PROSPECTS OF X-RAY HOLOGRAPHY

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The problem of X-Ray holography may be divided into three different items: the first one is the problem of using the optical holographic schemes in roentgenography ; the second is the solution of the phase problem in structural analysis using holographic methods ; the last one is the problem of the development of X-ray interference or holographic microscope by using X-ray optics methods. Let us analyse all these problems in succession.

a) on the possibility of using optical holographic schemes in X-Ray holography

At present, X-ray holograms have been obtained in Fourier's holographic schemes (fig. Ia), with beam separation by the Lloyd's mirror (Fig.Ib) and Fraunhoffer 's axial holography (Fig.Ic). In these schemes, holograms of the simplest objects were obtained with characteristic radiation AlKα (λ_x = 8,34 Å), BeKα (λ_x = 114 Å), CKα(λ_x = 44,8 Å) and synchrotron radiation with λ_x = 60 Å. The image was reconstructed in laser beams (λ_l = 0,63 µm). The experiments yielded a resolution of 2 to 5 µm with objects of several tens of microns (see the list of references in paper [1]).

A comparison of these modest results of experimental investigations with the theoretical conclusions about the possibilities of developing high resolution X-ray holographic microscopy suggests that direct extension of schemes of coherent optics, to roentgenography is inexpedient, as is an attempt to develop effective X-ray optics on the basis of usual optical elements. This conclusion was arrived at by estimating the maximum resolution of the holographic schemes which is limited by an insufficient coherency of X-ray radiation sources, by aberrations and low aperture ratio of holographic systems [1]. It was shown that presently the resolution of traditional schemes of X-ray holography cannot exceed the value 1 µm in the field of view of several tens of microns due to a limited power of X-ray sources. An increase in the resolution by only one order requires the source power to be increased by 10^6 times. The resolution is also restricted by wave front distortions during image reconstruction in visible light. It means that the use of the holography schemes represented in Fig. 1 to obtain holograms in X-rays is inexpedient, at present at least. In our opinion, in the X-ray wave lengths range, the development of coherent-optical systems is possible only by using X-ray diffraction from perfect crystals.

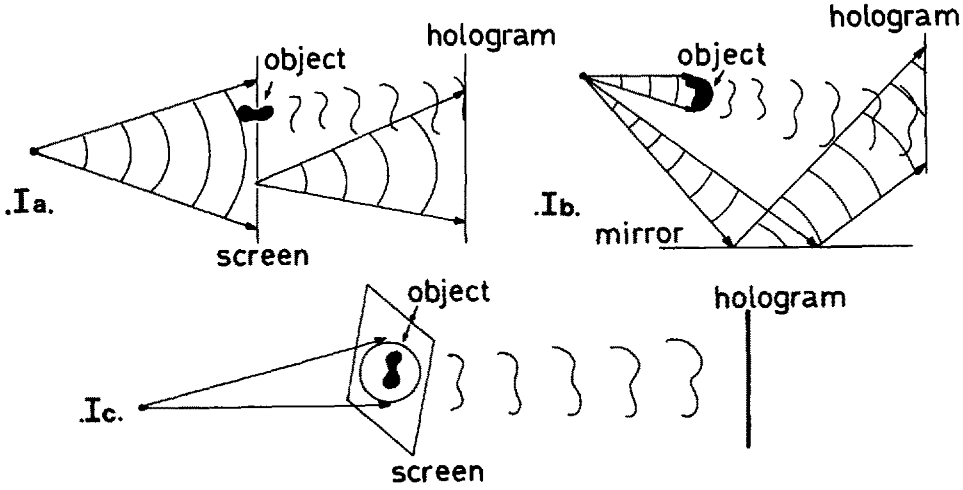

Fig. 1. Experimental schemes of hologram recording.

b) on the possibility of the solution of the phase problem in structural analysis using holographic methods

Let us consider a Bragg's X-ray microscope [2] . This microscope was intended for image reconstruction of the crystal lattice by light diffraction from an X-ray diffraction pattern. In a Bragg microscope the reconstruction of the atomic structure is possible only after the relative phases of the different reflections of the X-ray pattern have been determined. The methods to measure the phases are indirect, many of which, like the method of heavy atom, being similar to holographic ones. In several cases, these methods yield good results, but their application is limited to specific structures. In this respect, attempts have been made to solve the phase problem in structural analysis using direct holographic methods [3-4] . In our opinion, the possibility of utilizing holographic methods, in this case, is problematic too. The fact is, that the scattering of a monochromatic weakly diverging wave by a crystal gives rise to one diffracted wave only. To obtain another diffracted wave one has to change the geometry of the experiment. This means that apart from the usual requirement of holography to have coherent object and reference waves, one has to preserve constant the difference between the optical paths of the reference and diffracted waves for each of the diffracted waves or be able to measure it with an accuracy of fractions of the X-ray wavelength.

This requirement reduces substantially the range of possible schemes for experimental measurements of the phases. It can be easily shown that only the phases of the beams diffracted by a large perfect crystal can be experimentally measured using either the Kossel's method or multiwave scattering. In principle, relative phases of different orders of diffraction of three-crystals X-ray interferometer can be measured.

So, in the case of large highly perfect crystals not only amplitudes but also relative phases of the diffracted waves can be measured. Unfortunately, direct methods to measure phases are not of practical interest at present, because the majority of crystals, including biological ones, are imperfect.

c) on the possibility of constructing an interference microscope for short-wavelength X-rays ($0{,}5\ \text{Å} \lesssim \lambda_X \lesssim 3\ \text{Å}$)

Lately, X-ray diffraction optics that makes use of diffraction in perfect crystals has attained a success, namely : X-ray interferometers are constructed [5], X-ray diffraction focusing is accomplished [6-7] , the possibility of utilization of polychromatic diverging beam in interference experiments is shown [8] . All what is said above suggests the idea of the construction of an X-ray high resolution interference microscope. (When obtaining interferograms of some objects by means of a traditional X-ray interferometer [9] resolution in the horizontal direction is limited by the divergence of the wave field in the crystals and is equal to the size of the Bormann fan). One of the possible schemes for such a microscope is presented in fig. 2a). A polychromatic radiation from a point source 0 is diffracted in a thin crystal S. In the "mirror", the diffracted wave is diffracted again, during this process radiation for each wave-length is constricted to a narrow spot due to the effect of the diffraction focusing and the polychromatic radiation is focused in a point determined by the geometry of the experiment.

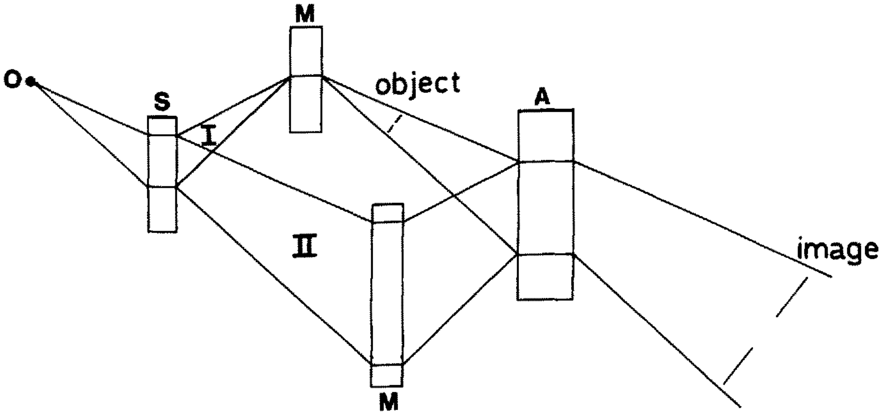

Fig. 2a. An example of a scheme of an high resolution interference microscope for short wavelength X-Rays.

This point is the source of a diverging wave with the size of the focus $2\Lambda \tan\theta/\pi < 10$ μm (Λ is the extinction lenght, θ is the Bragg angle). If an object is placed in a diverging wave I, then, behind the crystal A one can observe its magnified image with coherent field II superposed on it. At a substantially large magnification coefficient, the distortions introduced on passing by the object wave of crystal A can be ignored. The scheme considered is the simplest example of a scheme of an holographic microscope used to record an hologram of a focused magnified image.

So, using the methods of X-ray diffraction optics one can construct an holographic microscope with resolution at least up to 1 μm (likely up to 0,1 μm [10]). Principal elements of such a microscope must be an X-ray interferometer, diffraction focusing systems and a system to form a magnified image in order to reduce the aberration effect introduced by diffraction in different crystals of the interferometer. A partial compensation of these aberrations is also possible in using optical filtration methods to process the obtained images.

d) on the possibility of developing holographic settings for long-wave X-rays ($\lambda \geqslant 30$ Å)

The development of long-wavelength X-ray high resolution microscopy [11] and construction of special mirrors, which reflect X-ray at large incidence angles [12] , suggests a setting for long-wave length X-ray holography of biological samples (fig. 2b). This is an example of the setting for recording volume X-ray holograms like that of the Denisuk holography method. In order to reconstruct the image with visible light, the surface relief of the hologram was suggested to be magnified by λ_x/λ_1 times using X-ray contact microscopy methods [12] . For thin biological samples temporal and space coherence of the usual radiation

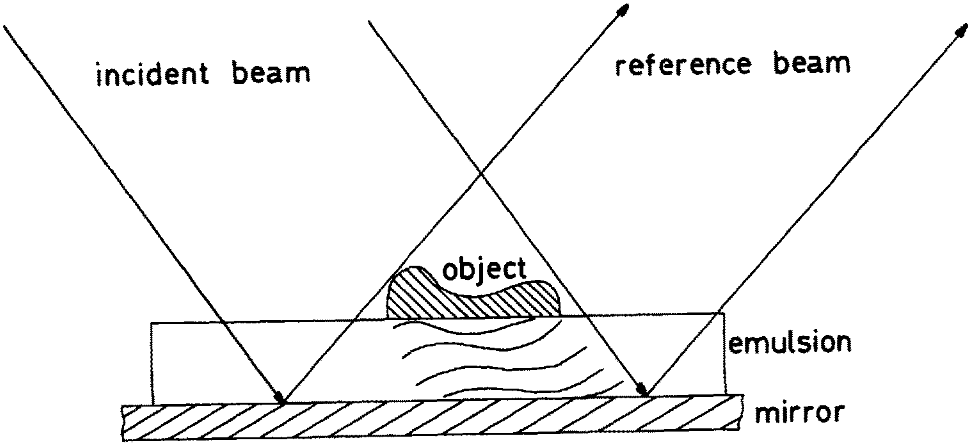

Fig. 2b. The holography schemes for long-wavelength X-rays.

source is sufficient for the hologram recording. The exposure time is *approximately the same as for contact microscopy* and wave front aberrations during image reconstruction are absent due to hologram size magnification. So, perhaps, the scheme under consideration will be useful for the development of high resolution (up to some tens of ängstroms) long-wavelength X-ray holographic microscopy.

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