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Scattering by a particle near the waveguide in the dark-field area using the T-matrix method

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An optical detection systems used in a biomarker sensor is a very promising technique, which allows rapid and sensitive detection of molecules in a raw biological sample. Using a non-homogeneous electromagnetic field eq. an evanescent wave excited by a waveguide helps to discriminate biomarker-induced and non-biomarker-induced signals. If the marker is bio-chemically bonded to the waveguide surface inside the penetration depth of the evanescent field of the waveguide, then it is excited and scatters light. Depending on the detection technique, the detector can be located in the dark-field or bright-field area.

To simulate the optical signal in a bio-medical sensor the Null-Field Method with Discrete Sources (NFM-DS) is extended to light scattering by a particle on or near a planar waveguide. The NFM-DS method, also known as the T-matrix method, allows to accurately simulating the light scattering by particles comparable to the wavelength. It presents the electromagnetic fields in terms of the regular and outgoing spherical vector wave functions (SVWF). Nowadays, the T-matrix method is widely used to study the scattering by non-spherical particles, aggregates, different materials and excitations.

Following the original approach, the solution of the scattering problem in terms of the T-matrix for a particle located near the waveguide can be written in the linear form

$$\begin{pmatrix} p_{nm} \\ q_{nm} \end{pmatrix} = \mathrm{T} \cdot \left\{ \begin{pmatrix} a_{nm} \\ b_{nm} \end{pmatrix} + \begin{pmatrix} a^R_{nm} \\ b^R_{nm} \end{pmatrix} + \mathrm{R} \cdot \begin{pmatrix} p_{nm} \\ q_{nm} \end{pmatrix} \right\}, \quad \begin{pmatrix} p^T_{nm} \\ q^T_{nm} \end{pmatrix} = \mathrm{R}' \cdot \begin{pmatrix} p_{nm} \\ q_{nm} \end{pmatrix},$$

where (a_{nm}, b_{nm}), (p_{nm}, q_{nm}) and $\left(p^T_{nm}, q^T_{nm}\right)$ are the expression coefficients of the incident field and the fields scattered in the upper half-space (bright-field area) and in the lower half-space (dark-field area), T is the T-matrix. The R and R' matrices are the reflection and transmission matrices describing the linear transformation of the expansion coefficients by the reflection and transmission through the waveguide. To compute these matrices we represent the scattered outgoing SVWF as an integral over plane waves and applying the Fresnel coefficients to each plane wave. Knowing the expansion coefficients of the scattered electromagnetic wave in the upper (lower) half-space allows computing the bright field (dark field).

The derivation of analytical formulas for the reflection and transmission matrices and several exemplar numerical simulations by the non-spherical magnetic beads will be presented.