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Directional Smith-Purcell radiation with coupled high-index gratings

Micro- and Nanophotonic Materials

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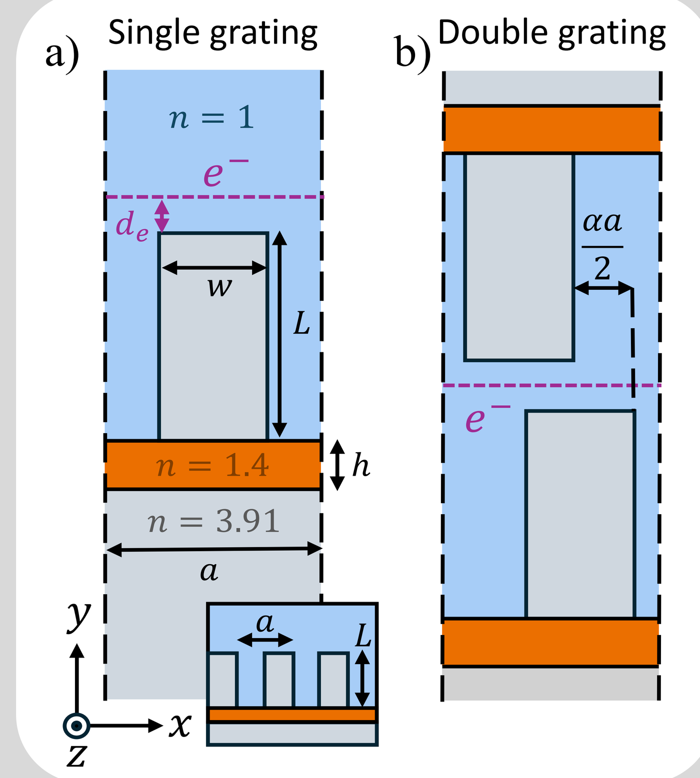
Introduction

Smith–Purcell radiation (SPR) occurs when an electron beam interacts with a periodic structure, producing coherent emission. While traditionally studied with metallic gratings, dielectric photonic systems offer better control over dispersion and directionality.

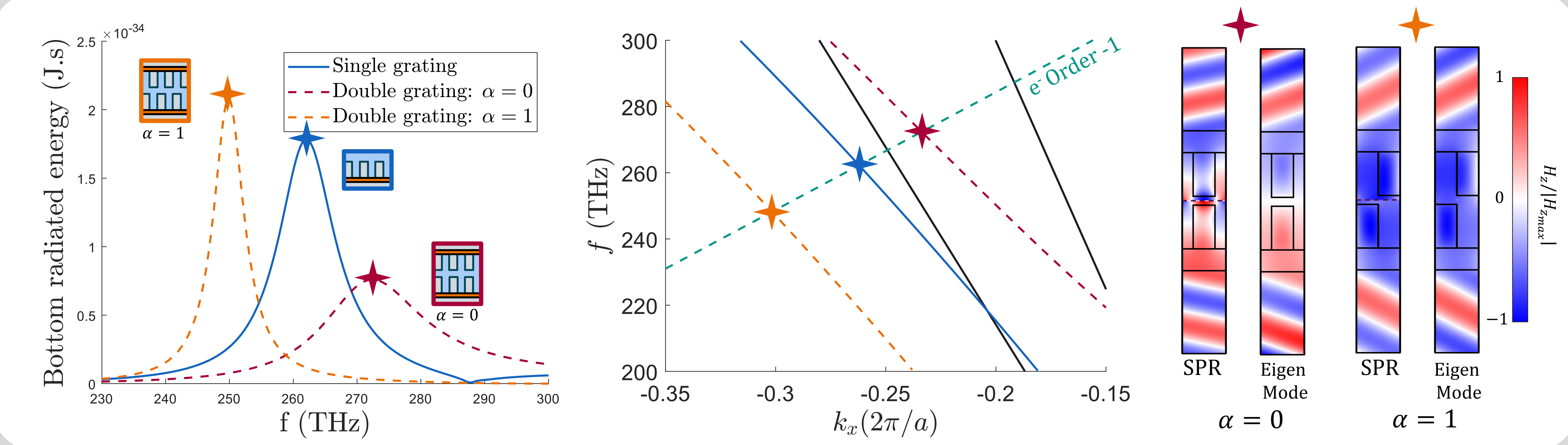
We explore a **high-index double-grating** structure where a lateral offset induces **asymmetric emission** via interference between coupled modes. A **Coupled Mode Theory (CMT)** model supports the simulations, providing physical insight and enabling efficient design of compact, directional SPR sources.

Structure



We study a **double grating** placed on each side of an electron beam. Each grating is made of a silicium (n=3.91) tooth placed on a slab of SiO_2 (n=1.4) supported by a **silicium substrate** and surrounded by air. The parameter α allows to **break the top-down symmetry** by sliding the gratings.

Guided mode coupling (α = 0 and α = 1)



Peaks of emission originate from **Bloch modes** excited by the electron.

The **coupling** between the top and bottom grating splits the initial **Bloch mode** of the single grating.

Coupled mode theory and asymmetric radiation

We use **CMT** to model the **interaction** between the resonant modes of each grating.

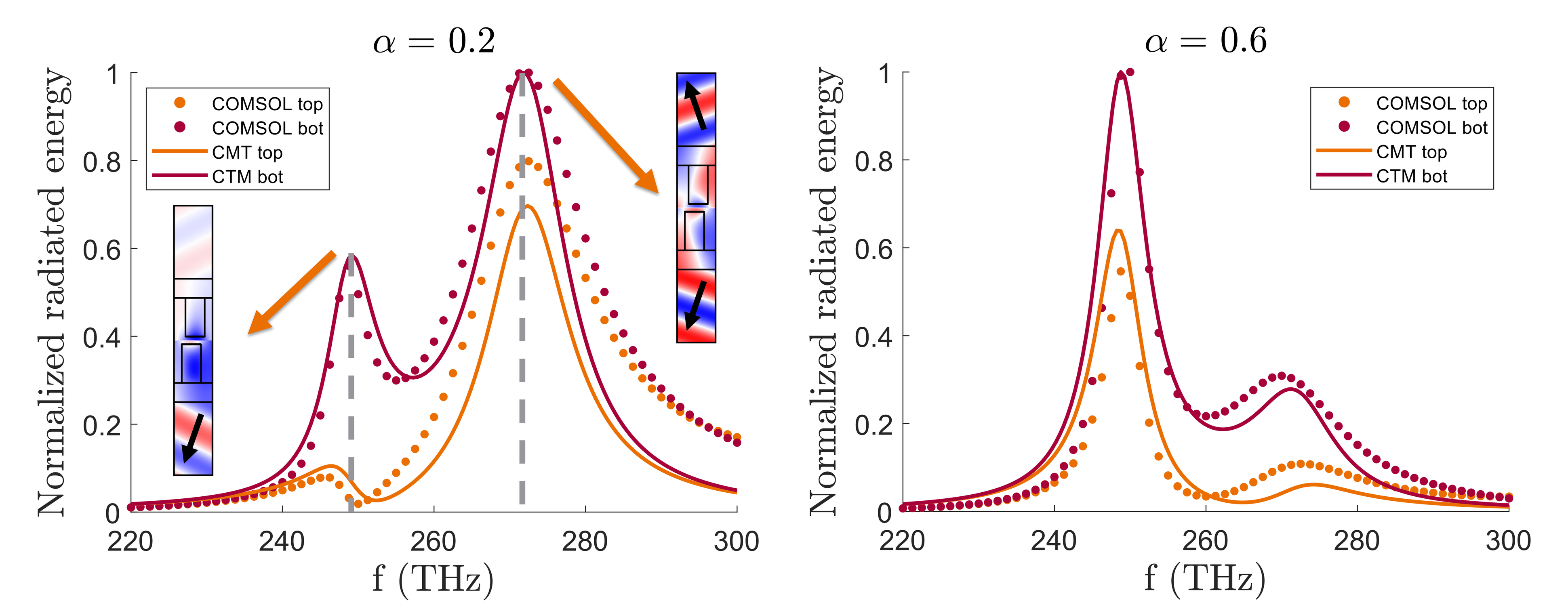
$$\frac{da_u}{dt} = (j\omega_0 - \gamma)a_u + j\kappa a_d + s_u$$

$$\frac{da_d}{dt} = (j\omega_0 - \gamma)a_d + j\kappa a_u + s_d$$

$$a_u = a_{u0}e^{j\omega t} \quad s_u = s_{u0}e^{j\omega t}$$

$$a_d = a_{d0}e^{j\omega t} \quad s_d = s_{d0}e^{j(\omega t + \phi)}$$

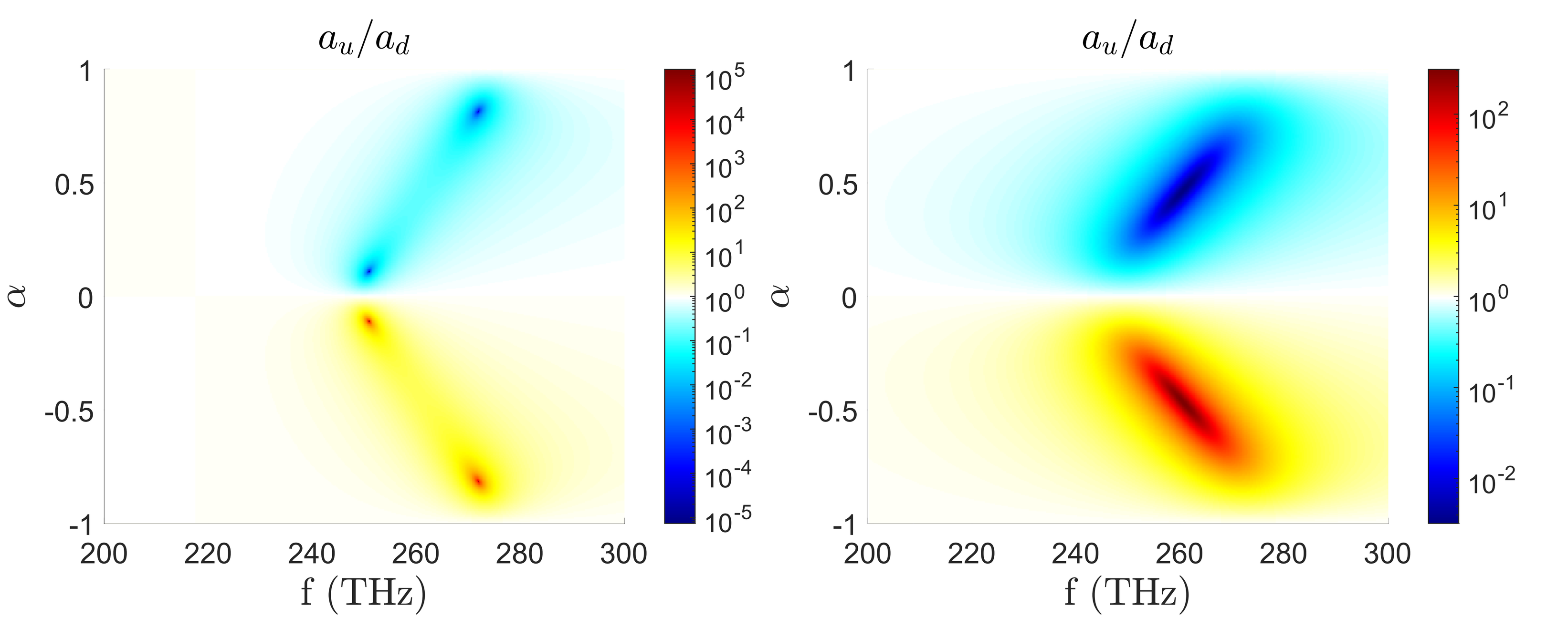
By adjusting the model parameters, we quantitatively reproduce the emission spectra obtained from **COMSOL** simulations.



For **0 < α < 1**, the **top-down symmetry is broken**, resulting in **asymmetric radiation** towards the top and the bottom of the double grating.

Conclusion and perspective

The **CMT** model enables fast exploration of a wide parameter space. For example, by varying the loss rate, we observe a qualitative **regime change** in emission asymmetry.
This framework allows efficient assessment of the impact of geometrical changes on **SPR** behavior.



$\gamma = \gamma_0$ $\qquad$ $\gamma = 2.5\,\gamma_0$

References

References:

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