Light Optical Convolution Computers in Electron Microscopy

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Correlation functions of electron micrographs calculated by light optical computers allow to visualize astigmatism and defocusing.

The use of light diffractograms of electron micrographs for the study of the transfer function of the instrument is well-known [1]. In direct space the autocorrelation function corresponds to the Fourier transform square, imaged in the light diffractogram *. This autocorrelation function has not yet found much interest, in spite of the fact that correlation functions became indispensible tools in computerized image reconstruction [3]. The reasons are that the Fourier transform is more directly connected with the transform function and that it can be represented by analogue computers. This easy access has also led to installations, which use the Fourier transform square for focusing and for correction of the astigmatism [4–6] in the microscope.

But there are also light optical computers for the computation of convolution functions. In fact, already in the early days of crystal structure analysis simple light opticals devices [7–9] have been used for the "computation" of Patterson structures (which are equivalent to autocorrelation functions of discrete atoms). Similar devices have also been used for general convolution functions [10]. We have undertaken a systematic study of these light computers in electron microscopy. According to [7–10] one needs a transparent copy of each of the two functions (micrographs) to be convoluted. For autocorrelation functions two copies of the same micrograph or copies of micrographs taken under identical conditions have to be prepared. In order to get a good contrast of the correlation peak against its background contrast amplification of the copies is advisable. For on-line work in the microscope one of the copies can be replaced by the monitor screen of the image intensifier of the microscope. The other copy can e. g. be prepared in a few seconds as a polaroid photograph of the screen. From the theory of correlation functions and from our experience in image reconstruction we expected that these light optical convolutions should provide an useful tool for the diagnosis of electron micrographs (astigmatism, focusing). A few examples for coherent bright field imaging will be given. Figure 1 a † shows the autocorrelation diagram of a slightly overfocused micrograph. The asymmetry in the fringe of the correlation peak corresponds to the axial astigmatism in the micrograph **. If one goes from overfocus to underfocus (Fig. 1 b) the asymmetry changes its orientation. Of further interest is the dependence on the focus. The size of the correlation peak is *not* – as one would perhaps believe – dependant on defocusing. The reason is that the correlation peak of the object function will be convoluted by the Fourier transform of the squared transfer function. This function is positive everywhere in reciprocal space and contains high frequency terms. But there is a secondary influence by partial coherence, which leads to a broadening and finally to an extinction of the correlation peak. A precise determination of defocusing is therefore not possible from the correlation peak alone, only the region of "good focus" can be determined ***. But there is another way to determine at least one defocus value quite precisely: If one correlates an overfocused image with a series of images from overfocus to underfocus the correlation peak reverses its contrast. Figure 1 c shows a cross-correlation function near the point of contrast reversal. – The correlation peak will be displaced, if one of the two correlated images (e. g. the image on the monitor screen) moves (e. g. by drift). This effect can be used for an one-line displacement correction of the image.

It should be mentioned that light optical convolutions could also be done with coherent computers. These devices are much more complicated. On the other hand accuracy and contrast in the correlation function will be higher.

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* see also [2], page 76 footnote 2.

† Figures 1 a–c on page 1932.

** There is a small additional influence of the line structure of the television signal.

*** In fact, this little dependance on defocus is the reason that resolution enhancing reconstructions schemes work in coherent bright field microscopy. The situation is completely different in incoherent dark field microscopy. The smallest correlation peak corresponds there really to the best focus.

[1] F. Thon, Z. Naturforsch. **21 a**, 476 [1966].
[2] W. Hoppe, Phil. Trans. Roy. Soc. **B 261**, 71 [1971].
[3] see e. g. W. Hoppe, Proc. Fifth Europ. Congr. on Electron Microscopy, Manchester 1972, p. 612.
[4] V. Witt, Proc. Fifth Europ. Congr. on Electron Microscopy, Manchester 1972, p. 632.
[5] O. Kübler u. R. Waser, Optik **37**, 425 [1973].
[6] H. P. Rust, Proc. Eighth Intern. Congr. on Electron Microscopy, Canberra (Australia), Vol. **I**, 92 [1974].
[7] J. M. Robertson, Nature London **152**, 411 [1943].
[8] G. Hägg, Nature London **153**, 81 [1944].
[9] W. L. Bragg, Nature London **149**, 470 [1942].
[10] R. Hosemann u. S. N. Bagchi, Direct Analysis of Diffraction by Matter, Amsterdam 1962, p. 47.

Fig. 1 a

Fig. 1 b

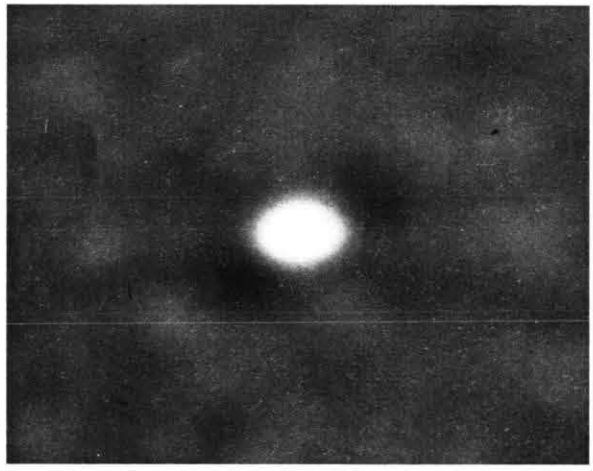

Fig. 1 c

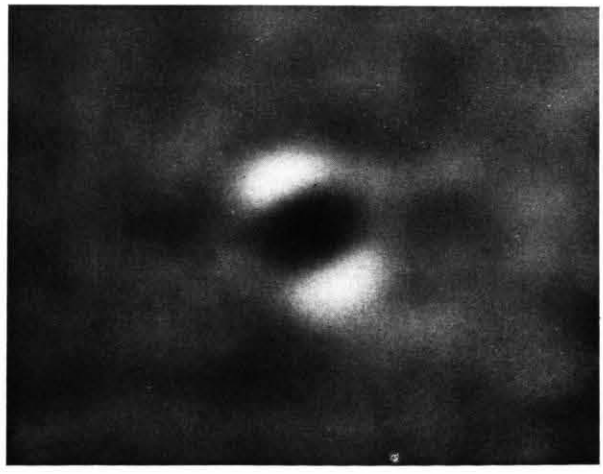

Fig. 1. Light optical correlation functions of electron micrographs (carbon foil, Elmiskop 101, M = 510 000), a) autocorrelation function at overfocus (Δz = 1000 Å), b) autocorrelation function at underfocus (Δz = −500 Å), c) cross-correlation function of two micrographs at overfocuse and underfocus (contrast reversal).