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MICROELECTRONIC TECHNOLOGY FOR COMPUTER OPTICS

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Abstract—The lithographic techniques of microelectronics are examined for their adaptability in the production of high-resolution diffraction optical components. Methods suitable for the preparations of optical topology are described. The major emphasis is placed on the application of electron beam lithography to computer optics problems. The operations of microstructural profiling are illustrated by diffraction elements prepared under a soft X-ray technology.

The paper reviews the processes of submicron microelectronic technology and shows how they can be adapted in the production of elements of diffraction optics for the soft X-ray range (1–10 nm). Prime emphasis is placed on electron-beam lithography as a basic process of pattern generation with a submicron spatial resolution.

Submicron microelectronic techniques developed in the early 1980s have contributed to the progress of many other fields of science and technology. For example, the techniques show a great potential for harnessing the ideas of computer synthesized optical elements. Indeed they completely revised X-ray diffraction optics, finding extensive application in plasma research, microscopy, lithography, and the like [1].

The principal method of microstructure profiling is known as planar technology [2]. The substrate of the microcomponent is coated with a radiation-sensitive polymer (photoresist). Certain areas are irradiated by photons, electrons or ions and so that a liquid development process then differentiates them from unexposed areas. The developer removes the irradiated areas of the photoresist (positive process) and exposes the substrate. The unremoved polymer serves as a mask in subsequent processing, such as wet or plasma etching, metal plating, etc. (Fig. 1).

This process of the mask generation is called photolithography in general, and particularly if carried out with the use of optical radiation; and X-ray electron- or ion-beam lithography if irradiated by X-rays, electrons or ion beams respectively. Photolithography has received wide acceptance because of its relative simplicity and high productivity. This method has achieved the theoretical limit of spatial resolution. This limit is associated with diffraction effects and is in the order of 1 μm (or 0.5 μm with excimer lasers).

X-ray lithography offers a resolution of tens of nanometres, but it is faced with technological difficulties in mask preparation and requires high-intensity radiation sources. Advances in microfabrication technology and the invention of commercial synchrotrons open new potentialities for X-ray lithography.

Ion-beam lithography is developed on the basis of ion-beam imagery systems and liquid-metal sources of focused beams of heavy ions. At the time of writing, applications of this method are still in the laboratory stage.

Electron-beam lithography seems to be more suitable as a fabrication technique of computer-synthesized optical components. We consider this technique in more detail below. The beam of electrons emitted by an electron gun is focused by an electron lens system onto the substrate. Deflection and blanking systems position the beam to irradiate areas of substrate with exactly defined boundaries. Beam steering is accomplished with the aid of a computer; therefore electron-beam lithographic systems afford great flexibility and can be reprogrammed to fabricate different topologies.

Spatial resolution of electron-beam lithography depends not only on the beam spot size, but also on electron scattering by the resist and the substrate. Studies of the physical nature of such interaction have produced algorithms to compensate for distortions of images of submicron structures.

Fabrication of computer-synthesized optical elements imposes a number of special requirements upon the generation of lithographic patterns. These are especially stringent (compared to integrated

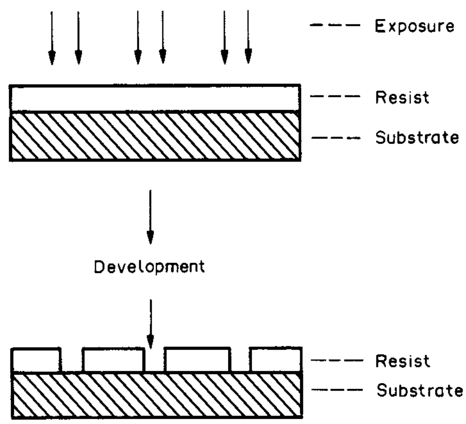

Fig. 1. Generation of a mask in lithographic processing.

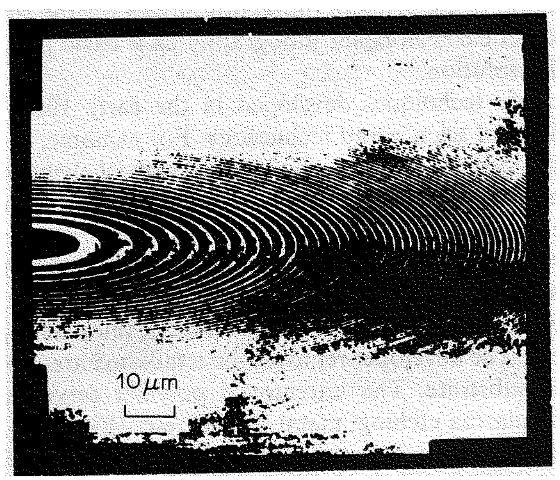

Fig. 2. Elliptical zone plate on the surface of a multilayer X-ray mirror.

circuit technology) concerning the relative positions of structural elements. Diffraction optical elements are phase-sensitive and therefore positional errors of individual structural elements would destroy the entire pattern. In X-ray optics for example, for a focusing system resolution of 0.4 μm, an absolute error of position for structural elements on a 1-mm^2 area should not exceed 100 nm. Therefore, to produce the topology for computer optics the aberrations of the electron-optical system should be controlled this much, and higher accuracy (compared to standard conditions) of electron beam steering should be achieved.

Second- and third-order curves are needed to describe the topology of computer synthesized optical elements, and the standard control systems of electron-beam lithography are not suitable for imaging such profiles. Accordingly, dedicated software and hardware are essential for the fabrication of structures with this complex spatial geometry and for the implementation of the algorithms that compensate for blurring of the submicron patterns during exposure.

A control system developed for electron-beam lithography (in the IPTM Institute of the U.S.S.R. Academy of Sciences) is tailored to the implementation of algorithms that create and correct complex geometric structures. It is built around a personal computer complete with floppy-disk drives. The IVK-2 computing system can be hooked up to store the description of complex structures and implement the three-dimensional correction algorithms. CAMAC modules interface the computer to the electron-beam lithographic system.

The control software (also from the IPTM Institute) executes a wide variety of jobs intended for the generating of precision structures as small as 0.3 μm, placed accurately to 0.06 μm in a field of several square millimetres. The structures may be specified either from the floppy disk, or

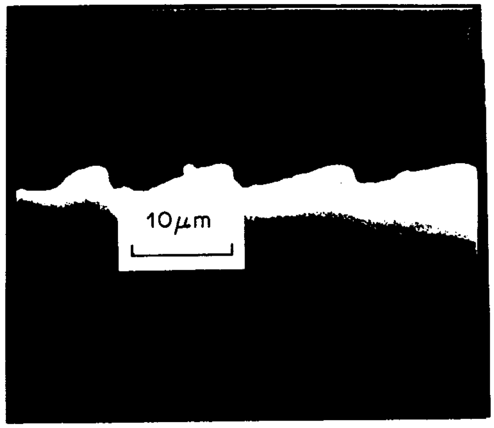

Fig. 3. Surface profile of a kinoform.

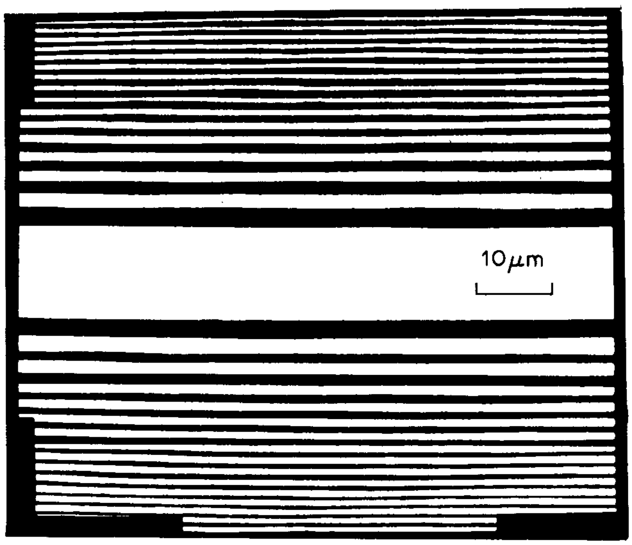

Fig. 4. Zone plate masked with golden coating.

directly by a human operator working with an interactive computing system, element-by-element or analytical in form. The set of utility programs selects a file and displays it on a colour terminal in order that the operator may inspect the topology while adjusting the electron-optical system. A high-level programming language (FORTRAN IV) affords the incorporation of algorithms not available in the standard system software and expands the functional capabilities of the lithographic system.

To introduce a third independent coordinate we need to know not only the two-dimensional distribution of electron-beam flow but also the three-dimensional topology of radiation-chemical conversions in the resist. The automated lithographic system controls the resist mask profile and allows for different techniques. Figure 2 shows a Fresnel elliptical zone plate for the soft X-ray range profiled by the system in a multilayer X-ray mirror. The minimum zone width is 250 nm. Variation of exposure permits custom-profile submicron structures. Figure 3 shows the cross-section of a grating with specially profiled elements.

The pattern developed in a polymer layer can be either a self-contained optical element or a mask for subsequent production operations. A popular fabrication method for metallic replicas of polymer matrices is by planting a metal onto the resist-free areas of the substrate. More than 20 metals and their alloys are known to be amenable to electroplating. By way of example, Fig. 4 shows a linear zone plate of gold printed into a suspended polymer membrane [3–5].

Dry etching techniques based on chemical or kinetic interaction between the ion beam and the

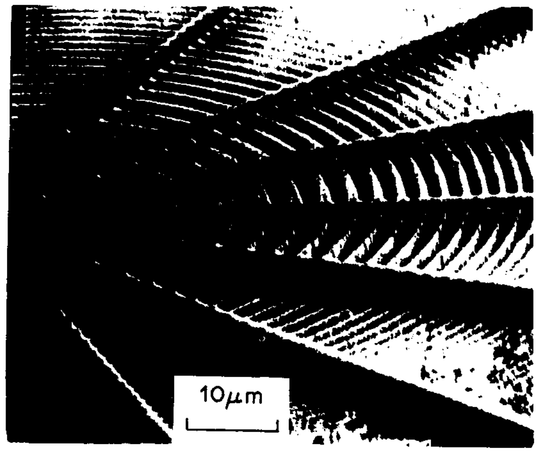

Fig. 5. Suspended silicon zone plate.

substrate show considerable promise for fabricating diffraction optical elements. Microstructures with a high aspect ratio have been produced. To illustrate, Fig. 5 shows a phase zone plate for wavelengths of 1–2 nm fabricated with electron-beam lithography and plasma etching. The single-crystal silicon substrate was etched down to 3 μm, the minimum zone width being 0.3 μm [6].

An important part of the technology covers thin-film deposition techniques. The choice of materials offered by conventional vacuum evaporation to specified accuracy is widened with electron-beam and laser-beam evaporation, and magnetron sputtering techniques. In particular, multilayer X-ray mirrors have been produced with more than a hundred layers, each of which being only nanometres thick. Corresponding measurement techniques can gauge thicknesses accurately to tenths of nanometres, if we include measurements carried out in the course of film deposition.

In summary, microelectronic technology makes possible the fabrication of precision optical elements with a spatial resolution down to tens of nanometres. This task, however, requires the further development of dedicated microstructure profiling techniques. Efforts toward high-resolution technology for computer optics are expected to advance microelectronic technologies, and to lay out a basis for such processes and stretch the capabilities of available instrumentation and technology close to their limit.

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