

Links between Holography and Lithography

Nicholas J. Phillips
Christopher A. Barnett
Ce Wang
Zane A. Coleman

Science and Engineering Research Centre, De Montfort University
The Gateway, Leicester, U.K. Tel. 0533 551 551 (U.K.)

ABSTRACT

Holography as a science owes its success to the recording of interference patterns in a variety of recording materials. Many of these materials are also used in the companion science of precision lithography. This paper discusses two important areas of holography and lithography. Both make use of the novel imaging polymers of DuPont. We discuss here the manufacture of micro-diffusers for diverse optical applications and the creation of phase holograms by contact lithographic methods using silver image amplitude holograms. Such copying methods are essentially incoherent using broad band UV light and bridge the gap between holography and lithography.

1. INTRODUCTION

The areas of work discussed in this paper stem from detailed studies over several years of effort on the behaviour of the DuPont imaging polymers under conditions of contact recording using lithographic methods. Simplistic references to this field of activity may be found in two previous publications^{1,2}. In these cited papers, we discussed the contact of DuPont materials against binary masks made by simple lithographic methods. The advantage of such methodology lies in the lack of stability requirements as in holography, the ability to exploit precision masks with hard-wearing characteristics and use of simplistic non-coherent UV beams generated by high power discharge light sources.

We remind the reader of the behaviour of the DuPont materials in Fig. 1.1(a) and 1.1(b). The polymer layer irradiated by say a UV beam through the window of a contact mask will be subject to partial polymerization in the irradiated zone and consequent diffusion of monomer leading to spatial changes of the refractive index.

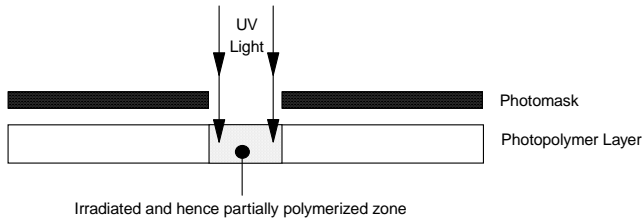


Fig. 1.1(a) Showing the irradiation of photopolymer through a contact mask

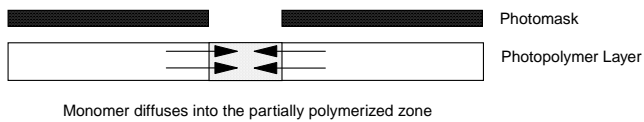


Fig. 1.1 (b) Showing monomer diffusion into the irradiated zone.

The net result of such diffusion is to cause two possible changes to the structure of the material:

- (i) A change of the local density and hence of the local refractive index
- (ii) An increase of thickness of the polymer layer in the locality of increases of polymer density

One or both of these effects may occur.

In fact, the relief effect (ii) can be enabled by using a contact mask which has a form of indigenous surface relief as shown in Fig. 1.2.

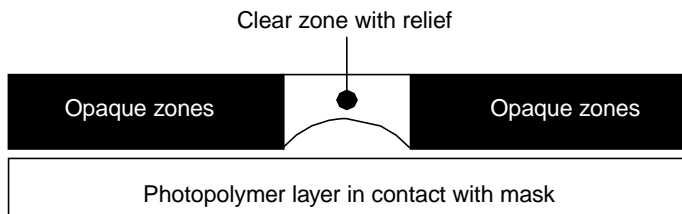


Fig. 1.2 Showing a mask with relief at a transparent window.

As monomer diffuses into the irradiated zone a replication of the mask's inherent relief is encouraged.

If masks are made using silver halide materials such as Agfa's Millimask™ then fixation of the mask encourages naturally the formation of relief at the polymer mask interface.

The phenomena described in (i) and (ii) above can obviously lead to a variation of the refractive index of the polymer and its thickness- as described in the simplistic sketches of Figures 1.3 and 1.4.

If the relief on the mask is not present, the migration of monomer is only permitted by the reduced volumetric occupation of the polymerized monomer.

Since this latter effect is small, the use of flat masks will result in reduced changes in the refractive index.

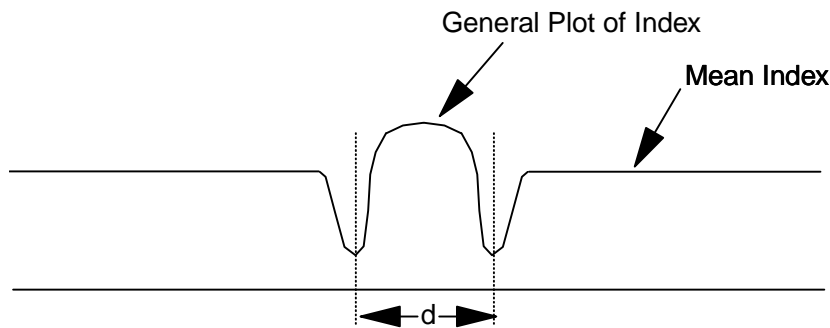


Fig. 1.3 Showing the expected index profile of irradiated polymer using the mask of Fig. 1.1(a) and the withdrawal of monomer from the borders of the irradiated zone.

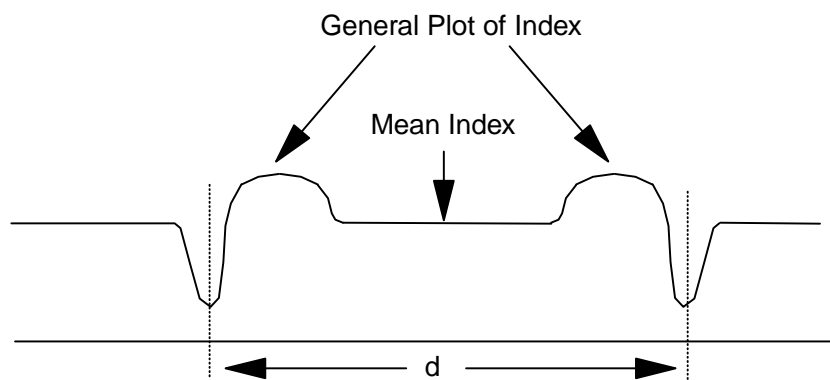


Fig. 1.4 An excessive width of the mask window will confine the index modulation effect to zones near the edge of the window.

N.B. Note that in any generalized mask some black zones are necessary to define the regions from which the monomer can diffuse. In the contact copying of an amplitude hologram the efficiency of the copy is actually enhanced by the presence of black in the original hologram.

At this stage, it is important to understand that the DuPont polymers are controlled by two basic parameters.

The first of these is the rate of polymerization at the given irradiation intensity. We can associate with this a time constant τ_p . The second is the characteristic time for monomer diffusion over the scale length (in our case d) designated by the mask. Let us call this time constant τ_d . If $\tau_p \ll \tau_d$ then irradiation will lead to polymerization without monomer transfer. If on the other hand $\tau_p \geq \tau_d$ then a sort of balance can be struck leading to good index modulation and in the case of holograms, high efficiency.

The rules for the optimized exploitation of contact lithography, based on the above ideas, are complex and refined in practice. We shall discuss two important areas of contact methodology that are of importance to the field of display holography. Of necessity, these descriptions are abbreviated because of space restrictions in this paper.

2. CONTACT LITHOGRAPHY AND ITS ROLE IN THE FORMATION OF MICRO-DIFFUSER MATERIALS.

In this area of activity, we have undertaken lengthy studies of the problem of contact lithography using micro-masks of the close packed array form as shown in Fig. 2.1 or using an irregular array of random windows as shown in Fig. 2.2.

By contacting a layer of DuPont material to such masks, an array of micro-lens like structures can be created using the methods described in section 1. Such lenses can be described as a mixture of surface relief and graded index (GRIN) effect. An array of such lenses can in principle be used as a diffusion screen for image display for say, TV or holographic stereography.

A regular array suffers from two main defects:

- (i) Sight of collective diffraction due to the array regularity hence leading to non-achromatic display effects.
- (ii) Sight of the source light behind the display due to lack of optical power in the un-irradiated zones of the array.

Much of our work has centered on irregular arrays of windows created by a variety of techniques, which largely bypass difficulties (i) and (ii).

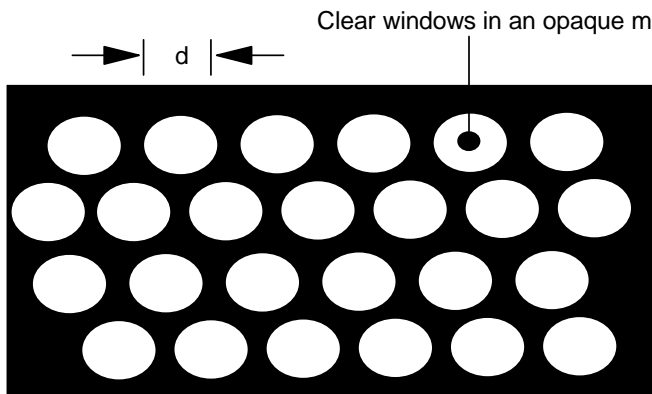


Fig. 2.1 (a) A regular array of clear apertures on an opaque mask

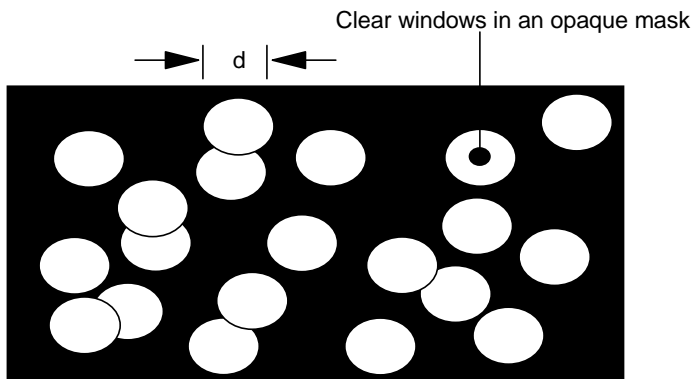


Fig. 2.1 (b) An irregular array of clear apertures on an opaque mask

The culmination of our study is in the generation of highly uniform masks which when contact copied into the DuPont materials lead to highly diffuse structures with polar diffusion plots ranging from very narrow angles to the result shown in Fig. 2.2.

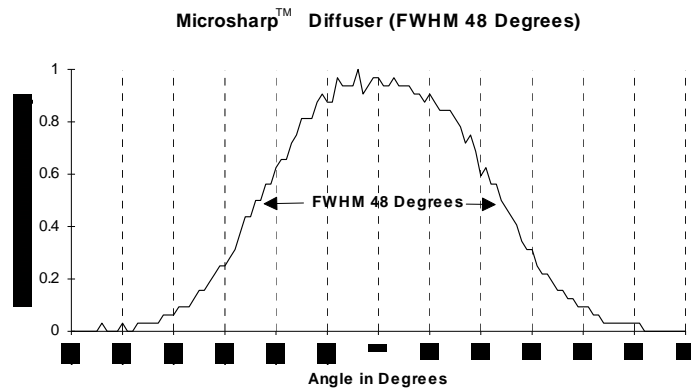


Fig. 2.2 The polar diffusion characteristics of a 48 Degree FWHM Microsharp™ Diffuser

Here the polar diffusion plot is obtained from a goniometer system as shown in Fig. 2.3.

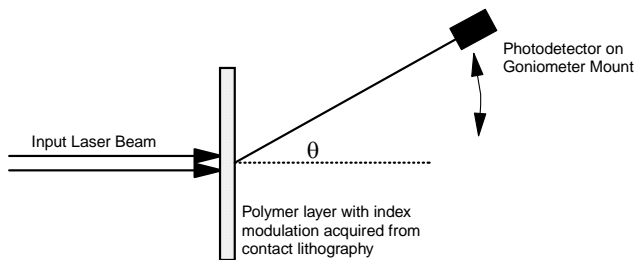


Fig. 2.3 Diffuser measuring system

An important parameter for measuring diffusion is the angular width of the scattered light plot at half maximum intensity (Full Width at Half Maximum-FWHM). Typically, higher Δn materials lead to larger values of FWHM. In our case Δn refers to the observation of index changes of an optically modified layer brought out by changes of molecular density and layer thickness.

3. CONTACT COPYING OF AMPLITUDE HOLOGRAMS USING DUPONT MATERIALS AND STRONG INCOHERENT BROAD BAND UV SOURCES

Arguably, if contact lithography can make effective diffusers then one might expect some sort of copy to be possible in a holographic regime as shown in Fig. 3.1.

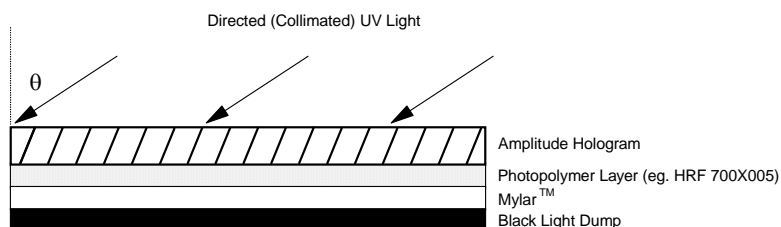


Fig. 3 Showing a simplistic contact copying of an amplitude hologram into DuPont's photopolymer. Here θ refers to the original holographic reference angle in a subtle way (see text). A typical exposure for a contact copy was of the order of 3 Joules/cm² as measured at 325nm on a Liconix Laser Power Meter. Because of the exceptional levels of refractive index of the Mylar™ base of the DuPont

polymers in the UV, it is critical that a black light dump be used to avoid the back reflection from the base material. The reader is referred to James³ for details of refractive indices and transmission coefficients of the relevant materials described in this paper. Of special importance is the apparent high level of refractive index and dispersion of the MylarTM base materials at the UV end of the spectrum. The reader will, however, understand that a critical issue is the dispersion of the broad band UV as it impinges on the glass surface of the hologram. In fact, the very high levels of dispersion associated with the MylarTM are not common to the gelatin of the photographic layer or the support glass of the hologram.

The idea is that the broad band UV impinges on the Bragg planes of the hologram, travels through the open spaces of the holographic layer and eventually emerges at the contact interface into the polymer layer. There is no question of coherence at the copy stage- the light is broad band as illustrated in Fig. 3.2.

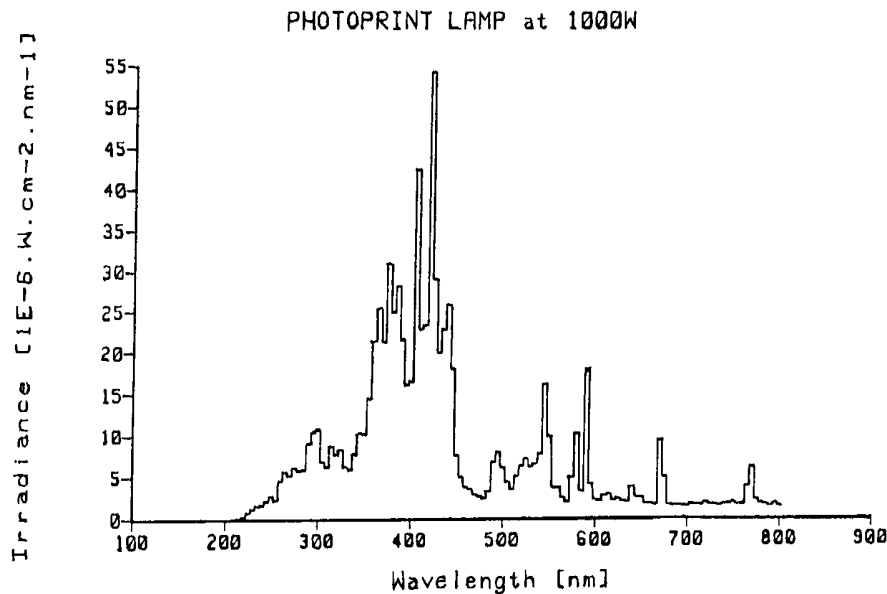


Fig. 3.2 Showing a typical spectral output of a doped mercury discharge lamp used for the photolithography described in this paper.

The Bragg planes of the hologram act as guides that control the passage of the UV through the holographic layer. The UV light entering the hologram is of course refracted into the hologram with, fortuitously, only a modest dispersive effect. Once inside the gelatin of the holographic layer the light is guided to travel out into the contacted polymer in a spatially modulated form. Note that no traditional Bragg effect as such is invoked- it is only the spatial modulation of the light emerging into the contact polymer that is required. This spatial modulation is controlled by the black fringes of the amplitude hologram. Once the light emerges from the hologram, the pattern blurs by broad band Fresnel diffraction, thus restricting the available pattern depth in the copy layer.

The unusual aspect of this type of contact copy method lies in its use of high contrast (non-sinusoidal) patterns of interference. Thus the driving force behind monomer migration is greater than that present in conventional holographic recordings where the optical patterns involve at best \cos^2 fringes. Once the monomer diffuses, then it contributes to a linearization of the high gamma silver

recording. Were the copy hologram to retain the effects of such high gamma, it would lose efficiency due to the need for a high level of beam ratio consistent with image linearity.

As a result of this discussion, we can perhaps conceive that the index modulation, Δn , referred to in Kogelnik's Diffraction model (based on sinusoidal interference) is not of the same numerical value as that derived by the method outlined in this paper. Further discussions of the relative merits of holographic (\cos^2) and binary fringes will follow in subsequent publications

From our earlier remarks, the surface of the hologram at the contact interface will perforce be expected to have relief as part of its structure. This effect is carefully designed into generalized masks and is discussed in the next section. Without the relief, no copying effect of significance occurs.

4. PROCESSING OF THE CONTACT HOLOGRAM FOR RELIEF

Many thousands of trials have revealed the need for high contrast development. We shall outline three favoured routes for the processing of the contact hologram.

The hologram should be recorded with significant and controlled relief whilst trying to avoid too wide a dynamic range in the holographic recording. Thus since such a hologram is inevitably an H2 of the usual H1, H2 situation, the master (H1) needs to be carefully structured. Stereographic copies with their restricted dynamic range are therefore ideally suited to this method. The beam ratio of the amplitude hologram should be carefully adjusted. The lower the ratio, the stronger is the attained relief.

Let us now outline the processing steps.

Develop: Suggested developers are as follows:

- (a) Kodolith + 50gms KNO_3 /litre of mixed developer
- (b) Agfa G284C High contrast liquid concentrate
- (c) Special Para-Aminophenol developer for relief.

Developers (a) and (c) can be used to create a density $D \approx 1-1.5$ in the holographic layer and should be run at a strict 20°C with a couple of minutes development time.

Developer (b) endows typical Agfa emulsion with unusual speed (sensitivity near $30\mu\text{J}/\text{cm}^2$). Note that this exceptional sensitivity is about **one order of magnitude** better than conventional wisdom for the Agfa materials. Thus low power lasers and short exposure times can be exploited.

Developer (c): Special developer for relief.

Part A
10 gms Sodium Sulphite (Anhydrous)
4 gms 4-Amino Phenol (Para-Aminophenol)
500 ml of distilled water

Part B
50 gms Potassium Nitrate
60 gms Sodium or Potassium Carbonate (Anhydrous)
500 ml of distilled water

Mix equal parts of A and B just before use (at 20 ° C). Develop for 3.5 - 5 minutes to a density $D \approx 1$.

After development, the hologram should be washed and fixed as follows:
Special Fixer (to avoid attack on the silver image)

100 gms Sodium Thiosulphate (Anhydrous)
10 gms Sodium Carbonate (Anhydrous)
1 Litre of water

Fix for 1 minute at 20° C.

5. DISCUSSION

The technique presented here is strange in that it appears to offer something for nothing. The exposure demands, in the making of the holographic image, can be very low and the light source for the copying phase can be cheap (relative to lasers) and extremely powerful. Essentially, the method manipulates a complex set of parameters to advantage, leaving an amplified phase copy hologram from the low efficiency amplitude master. The method works because of diffusion transfer of monomer and the fact that the black zones of the hologram define regions from which the monomer can diffuse in the neighbourhood of the contact zone. Thus the black zones of the hologram (or any generalized mask) are an essential and assistive ingredient of the physical process.

The examples demonstrated at this meeting have been confined to the Benton rainbow regime, but there is no good reason why open aperture results should not be achieved. Interestingly, the transition from the rainbow to the full parallax regime carries with it many familiar concerns for the practical holographer who generally finds it easier to make rainbow holographic copies. Furthermore, the major objection to production of the more elaborate full parallax H2 copies prior to embossing is based on the well-known stringency of development of photoresist which is of course exploited to produce relief images. In the work that we have cited here, the same care in the structuring of such relief is required as a precursor to the success of the method.

The DuPont materials are complex and offer manipulative techniques not available with other known materials. Where diffusion transfer of refractive molecules can take place, strong holographic amplification affects are possible⁴.

6. CONCLUSIONS

We have presented examples of lithographic techniques that spread over into the field of holography. We have shown that optically modifiable polymers are of great interest in the creation of new micro- optic and holographic products. Amongst advantages of using lithographic methods is the availability of enormously powerful (c 2kW) UV sources of the discharge type at relatively low cost (\$2,000 as opposed to say 7 watts of UV laser light at a cost of some \$200,000 or more). Though the methods presented here are unusual, they open new doors in the laboratory where the bane of holography- massive mechanical stability requirements, can be substantially alleviated.

7. ACKNOWLEDGEMENTS

The authors wish to acknowledge the enthusiastic financial and personal support of Mr. William Johnson and Durand Ltd. which has resulted in the developments described in this paper. We further wish to acknowledge the always rapid and helpful support offered by the team at DuPont Holographic Materials.

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