2.7 Photographic Recording

2.7.1 A Brief Description of the Chemical Processes

Over the past decades photographic films were widely used in optical systems to detect and store optical information. In some cases, they are still in use because of their high spatial resolution and possibly their availability. In the following, a short and simplified description of the chemical processes from exposure to fixing will be given, together with an introduction to the diagrams normally used to characterize film performance.

An unexposed photographic emulsion mainly consists of tiny silver halide grains in a gelatine support. The interaction of an impinging photon with the photographic emulsion consists of random events. The probability that a photon strikes a silver halide grain depends on the density of the grains. Those grains that have absorbed a sufficient number of photons are found to contain tiny patches of metallic silver. These patches are referred to as "development centers". During the developing process the chemicals used are diffusing from the surface through the gelatine. The existence of a single tiny development center precipitates the change from silver halide to silver. The unexposed grains are left unchanged and are removed during the "fixing".

2.7.2 Introduction to Performance Diagrams

The locally varying intensity transmittance of the emulsion after development is defined by [10]:

$$T(x,y) = \text{local average}\left(\frac{I_{\text{trans}}(x,y)}{I_{\text{inc}}}\right) . \tag{2.26}$$

I_{inc} is the intensity of a light source illuminating the recording after development, I_{trans} is the intensity of the light locally transmitted through the recording. The area of the *local average* is large with respect to the size of a film grain, but small compared with an area within which the transmitted intensity changes significantly. The local variance of $T(x,y)$ is – besides other process parameters – caused by the local variance of the prior exposure E, which is the integral of the intensity per unit area over the exposure time Δt:

$$E = \int_{\Delta t} I \, \mathrm{d}t . \tag{2.27}$$

Hurter & Driffield demonstrated that the logarithm of the intensity transmittance $\log[1/T(x,y)]$, the photographic density D_{photo}, is proportional to the silver mass per unit area of a developed transparency. Plots of the photographic density versus the logarithm of exposure $\log(E)$ are therefore commonly referred to as Hurter–Driffield curves. They are often given in data sheets of photographic films. The following figures display diagrams for two

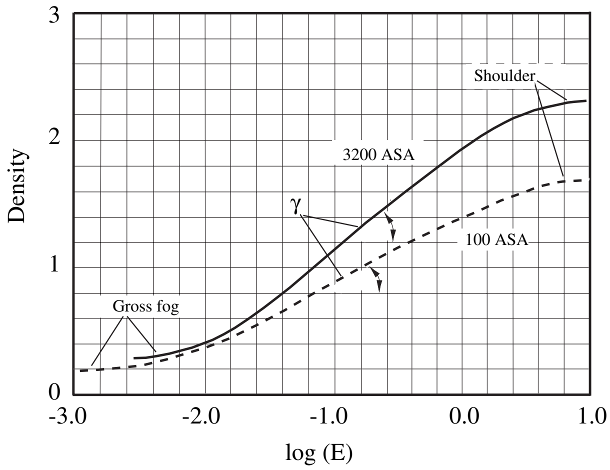

Fig. 2.44. Hurter–Driffield curves of the photographic density for two standard black and white films.

films of different sensitivity, which are widely used in black and white photography. It can be seen in figure 2.44 that the density is equal to a minimum value referred to as "gross fog" when the exposure is below a certain level. The density increases with increasing exposure at the so-called "toe". For further increase in exposure it is linearly proportional to the logarithm of exposure (see figure 2.44). The slope of the linear region is referred to as the photographic gamma γ. For further increase in exposures the curve saturates at a constant level. This region is called the "shoulder" of the Hurter–Driffield curve. The linear region of the curve is the portion generally used for PIV recording. Films can be classified as high contrast film for a photographic gamma of two or more or low contrast films for $\gamma < 1$. The photographic gamma can further be varied by varying the development time. This effect and the nonlinear features of photographic emulsions described by their Hurter–Driffield curves can be used in an additional photographic process – a contact copy[3] – which can be performed after evaluation and which reduces the noise in optical PIV evaluation as described in section 5.3.

Up to now it has been assumed that any spatial variation of the incident light during recording will be transferred into corresponding spatial density variations on the film. However, this is not valid if the spatial scale of exposure variations is too small. Generally speaking, a given photographic emulsion possesses only a limited spatial frequency response. Therefore, the highest spatial frequency that can be recorded with a sufficient contrast is a further important film specification. However, for many applications the evaluation of film resolution properties only on the basis of an upper limit of spatial frequency response is not sufficient. Especially for PIV, where high resolution is required, the response of a film over the entire operating frequency range is more useful. In figure 2.45, the spatial frequency response of black and white films with sensitivity of 100 ASA and 3200 ASA respectively is shown.

[3] A contact copy is a high contrast negative of the original photographic PIV recording used to improve the signal-to-noise ratio in the optical evaluation process by means of a probing laser.

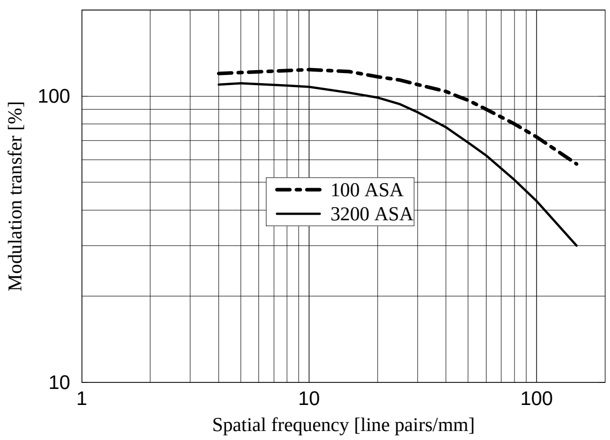

Fig. 2.45. Spatial frequency response (MTF) of two standard black and white films.

It can be seen that the film with the higher sensitivity offers lower frequency resolution. Such frequency response diagrams (MTF's) have become a widely used means of specifying the performance of films and lens systems. The concept of MTFs and the analysis of their effect on the obtainable particle image diameter has been described in more detail in section 2.6. Another important diagram for selecting the proper film for PIV recording is the curve of the spectral sensitivity. The sensitivity is defined as the reciprocal value of the exposure E, which is necessary to obtain a certain photographic density. Figure 2.46 shows such curves for two commonly used films. The curves are given for a density that is the density of the film fog plus one, in other words, they represent $\log(1/E)$ which is needed to obtain a film transmittance that is a tenth of the transmittance of the film fog. It can be seen that the 3200 ASA film shows superior sensitivity especially in the green. This was one of the reasons why frequency doubled Nd:YAG lasers with a wavelength of 532 nm (vertical line in figure 2.45) became fairly popular in PIV.

Fig. 2.46. Spectral sensitivity of two standard black and white films.