Optical Characterisation of Nanostructures in Embedded Materials

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Introduction

The purpose of the innovation consortium **FINST** (**http://www.finst.dk**) is to develop measurement techniques for industrial components with surface features on micrometer and nanometer scale. In particular, the consortium aims to

- identify the challenges presented by measurement tolerances on the micrometer and nanometer scale, and
- make publicly available the preferred techniques for meeting these challenges.

The FINST is a cooperation of

DTU Mathematics Department of Mathematics
DTU Fotonik Department of Photonics Engineering
Institut for Fysik og Kemi SYDDANSK UNIVERSITET
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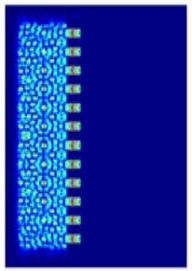
In an industrial context – for example, in mass production and in quality control – it is often needed to be able to (automatically) detect a deviation of a concrete micro or nano structure from a prespecified shape. Hence the relevant question here is:

How to characterise (measure) imperfections in a micro or nano structure?

Step 1: Solution of the direct scattering problem
The direct scattering problem *involving the unperturbed structure* (that is, 'the prespecified shape') is solved. The solution is obtained using, e.g., a finite element method.



Electromagnetic scattering off a grated dielectric.
Solution was computed using COMSOL.

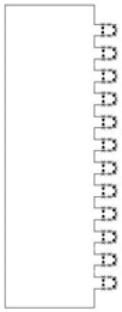
Step 2: Representation of the solution in terms of the Method of Auxiliary Sources (MAS)

The solution (the scattered electric field E^{scat}) is approximated by a finite weighted sum of *fundamental solutions* pertaining to the problem at hand. For two-dimensional time-harmonic, monochromatic electromagnetic scattering, the fundamental solutions are Hankel functions, and the approximation is given by

$$E^{\text{scat}}(x) \approx \sum_{j=1}^{N} A_j H_0^{(1)}(k|x-y_j|)$$

Each term in the sum represents the field radiated by a point source (also called an 'auxiliary source') located at y_j, and of complex magnitude A_j. The auxiliary sources are placed at the 'bright spots' found in the numerical solution from Step 1 (this approach is described in, e.g., Zaridze et al., *The Method of Auxiliary Sources and Scattered Field Singularities*, J. Electromagnetic Waves and Applications, 1998.) To determine the magnitudes A_j, point matching is enforced at M points x_m at the boundary. The resulting (possibly overdetermined) system of linear equations for the A_j is

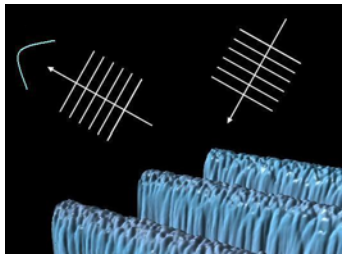
$$\sum_{j=1}^{N} A_j H_0^{(1)}(k|x_m - y_j|) = E^{\text{scat}}(x_m), \qquad m = 1, \ldots, M$$



The number N, the locations y_j and the magnitudes A_j of the auxiliary sources are associated with the prespecified structure and saved in a library. Steps 1 and 2 are repeated for a number of expected, canonical perturbations (imperfections) of the prespecified structure.

Step 3: Optical Diffraction Microscopy (ODM)

The actual sample under investigation is illuminated by, for example, visible light, and the power carried by the scattered field (scattered light) is measured by a photodiode.



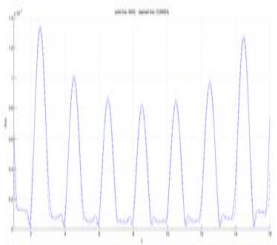
Modified from source: http://www.finst.dk

Step 4: Reconstruction of the measured field using auxiliary sources

The measured scattered field intensity is approximated by a finite weighted sum of fundamental solutions,

$$\left|E^{\text{measured}}(x)\right| \approx \left|\sum_{j=1}^{N} B_j H_0^{(1)}(k|x-w_j|)\right|$$

The locations w_j and the complex magnitudes B_j of the corresponding auxiliary sources are determined using numerical optimisation. The initial guess for the optimisation is provided by the abovementioned library. Finally, the topology of the measured sample is estimated based on the found values (w_j, B_j).



Comparison of the amplitude of the scattered electric near fields obtained by COMSOL and by MAS.