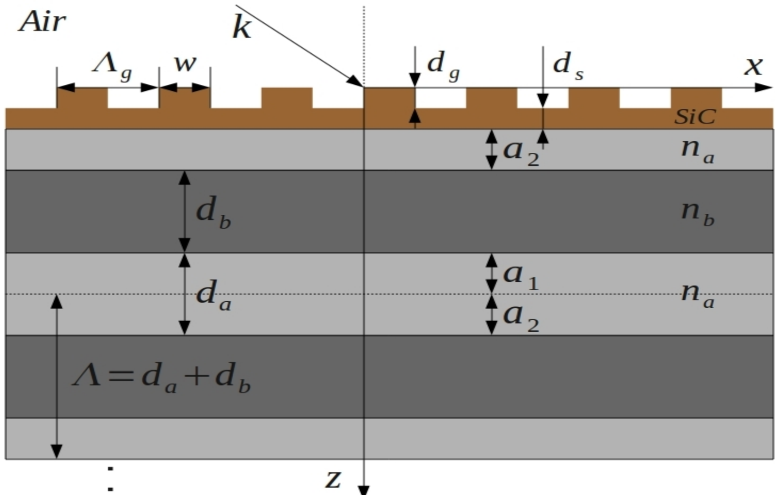
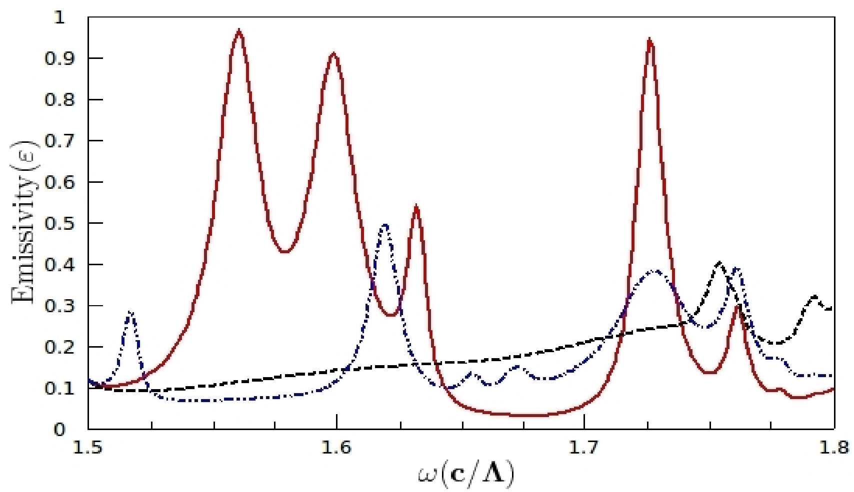
Decay of the radiant flux in the Si layer and the grating region for s-polarization

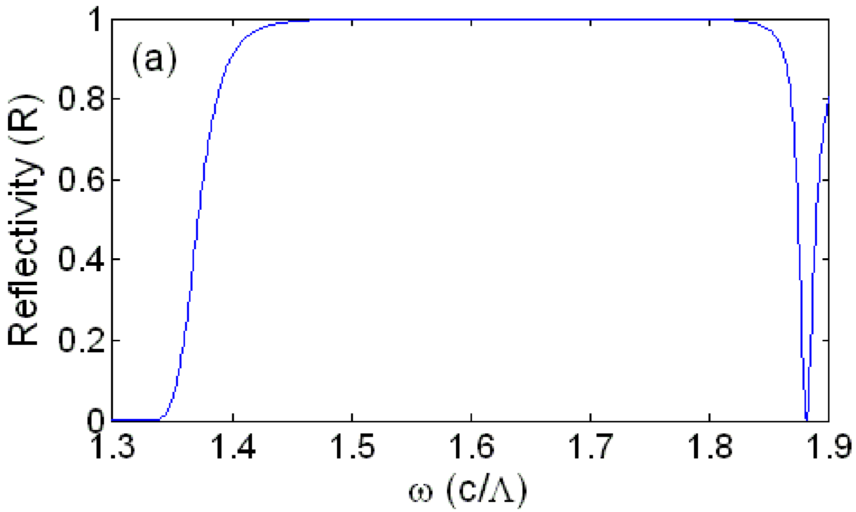


Fu and Tan, 2009, J. Heat Transfer

Periodic structure combining a grating and a PC

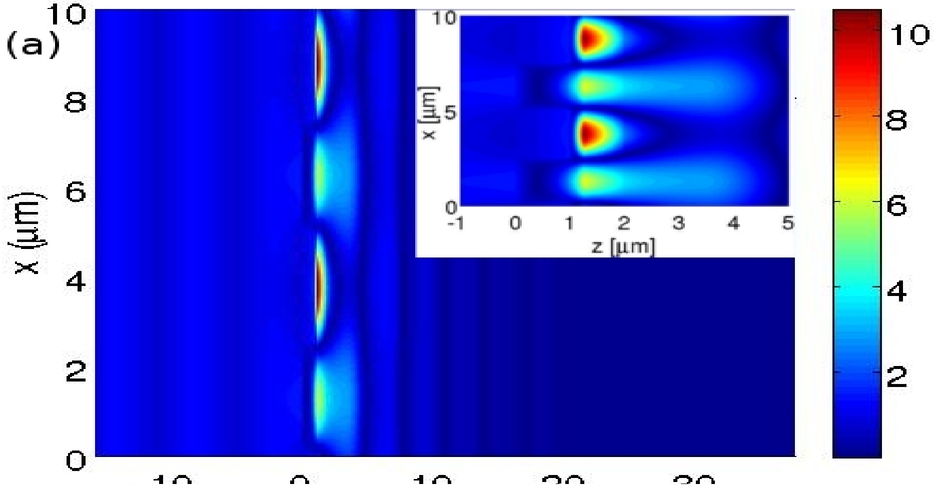


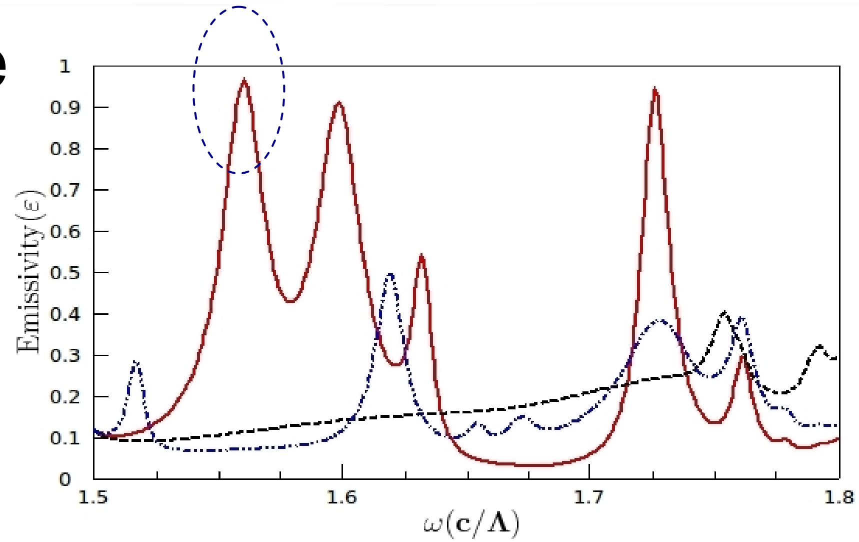


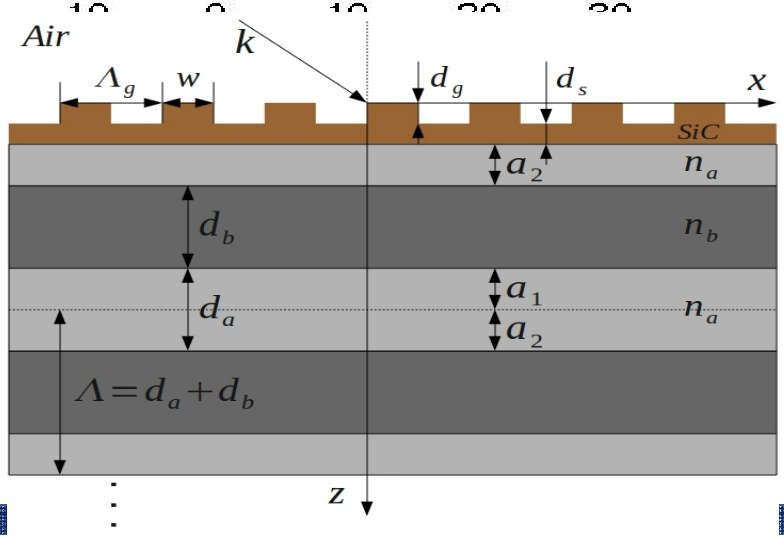


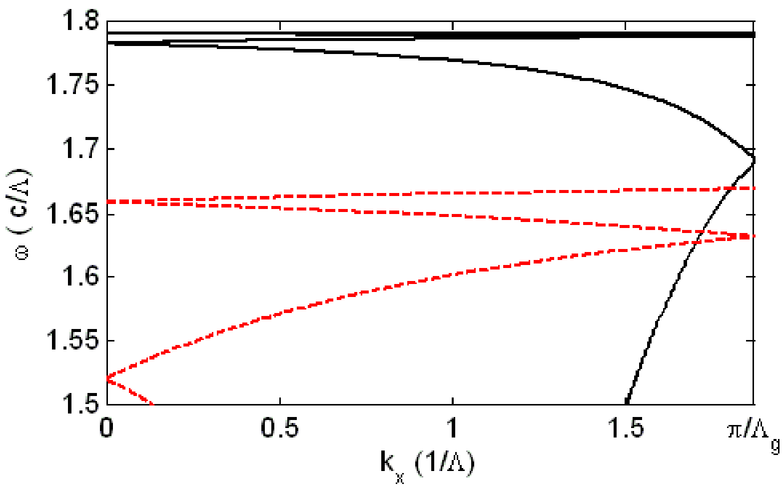
solid curve: the proposed structure;
dashed curve: the structure without PC;
dashed-dotted curve: the structure with PC replaced with a semi-infinite dielectric of n=2.4.

Coupled SPP with PC mode

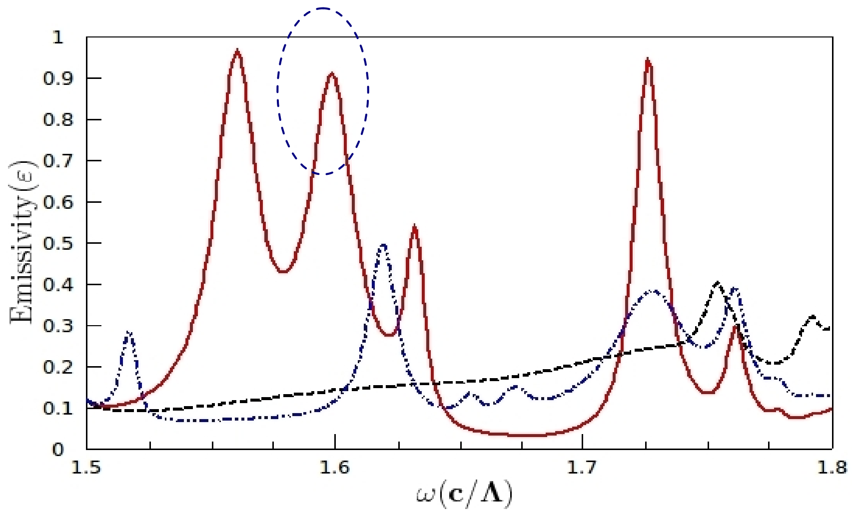


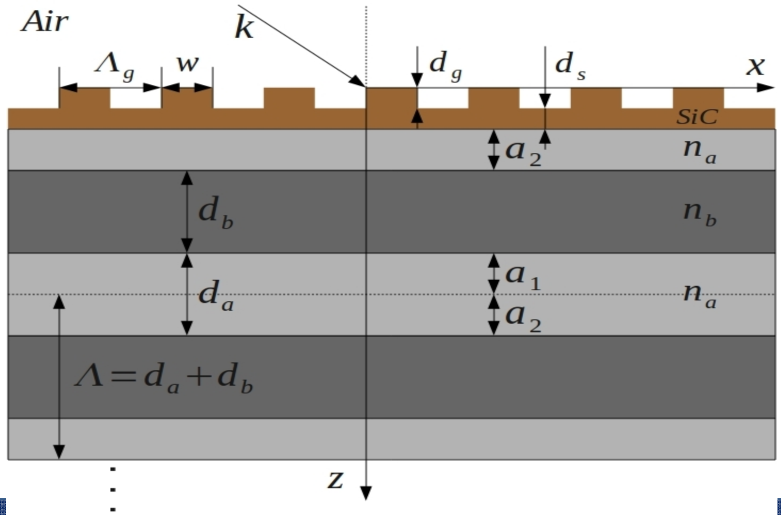


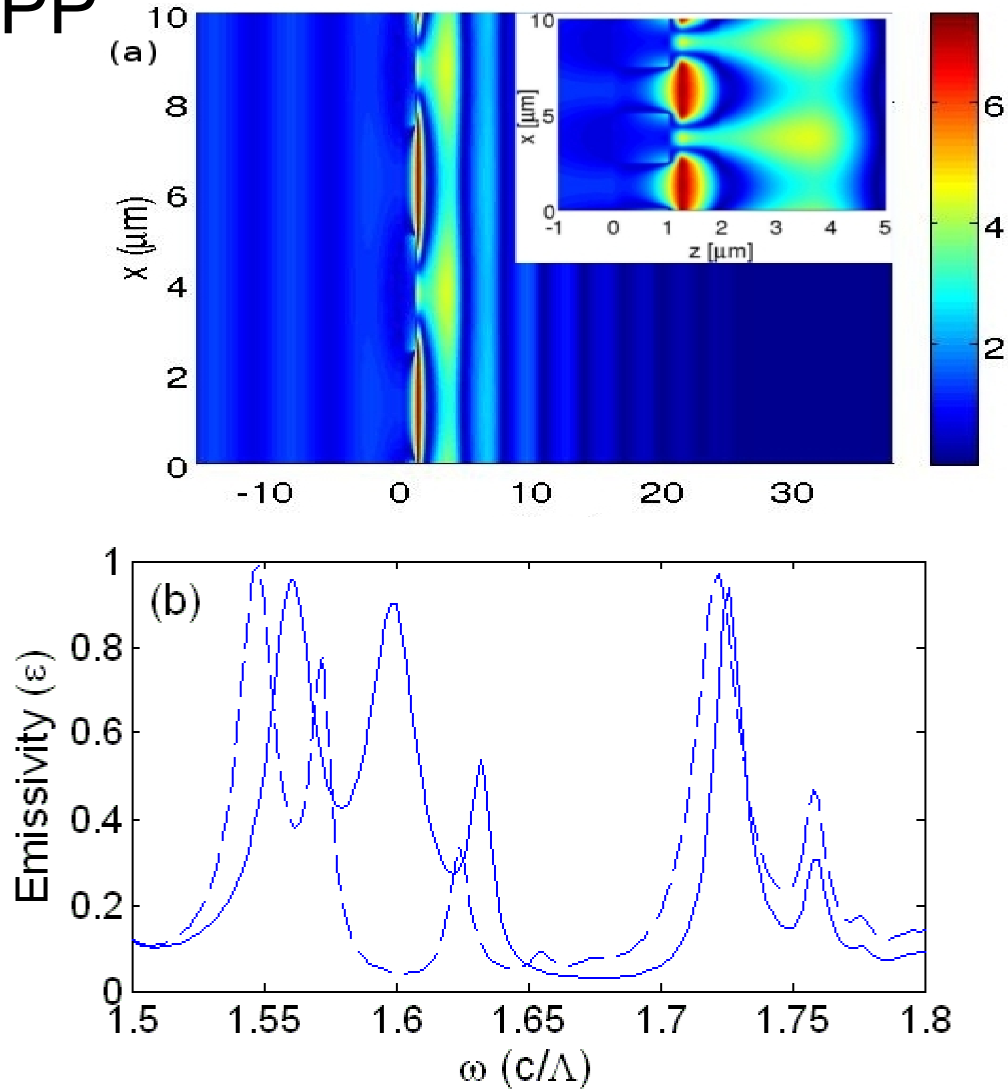




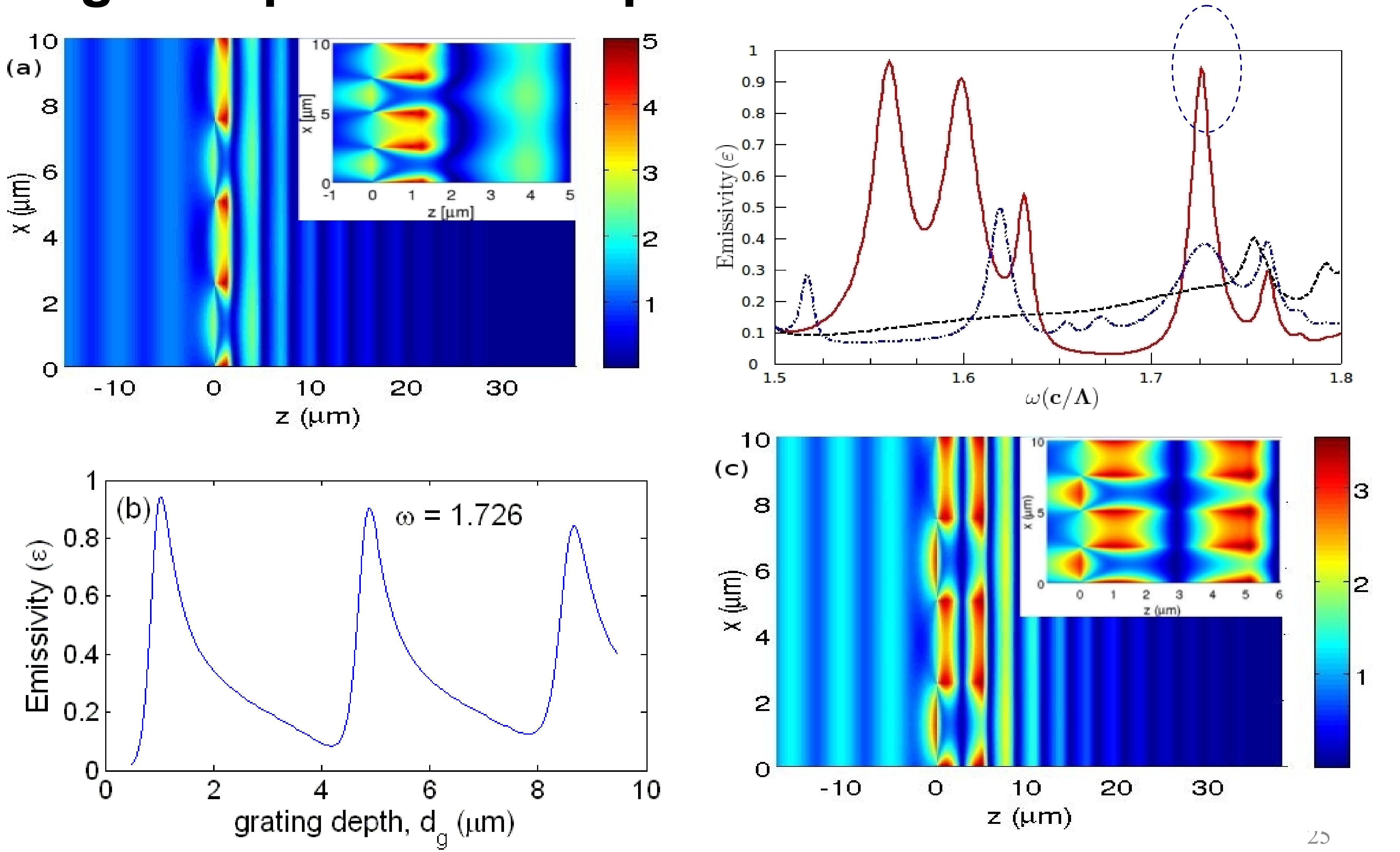
Coupled PC mode with SPP



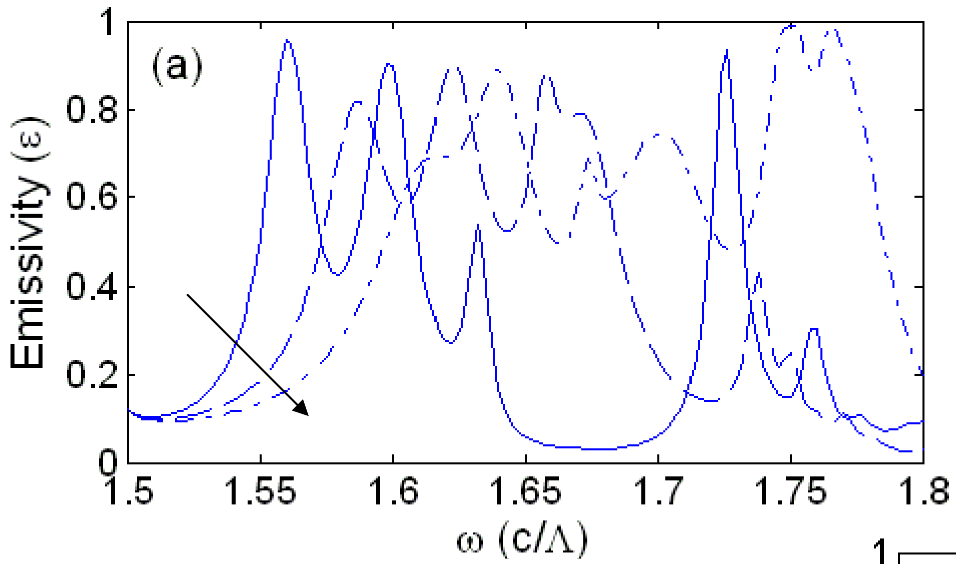


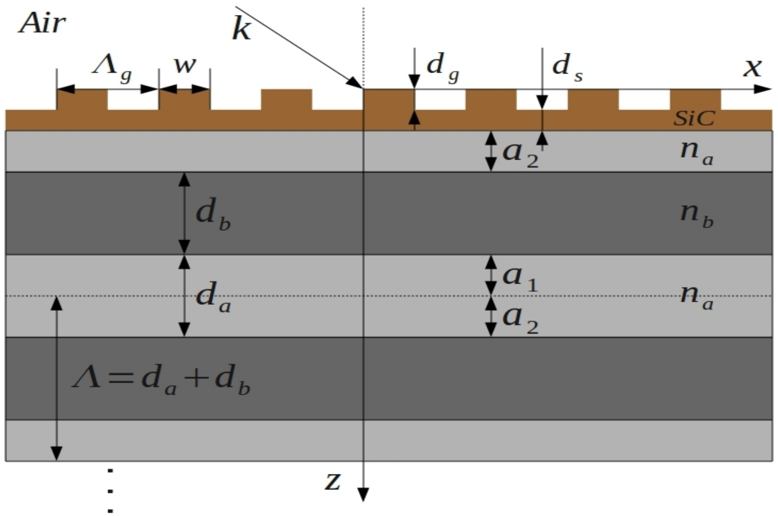


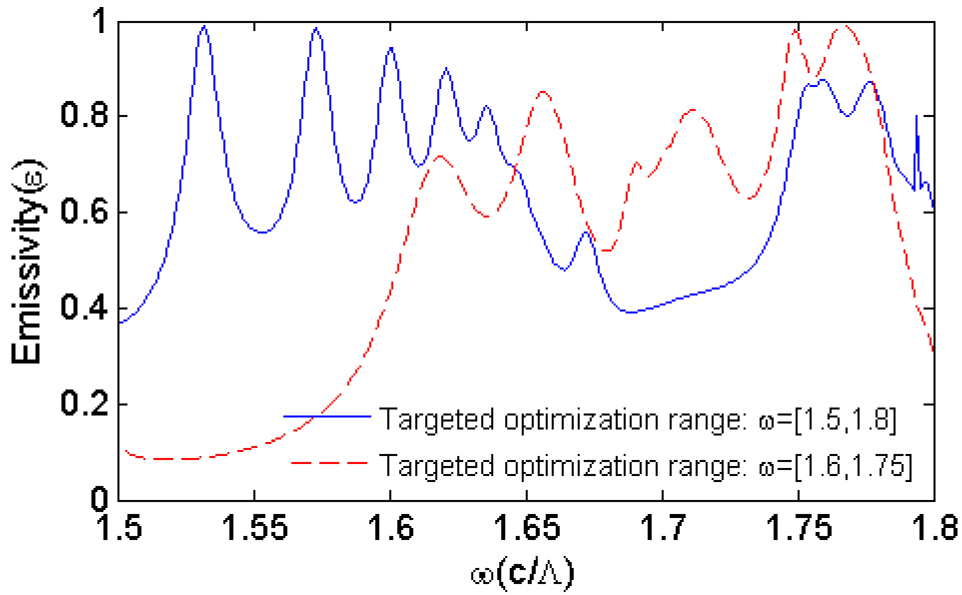
Magnetic polariton coupled with SPP



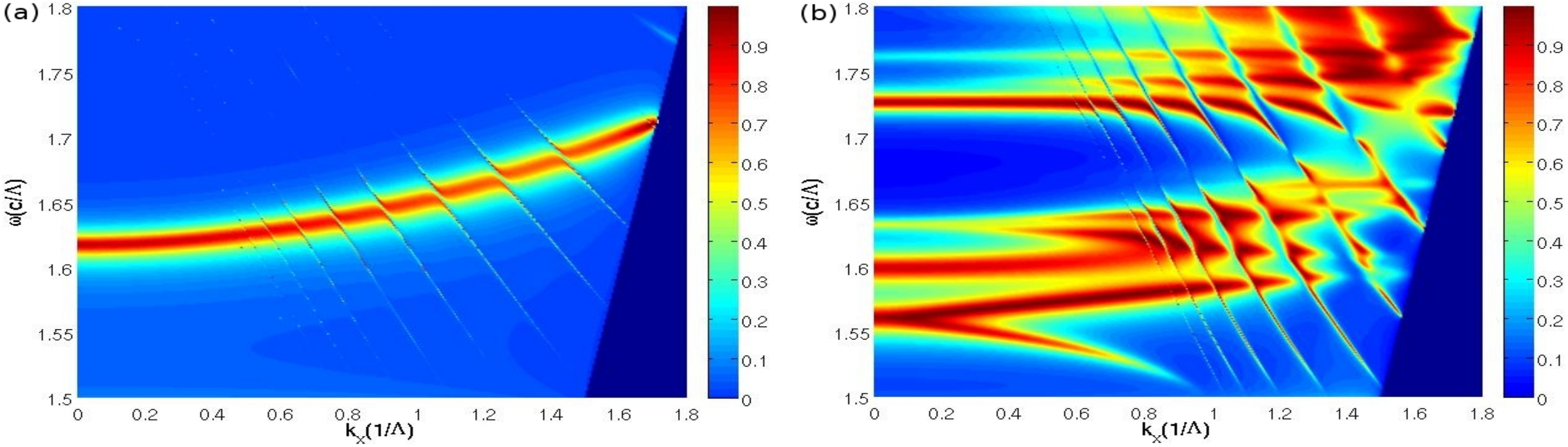
Geometric effect and optimization







Distribution of the emissivity as a function of and ω k_x

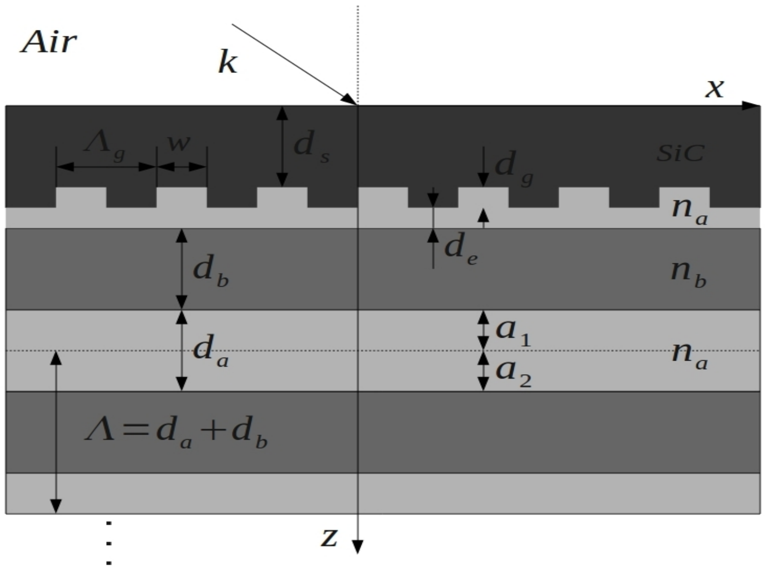


- TE-polarization
- The emissivity strongly depends on the direction
- PC surface mode and no SPhPs
- Sharp emissivity peaks

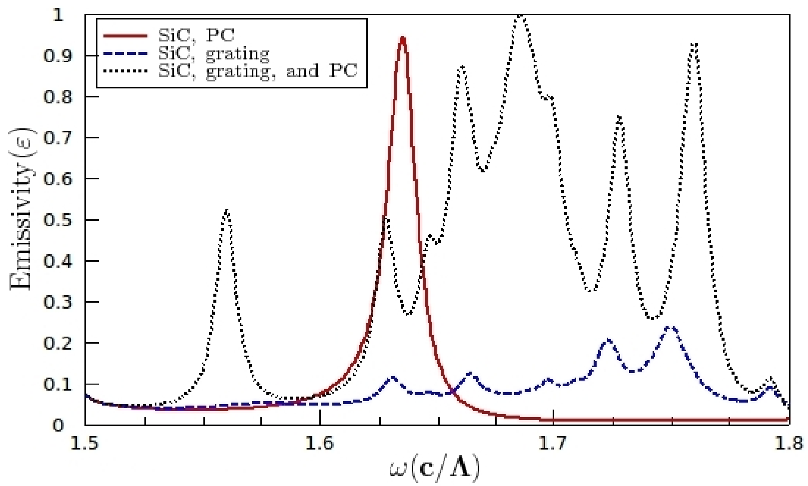
- TM-polarization
- The emissivity enhancement due to PC mode is quasi angle-independence.
- multiple modes

Wang, Fu, and Tan, JHT (in press)

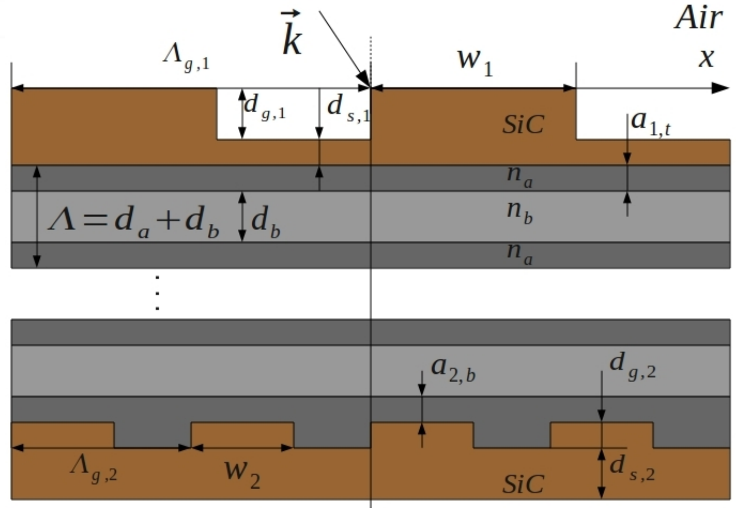
- grating beneath a film

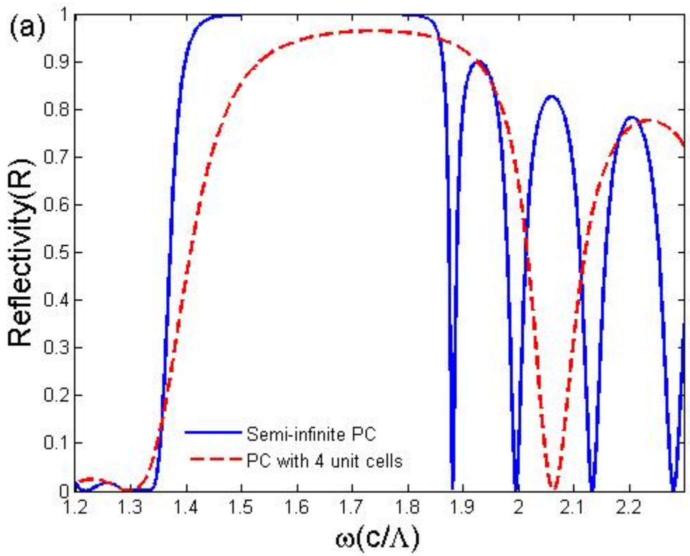


- Emissivity at normal direction

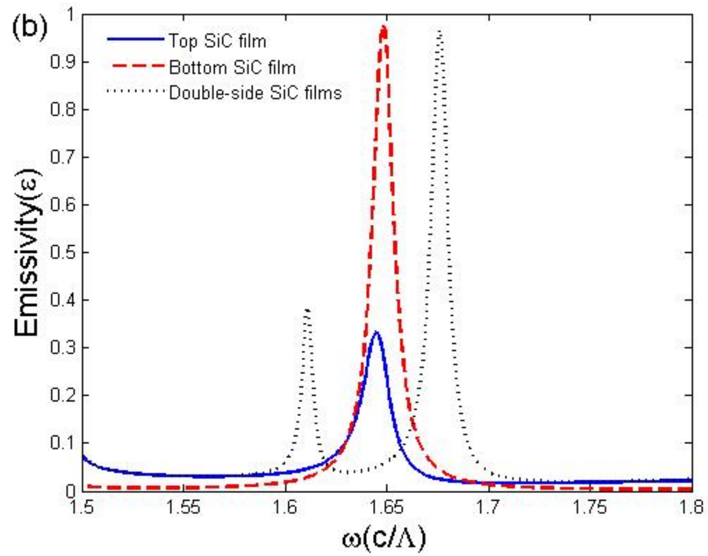


A structure with double-sided gratings: in this case the PC has finite number of unit cells

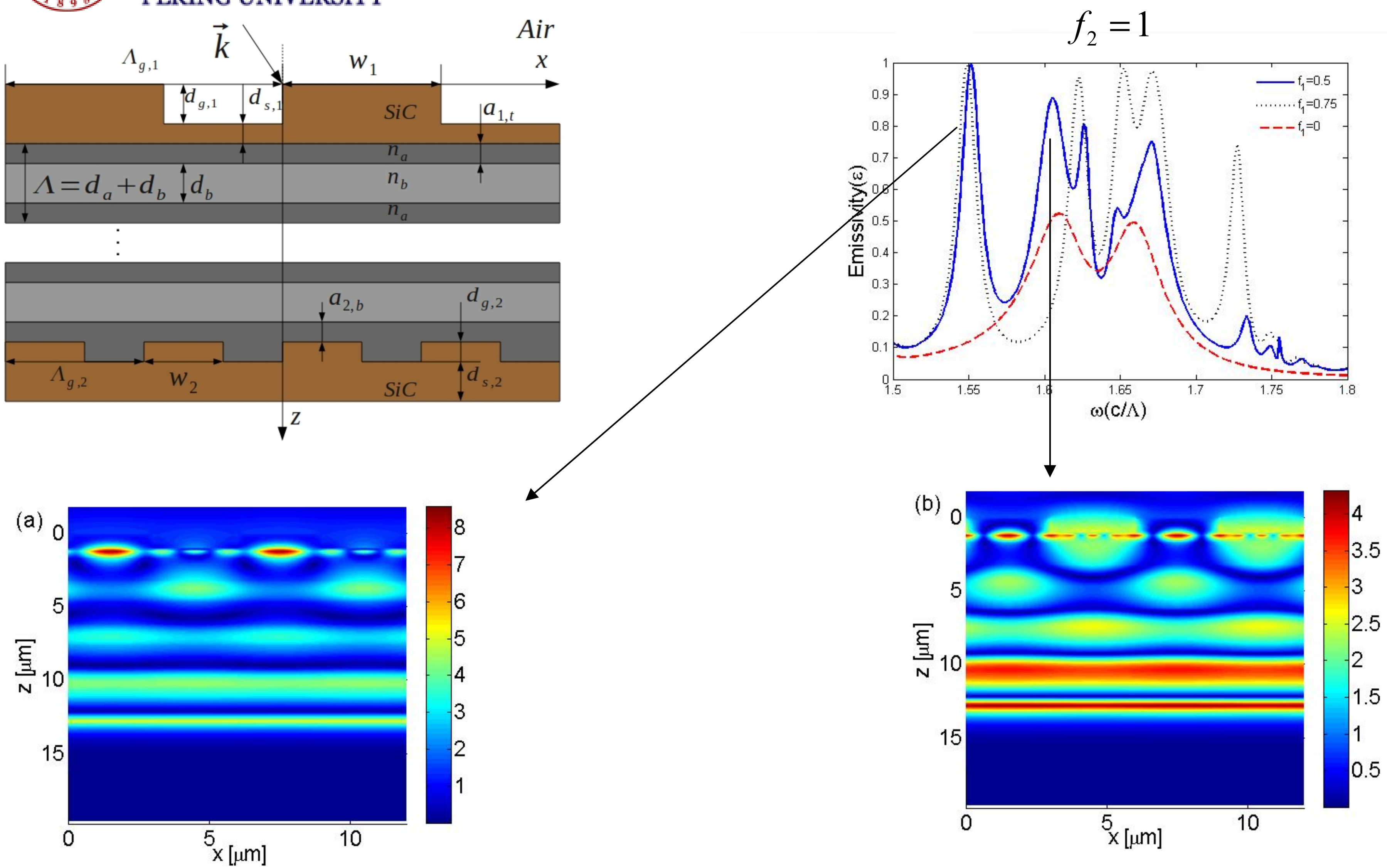




The band gap

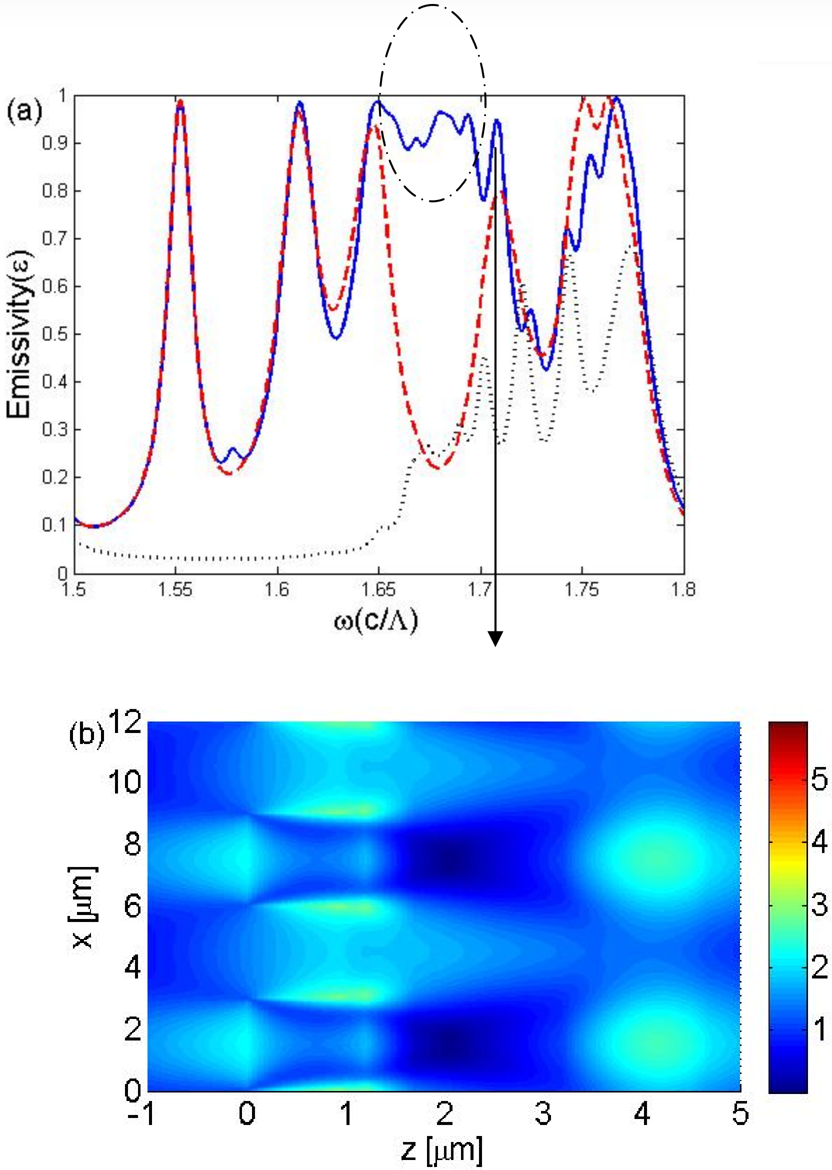


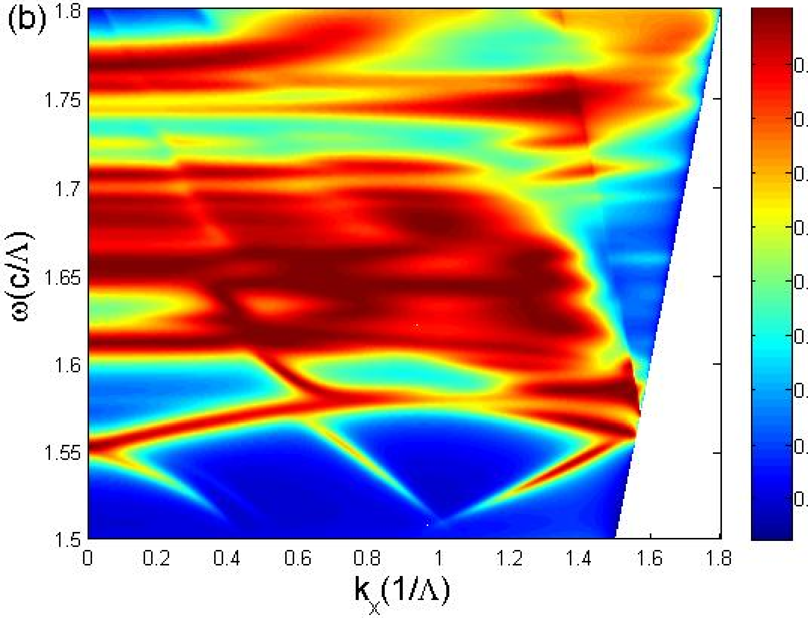
The PC mode


$f_2 = 1$
Air
$\vec{k}$
$\Lambda_{g,1}$
w_1
x
$d_{g,1}$
$d_{s,1}$
SiC
$a_{1,t}$
n_a
n_b
n_a
$\Lambda = d_a + d_b$
d_b
$a_{2,b}$
$d_{g,2}$
$\Lambda_{g,2}$
w_2
SiC
$d_{s,2}$
z
Emissivity(ε)
ω(c/Λ)
f_1=0.5
f_1=0.75
f_1=0
(a)
(b)
z [μm]
x [μm]

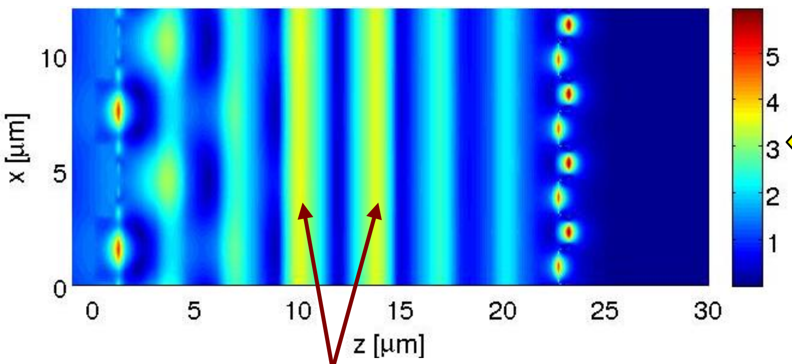
Emissivity of the structure

Dotted: $f_1=1$
Dashed: $f_1=f_2=0.5$





Effect of defect on the excitation of SPhP

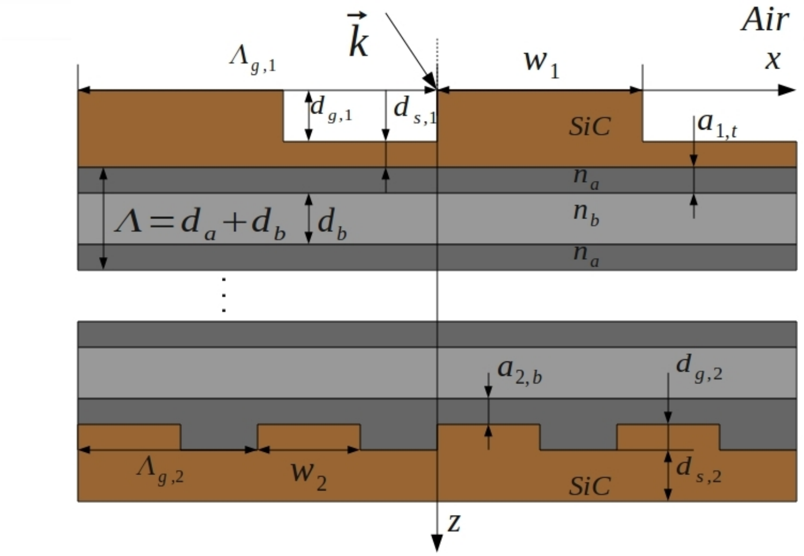


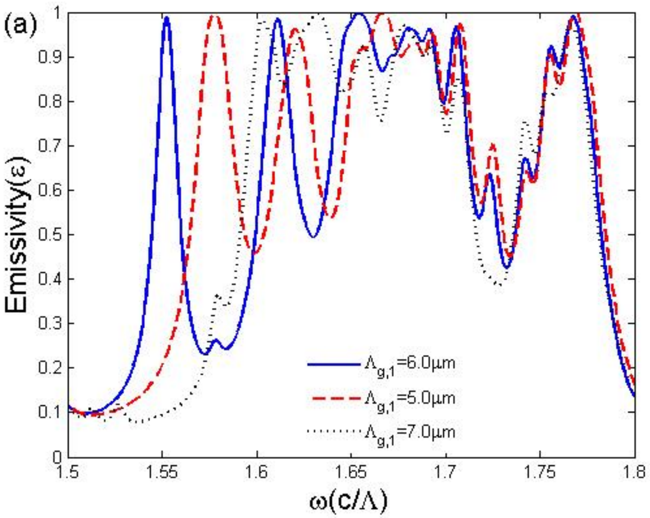
Excitation of a defect mode

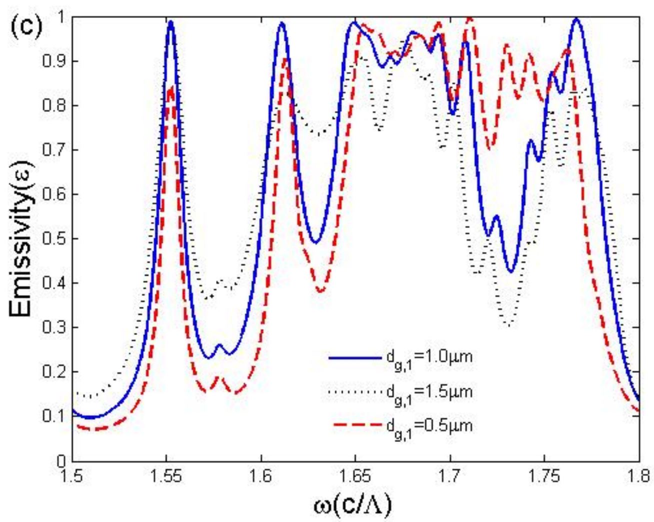
Excitation of SPhP, with the effect of a defect mode sustained by a defect located between 2th and 3th period. Normal direction for TM waves

$\omega = 1.68$

Effect of geometric parameters on the emission pattern

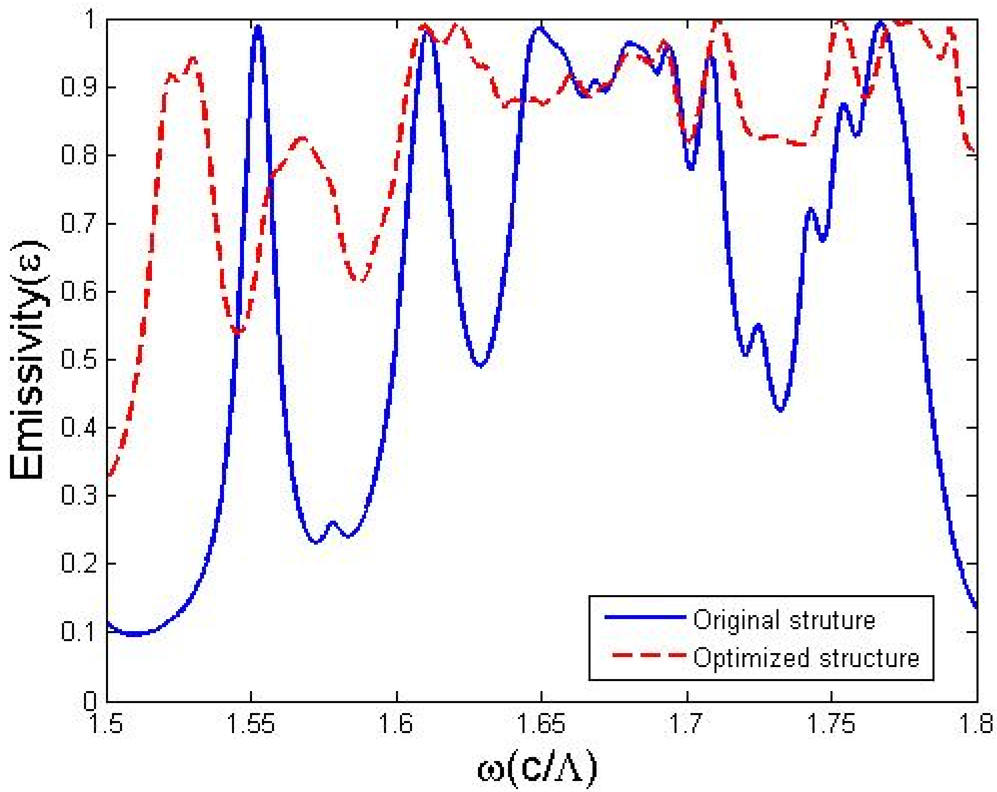




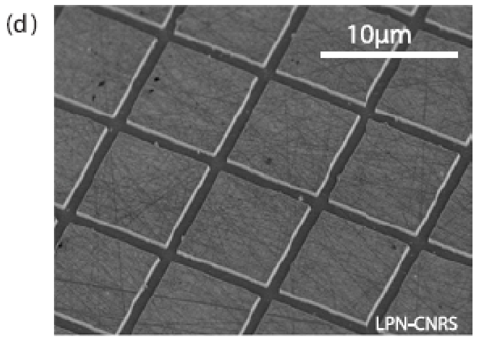


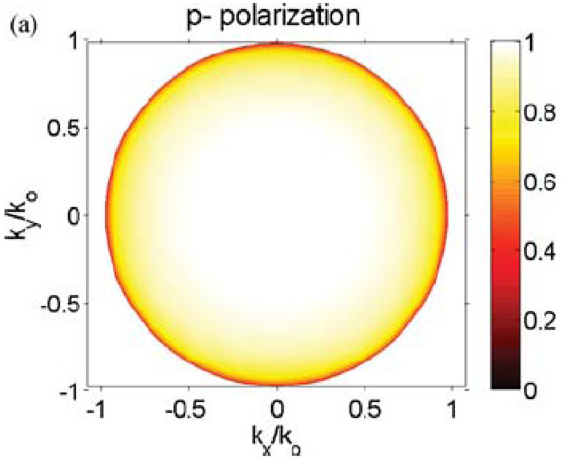
Wang, Fu, and Tan, JQSRT (in press)

Optimized emissivity at normal direction for p-polarization



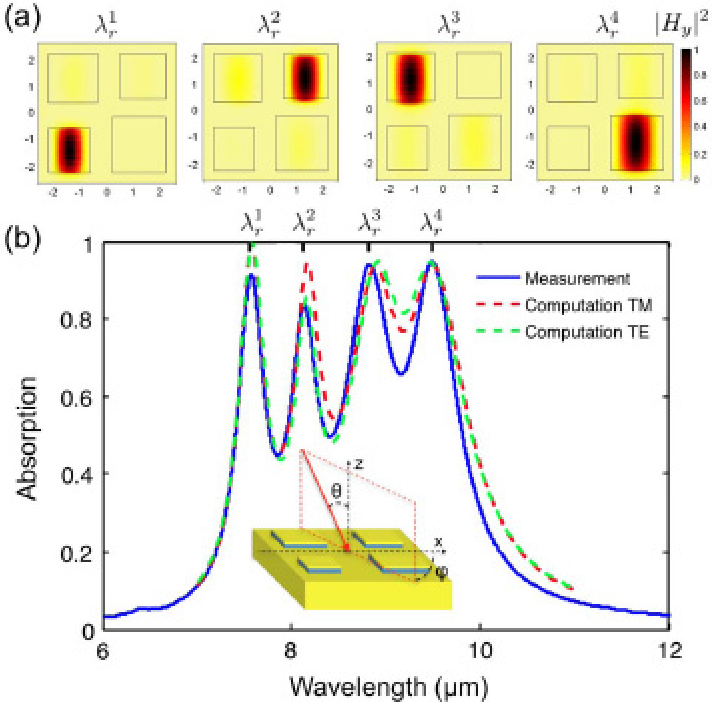
2-D gratings





Arnold et al, PRB, 2012

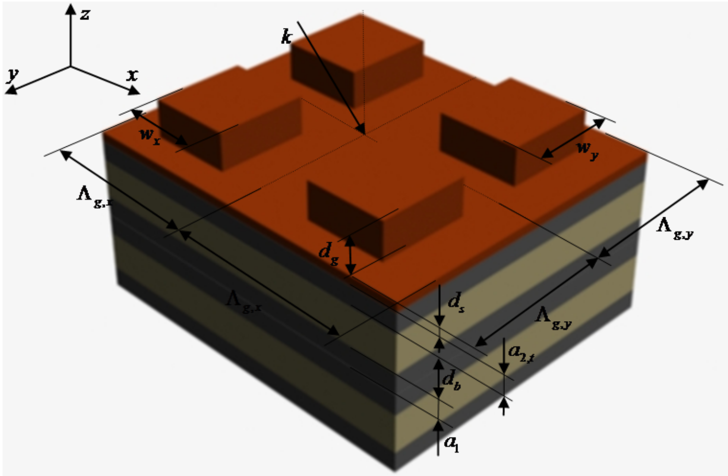
Omnidirectional emission is due to surface polaritons

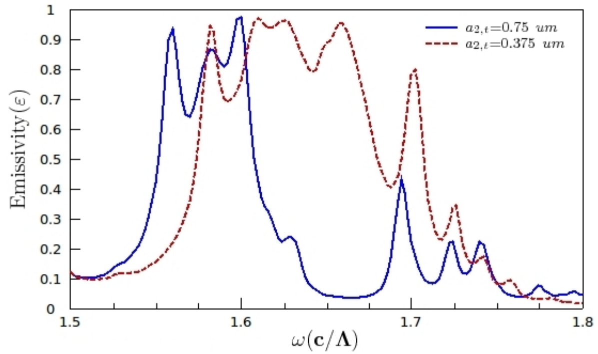


Bouchon et al, Opt Lett, 2012

Different resonant patterns are found in individual MIM patches

A 2D SiC grating on PC and the spectral normal emissivity





Summary

1. Interaction and coupling of different electromagnetic modes may result in large enhancement of the emissivity of a microstructure in broadened spectral band and range of emission angle
2. Manipulation and optimization of thermal emission from microstructures can be achieved by tuning the geometric parameters of the structure.

Thank you for your attention!