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CONICAL WAVEFRONTS IN OPTICS AND TOMOGRAPHY.

Topics of the review lecture

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I. INTRODUCTION

The efforts of many opticians are to suppress the aberrations of the imaging systems as much as possible. The aim of the optical factory is to escape any eccentric misalignment errors in the optical assembly. To attain these goals many books on optical aberrations have been published and enormous work of research and technology groups has been accomplished. Meanwhile there are some deadlock problems which can be principally solved only by holding a completely opposite way of thinking. Namely, to solve such problems we must increase and control the aberrations or we must introduce and control eccentricity in an optical system. To understand these very strange recommendations it is sufficient to consider two optical devices which have been suggested in the last decade: an optical tomographic microscope (J.Opt.Soc.Amer., I987, A4, № I, p. 292) and a mesooptical Fourier transform microscope (Nucl.Instr.and Methods, I989, A283, p. I3). The position of the exit pupil in the first device is extremely eccentric , and the degree of aberrations in the imaging element of the second device is maximal. In both cases we deal with conical wavefronts and only due to them we can attain many useful advantages.

There are some other situations in which the conical wavefronts are to be considered the best technique which leads to the upper levels of science and technology. For example, axicons can be used in metrology and for x-ray laser pumping with large productivity, lenses with large longitudinal chromatic aberrations can be used in the optical surface profile transducer, complex axiconic systems and mesooptical confocal systems can be used in the fast ophtolmological keratometers and in the precise industrial profilometers. Besides mesooptical autocollimators and multipath interferometers which can be illuminated by the conical wavefronts have been suggested for measurement and control. In the last decade new designs of the conical scanning systems, optical and mesooptical, with high performance have been suggested. All these and some new combined devices are the subject of the review lecture:

CONICAL WAVEFRONTS IN OPTICS AND TOMOGRAPHY.

The reader can acquaint himself with the properties of the gravitational lens, new candidates for the Einstein Ring and the properties of the moving gravitational lens. It will be shown that the gravitational lens is indeed a beam splitter. A comprehensive history of mesooptics is presented in the last chapter.

II. PHENOMENOLOGY OF THE CONICAL WAVEFRONTS

At the very beginning of this chapter we present a lucid explanation of the conical wavefronts without any mathematic formulations. We show that if the technology of the lens production is wrong and the optic axis of the lens does not coincide with the rotating axis of the cutting or polishing tool, the conical wavefronts as an admixture to the spherical wavefronts are created. Two kinds of the manufacturing errors lead to two types of the axicons: one with a line response and another with a ring response. The term "mesooptics" and the general classification scheme of the mesooptical elements are explained.

The difference between spherical and conical wavefronts is treated. The approach according to which the conical wavefront can be considered as an array of many spherical wavefronts is discussed graphically. It will be shown that inverse decomposition takes place as well. Various cross decompositions which involve four types of wavefronts (spherical, conical, cylindrical and plane) are demonstrated.

III. AXICONS

In this chapter we explain the properties of some mesooptical elements: a conical lens and a conical mirror, circular diffraction grating, Archimedean spiral grating, kinoform - axicons, systems with a lens plus an axicon systems with two axicons, a W-axicon with its polarization properties, and chromatic objective. The problem of sidelobes in axicons is treated in detail. Many experimental results are presented. The design of the acoustic scanning imaging devices are described.

IV. THEORY OF THE CONICAL WAVEFRONTS

The field amplitude of the light over the conical wavefront is given and explained. The synthesis of the conical wavefront in computer holography is considered. The properties of the imaging systems with an annular aperture are discussed. Then a new term "axial symmetrical diffraction free wavefronts" is introduced and the information properties of the J_k-family of the irradiation functions are treated. The longitudinal interference of the diffraction free wavefronts is described and experimental results are presented. Some kind of the Fourier transform theorem which relates to the amplitude distribution of the radial irradiation over the exit pupil of the mesooptical system and longitudinal axial intensity distribution is stated. A method of longitudinal interference suppression and possible applications of this phenomenon are described.

V. GRAVITATIONAL LENS

The basic properties of the point-like gravitational lens are explained. The experimental models of the gravitational lens are described. Then the diagnostic properties of the moving gravitational lens are reviewed. The problem "how to compensate the effect of the gravitational lens" is treated and a new design of the reflector mirror of the light telescope is suggested. The structure of the information which can be received by the gravitational lens in the case of a double star is analyzed. It is shown that the gravitational lens is indeed a beam splitter system.

VI. INTEGRAL TRANSFORMS IN MESOOPTICS

In this chapter we review the following integral transforms: ID- and 2D-Fourier transforms, anamorphotic Fourier transforms, Hartley transform, Hilbert transform, Radon transform and its inverse one, Abbe transform and a family of Hough transforms. Optical implementations of these integral transforms, in particular, Hough transform for straight-line object, for curves in a plane and for some 3D-objects are described. The interrelation between straight-line objects and conical wavefronts is explained. Some applications of these integral transforms to mesooptics, optical processors and optical tomography are presented.

VII. MESOOPTICAL ELEMENTS WITH RING RESPONSE ("MERR")

Various types of MERR's are presented and their general properties are treated by ray tracing in the meridional and sagittal sections of the MERR. The problem of coma aberrations and that of field of view are considered. Various types of MERR's are described: mirrors, dispersive elements, kinoforms, aberration free designs and combined systems with point and ring responces. The problem of detection of straight-line objects inside the 3D volume of depth which is much greater than the depth of focus of the imaging system is discussed.

The principle of the mesooptical Fourier transform microscope (MFTM) which is based on the synthesis of Fourier optics and mesooptics is explained. New properties of the MFTM are treated: ring stereo effect, depth viewing without depth scanning, spatial resolutions in meridional and saggital sections of the MFTM and its high rapidity. A general theory of the MFTM as one-shot imaging system is presented and the convolution kernel of the MFTM for straight-line objects is constructed. A mesooptical analog of the moire effect observed in the MFTM is described. The structure of the mesooptical images of the curves objects and the event searching algorithms working without any reconstruction stage of the straight-line objects in 3D-space are considered.

A fast version of the MFTM with a one-channel photodetector in each arm of the MFTM is described. It is shown that the new technique of signal-to-noise ratio improvement can be realized with this device. Applications of cylindrical and meso-cylindrical elements to the MFTM and new designs of the MFTM are discussed. Then a digital mesooptical Fourier transform processor as a new fast processing system to be used with particle track stack detectors in high energy physics is suggested.

VIII. OPTICAL TOMOGRAPHY AND CONFOCAL SCANNING MICROSCOPE

The principle of reconstructed tomography, digital algorithms of reconstruction stage and optical inverting systems are reviewed.

The inverse problems in holography and optical tomography are treated. The designs of various microscopic tomographers, in particular, with rotationally oblique illumination are described.

The MFTM as a new tomographic device which does display vector-valued functions is considered anew. The comparison between the MFTM and traditional tomography involving only scalar functions is made.

The principle of confocal scanning microscope is described. In comparison with the well-known book (T.Wilson, and C.J.R. Sheppard, 1984, Theory and **practice** of the scanning optical microscopy, Academic Press, London) only new results will be presented, in particular, methods of phase imaging, dark field illumination in the confocal scanning microscope, stereoscopic tandem scanning microscope and other techniques of light sectioning.

The mesooptical confocal scanning microscope and the mesooptical condensors are described. The mesooptical confocal scanning microscope for "vertical" particle tracks in the nuclear emulsion is presented. The problem of sidelobes in these devices is treated. A confocal mesooptical scanning Hilbert processor for phase objects is suggested. A tomographic algorithm of inverting of the intermediate data in mesooptical systems is discussed. A comparison of techniques used in optical tomography and in confocal scanning microscopes is given.

IX. MESOOPTICAL AUTOCOLLIMATORS AND INTERFEROMETERS FOR CONICAL WAVEFRONTS

We begin with traditional techniques of measurement and control of the objects with conical surfaces: optical autocollimators, interferometers, holographic interferometers and digital algorithms of data processing. Applications of axicons, conical mirrors, and mesooptical elements with ring response in the devices for conical surface diagnostics are described. New designs of these diagnostics systems, in particular, the true mesooptical autocollimators for external and internal conical surfaces are suggested. It is shown that in these designs the difference between the conical etalon and the controlling surface can be displayed instantly without any digital processing. A description of the Fabry-Perot interferometer with plane and spherical mirrors is given. Then the mesooptical multipath interferometer for conical wavefronts is described.

Cerenkov radiation of high energy charge particles in gases and liquids and Cerenkov counters of these particles are described. The traditional difference Cerenkov counter and mesooptical aberration free difference Cerenkov counter are treated.

X. ABERRATIONS IN MESOOPTICS

The problem of coma aberration suppression in optics, holography and mesooptics is treated. The ways to increase the field of view of the mesooptical imaging elements or to suppress meridional coma aberrations are discussed. An overview of the Abbe sine condition for minimizing coma aberrations in optics is given. The Welford theorem concerning the optimal surface of the holographic lens backing is presented. An aberration free holographic microscope objective is described. A typical example of the application of the generalized Abbe-Welford theorem for designing of the aberration free holographic mesooptical element with a high numerical aperture and with a large field of view is given.

A modified aberration theory for aspheric surfaces involving odd powers of the radial distance to the optical axis is described. Two isoplanatic mesooptical systems with conical wavefronts are suggested: on isoplanatic mesooptical Fourier transform microscope for nuclear research emulsion and an isoplanatic mesooptical axicon-objective lens with a large depth of focus for track chambers in high energy physics. In conclusion the chromatic aberrations in mesooptics are treated.

XI. HISTORY OF MESOOPTICS

A. When was the first gravitational lens in our universe created? Cerenkov radiation of cosmic rays in gases and water. Claudius Ptolemy (90-I68) - cylindrical and saddle mirrors. J.Lenpold (I7I3) - cylindrical and conical mirrors. G.B.Airy (I826) - cylindrical surfaces in optics. H.Emsman (I894) - conical and cylindrical mirrors. E.Reusch (I869) - theory of cylindrical lenses. C.Zeiss and E.Abbe (I897) - anamorphotic lens systems.

B. C.Chabrie (I904) - first mesooptical lenses in the diastoloscope. A.Whitwell (I9I0) - focal line of the cylindrical lens. A.Einstein (I9I5) - first remarks about the gravitational lens. G.C.Steward (I928) - a lens with an annular aperture. A.Einstein (I936) - detailed theory of the gravitational lens. F.Zwicki and G.Russel (I937) - first proposal concerning the gravitational lens.

C. J.H.Mc Leod (I954) - axicons, J.Dyson (I958) - circular diffraction grating and Archimedeon spiral grating. A.Lohmann et al. (I967) - computer synthesized holographic translator. G.Groh (I97I) - holographic tomography with a circular synthesized aperture, L.T.Chang (I976) - axial tomography in 3D-image reconstruction. C.J.R.Sheppard and A.Choudhury (I977) - confocal scanning optical microscope. J.W.Ogland (I978) - W-axicon. D.K. Campbell and D.W.Sweeney (I978) - holographic scanner, I.N.Sisakyan et al. (I98I) - one-shot focusator with arbitrary focal line.

D. L.M.Soroko (I982) - mesooptics, mesooptical Fourier transform microscope. A.V.Goncharsky, I.N.Sisakyan et al. (I983) - CO_2 focusator. V.P.Koronkevich et al., I.S.Soldatenkov et al., (I984) - kinoform axicon, kinoform with ring response. L.M.Soroko (I985) - mesooptical confocal scanning microscope. S.Kawata et al. (I978) - oblique illumination in optical tomographic microscope, J.Durnin et al. (I987) - diffraction free wave fields, S.M.Chitre and W.C.Saslow (I989) - moving gravitational lens, L.M.Soroko (I990) - longitudinal interference of the diffraction free wave fields.

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3.	Low energy experimental physics
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9.	Accelerators
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Сороко Л.М. E13-90-384

Конические волновые фронты в оптике и томографии

Обзорная лекция охватывает широкий диапазон методов, в которых информация переносится конически (несферическими и неплоскими) волновыми фронтами. Это — первый обзор работ, опубликованных в области мезооптики и томографии. После введения в новую область современной оптики — мезооптику — детально рассматриваются свойства конических волновых фронтов. Приводятся некоторые возможные применения мезооптики в науке и технике. Длинная история мезооптики, рассмотренная в последней главе этой обзорной лекции, охватывает раннюю стадию развития нашей Вселенной, гравитационные линзы, первые публикации по мезооптике в последнем столетии и современные нововведения в оптике, мезооптике и оптической томографии.

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The review lecture covers a wide range of techniques in which the information is transferred by conical (nonspherical and nonplanar) waverfronts and is indeed the first summary of papers published in the field of mesooptics and optical tomography. After the introduction into the new branch of modern optics — mesooptics — the properties of conical wavefronts are treated in detail. Some possible applications of mesooptics in science and technology are considered. The long history of mesooptics treated in the last chapter of this review lecture goes from the early stage of our Universe, gravitational lens, first publications in the last century and up-to-date innovations in optics, mesooptics and optical tomography.

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