AgX Image Capture

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Abstract

The characteristics of color films were analyzed from various viewpoints including their structure, efficiency of image formation, and system and compared with digital still cameras for amateur consumers. The analysis indicates that the sensitivity and image quality of color films are based on the efficiencies of absorption and conversion of photons into latent image centers on silver halide grains, and have room for improvement by several times in the future.

Introduction

The present status and future prospect of silver halide photography and electronic photography attract keen interests of imaging scientists and engineers.[1-8] The present author have been involved in the studies of the mechanism of photographic sensitivity for many years[8] and have found that the capability and future trend of silver halide photographic materials mostly depend upon their structure, mechanism, and efficiency.

Various kinds of digital still cameras have been produced recently, not only for amateur photography but also for office and professional uses. It is now possible to take pictures with high quality by use of digital still cameras. Those cameras are however too expensive for amateur consumers to purchase, while they could be acceptable to office and professional uses. It is therefore considered that the analysis from general aspect is confusing. This paper is thus focused on the analysis of color films as compared with digital still cameras for amateur consumers.

Structure of Color Films and Image Quality

A color film is composed of multilayers of photographic emulsions, which are suspensions of silver halide grains in gelatin or in its aqueous solution. In the multilayers, there are three major emulsion layers, which are sensitive to blue, green, and red lights. In each major layer, there are three sub-layers, sensitivities of which are high, medium, and low. The multi-layer structure of photographic emulsions with different functions make it possible for a color film with small frame area to capture a large amount of image information with full colors and large dynamic range.

The image quality depends upon the number of picture elements (pixels) per frame, and is thus proportional to frame area. There is not any essential problem to produce color films with large frame area, since the production yield of color films is high and nearly independent of their frame area. This comes from the fact that the function of a pixel in a color film is given by the integration of the functions of several hundreds of randomly arrayed silver halide grains, which respond independently to incident photons.[8] Namely, it is thought that the probability of the deterioration of a function of a pixel by dust particles and/or deficient silver halide grains is very small and independent of frame area.

Role of Latent Image Centers and Photographic Sensitivity

Silver halide grains absorb incident blue light to form latent image centers on their surfaces in blue-sensitive layers. In stead of silver halide grains with ability to absorb neither green light nor red light, sensitizing dyes on the grains in a green-sensitive layer and those on the grains in a red-sensitive layer absorb incident green and red lights, respectively, to form latent image centers on their surfaces. Only the silver halide grains with latent image centers on their surfaces are reduced to give silver grains during development process.

In a cubic silver bromide grain with edge length of 1 mμ, there are 2×10^{10} silver ions and bromide ions at lattice sites, while several hundreds or several thousands of silver ions are located at its interstitial positions, and mobile within a grain.[8] On a grain, there are many sensitization centers, which provide suitable sites for the formation of a latent image center by capturing photoelectrons. It has been proposed that a sensitization center on a highly sensitive emulsion grain is a dimer of substitutional sulfide ions associated with an interstitial silver ion and gold ion.[9,10]

A free electron, which is given by the light absorption of a grain or a sensitizing dye molecule, is captured by one of sensitization centers. This is called an electronic process. Then, a captured electron attracts an interstitial ion and combines with it to form a silver or gold atom. This is called an ionic process. The repetition of an electronic process and an ionic process at the same place gives a cluster of silver and gold atoms. It is known that the smallest latent image center is composed of three atoms of silver and gold, and that at least three free electrons are needed for the formation of a latent image center.

A latent image center is a deep electron trap, and captures an electron from a developer. The captured electron attracts an interstitial silver ion and combines with it to add a silver atom to the latent image center. Thus, a latent image center initiates the reduction of a silver bromide grain to a silver grain by a developer. A developer reduces a silver bromide grain with a latent image center on its surface, while it can not reduce a grain without a latent image center.

A latent image center with three atoms of silver and gold initiates the reduction of 2×10^{10} silver ions, giving the amplification of 6.7×10^{9} times. This amplification process should be one of the most important reasons for the achievement of color films with such high sensitivity and image quality.

According to the above-stated processes, photographic sensitivity depends upon (a) light absorbance of each emulsion grain, (b) quantum yield of the formation of a latent image center, and (c) size of the smallest latent image center.[8,11]

In 1985, the present author analyzed and predicted the possibility for the increase in sensitivity of color films in the future.[11] The factor (a) was analyzed in terms of the light absorbance of an emulsion layer in a high-sensitive negative film, which was reported by Bird and coworkers in 1969.[12] According to their measurement, only one third of the incident light was captured by the emulsion layer. It was therefore predicted that the sensitivity increase by about three times would be given by the improvement of the light absorbance of an emulsion layer.

Since the smallest latent image center is composed of three atoms of silver and gold in sulfur-plus- gold-sensitized emulsions,[13] at least three free electrons are needed for the formation of a latent image center on a grain. It is known that, according to the Lowe's mechanism,[14,16] one absorbed photon can creates two free electrons in the presence of reduction sensitization centers (i.e., R centers).[8 16] It is therefore considered that at least two absorbed photons are needed to form a latent image center.

Quantum sensitivity is defined as the number of absorbed photons per grain which is needed to render half of the existing grains developable and used as the measure of the efficiency of the formation of a latent image center on the grain. In 1985, the quantum sensitivity of about ten absorbed photons per grain were reported for emulsion grains which were large enough to be used for color films.[13] It was therefore considered that the increase in sensitivity of color films by about five times would be achieved by improving the quantum sensitivity of emulsions.

It was judged that the smallest latent image center in color films was composed of three atoms, since emulsions for color films were sulfur-plus-gold-sensitized. It is considered that the smallest development center should be a dimer of gold atoms. It was expected that the increase in sensitivity of color films by 1.5 times would be realized by achieving the formation of the latent image center composed of two gold atoms. In total, it was predicted in 1985 that the increase in sensitivity of color films by more than ten times would be achieved in the future.[11]

Since then, several progresses have been made on the light absorbance and quantum sensitivity of emulsions used for color films. One of those progresses is in the preparation of tabular grains. Tabular grains, which have been however known for many years, have large specific surface area and are inherently suitable for a spectrally sensitized emulsion with high sensitivity. Main points in the progress are the improvements in distributions of size and shape and in structure for achieving high sensitivity. Marchant reported in 1986 that, by using tabular grains, the absorbances of incident blue, green, and red lights by a color film could be as large as about one half.[17] It is assumed that the room for the improvement in light absorbances would be nearly two times.

Sasaki reported recent progress of color negative films,[18] showing that the size of emulsion grains and the thickness of emulsion layers in the color films have been reduced significantly for thse ten years without deteriorating their sensitivity and image quality. It is judged that less than 10 absorbed photons per grain are now needed to form a latent image center on an emulsion grain in a color film. Under the condition that the number of absorbed photons per grain fluctuates according to Poison distribution and the smallest latent image center is composed of three atoms, the ultimate limit of quantum sensitivity is regarded as 1.7 absorbed photons per grain. It is judged that the room for the improvement in quantum sensitivity of emulsions in color films would be several times.

It is now predicted that, in total, there is still big room for the increase in sensitivity of color films in the future. The degree of the improvement will be several times and probably ten times. It is noted that any progress which can increase the sensitivity of color films without deteriorating their image quality can be also used for improving image quality of color films without changing their sensitivity. It is therefore considered that the realization of the above-stated sensitivity increase will make it possible to design color films, which will be much more attractive for amateur consumers than current color films.

Capture of Images

In the step of capture of images by use of a camera and a color film, incident photons are absorbed by silver halide grains in it and memorized by the formation of latent image centers on the grains. Namely, a color film acts as a sensor and as a memory device at the same time, and a camera for it does not need to be equipped with a memory device. Since a color film is composed of multilayers of photographic emulsions, which can absorb and memorize various numbers of incident photons with three primary colors, it contains a large amount of image information per unit area. In addition, the capture and memorization of an incident light image can be achieved only by the energy of the absorbed photons. All these conditions make it possible to design cameras for color films very compact and easy to use.

Display of Captured Images

In order to display a captured and memorized image in a color film, an exposed color film is processed by sophisticated procedures with various chemical solutions. The display process of color films is thus too hard for amateur consumers to do by themselves. However, the above-stated processes for color films are entirely carried out as routine works for mass production by professional people, and amateur consumers can benefit the mass production, which provides them pictures with high quality and low price.

Image Processing and Digitalization

In color film system various kinds of image processing are carried out during color development. Colored couplers and development-inhibitor-releasing (DIR) couplers are representative among them. Colored couplers could provide a technique to improve the purity of colors of image-wisely formed dyes by substantially eliminating their side absorption bands. DIR couplers are used to improve graininess and brightness of colors by image-wisely releasing development-inhibitors. Namely, image-wisely released development inhibitors decrease the size of dye clouds by depressing the development process in the layer where they are present and increase the brightness of colors in the same layer by depressing the development processes taking place in the adjacent layers.

It is noted that the above-stated processes are taking place in parallel at any place in a color film during color development regardless of its frame area and number of pixels in a frame, on the contrary to the processing of digital images, which is carried out in series.

The digitalization of analog images, which should be made for the image processing on computers, meets its merits and demerit. One of the most important merits of the digitalization is to make it possible to process, edit, and transfer captured images, and should be effective especially for pictures, which were valuable or should be reproduced many times. The demerits of the digitalization are the cost and time for it, which might be in proportion to the number of pixels per frame. The digitalization should be effective when its merits overcome its demerits, and is not necessarily strong at amateur photography, since pictures for amateur photography should be cheap, composed of many number of pixels per frame, and are not usually reproduced many times.

Conclusive Remarks

The detailed analyses of photosensitive materials in the above sections indicates that color films has many strong points and big room for their improvement, which would keep their position firm in amateur photography in the future. Technical progresses in color film system in the future will expand the possibility of silver halide photography and achieve new attractive color film systems in the future by improving sensitivity and image quality of silver halide emulsions and by providing technologies which will achieve simpler, more rapid and environmentally kind processing. It is also probable that silver halide emulsions and color films will be designed to meet the demands for digital photography on the basis of hybrid technologies between silver halide and electronic photography.

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