

HOLOGRAPHIC CONSTRUCTION OF OPEN STRUCTURE, DISPERSION TRANSMISSION GRATINGS

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Received 11 June 1975, revised manuscript received 9 July 1975

A method of fabricating free-standing transmission gratings with line densities of the order of 1000 ℓ/mm is described. The technique involves a combination of two well-known procedures: application of photoresist and electroplating for the production of fine metal grids, and holographic (interferographic) manufacturing of dispersion gratings. Results of preliminary tests are mentioned.

1. Introduction

Spectral research in the soft X-ray and EUV wavelength region is mainly performed by means of grazing incidence reflection gratings and Bragg diffraction crystals. For broad-band spectral investigations thin plastic and metal filters or filter-gas combinations are applied. The intrinsic dispersive properties of detectors like gas-filled proportional counters and solid-state detectors are widely used for similar purposes. Our object being the development of moderately high dispersion elements ($\approx 5 \text{ nm mm}^{-1}$) suitable for high angular resolution imaging systems, we will confine ourselves to gratings and crystals. Both these elements can be produced with focusing characteristics. However, strong optical aberrations rule out spectral investigation of extended X-ray sources. Only double-focusing crystals might be used for combined imaging and dispersion. Holographically produced stigmatic gratings might also be used, but to our knowledge, these have never been produced for wavelengths below about 10 nm^{*}.

A common disadvantage of these dispersive elements is the low flux-gathering power and low detection sensitivity. This can evidently be obviated by application of a grazing incidence telescope. Then imag-

ing and dispersing functions are separated likewise, and plane reflection gratings and crystals can be used. However, the application of these components has intrinsic disadvantages arising from the asymmetrical off-axis mounting. Large areas have to be used, resulting in production problems caused by the required flatness, and heavy space and weight demands. Another drawback for reflection gratings and crystals is the wavelength dependence of the efficiency. Crystals, moreover, can be used only for high spectral resolution, and narrow energy bands; however, they are obviously the appropriate optical tools for spectral lineshape investigations. Application of transmission gratings with completely open slits removes these disadvantages or at least reduces them considerably. As a case in point, the angular deviation between the imaging and diffracted beams is diminished and permits the application of a single detection system. Moreover, extreme flatness of the grating plane is not required, and in principle any location in the imaging beam is allowed.

Using our experience gained in the application of holographic techniques to the development of Fresnel zone plates for solar soft X-ray heliography, we decided to consider the construction of transmission gratings with "free standing" structure. Our first zone plates were produced by electro-optical means according to the well-known formula for the classical Fresnel-type plate [1,2]. In order to avoid the contrast-reducing effect of the halo in the image formed by these

* A grazing incidence EUV monochromator with toroidal holographic grating (Jobin-Yvon) is described in ref. [3d] (information from the referee).

classical zone plates, the manufacturing of apodized (annular) and off-axis zone plates was taken up. Holographic methods have to be applied here, since conventional engraving and reduction techniques were not feasible, due to the large number of zones [3,4,5b]. We started making apodized zone plates by a method using the interference pattern of two spherical beams from an Ar-Kr-ion laser. For the off-axis zone plates we applied grating formulae developed by Werner [5d] (compare [5a]; such plates are actually transmission gratings with grooves curved so as to correct for first-order coma and astigmatism). The results of laboratory tests showed that proper imaging with acceptable spectral resolution could be obtained (see fig. 4), hence the application of our techniques to grating manufacture looked indeed very promising.

2. Ringshaped gratings for objective grating mountings

Our purpose being the production of free-standing ringshaped ** gratings, applied in combination with X-ray grazing incidence mirrors [5c], requiring the use of electro-deposition or etching methods, the application of photoresist techniques is imperative. Exposures should then be perfectly uniform, which is difficult for large areas and long exposure times. The large diameter, annular grating cannot be imprinted in a single shot and must be composed of a great number of smaller units. Moreover, the pattern lines exposed into the resist-layer must be removed completely from the nickel substrate below, enhancing the uniformity problem of the exposure. As a consequence only rather small grating areas are involved (about 24×24 mm) and the holographic setup can be rather simple (fig. 1). Plane mirrors are not required, because the hyperbolic part of the interference field is sufficiently rectilinear and equidistant [3b]. The resolving power of the complete grating will of course never be greater than the resolution of each unit, but an advantage of the composite mounting is the possibility of correction of the aberration caused by the conical beam emerging from

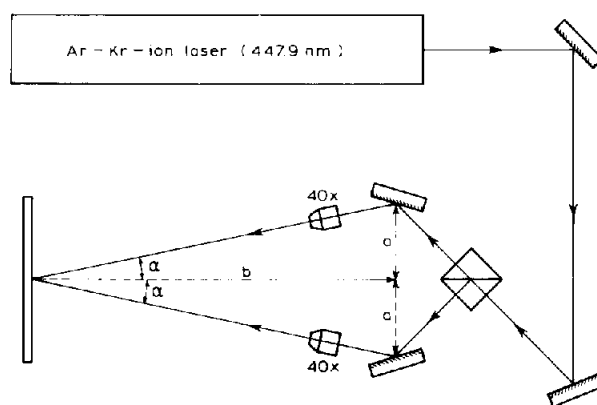


Fig. 1. Transmission grating manufacture. The holographic interference pattern is determined by a and b . The grating period is $d = \frac{1}{2} \lambda / \sin \alpha$.

the mirror by variations of the line period. Shipley AZ 1350 is used as a photoresist throughout: its line resolution is high and because it is positive the numerous manufacturing steps are easier to perform.

3. Manufacturing

3.1. Grating pattern

The manufacturing proceeds briefly as follows. The geometry of the setup is determined by the formula

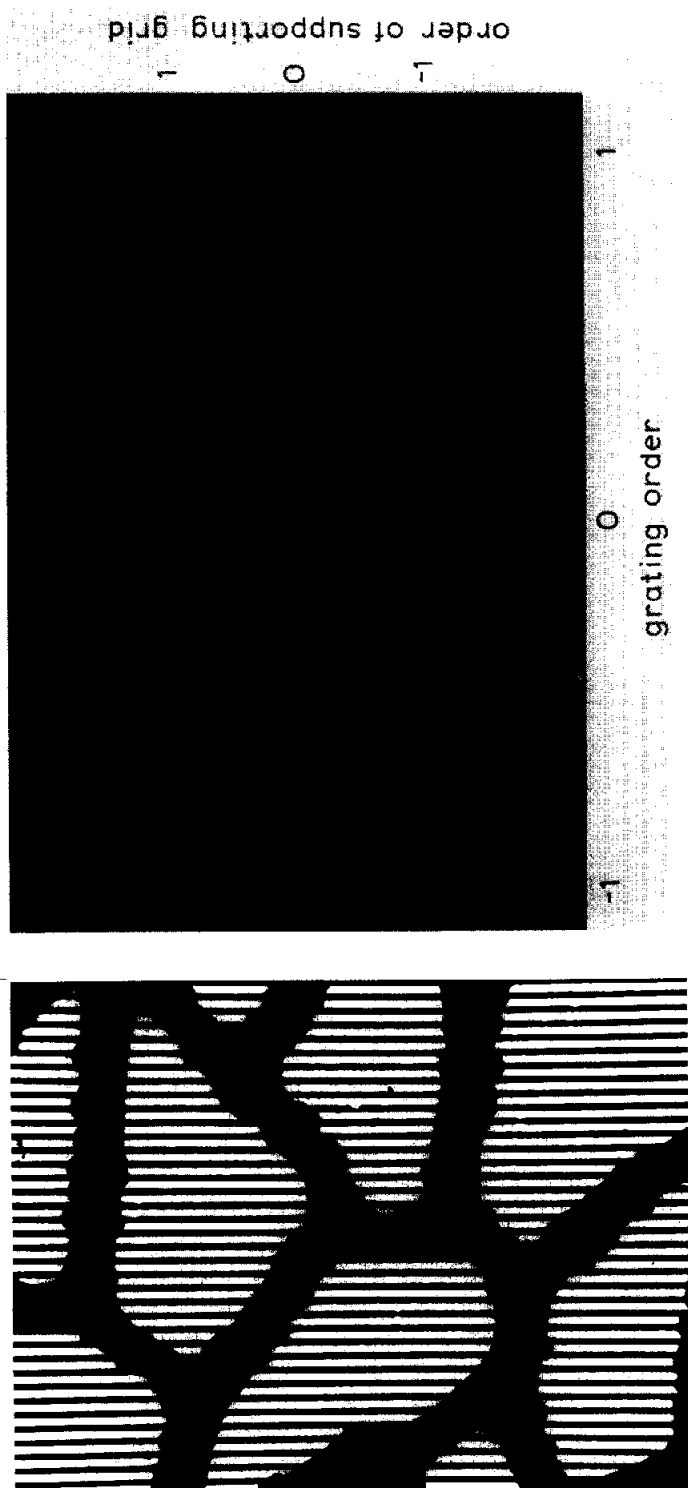
$$\lambda = 2d \sin \alpha,$$

where λ is the wavelength of the laser radiation (447.9 nm), d is the grating constant to be aimed at and α is half the angle between the central rays of both beams.

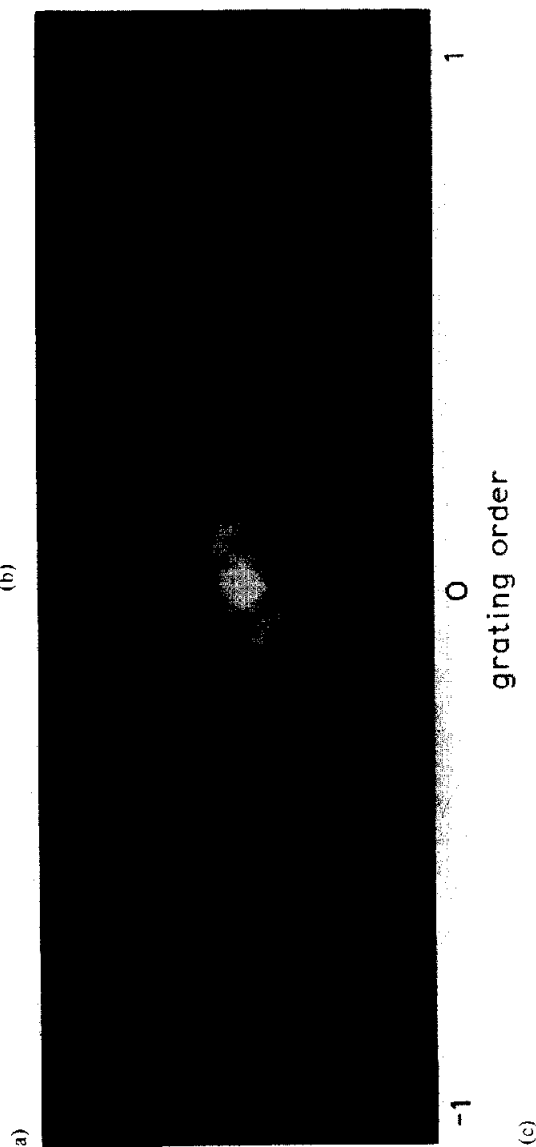
For the further procedure we have investigated three different methods:

1. Contact printing was considered first in order to facilitate the production of a large number of grating units. The interference pattern, exposed in a photographic plate, is contact printed onto a glass-chromium-photoresist plate and after etching, the pattern is used as a master for further contact printing in similar home-made glass-nickel-photoresist plates. After the ordinary procedure of developing, cleaning, etc., the grating pattern is electro-deposited in a gold plating bath. For periods of about $200 \text{ lines mm}^{-1}$ this meth-

** "Ringshaped" or "annular" means that a ringshaped excision of the equidistant and parallel-lined grating ("linear" grating) is applied. Evidently the diameter and the width of the ring are determined by the cross-section of the grating plane and the hollow conical imaging beam emerging from the mirror and converging into the focal point (or plane).



(a)



(b)

Fig. 2. Microscopic picture of grating (magnification $\times 320$); period: 200 lines mm^{-1} ($5 \mu\text{m}$). The supporting network ("flagstone pattern") (a) reduces the side images of a coarse conventional parallel grid (b) almost completely (c).

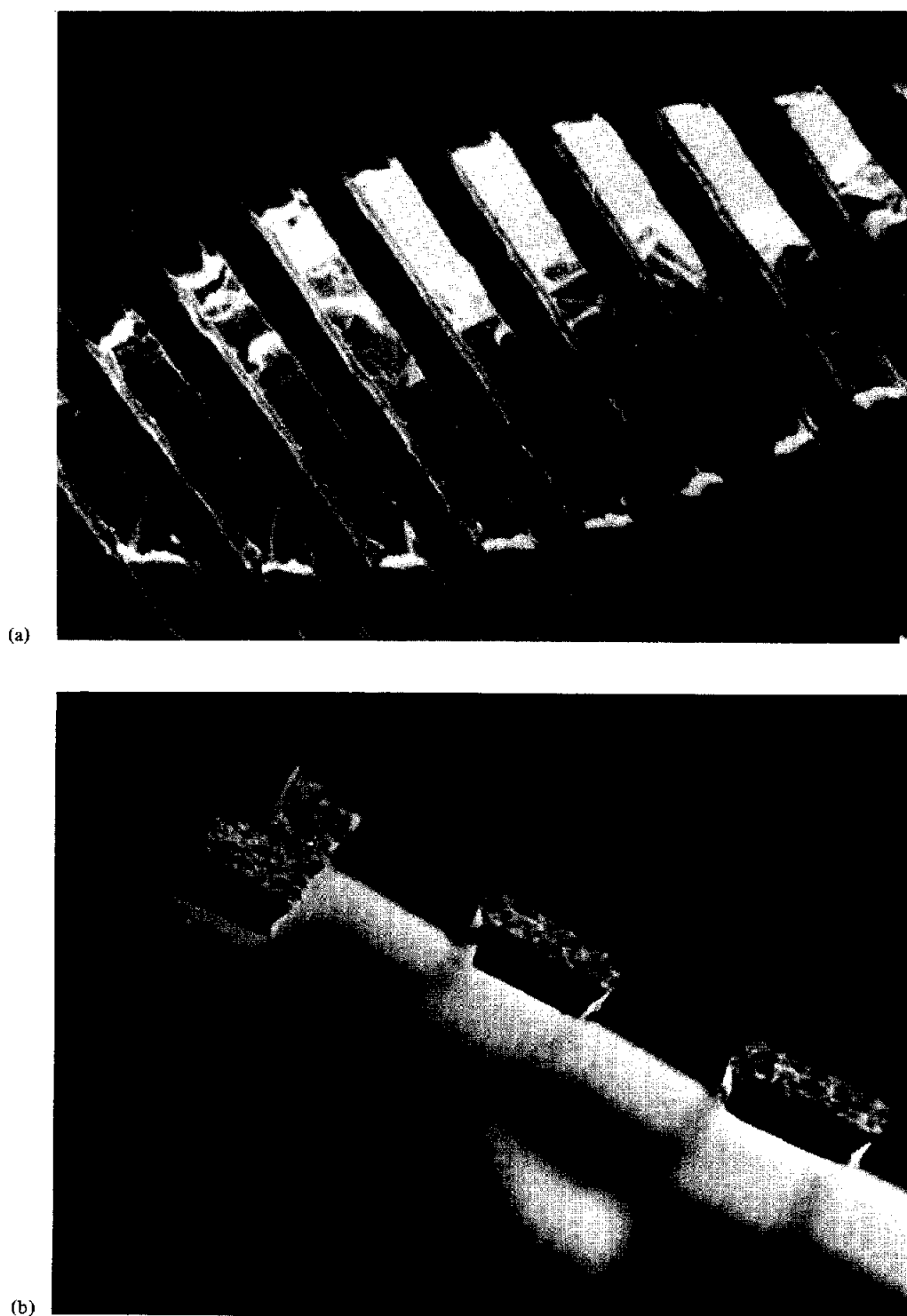


Fig. 3. Scanning electron microscope picture of grating: a. view through a network-hole from the electro-deposition side; b. cross-section through grating bars; width $2.5\text{ }\mu\text{m}$, gold.

od proved to be successful.

2. Photographic reduction of a 200 lines mm^{-1} master, applying a step-and-repeat method with condensor and Nikkor UV-lens turned out to be feasible until about 500 lines mm^{-1} .

3. For larger line densities, only the direct method was applicable. Each individual unit is directly and subsequently produced in a stable holographic mounting on the anti-vibration optical bench. We have obtained 1000 lines mm^{-1} in an area of 24×24 mm, and even higher line numbers, but, of course, with gradually inferior characteristics. Our former zone plates, though smaller in area, were of similar quality.

3.2. Supporting structure

Because the slits of the grating are completely open (no plastic is left behind) the bars must be supported by some auxiliary grid. In order to prevent bending and sticking of the grating bars this grid cannot be coarser than about $30 \times$ the grating period. This grid is contact printed in a photoresist layer and deposited by centrifuging. Here a difficulty is the dispersive effect of the supporting grid, especially with rectilinear elements. Several model structures have been tried (fan shaped grid, random holes), but the best results were obtained with a network, somewhat similar to a "flagstone" pattern as used by landscape gardeners, refined and stretched somewhat perpendicular to the grating slits to enhance the transmission. The support-

ing grid and the mounting frame are deposited by means of contact printing after finishing the gold-plating of the grating. The remaining photoresist being removed, the completed grating is detached from the glass plate by selective etching of the nickel substrate.

Fig. 2 shows the performance of the supporting network as compared with a fan and a random-hole grid. The radiation contained in the inconvenient side images of the latter two grids will show up as a general background in the case of the network. The tests of the grating will comprise a closer investigation on this phenomenon with X-rays.

4. Testing

A scanning electron micrograph is shown in fig. 3a and a cross-section of the grating bars can be seen in fig. 3b. The result of a test with 30.4 nm He radiation from a capillary arc discharge, a 0.04 mm slit, an off-axis zone plate as imaging element and a grating just behind the zone plate is shown in fig. 4. A test of the complete composite annular grating will have to be performed with the grating behind a grazing incidence X-ray imaging mirror as applied e.g. in the Apollo Telescope Mount in Skylab [5c]. The required large diameter X-ray beam could be produced in a long vacuum tube or mirror mount using an X-ray point source. The units composing the grating must be aligned with accurately parallel slits. This was performed roughly

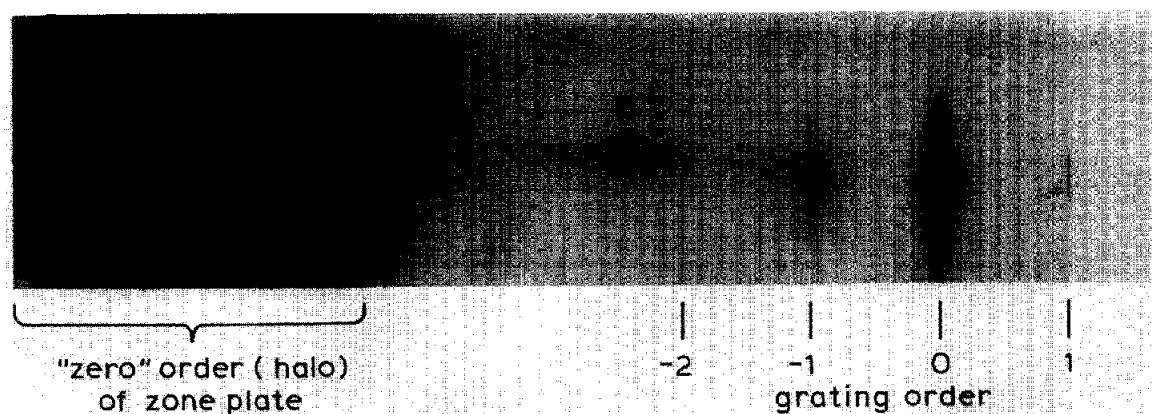


Fig. 4. Diffraction orders from transmission grating (200 lines mm^{-1}) of slit imaged by off-axis zone plate. Wavelength 30.4 nm, grating close behind zone plate, 40 μm slit, object-image distance = 144 cm.

by means of a laser beam and a translation x - y manipulator. The parallelism was checked afterwards with a large diameter lens and an expanded laser beam; in our case the accuracy was about 1 arc min. This accuracy is sufficient for a 10 arc sec resolution mirror, but depending on the angular resolution of the detector (position-sensitive proportional counter or channel photomultiplier array) may become marginal for 2 arc sec resolution. In the latter case a corrected large diameter lens system or a laboratory measuring microscope (e.g. Leitz) for mechanical alignment must be used.

The ultimate requirement will be a trade-off between the obtainable resolution of each grating unit, the expected X-ray source extension, the expected intensity and intensity distribution in the source, spectral composition (broad or narrow lines, continuum), and overall and spectral sensitivity as well as spatial resolution of the detector. More details concerning the manufacture and testing procedures of our zone plates and gratings will be published in due time.

Acknowledgements

Our thanks are due to Professor C. de Jager for

stimulating the work described in this paper, and to Dr. L.D. De Feiter for valuable and stimulating discussions.

References

- [1] B.E. Bol Raap, J.B. Le Poole, J.H. Dijkstra, W. de Graaff and L.J. Lantwaard, in: *Small Rocket Instrumentation Techniques* (North-Holland Publ. Company, Amsterdam, 1969), p. 203;
M. Burger and J.H. Dijkstra, *Solar Phys.* 24 (1972) 395.
- [2] L.D. de Feiter and C. de Jager, *Solar Phys.* 28 (1973) 183.
- [3] H.H.M. Chau, *Appl. Opt.* 8 (1969) 1209;
D. Rudolph and G. Schmahl, *Optik* 30 (1970) 475;
A. Labeyrie, J. Flamand, *Opt. Com.* 1 (1969) 5;
D. Lepère, *Nouv. Optique* 6 (1975) 173.
- [4] J.H. Dijkstra, W. de Graaff and L.J. Lantwaard, in: *New Techniques in Space Astronomy*, Labuhn and Lüst (eds.), I.A.U. 1971, p. 207.
- [5] A. Labeyrie, *Elec. Opt. Sys. Des.* 32 (1971) 32;
L.J. Lantwaard and H. van de Stadt, *J. Phys. E, Sci. Instr.* 4 (1971) 879;
R. Giacconi, W.P. Reidy, G.S. Vaiana, L.P. van Speybroeck and T.F. Zehnpfennig, *Space Sci. Rev.* 9 (1969) 3;
W. Werner, thesis, 1970, Ed. Waltman, Delft, Holland,
Appl. Opt. 6 (1967) 1691.