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Electron Beam Writing of Spatial Filters*

Abstract: A method is described for the generation of optical spatial filters using electron beam-addressed crystals of KDP. Some examples of simple filters which have been successsfully written by this method are presented.

Introduction

Optical systems are particularly suited to the processing of two-dimensional information since they represent the natural medium for the transmission of such information. Furthermore, under coherent illumination, an optical imaging system is capable of presenting the information in a very convenient form, i.e., as a well-resolved set of spatial frequencies which correspond to the Fourier frequencies of the object. Processing consists, in general, of modifying the amplitude and/or phase of these Fourier components by the introduction of a spatial filter in the Fourier plane.

The problem which continues to plague and to inhibit the utilization of such a technique for image processing is that the filtering operation is laborious and time consuming. Even when the processing requires application of only a single filter, the filter must be critically aligned with and have the same size as the components of the Fourier spectrum. If a set of filters is required, each filter must first be sequentially introduced into the Fourier plane and then be carefully oriented, which compounds the difficulty.

Conventionally these filters are made as photographic transparencies, which are neither adaptable to a variety of incoming signals nor easily positioned to match the coordinate system of the Fourier spectrum. Thus the potential usefulness of spatial filtering in the processing of optical data is severely hampered by the time-consuming off-line production of spatial filters and the need for their mechanical exchange and positioning.

This paper discusses a means whereby the inherent power of optical processing can be exploited without suffering the speed limitations usually associated with static spatial filters. The method consists of using an electron beam-addressed electro-optic light valve (EOLV)[1] as the spatial filter. Thus the filter need no longer be a fixed transparency, but can instead be a dynamic device whose orientation is controlled electronically rather than mechanically. This opens the method of optical processing to the domain of real time and presents exciting possibilities for its use in a variety of applications.

Electro-optic spatial filters

One solution to the problem of fixed, photographic-type spatial filters is to produce them dynamically by substituting an electro-optic device for photographic film. Electro-optic crystals have all of the characteristics required to write either amplitude-varying or phase-varying filters by the application of a spatially varying electric field, in addition to having the key properties of fast response and erasability. The property of fast response means that the filter can be both written and erased in the time needed to change the electric field pattern. Thus it becomes possible to rewrite the filter instead of either repositioning it or mechanically introducing another filter. Such a system requires a computer-controlled feedback loop for maximum efficiency.

While the realization of such a scheme requires the development and perfection of many components, it is

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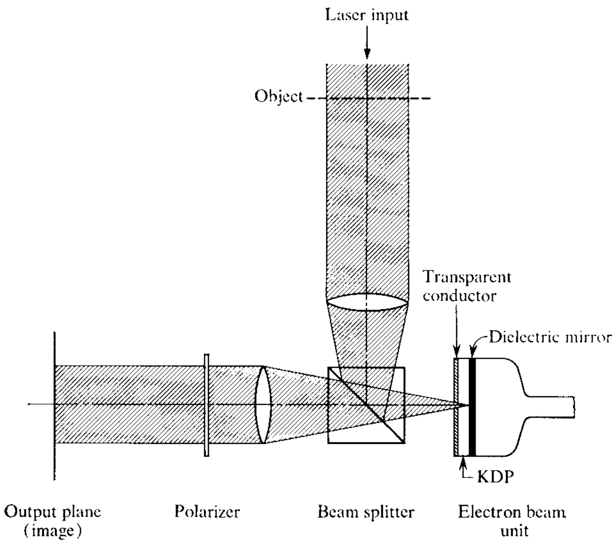

Figure 1 Schematic diagram of apparatus used to generate electro-optic spatial filters and to produce optical patterns altered by these filters.

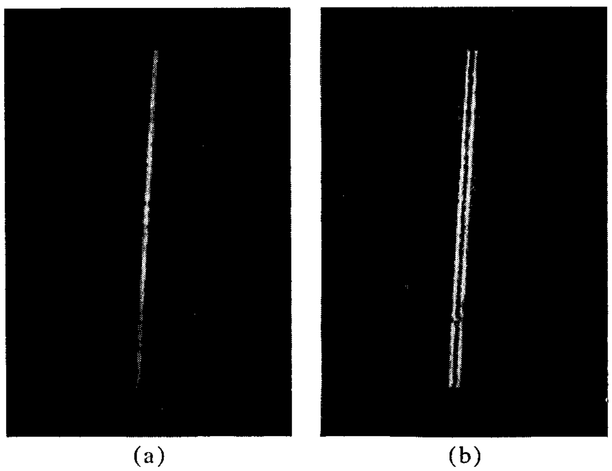

Figure 2 (a) Reproduction of a single slit; (b) altered image of the slit produced by a point spatial filter.

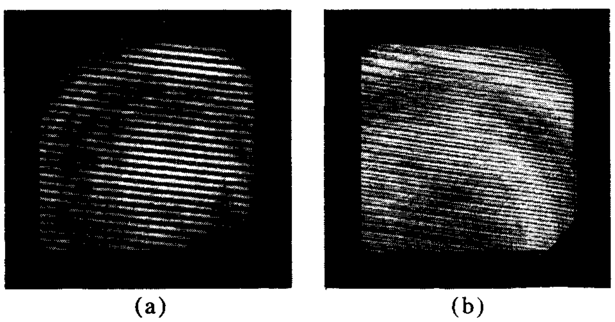

Figure 3 (a) Reproduction of a square wave grating; (b) doubling of the grating frequency produced by a two-line spatial filter.

possible to demonstrate the basic feasibility of the idea by generating a simple electro-optic spatial filter. The remainder of the paper discusses the writing of such filters and a few experimental results achieved by their use.

Figure 1 is a schematic diagram of the electron-beam-addressed filter. It consists of a KDP crystal in tandem with a polarizer. In one application, polarized coherent light passing through the crystal is extinguished by the polarizer unless a field-producing charge is deposited on the crystal. Alternatively, the polarizer may be oriented to pass the input light except when the field alters its polarization. To enable the electron beam to access the crystal without skewing either the optical or electron beams, a reflective optical system is used with a multilayer dielectric coating acting as the interface between the optical and electron beams. Charge deposited on the dielectric mirror by the electron beam induces a local birefringence within the KDP crystal which causes it to operate as a spatially modulated light valve, i.e., an amplitude spatial filter. This filter operates on the Fourier spectrum of the object in the plane of the dielectric mirror by means of a lens. Because binary filters are the easiest to produce, the experiments discussed here were performed exclusively with such filters. In practice this means that the electron beam requires only on-off modulation.

The first object that was chosen to demonstrate such a filter was a single slit of width d, shown reproduced in Fig. 2a. A slit yields the usual $[\sin(\pi pd)/\pi pd]^2$ intensity envelope in the Fourier plane with the nulls of the frequency spectrum occurring at the positions $x_n = n\lambda f/d$ for integral values of n. The easiest way to alter the image of such a pattern is to omit the low frequency part of the Fourier spectrum that appears between the two lowest order nulls ($n = \pm 1$) and pass the higher frequency Fourier components; this is usually called the "dark field" method. What remains of the pattern in the image plane is a region in the vicinity of the edges of the slit, i.e., the image appears to be an optical differentiation of the object. This is achieved by adjusting the output polarizer to pass the unfiltered image and by inserting a spatial filter in the shape of a small stop at the center of the Fourier pattern. The spatial filter was written by a stationary electron beam. The altered image obtained by generating and correctly positioning such a spatial filter is shown in Fig. 2b.

An equally illustrative form of spatial filtering is demonstrated in Fig. 3. Here the object pattern consists of a simple square-wave intensity grating (Fig. 3a). The Fourier pattern of this grating is a series of sharp intensity maxima representing the focused harmonics of the grating frequency. If the spatial filter passes the two orders $n \pm 1$ in this series and blocks the one between them, i.e., if the filter picks off a pair of harmonics separated by twice the fundamental frequency, the image will have twice

Figure 4 Intensity-modulated reproduction of phase-modulated information produced by a spatial filter that passes the first order of the phase grating.

the frequency of the original grating. In the experiment the output polarizer was crossed with the polarization direction of the input beam and the spatial filter consisted of a two-line raster written parallel to the direction of the grating lines. With the spacing and positioning of the raster lines carefully adjusted to allow the two first orders of the grating to be transmitted, the image shown in Fig. 3b was obtained.

In the final example, which is similar to the Eidophor or thermoplastic projection, continuous tone phase information is superimposed on a phase grating and can be converted to intensity-modulated information by operating the filter in a Schlieren-type mode. In this experiment the principle can be demonstrated by passing only the first order component of the diffracted light, making sure that the transmitting zone is large enough to include the band of frequencies with which the object modulates the carrier (i.e., grating) frequency. The spatial filter is a raster only slightly larger than the diameter of the focused electron beam and centered about the first order maximum of the grating. Figure 4 shows the image produced by such a filter. A negative image is obtained if the filter is moved to allow only the zero order to pass through the output polarizer.

In general the beam current required for binary-type spatial filters depends on the type of crystal used, on the nature of any conductive paths available to the charge, and on the complexity of (i.e., total number of bits contained in) the spatial filter. The choice of the KDP crystal and the low bit density of the filters allowed us to use beam currents that never exceeded 30 nA. Because of the simplicity of the filters it was a simple matter to align each filter with the Fourier pattern manually. However, the attractiveness of the method would be realized only if such searching were done electrically.

Discussion

In this paper we have shown that the concept of electro-optic spatial filters is feasible and realizable. However, considerable improvement is desirable in several aspects of the system. The filters written to date have made little demand on the resolution of the electron beam. Yet complex objects will require one-dimensional resolution of about one part in 1000. This requires either large, high-quality electro-optic crystals or high-resolution electron guns. Furthermore, the need for focusing the optical beam within a nonisotropic crystal results in a series of rings which appear as an undesirable background (see Fig. 4). These rings can be traced to the spread of values of the angle of incidence that is inherent in a convergent light beam. This difficulty can be alleviated somewhat by the use of very thin crystals which considerably broadens the rings, but such thin crystals present problems of stability or require adhesion to rigid support structures. Finally there is the problem of feedback-controlled orientation search, which is perhaps the most difficult aspect of the system but one that is essential to make fast optical processing a reality.

Acknowledgment

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Reference

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