

Influence of the Aspect Ratio of Tabular Grains on the Light Scattering

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Abstract

Light scattering calculations are an important tool to optimise the optical behaviour of the complicate layer structure of colour negative (CN) films. The calculation of light scattering properties of spheres is a well-known technique. Such kind of data may be used to calculate with a Monte Carlo procedure the diffusion of light in the photographic layer. Today for modern CN films tabular formed silver halide crystals were used. Therefore an extension of the calculation to other particle shapes was done, using the Multiple Multipol method. It enables good approximate solutions of the Maxwell Equations for more general shapes. The paper presents some results of light scattering calculations for tabular silver halide crystals with different diameters and thicknesses. The consequences regarding the diffusion of light in the photographic layer structure of CN films are discussed.

Introduction

The use of the Monte-Carlo method for light scattering simulation to optimise a complex photographic layer system is an established method. For cubic AgX-crystals in emulsions the Modulate Transfer Function (MTF) and the absorption of single layers were determined.

The light scattering at cubic crystals was approximated by calculations with spheres (Mie-theory [1]). On the other hand the scattering properties of flat crystals like tabular formed grains can not be approximated by this method. Instead of the Mie-theory the use of the Multiple Multipol Method (MMP) makes it possible to calculate the light scattering of particles of any form with a minimum amount of calculation capacity. Nevertheless it is essentially necessary for this method to optimise the mathematical formulation of the scattering problem for a preferred crystal habitus, here tabular grains. In this way the calculation quantities can be reduced for small crystals from some hours to a few minutes and for the big crystals to an amount which is practical with the actual compution capacity.

Method used for the calculation of light scattering

MMP-Method

The MMP-method, described by Hafner [2] and Bomholt [3], is followed by the general GMT technique (Generalised Multipole Technique [4]). The application of the method is limited by the fact, that the area of the scattering process is separated in parts of constant optical behaviour.

The electromagnetic field of the scattering process is divided into three parts, the incident, the induced (the interior field of the scattering particle) and the scattered field. The scattering process is the transition from the interior field to the field of the environment of the scattering particle, which is described by the boundary conditions of the electrical field *E* and the magnetic field *H*. The tangential field components have to be continuous and the normal components are influenced by the properties of the material leading to the following equations:

$$\vec{n}x(\vec{E}_1 - \vec{E}_2) = 0$$
$$\vec{n} \bullet \left((\sigma_1 + i\omega\varepsilon_1)\vec{E}_1 - (\sigma_2 + i\omega\varepsilon_2)\vec{E}_2\right) = 0$$
$$\vec{n}x(\vec{H}_1 - \vec{H}_2) = 0$$
$$\vec{n} \bullet (\mu_1\vec{H}_1 - \mu_2\vec{H}_2) = 0$$

with
n = normal vector
ϖ = circle frequency
σ = conductivity
ε = dielectric constant
μ = permeability constant

The boundary conditions are used for points at the surface of the scattering particle, which are taken to modulate the scattering particle, to get information about the induced and scattered field which are generated by an excitation of an electromagnetic wave like laser light. These points are the so-called Matching-Points.

All fields can be described by functions which have to fulfil the three dimensional Helmholtz equation

$$\left(\vec{\nabla}^2 + k^2\right)\vec{U} = 0 \qquad \text{mit} \quad \vec{U} \in \{\vec{E}, \vec{H}\}$$

Therefore all functions can be expanded to eigenfunctions f_i of the operator:

$$\left(\vec{\nabla}^2 + k^2\right)$$

In general a function U for example expands to eigenfunctions like:

$$U = \sum_{i=0}^{\infty} c_i f_i$$

U is known if the coefficient c_i is calculated.

In this case a spherical coordinate system is used and the eigenfunctions contain spherical Besselfunctions of first order, spherical Hankelfunctions of second order and Legendrefunctions.

Putting the so expanded functions into the boundary conditions, one gets a system of linear equations with the expansion coefficients as unknown quantities. The system has to be over-determined by using more Matching points as necessary for carrying out the boundary conditions. The over determined equation system could be solved with the method of smallest squares

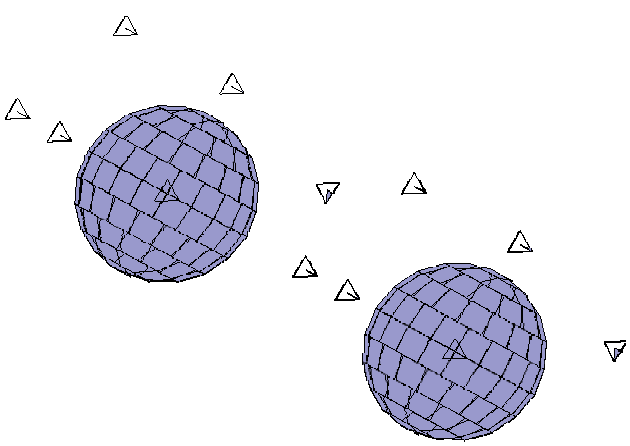

Figure 1: Two particle scattering problem with the matching points (quadratic surface elements) and the multipoles (triangulars)

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The position of the multipoles has to be chosen in respect to the habitus of the surface of the scattering particle to get a well conditioned matrix which follows from the application of the boundary conditions for all surface points. The efficiency of the method depends strongly on the skilful choose of the type and position of the multipoles.

The surface is described by the matching points, which are presented in figure1 as quadratic surface elements. These surface elements which are related to one matching point contact the particle surface tangentially at the place of the matching point. The triangulars present the local co-ordinate system and the position of the multipoles. The multipoles in the interior of the particles are used to calculate the scattered field outside the particle whereas the multipoles in the environment are used to calculate the field in the interior of the particle.

The basis for an optimal choice for the position and the order of the multipoles is followed from the rule given in the literature [5,6].

Calculation of the light scattering in an emulsion layer

In figure 2 the stepwise procedure for the calculation of the light scattering of a photographic layer is presented. The first step is to calculate the scatterindikatrices of the tabular formed crystals with the MMP-method. It is assumed that the crystals are circle plates. The result is the components of the long-distance field amplitude of the electromagnetic field. The calculations will be done for 11 directions of the incident light and for two polarisations. The introduction of the rotation symmetry for the crystals lowered the calculation time significantly. The incident directions are therefore between 0 and 90 degrees in respect to the rotation axis.

The second step is the application of the Monte-Carlo Method. The calculation is done for the 11 incident directions. A typical result is shown in figure 3. The upper part shows the light scattering, the lower part the absorption points, which is the basis for the calculation of the MTF.

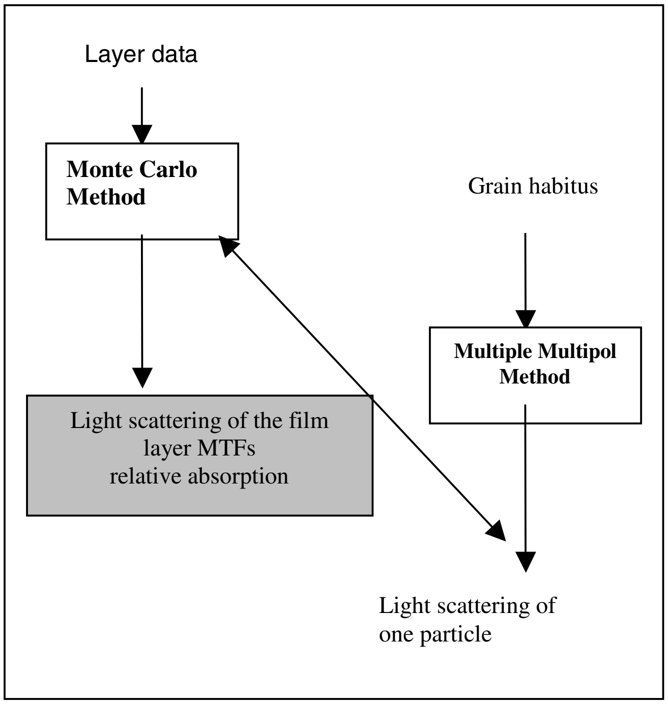


Figure 2: Schematic presentation of the workflow of the calculation of the light scattering of a photographic layer

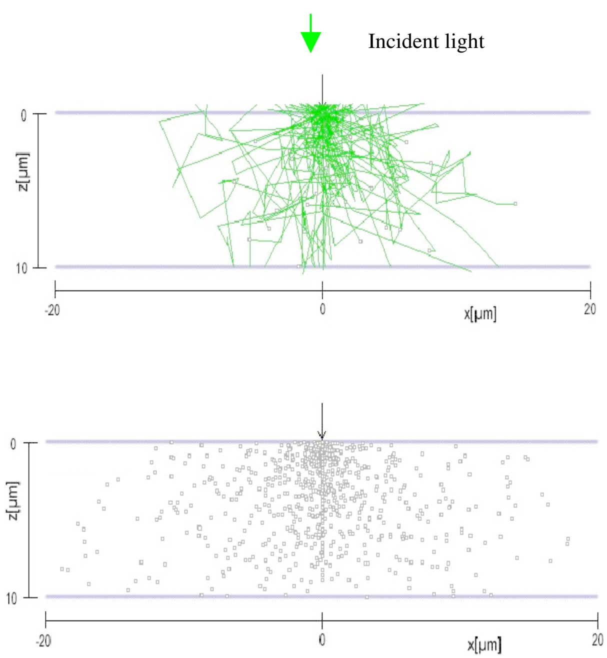


Figure 3: Monte Carlo calculation for a photographic layer. The upper part shows the light scattering, the lower part the absorption points

Results

Optical behaviour of tabular formed crystals

With the MMP method the scattered electromagnetic field of emulsion grains can be calculated. Figure 4 presents a comparison between a cubic-formed crystal and a tabular grain. A significant difference of the scattered field is obvious. Whereas the cubic crystal shows a scattered light field in the whole room around the crystal, the tabular crystal shows a more anisotropic scattered field with a strong back scattering and forward scattering. This principle difference leads to different qualities of photographic layers like absorption and MTF depending on the habitus of the grains, which were used.

Comparison of cubes and tabular grains

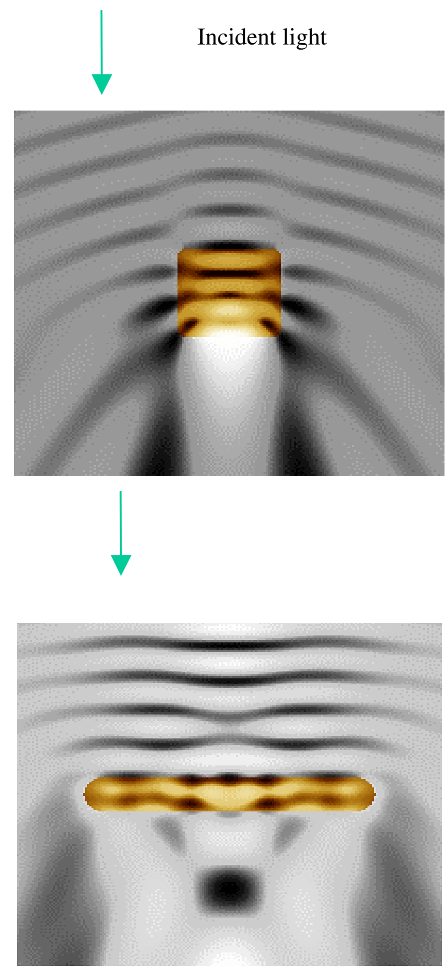
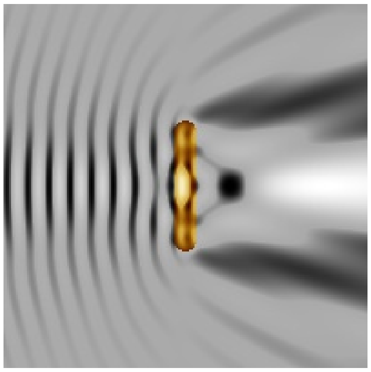


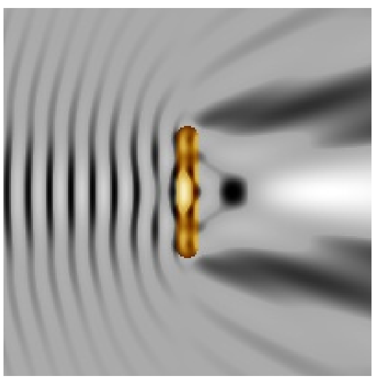
Figure 4: Comparison of cubic and tabularly formed crystals for the scattered electromagnetic field. The grey steps give the information about amplitude of the field (dark=small amplitude).

Comparison of different tabular grains

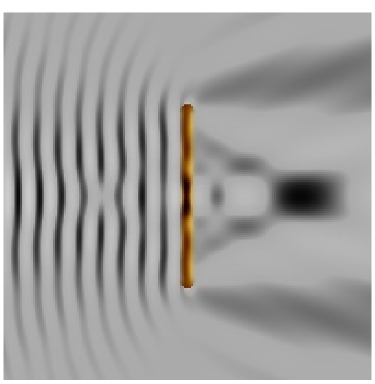
AR 6,2
Thickness 0,18



AR 10,3
Thickness 0,13



AR 18
Thickness 0,089



Volume = 0,18 µm

Figure 5: Light scattering dependency on the aspect ratio (AR) of tabular grains. The incident light comes from the left side.

In figure 5 the influence of the aspect ratio (AR) of the tabular grains on the scattered field is presented. The principle tendency is that with increasing aspect ratio the anisotropic light scattering increases. In some special cases, in figure 5 for the aspect ratio of 10, there is a decrease of the anisotropic scattering.

The optical behaviour of different grain types in a photographic layer can be calculated using the Monte-Carlo Method. The calculations were done for a layer thickness of 5 µm and an Ag coating weight of 2g/qm. Figure 6 shows the calculated optical behaviour depending on the aspect ratio.

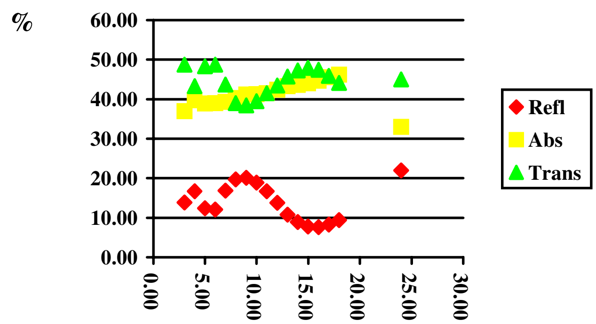


Figure 6: Absorption, transmission and reflection depending on the aspect ratio of tabular grains for a photographic layer with a thickness of 5 µm and a Ag coating weight of 2 g/qm. The wavelength of the incident light is 450 nm

Aspect Ratio

From the graph it can be seen, that the optical behaviour of tabular grains does not change linearly with the aspect ratio. This behaviour has to be taken into account for an optimisation of a complicate photographic layer structure like CN films.

More details of the dependence of aspect ratio, layer thickness and silver coating weight on the absorption and MTF will be given.

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