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ENHANCEMENT OF ELECTRON MICROGRAPHS BY HOLOGRAPHIC IMAGE DEBLURRING

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The long-sought solution to the deblurring of electron micrographs has been obtained by a new extension of the Stroke et al. holographic image deblurring methods. The method is applicable to transmissions as well as to scanning electron microscopy.

Fig. 1b shows an enhanced (deblurred) image which we extracted from the blurred scanning electron microscope microphotograph of fig. 1a by means of a new extension of our holographic Fourier-transform division optical image-deblurring methods, which we have been developing for such applications since 1966 [1-3]. Ever since the work of Gabor in 1948 [4] it has been clear that atomic resolutions could be obtained in electron microscopy if certain inherent instrumental imperfections could be surmounted by *a posteriori* methods, variously called "enhancement", "restoration" or "deblurring". The original suggestions of Gabor have most recently again been taken uo and extended [5] in view of the enhancement of resolution in electron microscopy by image holography, but no experimental results have been reported. In these methods an electron-beam hologram of an imperfect (aberrated) image would be compensated optically in the reconstruction step. Our optical image-deblurring methods, on the other hand, are being used to extract greatly sharpened "deblurred" images from imperfect photographs

a

b

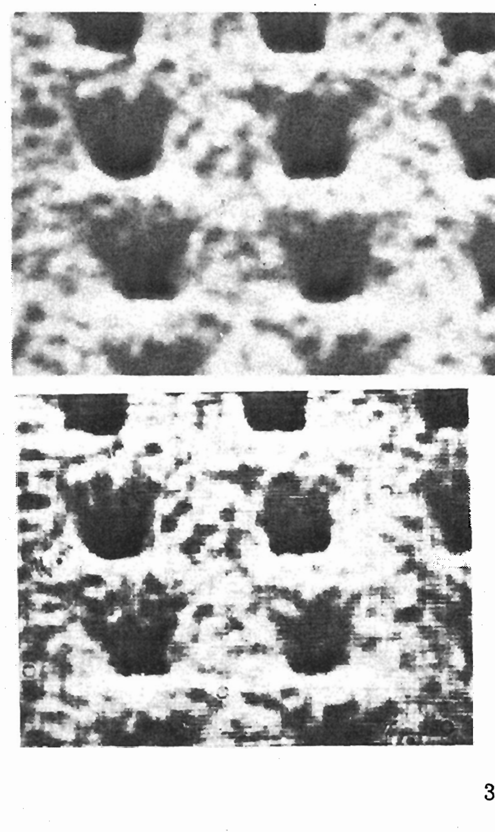

Fig. 1. a) Blurred scanning electron microscope (SEM) continuous-tone microphotograph of a prickly gold grid (1 000 lines/inch) [Materials Analysis Co. Model 700A scanning electron microscope, "secondary electron" mode of operation, accelerating voltage: 20 kV]. b) Deblurred image, extracted from blurred photo of fig. 1a by holographic Fourier-transform division deblurring according to [1,2] using "extended dynamic range" holographic filter with $\gamma = 1$ according to [3]. Note that both the resolution and the related contrast have been enhanced. Auxiliary optical tests show that the blurring in fig. 1a corresponds to a blurr "circle" of 2mm diameter, at the scale shown (it is equivalent to a 22 mm defocusing with $f/11$ lens), and that the deblurring corresponds to a 40% reduction of the blurr circle in this early experiment.

(and now electron microphotographs) themselves, notably in cases where they have been blurred by imperfect focus, motion, vibrations, and especially also image-system imperfections (such as spherical aberration) which cannot be readily suppressed by instrumental design or realization. A most distinctive feature of our optical computing method is 1) that the required holographic image deblurring filter may be realized by direct experiment from the readily available blurred image of a "point" in the specimen (object) space, i.e. from the "point spread function" [2], and 2) that the deblurred image may be extracted from the blurred photograph in a very simple optical "spatial filtering" arrangement [6], without the need for any microdensitometer scanning of the photos and electronic digital Fourier-transform computing [7]. In fact so far the only known digital computer manipulation of electron micrographs in view of image "enhancement" has been restricted to noise "averaging" of a binary (black and white) periodic structure [8], and not to image-deblurring "deconvolution", which we present here.

The mathematical and physical principles of our holographic image deblurring method have been previously described [1-3]. Two new problems of crucial importance have now been solved: 1) the deblurred image was extracted from a photograph actually blurred in the scanning electron microscope (the spread function was estimated by an auxiliary experiment, rather than from a particle test-specimen image from which it could be determined even more precisely); 2) the otherwise unacceptable coherent (laser) noise in the optical filtering arrangement which would have existed from the very grainy Polaroid P/N 55 material of the blurred photograph was completely suppressed by its white-light re-imaging on a fine-grain Agfa-Gevaert Scientia 10E-70 plate, without loss of resolution. Our method is fully applicable also to transmission electron microscopy, notably in cases of generally complicated spread functions.

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