Design of a directional optical antenna

1 Introduction

The prototypical source of electromagnetic radiation is the electric dipole, featuring a radiation pattern preserving the dipole’s symmetry properties. To control the radiation pattern of a source, engineers have conceived antenna structures. Passive antennas are scattering structures arranged around the active source such that the interference of the radiation from the source and the passive scatterers leads to the desired directionality. One particularly popular directional antenna design is the Yagi-Uda antenna, where the active element is surrounded by (at least) one reflector element on one side and (typically) several directing elements on the opposing side. The design parameters for the antenna are the spacing between the scattering elements and their size, determining their resonance properties, i.e., their spectral response.

The advent of nanofabrication techniques has allowed to transfer the concept of the antenna to the optical domain. At first sight, the scale invariance of Maxwell’s equations only requires scaling down the antenna structure size together with the wavelength. Importantly, however, the material parameters of metals differ strongly between the radio-frequency and the optical domain. The material resonances of metal nanoparticles can be used as a resource to design their resonant scattering properties.

The basic requirement of this project is to understand the scattering properties of nanoparticles in the dipolar approximation. Based upon this understanding, the goal of the project is to design a directional antenna for an optical emitter.

2 Research questions

(a) What is the scattering cross section of a dipolar scatterer? What is the difference between metallic and dielectric scatterers? Use a Drude model to describe the optical properties of the metal [1].

(b) Develop a computer program implementing a coupled-dipole model (including radiation loss) to describe the response of an arbitrary arrangement of dipolar scatterers to an electromagnetic field [2].

(c) Test your code with a dimer antenna driven by a dipole. Show that the antenna has a symmetric and and antisymmetric mode with strongly different radiation loss.

(d) Design a directional antenna composed of dipolar scatterers. You may take inspiration from the Yagi-Uda design [3]. Use a sensible figure of merit for the directionality.

(e) Besides the angular emission pattern of the antenna, consider the LDOS of your structure.

(f) Can you give a limit for the achievable directionality for a given physical size of the antenna structure?

(g) Do you have ideas for actively switchable directional optical antennas using realistic parameters and available fabrication technology?
3 General instructions

For your work and your report, keep the following points in mind:

- Get in touch with your supervisor regularly.

- Write an article demonstrating your understanding of dipolar scattering theory. Focus on presenting your ideas for directional optical antennas based upon your understanding of optical resonances. Your report must not exceed five A4 pages.

- Use the research questions above to inspire your thinking and answer them throughout your work. However, try to keep your document in the form of a research paper presenting your ideas, instead of a lab report answering predefined questions. Put yourself in the situation of a scientist or an engineer trying to convey a new idea to his/her peers.

- Make use of accessible literature and cite correctly.

- When necessary, get in touch with the contact person mentioned above.

References

