COST MP0702 EXERCISE ON METAL-DIELECTRIC LAYERED SUPERLENSES

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OBJECTIVE:

Within the framework of this exercise we plan to develop and benchmark modelling techniques and later to manufacture and characterise a metal-dielectric superlens.

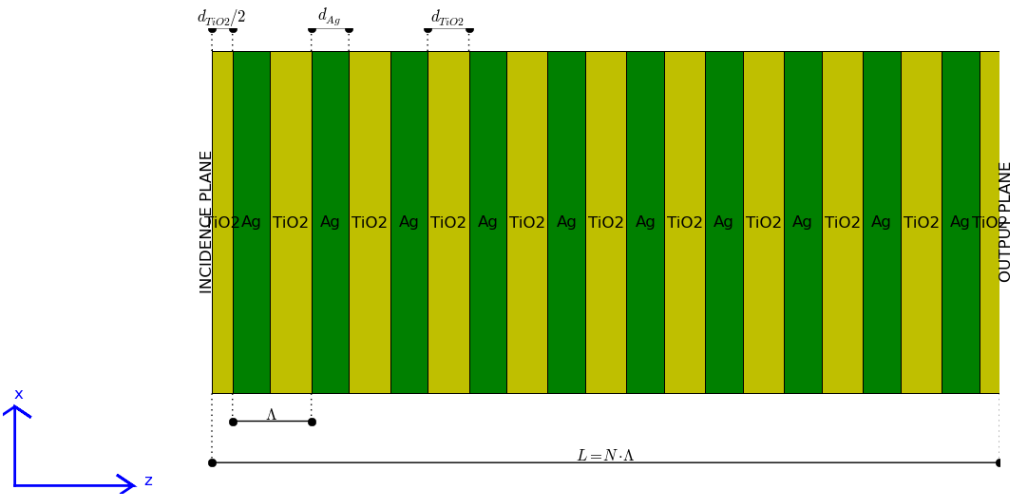
Presently, we propose the modelling part of the exercise. The objective of this part is to involve several numerical methods available among the participants (Transfer/scattering matrix method, method of single expression, FDTD, perhaps FEM or other) and compare the results which they produce for a specific layered structure. Notably, these methods do not assume the same boundary and incidence conditions, therefore we may expect some discrepancies, which will have to be explained and may lead to interesting conclusions. The second objective is to perform a simple tolerance analysis, and to determine which of the parameters involved are the most crucial for the success of the experiment. We plan to conclude this part of the exercise with a publication.

ASSUMPTIONS:

We will focus on a layered, periodic Ag-TiO2 multilayer with infinite and parallel layers (1D periodic stack). We assume that the structure may be modelled in 2D, independently for the TE and TM polarisations. For simplicity, we may initially assume that the multilayer is suspended in air, rather than on a substrate. The substrate, in fact is likely to destroy the super-resolving properties and this problem will have to be tackled somehow in the experimental stage of the exercise.

DEFINITION OF THE STRUCTURE:

The stack consists of N equal periods, each of which is composed of three layers: TiO2-Ag-TiO2.



Therefore subsequent TiO2 layers from neighbouring periods join each other inside the stack and remain thin only at the external layers (for such a composition the transmission is higher than for a simple TiO2-Ag stack of the same thickness).

The stack has been preliminarily optimised for being transparent and diffraction-free, and is described with the following parameters:

$N=1,10,20,30$ -number of periods to be investigated,

$\lambda=441\text{nm}$ - free space wavelength (later to be used in the measurements with SNOM),

$d_{Ag}=20\text{nm}\pm 2\text{nm}$ -thickness of silver layers,

$\frac{d_{TiO_2}}{2}=11\text{nm}\pm 2\text{nm}$ -thickness of external TiO2 layers,

$d_{TiO_2} = 22\text{nm} \pm 2\text{nm}$ - thickness of internal TiO2 layers ,
$n_{TiO_2} = 2.47 \pm 0.02$ - refractive index of amorphous TiO2 [J. Phys. D: Appl. Phys. 41 095307, 2008] – perhaps someone is able to provide other data or information on uncertainty,
$n_{Ag} = (0.04 \pm 0.02) + (2.562 \pm 0.007)\, i$ [Johnson and Chrisity, Phys. Rev B 6, 4370],
$\Lambda = d_{Ag} + d_{TiO_2}$ - period of the stack,
$L = N \cdot \Lambda$ - thickness of the stack (this is also the distance between the input and output plane).

WHAT IS TO BE CALCULATED:
We are interested in the imaging properties of the structure – namely in the imaging from the front-plane to the back-plane of the structure. The imaging properties can be derived from the coherent amplitude **point spread function (PSF)** $PSF_H(x)$ or **transfer function (TF)** $t_H(k_x)$ of the system but other results are also welcome.
The transfer function is defined as the complex amplitude transmission coefficient of a selected field component in the function of the parallel component of the wavevector k_x of an incident propagating or evanescent planewave. For the TM polarisation it is the most convenient to refer to the perpendicular component of the magnetic field H_y (where the simulation takes place in the x-z plane, and the imaging takes place along the z-axis, perpendicular to layer boundaries). Therefore the transfer function is $t_H(k_x) = H_y^{outgoing}(k_x) / H_y^{incident}(k_x)$, where $H_y^{outgoing}(k_x)$ is the field at the output plane and $H_y^{incident}(k_x)$ is the incident part of the field at the input plane. Therefore the ideal condition for perfect imaging would be: $t_H(k_x) \equiv 1$. We note that k_x is conserved throughout all the layers for any incident planewave.
The PSF and TF are interrelated by a Fourier Transform, and at the same time the PSF is the complex amplitude distribution at the output plane $H_y^{outgoing}(x)$ resulting from a delta-like excitation at the front plane $H_y^{incident}(x) = \delta(x)$. The ideal condition for perfect imaging expressed with regard to PSF is: $PSF(x) = \delta(x)$. It is more direct to calculate the PSF with FDTD or FEM, while the TF with the transfer matrix method etc.

We would like to obtain the following numerical results for the TM, and optionally TE, polarisation:

1. the transfer function TF, the point spread function PSF and the measure of resolution (eg. Full Width at Half Maximum of PSF) of the multilayer (with $N = 1, 10, 20, 30$ layers)
2. the uncertainties (errors) of the calculations of TF, PSF and FWHM resulting separately from the uncertainties of the input data.
3. Perhaps if somebody is able to to this: the uncertainties of the calculations resulting from the surface roughness of the layers (this requires a general purpose calculation method such as FDTD, and in principle is not a 2D problem any more).