The Mechanism of Latent Image Formation by Ionizing Radiations in Silver Halide Emulsion

Mikio Ihama
Fuji Photo Film Co.
Minamiashigara-shi, Kanagawa / Japan

Abstract

It is reported that natural background radiation and X-ray radiation for the baggage check in an airport affect the photographic properties of silver halide imaging materials. Since the mechanism of latent image formation for these ionizing radiations has not yet been established precisely, it was investigated here for ^{60}Co-γ ray and 80kVp X-ray with octahedral AgBr emulsions. As a result, the sensitivities to these ionizing radiations could be quantitatively predicted from their characteristic curves for visible-light.

Introduction

The damage of silver halide imaging materials caused by natural background radiation is a crucial problem for achieving the materials with enhanced speed[1]. X-ray radiation used for the baggage check in an airport also affects the photographic properties of the materials with usual speed. These ionizing radiations increase fog and deteriorate granularity of color negative films. The influence of the ionizing radiation on the granularity of color negative films was investigated thoroughly and the new mechanism for the granularity deterioration was proposed[2].

However, the detailed mechanism of latent image formation by these ionizing radiations has not yet been established precisely. The purpose of this study is to understand the mechanism of latent image formation by the ionizing radiations on the basis of that by visible-light, and to attain the countermeasure in the near future.

Experiments

Mono-dispersed octahedral AgBr emulsion grains with equivalent spherical diameter of 0.4, 0.6 and 0.8 μm were prepared by a conventional method and used in this experiment. Sulfur sensitization was carried out by the digestion of the above-stated emulsions at 55℃ in the presence of proper amount of sodium thiosulfate. Sulfur-plus-gold sensitization was carried out similarly except the presence of proper amount of chloroauric acid in addition to that of thiosulfate. These unsensitized, sulfur-sensitized and sulfur-plus-gold-sensitized emulsions were coated with coupler dispersion and coating aid on the TAC base at AgBr of 2.4g/m^2 and gelatin of 6.0g/m^2. The mole ratio of AgBr to coupler was 6.6 by use of a pyrazoron 4-equivalent magenta coupler.

Exposure of a sample to visible-light was carried out through a BPN-42 filter (i.e., blue light exposure) and a continuous wedge. High energy irradiation was performed for 30 minutes by using ^{60}Co-γ ray. Low energy irradiation was performed for 1 second by using 80kVp X-ray. The amount of irradiation was varied by changing the distance between a coated sample and an irradiation source. Samples were developed in CN-16 color developer for 2'45" at 38℃, bleached, and fixed according to a conventional way. The obtained magenta density was measured and used for representing density-irradiation characteristics.

Results and discussions

The characteristic curves of the emulsions in this study for visible-light indicated, as usual, that the speed increased with increasing the grain size, and that the sensitizing effect was larger for sulfur-plus-gold sensitization than for sulfur sensitization.

The plot of density against the amount of irradiation of a sample to ^{60}Co-γ ray or 80kVp X-ray gave a straight line, suggesting that the hit of a single electron on a grain could render the grain developable. The speed for these ionizing radiations was obtained from the slope of the straight line. The relations between the speed and the grain size were summarized for unsensitized, sulfur-sensitized and sulfur-plus-gold-sensitized emulsions. Figure 1 shows the result for 80kVp X-ray irradiation. The speed increased with increasing the grain size. However, the sensitizing effect of chemical sensitization was different among the grains with different size. In the case of a grain with 0.8 μm equivalent spherical diameter, chemical sensitization hardly affected the speed. The result for ^{60}Co-γ ray irradiation was different from that for X-ray irradiation. These results have to be interpreted quantitatively on the basis of the mechanism of latent image formation by visible-light.

The latent image formation by ionizing radiations in a silver halide emulsion occurs by the hit of a secondary electron on a grain, while the secondary electron is generated from the absorption of ionizing radiations by the emulsion. By using the velocity of an electron in air, the time that is necessary for an electron to pass through a silver halide grain is estimated to be in the order of 10^{-14} second. It is therefore considered that the hit of a secondary electron on a grain corresponds to high intensity exposure. The reciprocity law characteristics of the sulfur-sensitized emulsion revealed that the characteristic curve for 10^{-5} second exposure agreed with that for 10^{-6} second exposure in spite of the appearance of severe high-intensity reciprocity law failure. This means that the bend-over of high intensity reciprocity law failure occurs at 10^{-5} second exposure[3]. It was concluded that the characteristic curve for 10^{-14} second exposure would be the same as that for 10^{-5} second exposure.

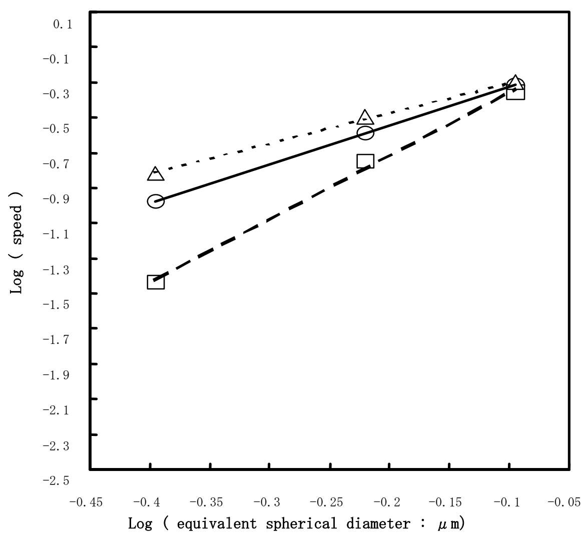

Figure 1. The relationship between the speed for 80kVp X-ray irradiation and the grain size of octahedral AgBr emulsion. Circle : Unsensitized emulsion, Square : Sulfur-sensitized emulsion, Triangle : Sulfur-plus-gold-sensitized emulsion.

The reciprocal of the exposure giving the density of 0.5 above fog was defined as the speed for 10^{-5} second exposure and the relation between the speed and the grain size was summarized for unsensitized, sulfur-sensitized and sulfur-plus-gold-sensitized emulsions. However, the result of the relation between the speed and the grain size for high intensity exposure agreed neither with the result for 80kVp X-ray irradiation nor with that for ^{60}Co-γ ray irradiation. The behavior of the emulsions for ionizing radiations could not be simply explained by their behavior for high intensity visible-light exposure.

The characteristic curve for visible-light means that the number of average absorbed photons per grain increases, the number of the grains with latent image centers increases, and consequently the density increases with increasing the exposure. In the case of ionizing radiations, the number of secondary electrons increases, the number of grains on which the secondary electrons hit increases, and consequently the density increases with increasing the amount of the irradiation. The number of electron/hole pairs generated by the hit of a secondary electron on a silver halide grain could be evaluated as (the linear collision stopping power of an electron in silver halide) × （the pass length of an electron） / （the energy loss of an electron per a generated electron/hole pair）. The linear collision stopping power of an electron in silver halide was determined from the energy of the secondary electron. The pass length of an electron was postulated as an equivalent spherical diameter of the silver halide grain. The value of 5.8eV was used as the energy loss of a secondary electron per generated electron/hole pair in silver bromide[4]. The energies of a Compton secondary electron generated by the irradiation of ^{60}Co- γ ray and a secondary electron generated by the photoelectric effect of 80 kVp X-ray irradiation were postulated as 1MeV and 30keV, respectively. The linear collision stopping powers for a 1MeV electron and for a 30keV electron in silver bromide are 0.77keV/μ and 3.5keV/μ, respectively. Under these assumptions, the number of electron/hole pairs generated by the irradiation of ^{60}Co-γ ray in a 0.4, 0.6 and 0.8 μm grains were evaluated as 50, 80 and 100 pairs, respectively, while the number of electron/hole pairs generated by the irradiation of 80kVp X-ray in a 0.4, 0.6 and 0.8 μm grains were evaluated as 250, 350 and 500 pairs, respectively.

The probability of latent image formation for the exposure that corresponds to the above-stated number of electron/hole pairs can be obtained from the characteristic curve for 10^{-5} second exposure. That is 〔（the density at the exposure corresponding to the generated electron/hole pairs）－（fog density）〕／〔（maximum density）－（fog density）〕. The noticeably deviation of the ionizing radiation speed of the unsensitized and sulfur-sensitized emulsions from that of the sulfur-plus-gold-sensitized one, as shown in Figure 1, was then predicted and explained on the basis of the above-stated probability of latent image formation. Figure 2 shows the predicted relation between the speed and the grain size for 80kVp X-ray irradiation. From the comparison with the result shown in figure 1, it was found that the effect of chemical sensitizations on the grains with different size could be predicted quantitatively. The relation between the speed and the grain size for ^{60}Co-γ ray irradiation could be also predicted quantitatively.

Conclusion

The speed for ionizing radiations could be quantitatively predicted from the characteristic curve for visible-light under simple assumptions. This means that the mechanism of latent image formation by ionizing radiations is the same as the mechanism that occurs by the absorption of the corresponding number of photons by a grain for 10^{-5} second in visible light region. It is however noted that, not the number of generated electron/hole pairs in a grain, but the number of the grains on which secondary electrons hit change with increasing amount of irradiation on the contrary the case of visible-light exposure.

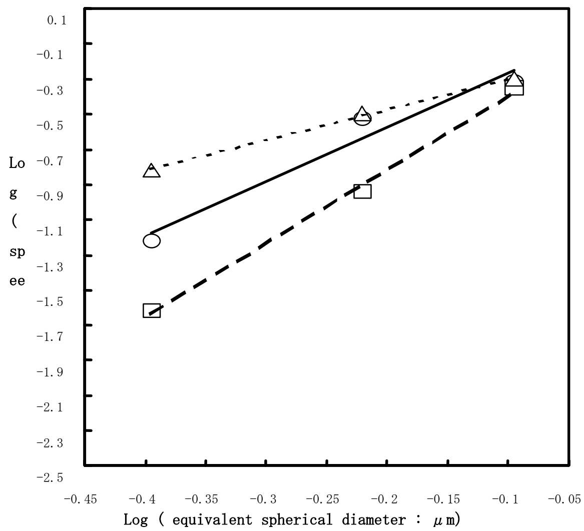

Figure 2. The relationship between the predicted speed for 80kVp X-ray irradiation and the grain size of octahedral AgBr emulsion. Circle : Unsensitized emulsion, Square : Sulfur-sensitized emulsion, Triangle : Sulfur-plus-gold-sensitized emulsion.

References

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Biography

Mikio Ihama received his B.S. degree in Engineering from Osaka University in 1980 and a M.S. degree in Chemistry from Osaka University in 1982. Since 1982 he has worked in the Research Laboratories of Fuji Photo Film Co., Ltd. in Minamiashigara, Kanagawa. His specialty has primarily been focused on silver halide emulsion technology, including precipitation of silver halide grains, chemical sensitization and spectral sensitization. He is a member of SPSTJ.