Assignment Nanophotonics: Near-field optics

Simulating image formation in a near-field microscope

Note: for this assignment, the review article by Sandoghdar (in particular sections 2-3) can be of assistance, in addition to the class slides.

We will simulate and compare the image formation of a nanoscale object by an aberration-free conventional microscope with the same object imaged using a scanning near-field aperture. The object is a nanostructured plane illuminated with a plane wave under normal incendence (i.e., the field in the object plane has a unique phase). We will describe the field as a scalar quantity.

The electric field distribution in the object plane (z = 0) is contained in the ASCII data file 'object.dat', that can be downloaded from www.erbium.nl/nanophotonics. It is a 512×512 pixel matrix that represents the field in a 5120×5120 nm area. The maximum intensity is 127, the minimum 0. The wavelength of illumination is 600 nm.

Import the matrix in Mathematica (or another program that can perform Fourier transformations and plot images). You can use a Mathematica notebook that already contains some of the steps to answer assignments *a*, *c*, *d*, and *e*. It can be downloaded at www.erbium.nl/nanophotonics. In the rest of the exercise, indicate how you performed the calculations.

a)
Make an image of the electric field *intensity* in the object plane.

The field is described by a matrix a, that has elements a_{pq} that describe the field at and $x = (p-1)\Delta x$ and $y = (q-1)\Delta y$. Δx and Δy are the separations between the points in the x and y direction, respectively. Because the field is known at a discrete set of positions, we can perform a *discrete* two-dimensional Fourier transform of this matrix to obtain the angular spectrum representation of the field. This is the function '**Four[]**' in the Mathematica notebook, defined as

$$\hat{a}_{uv} = \frac{1}{N}\sum_{p=1}^{N}\sum_{q=1}^{N} a_{pq} \exp\left\{-2\pi i\left[\left(u-1-\frac{N}{2}\right)(p-1)+\left(v-1-\frac{N}{2}\right)(q-1)\right]/N\right\}$$

where a_{pq} is element (p,q) of the N×N field matrix a, and $\hat{a}_{uv}$ element (u,v) of the Fourier transformed matrix $\hat{a}$. The discrete inverse Fourier transform is implemented as '**InvFour[]**'.

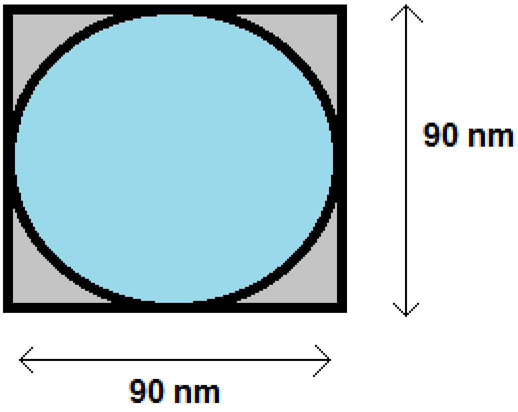
b)
What is the relation between u and v in the discrete Fourier transform defined above and the quantities k_x and k_y in the Fourier transform defined on slide 3 of the class presentation? Which matrix element $\hat{a}_{uv}$ contains the zero-spatial-frequency component of the field?

c)
Calculate the angular spectrum representation of the field in the plane of the object. Use it to simulate the intensity distribution in an image plane, formed by an aberration-free lens

system that collects all propagating angles (i.e., a microscope objective with NA = 1). Plot this image. Explain what you see and how this is caused.

d)
The aperture is scanned at a constant height of *z* = 35 nm. Calculate the field in the plane of the aperture, and plot the field intensity in that plane. Again, explain what you see and how this is caused.

e)
The aperture is a circular hole with a diameter of 90 nm mounted in a square tip also with sides of 90 nm (see image). Simulate the image formed when the aperture scans over the sample in steps of 10 nm. The amount of light scattered by the aperture only depends on the intensity under the aperture, and all of the scattered light is collected at the other side of the screen. Compare with question *c* and *d* and explain the result.



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