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Model examination of the reflex-halation in single-layer light-sensitive system

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The results of computer simulation of the effects of light scattering in a system composed of single silver halide light-sensitive layer coated on a transparent base are presented. The scattered light penetrating the base film can suffer from internal reflection from its lower surface and thus contributes to some loss of image sharpness. This effect, called reflex-halation, is very disadvantageous. The qualitative dependence of the MTF curve of the system on its geometric and optical parameters is examined. It has been shown, among others, that the deterioration of image quality is the stronger the thinner the light-sensitive layer is and the more elongated the elementary scatteing indicatrix of silver halide crystals is. The result is similar to that obtained in the case of crossover effect, though in the presence of the antihalation layer the observed dependences are opposite to those just mentioned.

1. Introduction

The minimization of signal attenuation occurring in the optical recording process is of some significance. Therefore, when designing the light-sensitive silver halide materials it is essential that their structurometric properties be optimized while retaining their given sensitometric properties. The attenuation of the recorded signal is caused, above all, by the scattering of the actinic radiation while passing through the light-sensitive layer of heterogeneous structure. The crystals of silver halide applied in such materials range from 0.05 to 2 μm in diameters. These magnitudes are comparable with the wavelength of the actinic radiation and therefore, both intensity and character of scattering depend strongly on the crystal sizes. The directional intensity characteristic of radiation scattered by single crystals is called the elementary scattering indicatrix. Very small crystals have symmetric characteristics, however, the greater the crystal, the more elongated the indicatrix in the propagation direction of radiation incident on the crystal.

The light beam concentrated at a light point while entering the inside of a heterogeneous layer suffers from scattering and therefore the recorded image will have a component in the form of a blurred spot. This effect is called diffuse-halation and the blurred spot is called diffusion halo. If the light-sensitive layer is coated on a transparent base, the rays of the scattered light reaching the lower surface of the base at an angle greater than critical one are totally reflected. The reflected rays return to the light-sensitive layer at some distance from the light point creating a reflection halo ring in the image. This effect is called by reflex-halation [1]. The principle of creation of these effects is illustrated in Fig. 1, while Fig. 2 shows a distribution of the light absorbed in the heterogeneous layer obtained in one of the computer simulations. Application of antihalation (AH) layers appears to be an efficient method of preventing light-sensitive system from the reflex-halation.

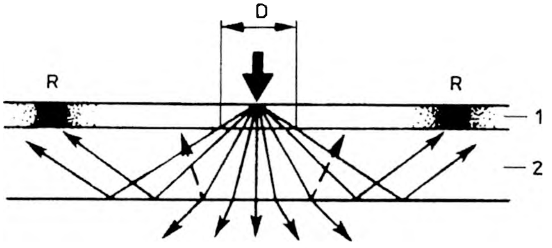


Fig. 1. Principle of creation of both the diffus-halation D and reflex-halation R effects in the light-sensitive system composed of a heterogeneous layer (1) and transparent base (2). In order to simplify the interpretation of the effect the scale is not preserved in the picture.

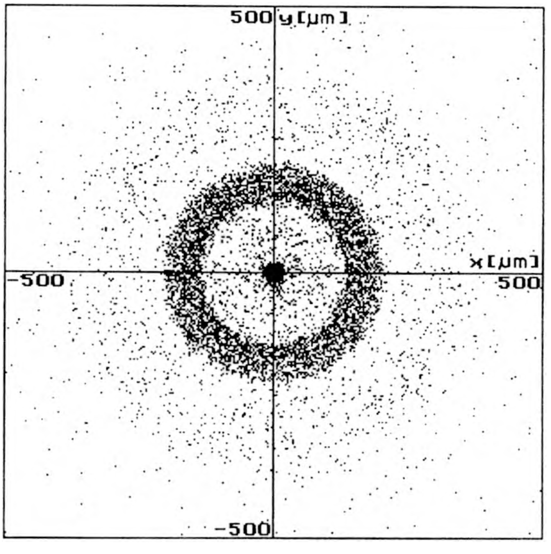


Fig. 2. Distribution of the light absorbed in the heterogeneous layer obtained in one of the computer simulations as a result of point irradiation of the model light-sensitive system. Black dots represent places in which photon absorption by the silver halide crystal occurred.

The quality of image can be characterized by optical modulation transfer function (MTF). The domain of this function is spatial frequency expressed by a number of cycles (pairs of bright and dark lines) occurring along a unit distance in the recorded image. The MTF expresses frequency dependence of the ratio of modulation of the recorded signal to modulation of the original signal [2]. The high spatial frequencies correspond to the fine details as well as the edges, hence the course of MTF of a light-sensitive material makes it possible to estimate its capability of sharp imaging of details in the image. The MTF is strictly connected by suitable transforms with both the point spread function (PSF) and the line spread function (LSF), which describe exposure distribution in the image of point and line.

The purpose of the simulation examinations was to analyze the influence of the selected physical parameters of a single layer light-sensitive system on the MTF course caused by scattering and internal reflection of actinic light.

2. Characteristics of the model

The models based on the Monte Carlo method used to examine the scattering effect inside the photographic layers have been known for many years and their descriptions and results obtained are given, *e.g.*, in works [3]–[13]. In this work, some modification of the stochastic model applied earlier [9]–[13] is proposed based on the following assumptions:

– photons penetrate into the layer at one point, in the direction perpendicular to the layer surface,

– refractive index of the base and of the photographic gelatine are the same,

– refraction and internal reflection of light from the layer uppersurface and the base lower surface are subject to the laws of geometric optics, the critical angle being $41° 8'$,

– if the antihalation layer is applied in the system no internal reflection from the lower surface of the base occurs,

– probability distribution of a photon travelling along a given free path between the consecutive collisions with the silver halide crystals is described by an exponential function the parameter of which is the average free path l of the photon; a standard value of $l = 1.0$ μm has been assumed,

– standard value of the photon absorption probability during collision with the silver halide crystal is $p = 0.05$,

– indicatrix of radiation scattering by single silver halide crystals is of ellipsoidal shape, the focus of the ellipsoid is located in the middle of the crystal and the elongation of the indicatrix is expressed numerically by averaged cosine of the scattering angle c; standard value being $c = 0.55$,

– standard value of the light-sensitive layer thickness $h = 5$ μm,

– standard thickness of the base $h_B = 175$ μm.

3. Results

After elaborating appropriate computer program five series of simulation experiments were performed in which one of the physical parameters of the system was variable while the other four were of their standard values. For the sake of

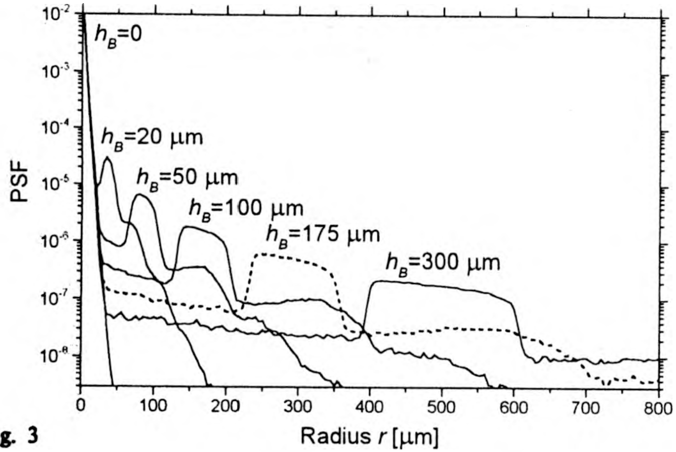


Fig. 3

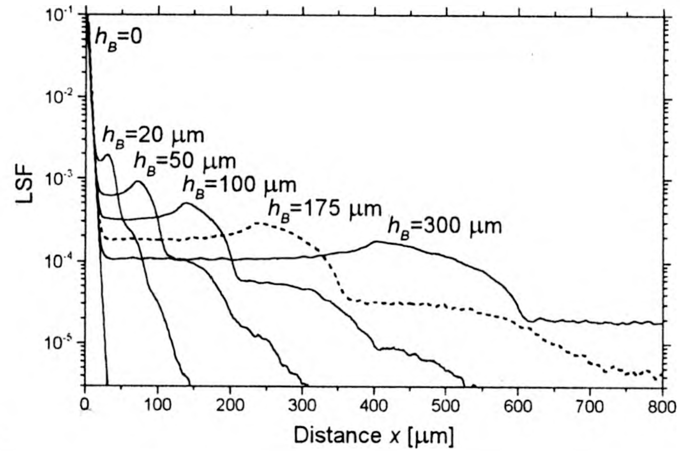


Fig. 4

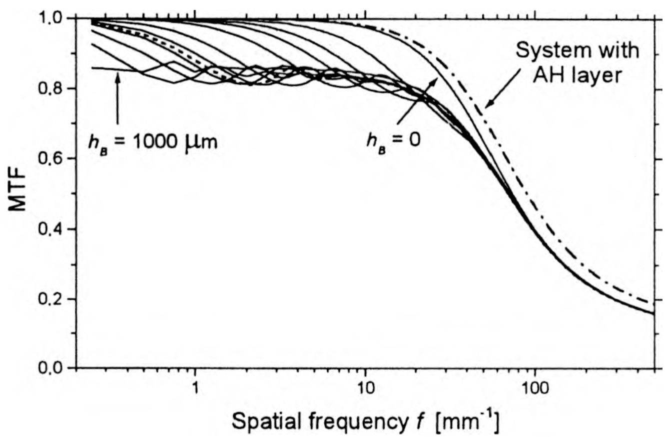
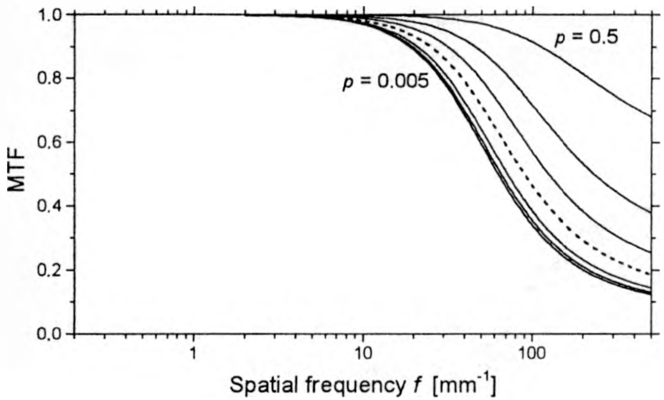


Fig. 3. The PSF of the system without AH layer varying base thickness, h_B = 0, 20, 50, 100, 175 and 300 μm.

Fig. 4. The LSF of the system without AH layer for varying base thickness, h_p = 0, 20, 50, 100, 175 and 300 μm.

Fig. 5. The MTF of the light-sensitive system without AH layer for varying base thickness, h_B = 0, 20, 30, 50, 100, 150, 175, 200, 300, 500 and 1000 μm. Additionally, the MTF for the sysetm with antihalation layer is plotted (then base thickness is inessential).

◄ Fig. 5.



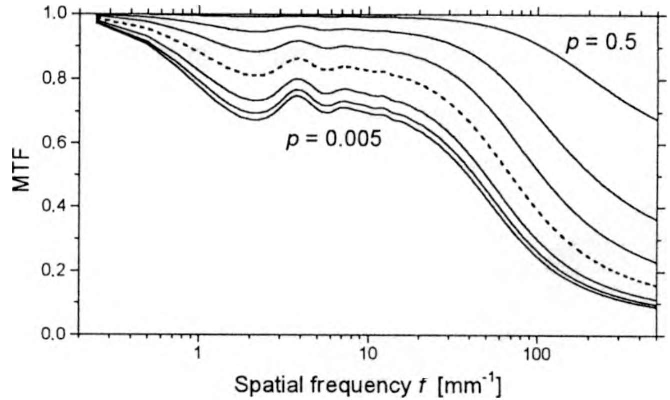
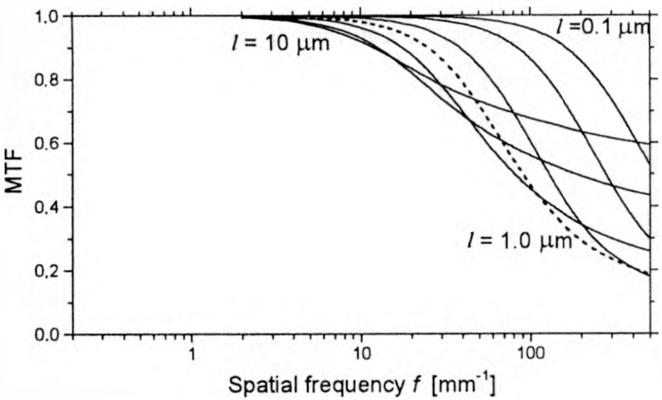


Fig. 6. The MTF of the light-sensitive system with AH layer for variable photon absorption probability, $p = 0.005$, 0.01, 0.02, 0.05, 0.1, 0.2 and 0.5.
Fig. 7. The MTF of the light-sensitive system without AH layer for variable photon absorption probability, $p = 0.005$, 0.01, 0.02, 0.05, 0.1, 0.2 and 0.5.



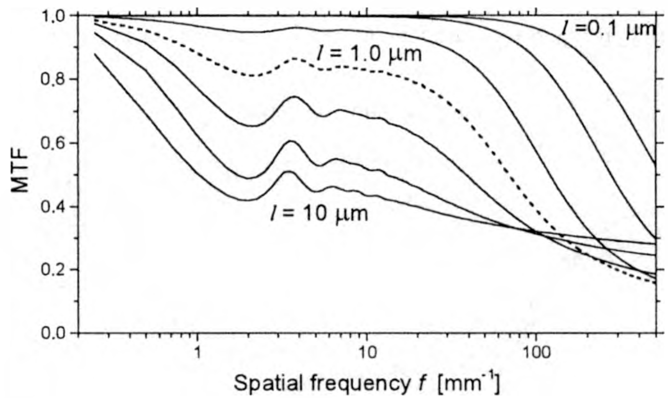
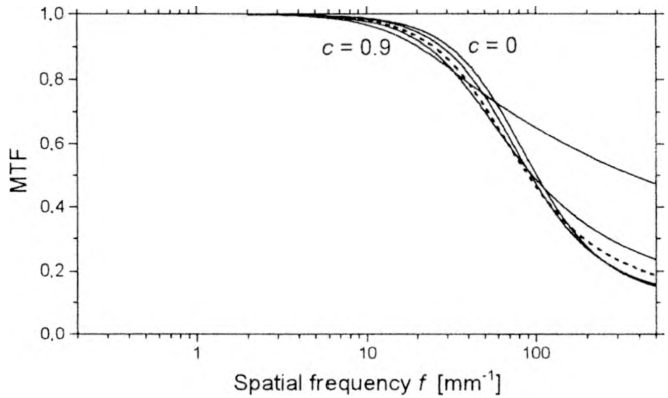


Fig. 8. The MTF of the light-sensitive system with AH layer for variable average free paths of the photon, $l = 0.1$, 0.2, 0.5, 1, 2, 5 and 10 μm.
Fig. 9. The MTF of the light-sensitive system without AH layer for variable average free paths of the photon, $l = 0.1$, 0.2, 0.5, 1, 2, 5 and 10 μm.



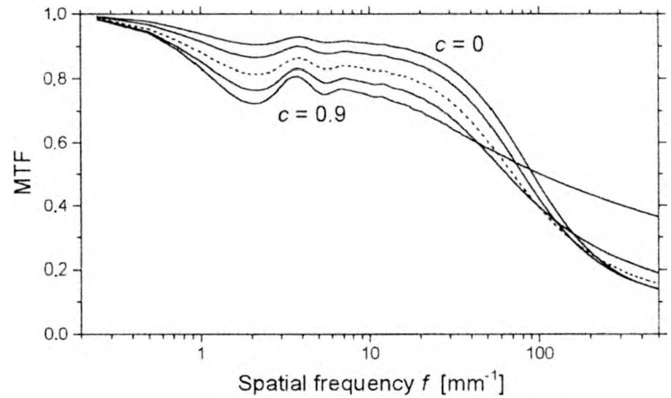


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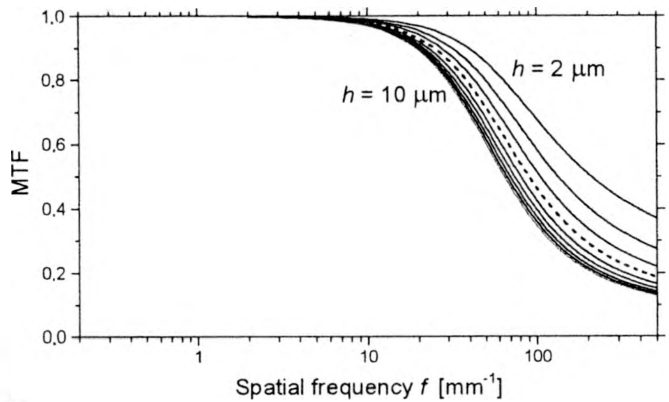
Fig. 10. The MTF of the light-sensitive system with AH layer for variable elongation of elementary scattering indicatrix $c = 0$, 0.3, 0.55, 0.7 and 0.9.

Fig. 11. The MTF of the light-sensitive system without AH layer for variable elongation of elementary scattering indicatrix $c = 0$, 0.3, 0.55, 0.7 and 0.9.



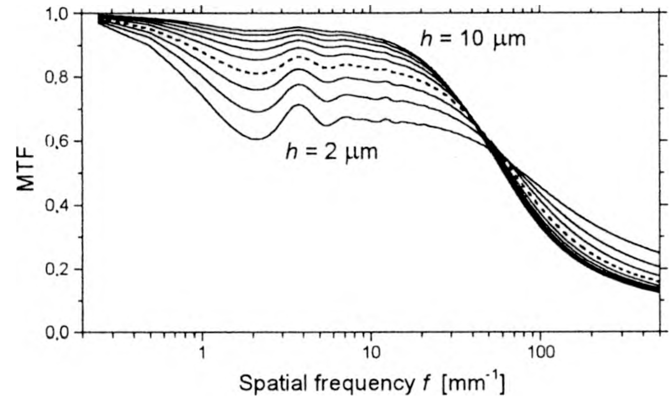


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Fig. 12. The MTF of the light-sensitive system with AH layer for variable thickness of silver halide layer $h = 2$, 3, 4, 5, 6, 7, 8, 9 10 µm.

Fig. 13. The MTF of the light-sensitive system without AH layer for variable thickness of silver halide layer $h = 2$, 3, 4, 5, 6, 7, 8, 9, 10 µm.

comparison four series of simulations were carried out, assuming that a perfect antihalation layer was applied in the model system. The relations derived are presented in Figs. 3–13, where the broken line marks the curve obtained for the system characterized by standard parameters. In Figures 3 and 4, relevant functions PSF and LSF of the system are illustrated for chosen values h_B. In Figure 5, changes of MTF are shown for systems without AH layer and with AH layer for varying value of h_B. In Figures 6, 8, 10 and 12 changes in MTF are shown for a system with AH layer and other parameters changing, while in Figs. 7, 9, 11 and 13, chages in MTF for a system without AH layer are illustrated.

4. Discussion and conclusions

The results of the computer simulation showed that all of the optical and geometrical parameters of the light-sensitive systems under examination influence essentially the curse of its modulation transfer function. In the presence of the antihalation layer only the diffusion halo occurs. Then, irrespective of the base thickness, only high spatial frequencies are attenuated in the signal. When also the reflection halo occurs, then with increasing thickness of the base, increasing attenuation occurs for signals of not only higher but also lower spatial frequencies ranging from 0.01 to 10 mm^{-1}. This is manifested by increasing deformation of the MTF curve (Fig. 5). There also appear maxima in the PSF and LSF (Figs. 3 and 4) connected with the halo ring the diameter of which depends on the base thickness.

The decrease of the photon absorption probability results in disadvantageous changes in the MTF course, such as attenuation of the high spatial frequencies, and if there is no AH layer the low spatial frequencies are also attenuated (Figs. 6 and 7). On the other hand, an increase of the average free path of photons in the absence of the reflection halo produces a twofold effect: initial increase of the attenuation of high and medium spatial frequencies and subsequent decrease of the attenuation of high spatial frequencies and stabilization in the remaining range of frequencies (Fig. 8). The lack of antihalation layer makes the situation considerably worse by strongly increasing the attenuation of low and medium frequencies (Fig. 9).

When only diffuse-halation occurs the loss of image quality is the stronger the thicker the respective light-sensitive layer, especially within the range of high spatial frequencies (Fig. 12). When also the reflex-halation appears, then with an increasing layer thickness the attenuation diminishes considerably in the lower spatial frequencies within the range of about 30 mm^{-1} (Fig. 13). This effect comes from considerable attenuation of scattered light in thick layer.

Striking thing is that, together with an increase of elementary scattering indicatrix elongation, in addition to decreasing attenuation of high spatial frequencies, the attenuation of lower frequencies increases (Fig. 10). This effect can be observed even in the absence of the reflex-halation (Fig. 11).

In the investigation, it has not been examined how the actinic light absorption inside the layer depends on its physical and optical parameters. Such dependences, however, have been observed and we intend to examine them more carefully since these may have influence on the sensitometric properties of the system, for instance, photosensitivity and contrast. The model elaborated can find an application in designing and optimizing the features of the silver halide materials for image information recording.

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